STATE OF MONTANA
NATURAL RESOURCE DAMAGE PROGRAM

TERRESTRIAL RESOURCES INJURY ASSESSMENT REPORT UPPER CLARK FORK RIVER NPL SITES

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TERRESTRIAL RESOURCES
INJURY ASSESSMENT REPORT

UPPER CLARK FORK RIVER BASIN

TERRESTRIAL RESOURCES INJURY ASSESSMENT REPORT

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STATE OF MONTANA
NATURAL RESOURCE DAMAGE LITIGATION PROGRAM

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ACRONYMS

AMC	Anaconda Minerals Company
ASI	Anaconda Soil Investigation
ASTM	American Society for Testing and Materials
ARCO	Atlantic Richfield Company
BWC	Bottom of Water Column
CEC	Cation Exchange Capacity
DOI	United States Department of the Interior
DTPA	Diethylenetriaminepentaacetic Acid
GPS	Global Positioning System
HEP	Habitat Evaluation Procedures
HPS	Handling/Process/Storage Area
HSI	Habitat Suitability Index
MBMG	Montana Bureau of Mines and Geology
MDFWP	Montana Department of Fish, Wildlife, and Parks
MSU	Montana State University
NPL	National Priorities List
NRDA	Natural Resource Damage Assessment
NRDLP	Natural Resource Damage Litigation Program
OM	Organic Matter
OU	Operable Unit
PSCI	Preliminary Site Characterization Information
QA	Quality Assurance
QA/QC	Quality Assurance/Quality Control
QC	Quality Control
RI/FS	Remedial Investigation/Feasibility Study
SBC	Silver Bow Creek
SI	Suitability index
SM	Shrub Midstory
SOP	Standard Operating Procedure
STARS	Streamside Tailings and Revegetation Studies
SW	Surface Water Layer
TB	Tree Bole
TC	Tree Canopy
TS	Terrestrial Subsurface
US	Understory
U.S. BLM	United States Bureau of Land Management
U.S. EPA	United States Environmental Protection Agency
U.S. FWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
U.S. SCS	United States Soil Conservation Service

ACRONYMS

UTM	Universal Transverse Mercator Grid
WC	Water Column Layer
XRF	X-Ray Flourescence

1.0 INTRODUCTION AND SUMMARY

Terrestrial resources of the upper Clark Fork River Basin have been injured as a result of historical and ongoing releases of hazardous substances from mining and mineral-processing operations. This report describes the results of injury determination and quantification for terrestrial resources. The resources addressed are soils, vegetation, wildlife, and wildlife habitat. The geographic scope of the injury assessment includes upland areas near Anaconda, and riparian areas along Silver Bow Creek (from upstream of the Colorado Tailings in Butte to the Warm Springs Ponds) and the Clark Fork River (from its headwaters just below the Warm Springs Ponds to the Milltown Reservoir) (Figure 1-1).

Injuries to soils, vegetation, wildlife, and wildlife habitat have been caused by historical and ongoing releases of the hazardous substances arsenic, cadmium, copper, lead, and zinc from mining and mineral-processing operations in Butte and Anaconda. The following information on terrestrial resources is presented in the various chapters of the report:

Soils

- Riparian (floodplain) soils have been injured throughout the length of Silver Bow Creek, at least the upper 17 miles of the Clark Fork River, and approximately 3,400 acres of the Opportunity Ponds. These soils were found to be severely phytotoxic in controlled laboratory tests; little to no vegetation exists on these injured soils.

- Riparian soils are exposed to hazardous substances primarily through exposure to surface water pathways.

- Riparian soils serve as an exposure pathway to riparian vegetation, wildlife, and wildlife habitat. In addition, riparian soils, through surface runoff, serve as a pathway to surface water (and hence to both aquatic resources and to downstream riparian soils).

- Upland soils have been injured throughout approximately 17.8 square miles near Anaconda. Soils from these upland areas, including portions of Stucky Ridge, Smelter Hill, and the Mt. Haggin area, were found to be phytotoxic in controlled laboratory tests. These soils have caused injury to vegetation communities in these upland areas.

- Upland soils have been exposed to hazardous substances by smelter emissions and ongoing fugitive releases from contaminated soils. Hence, both air and soils act as pathways to soil resources.

- Upland soils serve as exposure pathways to upland vegetation, wildlife, and wildlife habitat resources.

Vegetation

- Riparian vegetation has been injured throughout the length of Silver Bow Creek, the upper 17 miles of the Clark Fork River, and the approximately 3,400 acres in the Opportunity Ponds. These soils were found to be severely phytotoxic in controlled laboratory tests; little to no vegetation exists in these areas.

- Injuries to riparian vegetation include reduced cover, increased bare ground, reduced forest/shrub community, and reduced habitat complexity (number of habitat layers).

- Upland vegetation has been injured throughout approximately 17.8 square miles near Anaconda. Soils from these upland areas, including portions of Stucky Ridge, Smelter Hill, and the Mt. Haggin area, were found to be phytotoxic in controlled laboratory tests; vegetation communities have been injured in these upland areas.

- Injuries to upland vegetation include reduced cover, increased bare ground, reduced forest/shrub/grassland communities, and reduced habitat complexity (number of habitat layers).

Wildlife and Wildlife Habitat

- Riparian wildlife and wildlife habitat have been injured throughout the length of Silver Bow Creek, the upper 17 miles of the Clark Fork River, and the approximately 3,400 acres in the Opportunity Ponds. These injured areas no longer provide sufficient habitat to support viable populations of wildlife species typical of Montana riparian habitat.

- Semi-aquatic furbearers, including otter, mink, and raccoon, have been injured as a result of exposure to hazardous substances in their food. Mink and raccoon populations have been reduced throughout the length of Silver Bow Creek and the Clark Fork River (from Warm Springs Ponds to Milltown). Otter have been entirely eliminated from this area.

- Upland wildlife and wildlife habitat have been injured throughout approximately 17.8 square miles near Anaconda. These areas no longer provide sufficient habitat to support viable populations of wildlife species typical of Montana upland habitat.

Injury to these individual upland terrestrial resources has disrupted fundamental ecological processes and cycles, and has resulted in ecosystem-level injury. Table 1-1 provides a summary of injuries and pathways to terrestrial resources.

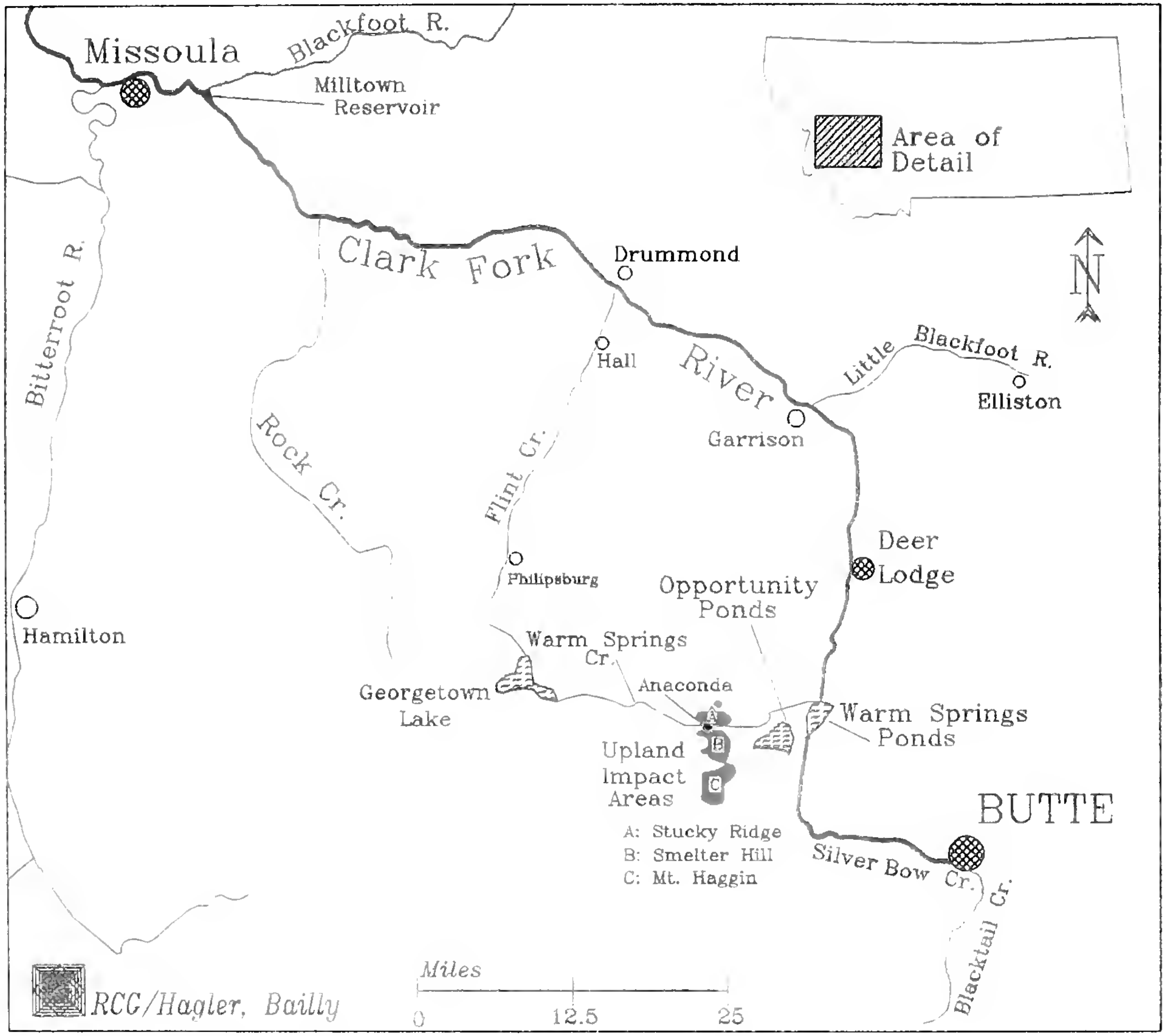

Figure 1-1. Upper Clark Fork River Basin Assessment Area: Terrestrial Resources.

Table 1-1
Injury and Pathway Summary for Terrestrial Resources

Resource	Location	Injuries	Pathways to Injured Resource
Soils	▸ Silver Bow Creek ▸ Clark Fork River[1] ▸ Anaconda uplands	▸ Concentrations of hazardous substances cause phytotoxicity ▸ Soil pH < 4.0 ▸ Concentrations of hazardous substances cause injury to vegetation	▸ Air ▸ Surface water ▸ Other soils
Vegetation	▸ Silver Bow Creek ▸ Clark Fork River[1] ▸ Anaconda uplands	▸ Phytotoxicity (death) ▸ Phytotoxicity (reduced growth)	▸ Soils
Wildlife — riparian	▸ Silver Bow Creek ▸ Clark Fork River[1]	▸ Reduced habitat ▸ Reduced population viability	▸ Soils
Wildlife — upland	▸ Anaconda uplands	▸ Reduced habitat ▸ Reduced population viability	▸ Soils
Wildlife — furbearers	▸ Silver Bow Creek ▸ Clark Fork River[2]	▸ Reduced viability, including population reductions	▸ Fish

[1] Injury to soils, vegetation, and riparian/terrestrial wildlife and wildlife habitat was assessed in the Clark Fork River from Warm Springs Ponds to Deer Lodge.

[2] Injury to semi-aquatic furbearers was assessed in the Clark Fork River from Warm Springs Ponds to Milltown.

1.1 INJURY ASSESSMENT

The U.S. Department of the Interior (DOI) has promulgated regulations for the performance of natural resource damage assessments [43 CFR Part 11]. This assessment was performed in accordance with these regulations.

The term injury is defined as a 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 assessment of injury to terrestrial resources of the Clark Fork River Basin included three steps. The first two steps constituted the injury determination phase, and the final step was the injury quantification phase:

- *Injury Definition.* In the injury definition phase, those injuries that were found to meet the definitions of injury in 43 CFR § 11.62 were evaluated.
- *Pathway Determination.* In the pathway determination phase, exposure pathways of hazardous substances to injured natural resources were identified [43 CFR § 11.63]. The DOI notes that pathway determination may be accomplished by the "demonstration of sufficient concentrations in the pathway for it to have carried the substance to the injured resources." [51 FR 27684]. In this assessment, "sufficient concentrations" of hazardous substances in pathway resources have been demonstrated in air (through known smelter emissions), soils, and fish.
- *Injury Quantification.* The effects of the releases of hazardous substances were quantified in terms of changes from "baseline conditions" [43 CFR § 11.70 (a)].

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)]. Baseline conditions should take into account both natural processes and human activities, and should include the normal range of physical, chemical, or biological conditions for the assessment area or injured resource [43 CFR § 11.72 (b)]. In addition, baseline data collection "shall be restricted to those data necessary for a reasonable cost assessment" [43 CFR § 11.72 (b)(4)]. Where historical baseline data are not available, "baseline data should be collected from control areas" [43 CFR § 11.72 (d)]. "Control area" is defined as "an area or resource unaffected by the discharge . . . or release of the hazardous substance under investigation. A control area or resource is selected for its comparability to the assessment area or resource and may be used for establishing the baseline condition and for comparison to injured resources" [43 CFR § 11.14 (i)]. Control area selection is based on criteria set forth at 43 CFR § 11.72 (d)(1-7):

- One or more control areas shall be selected based upon their similarity to the assessment area and lack of exposure to the . . . release.
- Where the . . . release occurs in a medium flowing in a single direction, such as a river or stream, at least one control area upstream or upcurrent of the assessment area shall be included, unless local conditions indicate such an area is inapplicable as a control area.

- The comparability of each control area to the assessment area shall be demonstrated, to the extent technically feasible, as that phrase is used in this part.

- Data shall be collected from the control area over a period sufficient to estimate normal variability in the characteristics being measured and should represent at least one full cycle normally expected in that resource.

- Methods used to collect data at the control area shall be comparable to those used at the assessment area, and shall be subject to the quality assurance provisions of the Assessment Plan.

- Data collected at the control area should be compared to values reported in the scientific or management literature for similar resources to demonstrate that the data represent a normal range of conditions.

- A control area may be used for determining the baseline for more than one kind of resource, if sampling and data collection for each resource do not interfere with sampling and data collection for the other resources.

Control areas were identified for this assessment. These control areas are described in greater detail in the injury chapters and accompanying appendices.

1.2 REPORT ORGANIZATION AND SUMMARY OF FINDINGS

Soil, vegetation, and wildlife resources are ecologically inter-dependent (Figure 1-2). For example, hazardous substances released from sources are transported in the air to soils. Accumulation of these substances in the soil causes phytotoxic responses, including plant mortality and reduced seed germination. This, in turn, eliminates vegetation required as habitat by wildlife species and reduces the viability of wildlife populations. Because of these relationships, the assessment of injury to these components has been conducted and reported collectively.

Chapter 2.0 demonstrates that the Anaconda smelter was the primary source of hazardous substances in the upland areas near Anaconda. Additional sources include waste piles and ongoing fugitive emissions from waste piles and contaminated soils. Chapter 2.0 also describes leaching, erosion, and biological uptake pathways by which soil and vegetation resources have been and continue to be contaminated by hazardous substances.

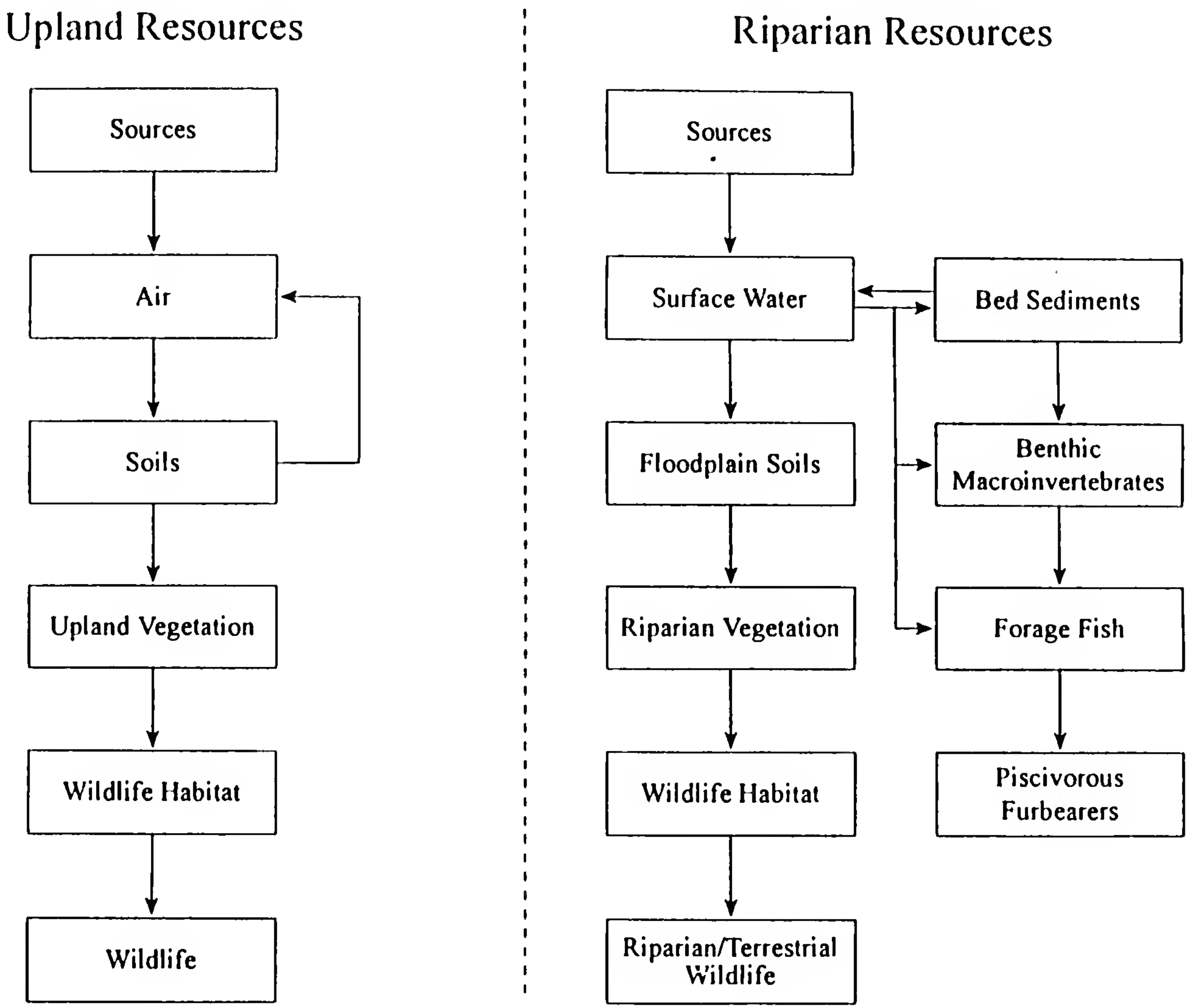

Figure 1-2. **Ecological Relationships of Terrestrial Resources in the Upper Clark Fork River Basin.**

Chapter 3.0, together with two related appendices, Assessment of Injury to Soils (Appendix A) and Assessment of Phytotoxicity (Appendix B), presents the determination and quantification of injury to upland soils. The results of the assessment of injury to these soils demonstrate that:

- 17.8 square miles of surface soils in the uplands surrounding Anaconda contain concentrations of the hazardous substances arsenic, cadmium, copper, lead, and zinc that are significantly elevated relative to baseline.
- Concentrations of hazardous substances decrease with depth, indicating a recent and common origin of the hazardous substances.
- Concentrations of hazardous substances decrease with distance from the Anaconda smelter, confirming that it was the principal source of hazardous substance releases to upland soils; fugitive emissions from exposed soils confirm that re-releases are ongoing.
- Controlled laboratory studies of phytotoxicity using standard laboratory test species grown in exposed soils confirmed that they are phytotoxic and hence are injured. Phytotoxic effects included reduced seed germination rates (death), and reduced growth of roots and shoots.
- Concentrations of hazardous substances in impacted soils are correlated with the degree of phytotoxicity determined in laboratory phytotoxicity tests.
- Injury to soils is further confirmed by injuries to vegetation communities, as quantified in field studies.

Chapter 4.0, together with Appendices C and D, describe the degree and extent of injury to upland vegetation and wildlife (through the loss or degradation of wildlife habitat). The results of the assessment of injury to vegetation and wildlife habitat indicate that:

- 17.8 square miles, including portions of Stucky Ridge, Smelter Hill, and the Mount Haggin area, are extensively devegetated or support impoverished vegetation communities.
- Throughout the 17.8 square mile injured area, a community-level phytotoxic response has occurred. This is characterized by reductions in or complete loss of vegetative cover; decreased cover of native plants and increased cover of invasive weed species; and shifts in plant community types from predominantly forests with open grassland to predominantly sparse grassland or bare ground.

- The observed community-level response is consistent with the effects of accumulated metals and arsenic in surface soil horizons. The response is inconsistent with known effects of fire, logging, grazing, and SO_2 deposition on vegetation communities.

- Vegetation reduction and loss (measured as percent bare ground) was positively (and statistically significantly) correlated with degree of phytotoxicity and concentrations of hazardous substances.

- Vegetation community complexity and habitat availability and suitability (measured as number of habitat layers) were negatively (and statistically significantly) correlated with degree of phytotoxicity and concentrations of hazardous substances.

- The structural complexity normally provided by indigenous upland vegetation communities in southwest Montana has been significantly reduced in the Anaconda uplands. This structural simplification has reduced the available habitat for wildlife species.

- Habitat for wildlife species that depend on the two main indigenous habitat types (conifer forest or forest/grassland edge), is significantly reduced in suitability and availability relative to baseline.

- The loss of suitable habitat (including protective cover and forage) has resulted in decreased viability of wildlife populations.

- The ability of the injured upland areas to revegetate and provide wildlife habitat is precluded by phytotoxic levels of hazardous substances in soils. Throughout much of the injured upland area, current injuries are likely to persist indefinitely without restoration.

Chapter 5.0 briefly describes sources of hazardous substances to riparian resources. These sources are described in detail in the *Aquatic Resources Injury Assessment Report* (Lipton et al., 1995). Upstream sources associated with mining and mineral-processing operations in Butte and Anaconda are identified as the sources of hazardous substance releases to riparian resources.

Chapter 6.0, together with Appendices A and B, presents the determination and quantification of injury to riparian soils. The results of the assessment of injury to soils indicate that:

- Some 800 acres of floodplain soils along Silver Bow Creek, 215 acres on the upper Clark Fork River, as well as the approximately 3,400 acres of the Opportunity Ponds, contain the hazardous substances arsenic, cadmium, copper, lead, and zinc at concentrations that are significantly elevated relative to baseline.

- Controlled laboratory studies of phytotoxicity using standard laboratory test species and hybrid poplars (a surrogate for native riparian willows and cottonwoods) grown in exposed soils confirmed that these soils are severely phytotoxic and hence are injured. Phytotoxic effects included reduced seed germination rates (death), and reduced growth of roots and shoots. In addition, riparian soils throughout this injured area demonstrate pH values less than 4.0, and hence are injured.

- Injury to riparian soils is further confirmed by field studies demonstrating the almost complete absence of vegetation on impacted floodplains.

Chapter 7.0, together with Appendix C, describes the degree and extent of injury to riparian vegetation and wildlife (through the loss or degradation of wildlife habitat). The results of the assessment of injury to vegetation and wildlife habitat indicate that:

- Some 1,000 acres of floodplain soils along Silver Bow Creek and the upper Clark Fork River, as well as the approximately 3,400 acres of the Opportunity Ponds, are almost completely devegetated or support impoverished vegetation communities.

- Throughout these areas, a community-level phytotoxic response has occurred. This is characterized by reductions in or complete loss of vegetative cover; decreased cover of native plants; shifts in plant community types from predominantly riparian forest/shrub-communities and agricultural use to predominantly grassland or bare ground; and loss of habitat layers.

- The structural complexity normally provided by riparian vegetation communities has been significantly reduced. The result of this structural simplification is a reduction in the available habitat for wildlife species.

- Habitat for wildlife species that depend on riparian forest/shrub communities is significantly reduced in suitability and availability relative to baseline.

- The loss of suitable habitat (including protective cover and forage) has resulted in decreased viability of wildlife populations.

- The ability of the injured riparian areas to revegetate and provide wildlife habitat is precluded by phytotoxic levels of hazardous substances in soils. Throughout much of the injured upland area, current injuries are likely to be persist indefinitely without restoration.

Chapter 8.0, together with Appendix E, determines and quantifies injuries to piscivorous furbearers, specifically otter, mink, and raccoon. The results of this analysis demonstrate that:

- Piscivorous furbearers have been, and continue to be, exposed to elevated concentrations of hazardous substances in their diets — as demonstrated by tissue analysis of representative prey and by significantly elevated tissue concentrations in mink trapped from the Clark Fork River relative to those in minks trapped at control sites.
- Dietary exposure concentrations of lead exceed a safe tissue residue criterion.
- Populations of otter, mink, and raccoon are significantly reduced relative to baseline conditions. Otter are completely absent from Silver Bow Creek and the Clark Fork River from Warm Springs Ponds to Milltown. These population reductions are not caused by human disturbance, trapping, land use, or other human impacts.

1.3 REFERENCE

Lipton, J., H. Bergman, D. Chapman, T. Hillman, M. Kerr, J. Moore, and D. Woodward. 1995. Aquatic Resources Injury Assessment Report, Upper Clark Fork River Basin. Prepared by RCG/Hagler Bailly for the State of Montana, Natural Resource Damage Litigation Program. January.

2.0 SOURCES AND PATHWAYS OF HAZARDOUS SUBSTANCES TO UPLAND RESOURCES

This chapter describes the sources of hazardous substances to upland terrestrial resources. Sources of hazardous substances to riparian resources are described briefly in Chapter 5.0 and in greater detail in Lipton et al. (1995).

The data presented in this chapter support the following conclusions:

- Air has been exposed to hazardous substances through smelter emissions and ongoing releases from exposed soils and waste piles.
- Air has served as an ongoing pathway to terrestrial resources.
- Areal patterns of soil contamination are indicative of a point source located in the Anaconda area.
- The vertical distribution of soil contamination demonstrates that hazardous substances have been released by a surface source rather than reflecting geologic parent material.
- The areal extent of exposure exceeds 100 square miles.

2.1 SOURCE/PATHWAY SUMMARY

Smelting and ore refining began in the Anaconda area in 1884 (Tetra Tech, 1987). From that time until the closure of the Anaconda smelter in September 1980, the smelters owned by ARCO and its predecessors operated nearly continuously. Smelter emissions, transported by air pathways, are a primary source of hazardous substances for hundreds of square miles of surface soils. Mining and mineral-processing wastes disposed of in the Anaconda area are additional sources of hazardous substances. These waste piles and contaminated soils are sources of continuous and ongoing releases of hazardous substances to this day. The principal pathway by which hazardous substances have been transported from the smelter stack and waste deposit sources to upland geologic and biologic resources is the air (either directly from the smelter stack or through aerial re-entrainment of hazardous substances from unconfined waste piles and contaminated soils).

2.2 AIR PATHWAY: EXPOSURE OF AIR TO HAZARDOUS SUBSTANCES

To determine that air has served as a pathway, it was determined that the air resource has been exposed to the release of hazardous substances [43 CFR § 11.63 (d)].

2.2.1 Smelter Stack Emissions

Air has been exposed to hazardous substances by direct contact with smelter stack emissions. Stack emissions included compounds of arsenic, copper, cadmium, lead, and zinc (Tetra Tech, 1987). Emissions content varied over the 96 years of operation, changing with the rate of copper production, smelting technology, and efforts at emissions control (Tetra Tech, 1987). The smelting of these ores in Anaconda resulted in oxidation and release of oxides of arsenic, cadmium, copper, lead, and zinc, as well as sulphurous compounds. Smelting thus released hazardous substances to the air. Estimates of emissions are summarized below:

- A study conducted in 1907 measured the average *daily* release from the main chimney in Anaconda at 59,270 pounds (29.65 tons) arsenic trioxide, 4,340 pounds (2.17 tons) copper, 4,775 pounds (2.39 tons) lead, and 6,090 pounds (3.05 tons) zinc (Harkins and Swain, 1907).

- Between 1911 and 1916, the average arsenic discharge from the smelter ranged from 40 to 62 tons *per day* (Anaconda Smelter Smoke Commission, as cited in Taskey, 1972).

- Between 1914 and 1918, arsenic emissions were estimated at 75 tons *per day* (Wells, 1920, as cited in Taskey, 1972).

- In 1962, the arsenic content of air in the town of Anaconda averaged 0.45 $\mu g/m^3$, and was among the highest concentrations in the country (Montana State Board of Health, 1962, as cited in Taskey, 1972).

The Anaconda Minerals Company kept monthly records of main stack emissions during the 1970s (B. Raisch, Montana Air Quality Bureau, pers. comm.). The data from one of the reports (October 1976) are presented in Table 2-1. These data show that in October 1976, some 190 tons of arsenic and 160 tons of copper were released to the air. Information regarding main stack emissions is available for all months during 1974, eight months in 1975, one month in 1976, three months in 1979, and two months in 1980 (see Figure 2-1 and Appendix A). Overall, these data demonstrate that air was exposed to hazardous substances. In addition, the U.S. Environmental Protection Agency (U.S. EPA) collected emission samples downwind from the baghouse, installed in 1975, and found that elemental arsenic was 60% of the mass of fine particulates released (U.S. EPA, 1983; Tetra Tech, 1987).

Table 2-1
Record of Main Stack Emissions for the Period Between October 1 and October 31, 1976

Constituent	Assay	Quantity (total tons)
Copper	14.1%	160.022
Lead	4.88%	55.383
Zinc	5.91%	67.073
Arsenic	16.74%	189.983
Sulfur	9.0%	102.141
Bismuth	0.59%	6.695
Antimony	0.36%	4.426
Cadmium	0.46%	5.220
Tellurium	0.29%	3.291
Insoluble	14.4%	163.427
Silver	9.44 (oz/ton)	10,713.550 (total oz)
Gold	0.0575 (oz/ton)	65.257 (total oz)

Source: Report signed by Morris W. Bowman, Chief Environmental Engineer, The Anaconda Company, Montana Mining Division, December 21, 1976 (Bowman, 1976).

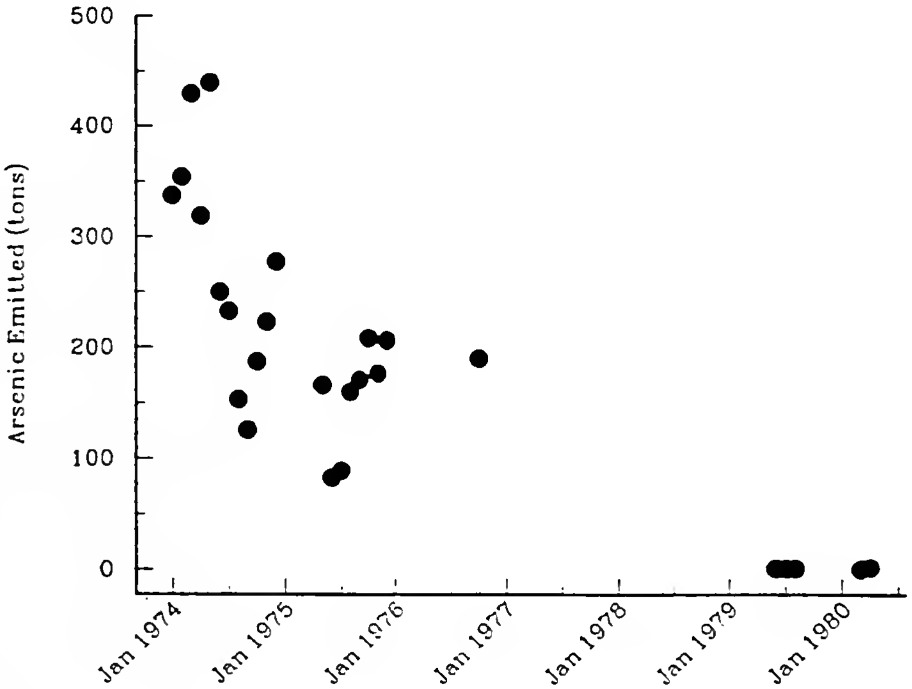

Figure 2-1. Arsenic Emitted from the Anaconda Smelter Main Stack, 1974-1980.

Engineering controls to reduce emissions were added in 1971, 1975, and 1976 (Table 2-2), and together with reduced production beginning in 1977, resulted in an exponential decline in the release of arsenic (and other hazardous substances) (Figure 2-1). Since no major emissions control modifications appear to have been made between 1924 and 1971, releases of hazardous substances during the 96 years of operation were most likely substantially greater than those indicated by 1970s data.

2.2.2 Fugitive Emissions

Air continues to serve as a pathway through re-entrainment of previously deposited hazardous substances. Exposure of air to these fugitive emissions from unconfined waste sources has been confirmed at numerous sites associated with the Anaconda smelting operations. A U.S. EPA Record of Decision (ROD) issued in 1987 ordered the removal and relocation of the town of Mill Creek and its inhabitants, in part because of fugitive emissions of flue dust near the smelter and from adjacent highly contaminated soils (U.S. EPA, 1987).

The disposal of large volumes of waste from mineral processing in Anaconda in tailings ponds, waste piles, and structural fill areas has resulted in large source areas for fugitive emissions releases. In the Old Works/East Anaconda Development Area Operable Unit, waste sources include the Old Works structural areas, flues 1-6, waste piles 1-8, heap roast slag piles, Red Sands waste, (former) Old Works Waste Ponds, Warm Springs Creek floodplain, railroad beds, soils in disturbed areas contaminated with mixed deposits of processing wastes, flue dust piles, and physically undisturbed soils that have been impacted by smelter emissions (ARCO, 1992; PTI, 1992a).

In the Smelter Hill Operable Unit, waste sources include soils in the primary Handling/ Process/Storage areas to depths exceeding 48 inches, and soils in the East Anaconda Yard (location of the main entrance, a sulfuric acid plant, a crushing plant, a brick plant, and a railroad yard during the period of operation, and the Bradley Ponds, which received sludge from the flue gas scrubber during smelter operation) (PTI, 1991a). Hazardous substance concentrations increase with depth in the East Anaconda Yard, reaching maximum concentrations measured at depths greater than 48 inches. Where reclamation has taken place (covering with 18 inches of imported soils), metals concentrations are lowest. The coal pile tracks, railroad beds, and soils in the main stack area also contain waste materials and exhibit extreme concentrations to depths of 48 inches or more (PTI, 1991a). Reclaimed soils, wastes underlying reclaimed soils, and all unreclaimed soils impacted by smelter emissions during the period of operation also serve as sources of hazardous substances to upland resources. Evidence of exposure via fugitive emissions includes data from 24-hour average concentrations of total suspended particulates, arsenic, cadmium, and lead in Anaconda air. Four stations were monitored between April 1984 and March 1986; concentrations ranged over two or more orders of magnitude (compare maximum and minimum columns in Table 2-3) (Tetra Tech, 1987).

Table 2-2
Anaconda Smelter History

1884	Upper Works begins operations, 26 reverberatory furnaces with individual stacks, capacity = 500 tons of ore/day.
1886	Upper Old Works capacity doubled (1,000 tons ore/day). All furnaces connected to a 200 ft stack.
1888	Lower Old Works begins operating. 29 reverberatory furnaces connected by flues to 3 stacks. 800 tons ore/day capacity.
1889	Lower Old Works destroyed by fire, rebuilt. Total capacity of Old Works : 4,000 tons ore/day.
1890	Converter plant built between Upper and Lower Works.
1894	Second converter built east of Lower Works, connected to a single stack.
1902	Washoe Smelter begins operations, 14 furnaces, 12,000 tons ore/day capacity. Roasters, blast furnaces, and converters connected by flues to four separate stacks.
1903	Upper and Lower Works closed. New flue system installed and connected to single 300 ft. stack.
1918	Cottrell electrostatic precipitators installed on main flue. Precipitator dust sent to arsenic recovery plant.
1919	New 585 ft stack completed on main flue.
1924	Selective flotation process begins. Reduced volume and temperature of flue gases entering Cottrells allows increased recovery of flue dust and reduces SO_2 emissions.
1942-1969	Three H_2SO_4 (sulfuric acid) production plants built.
1961	Concentrate brought from Weed concentrator in Butte. Washoe concentrator use becomes intermittent.
1964	Arsenic recovery plant closed. 1,000 tons flue dust/month shipped to ASARCO in Tacoma, WA.
1971	Steel balloon flue built, gas and dust collection improved. Spray chambers built, temperature control of flue gas improved.
1972	Flue dust shipments to ASARCO cease.
1973	Acid plant built. SO_2 emissions reduced.
1974-1977	Arbiter plant operates.
1975	Baghouse dust collector built, particulates emissions reduced. Converter hoods built, fugitive gas emissions reduced.
1976	New flue from electric furnace to baghouse built.
1977	Reverberatory furnaces closed. Two maintained on standby status. Cottrells closed.
1980	Washoe Smelter closed.

Source: Tetra Tech, 1987.

Table 2-3
Summary of Air Quality Data for Four Stations in the Anaconda Smelter Site Area — High-Volume Sampler Data

Station (operator)	Variable	Period of Record	Number of Samples	Arithmetic Average (µg/m³)	Minimum (µg/m³)	Maximum (µg/m³)
Johnson's Curve (AMC)	TSP	1/1/84 - 3/27/84	134	20	1	96
	Arsenic	4/6/84 - 3/27/86	118	0.007	0.001	0.127
	Cadmium	4/6/84 - 3/27/86	118	0.009	0.001	0.092
	Lead	4/6/84 - 3/27/86	118	0.02	0.01	0.19
Highway Junction (State)	TSP	7/14-84 - 6/1/86	216	35	1	825
	Lead	7/14/84 - 4/1/85	77	0.08	0.01	1.22
Lincoln School (AMC)	TSP	1/1/84 - 3/27/86	135	55	10	418
	Arsenic	4/6/84 - 3/27/86	120	0.016	0.001	0.221
	Cadmium	4/6/84 - 3/27/86	120	0.003	0.001	0.021
	Lead	4/6/84 - 3/27/86	120	0.04	0.01	0.21
Lincoln School (State)	TSP	1/1/84 - 6/1/86	140	54	12	245
	Lead	1/1/84 - 4/1/85	69	0.03	0.01	0.13

Source: Tetra Tech, 1987.

The highly variable air quality is due in part to wind-induced fugitive dust levels. These data confirm that air has continued to be exposed to ongoing releases of hazardous substances.

Ongoing exposure of air to hazardous substances through re-entrainment of wastes on Smelter Hill is also confirmed by concentrations of arsenic, cadmium, copper, lead, and zinc determined in dustfall samples. Thirteen dustfall samplers were placed downwind of source areas at or near Smelter Hill property boundary lines in July 1989 (McVehil-Monnet, 1992a,b; PTI, 1991a). Maximum monthly concentrations of hazardous substances in dustfall through March 1991, as reported in the Preliminary Site Characterization Information Report for the Smelter Hill RI/FS (PTI, 1991a), were 115,333 ppm arsenic, 10,800 ppm cadmium, 390,000 ppm copper, 51,333 ppm lead, and 199,677 ppm zinc. Maximum concentrations reported for dustfall sampling in 1992 were substantially lower (Table 2-4) (ARCO, 1992; McVehil-Monnet, 1992a,b). All concentrations reported (PTI, 1991a; ARCO, 1992; McVehil-Monnet, 1992a,b) demonstrate a continuing release of hazardous substances from Smelter Hill, and a potential for exposure and transport of hazardous substances away from Smelter Hill.

The Anaconda Soil Investigation (ASI) has identified patterns of high surface soil concentrations of arsenic (exceeding 600 ppm) and copper in soils north and northwest of the Opportunity Ponds (PTI, 1992b). These high soils concentrations have been attributed to fugitive emissions from the Opportunity Ponds based on the prevailing wind directions in the Deer Lodge Valley and proximity of the contaminated soils to the Opportunity Ponds (PTI, 1992b). In addition, in the Old Works area, Red Sands (a waste deposit) material has been detected in soil samples collected west and southwest of the sewage treatment ponds, and in soils adjacent to the Red Sands waste pile, suggesting wind or water erosion as pathways of transport (PTI, 1992a). Arsenic concentrations exceeding 300 ppm in the extreme eastern section of Anaconda have been attributed to prevailing wind patterns and close proximity to the Old Works and Washoe Smelter sites (PTI, 1992b).

2.3 AIR PATHWAY: AREAL EXTENT OF EXPOSURE

2.3.1 Historical Accounts

The areal extent of exposure is defined as the geographical surface area or space where emissions from the source of discharge or release are found or otherwise determined to be present for such duration and frequency as to potentially result in injury to resources present within the area or space [43 CFR § 11.63 (d)(3)(ii)]. The areal extent of air exposed to concentrations and duration of emissions sufficient to have caused injury can be defined by the areal extent of injured soils and vegetation. Historical accounts document the visible reach of the smelter plume extending as far north as Garrison, south to Butte, and southwest up Mill Valley to the Continental Divide (Swain and Harkins, 1908; Peirce et al., 1913):

Table 2-4
Summary of Trace Metal Concentrations (ppm) in Dustfall Samples Collected by 13 Dustfall Samplers

Month	Arsenic			Cadmium			Copper			Lead			Zinc		
1992	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
Jan	2,423	10,986	43	72	183	3	7,911	12,700	413	1,144	4,564	23	2,772	3,686	388
Feb	2,516	12,100	520	62	210	20	6,975	18,800	1,460	1,408	3,015	380	7,315	16,100	2,470
Mar	672	2,350	9	25	85	1	2,016	4,890	49	388	1,150	9	4,011	8,099	236
Apr*	1,242	4,633	117	46	189	3	2,933	7,950	786	607	1,621	118	3,176	8,950	1,292
May	244	1,261	35	8	22	2	821	3,595	128	122	550	5	1,018	4,405	188

Note: Samplers were maintained as part of the Anaconda Smelter RI/FS Air Resources Sampling Program (McVehil-Monnet, 1992a,b).
* Data from 10 samplers only.

> . . . the smoke stream can be traced as far as the eye can reach . . . trailing down the valley for 30 miles toward Garrison, or often eastward in the direction of Butte, or sweeping over into the Mill Valley and filling the narrow ravines which lead down from the Continental Divide, 14 miles to the south.
>
> The Mill Valley district southwest of the smelter is the one toward which the smoke blows most during the early summer, while in late August the air currents begin to go northward down the Deer Lodge Valley, and from this time until the snow covers the ground the greater part of the smoke blows in this direction (Swain and Harkins, 1908).

Smelter fumes could be detected as far west as Georgetown Lake, and 25 miles southwest, across the Continental Divide (Peirce et al., 1913). Farmers and ranchers in the Deer Lodge Valley reported heavy dust accumulations on floors and rafters of barns. The dust was subsequently determined to have a range of As_2O_3 from 410 to 9,190 ppm (310 to 6,957 ppm As) (Swain and Harkins, 1908). Peirce et al. (1913) reported a pattern of visible injury in forests, including poor needle retention, slow growth, and absence of regeneration, extending 19 miles north, 12 miles east, 10 miles south, 25 miles southwest, and 19 miles west of Smelter Hill.

2.3.2 Areal Patterns Indicative of a Point Source

Measured levels of arsenic, cadmium, copper, lead, and zinc in soils and plants in the Deer Lodge Valley serve as proxy measures of past aerial loadings, and as indicators of dispersal distances of stack emissions. As receptors of hazardous substances, soils and biota also define the extent of injury caused by hazardous substances transported in air.

Previous studies have shown that, in general, concentrations of arsenic, cadmium, copper, lead, and zinc decrease with increasing distance from the smelter (Taskey, 1972; Munshower, 1972; Munshower, 1977). For example:

- Harkins and Swain (1907) measured arsenic concentrations in plant tissue and found arsenic concentrations in grass and hay grown as far as 35 miles from the stack were two to four orders of magnitude (i.e., 100 to 10,000 times) higher than in hay and grass grown 100 miles northwest of the smelter.

- Taskey (1972) found that arsenic, copper, lead, and zinc in the soils near Anaconda were concentrated within the upper 8 inches of the soil profile, and that the highest concentrations were generally within 5 miles of the Old Works and Washoe Smelter sites.

However, because of the topographic complexity of the terrain surrounding the smelter, concentrations of hazardous substances do not decline monotonically with distance:

- Haywood (1910, as cited in Taskey, 1972) found a range of copper concentrations in soils increasing from 485 ppm 9.5 miles northeast of the smelter to 2,791 ppm 12 miles northeast of the smelter.

- Taskey (1972) demonstrated that soils 24 miles north of the smelter possessed greater trace metal content than soils half that distance from the stack, in the same direction, and he identified soils on prominent terrain with unusually high concentrations of hazardous substances. The nonlinear distribution pattern was similar to that reported by Haywood (1910, as cited in Taskey, 1972) for copper.

Munshower (1972) analyzed Deer Lodge Valley grassland soils for cadmium at 53 sites along a 27-mile-long transect extending northeast from the smelter, and two east-west transects 9 and 21 miles northeast from the smelter. Cadmium content in surface soils increased gradually from 2 ppm to the south of Deer Lodge to approximately 3 ppm within 7 miles of the smelter, then rapidly to 30 ppm within 1.5 miles of the smelter (Munshower, 1972) (Figure 2-2). The remaining variation was attributed to fugitive emissions from dry tailings ponds and slag heaps. Cadmium was shown to be elevated in soils relative to background levels (0.2-0.6 ppm) as far as 37 miles from the smelter (Munshower, 1977).

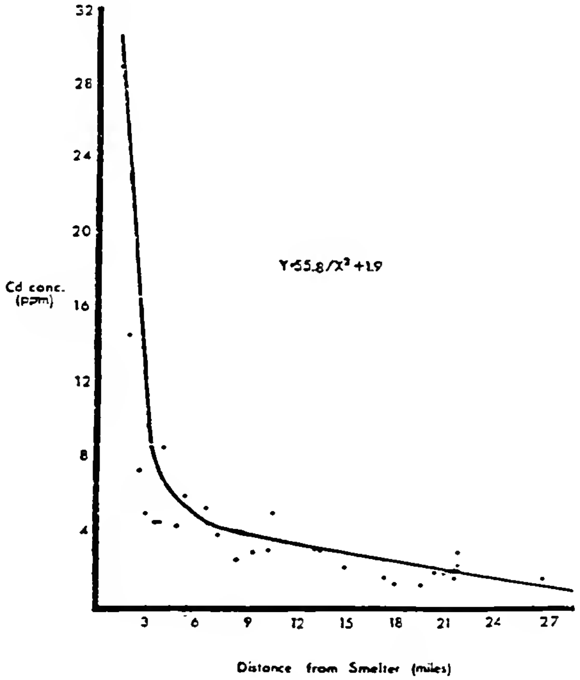

Figure 2-2. Distribution of Cadmium (ppm) in Soil with Distance from the Main Smelter Stack. Source: Munshower, 1972.

Within a 5 ppm cadmium isopol, low soil pH values and high concentrations of heavy metals in the soil were determined to restrict plant community development and germination (Munshower, 1972). Observation of vegetation grown in soils 2 miles from the smelter revealed reduced seed germination rates and restricted root development in plants that survived the seedling stage (Munshower, 1972). In addition, cadmium was determined to be accumulating in forb species and herbivore species to concentrations exceeding the soil concentrations (Figure 2-3). The accumulation of cadmium in herbivores was attributed to both ingestion of contaminated plants and respiratory intake (Munshower, 1972).

Recent sampling efforts have determined patterns of soil concentrations of hazardous substances in proximity to the smelter; most samples have been collected from the Anaconda Smelter site, the Old Works, Anaconda, Opportunity, and Mill Creek (e.g., Appendix A, this report; Taskey, 1972; AMC, 1983; Tetra Tech, 1985a,b; Tetra Tech, 1986; Tetra Tech, 1987; CDM, 1987; CDM, 1988; PTI, 1990; PTI, 1991a,b; PTI, 1992a,b). Within 3 miles of the Anaconda smelter, copper concentrations exceed 1,000 ppm, and arsenic concentrations exceed 1,000 ppm within a 2-mile radius of the stack (Tetra Tech, 1987). The most comprehensive study performed to date is the Anaconda Soil Investigation (ASI) (PTI, 1992b). The ASI covers a 120 square mile area, but does not determine the spatial extent of

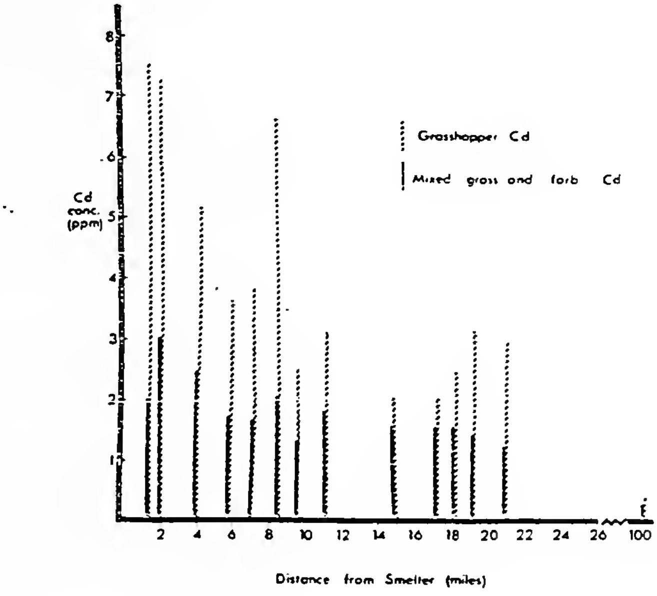

Figure 2-3. **Cadmium Concentrations in Vegetation and Grasshoppers in 1970.** The control site (far right on the x-axis) was 100 miles from the main smelter stack. Source: Munshower, 1972.

elevated metals concentration. Contoured[1] metals concentrations (PTI, 1992b) have shown that the dispersal of metals from smelting in Anaconda is approximately radial with slight elongation to the northeast, possibly reflecting the dominant downwind direction. However, no samples were collected as part of the ASI from the uplands north, west, and southwest of the smelter to identify possible elongation in other directions.

Figure 2-4 shows the location of transects used to describe soil exposure to hazardous substances based on existing data; plots of metal concentration with distance from the smelter, based on data from Taskey (1972), Tetra Tech (1987), and PTI (1992b), are shown in Figures 2-5 through 2-9. Note that the baseline values presented in Figures 2-5 through 2-9 (Brick and Moore, 1992) are mean values of baseline concentrations for U.S. and world soils reported in the scientific literature (Kabata-Pendias and Pendias, 1984; Adriano, 1986; Alloway, 1990; CH_2M Hill et al., 1991). Where a wide range of values was reported, an average value was used, or, in the case of lead, 15 ppm was used because that number was cited by two different authors (Brick and Moore, 1992).

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[1] Contouring of metals concentrations is similar to contouring land surfaces by elevation. Lines of equal concentration (isopleths) are drawn to demarcate the patterns of soil contamination.

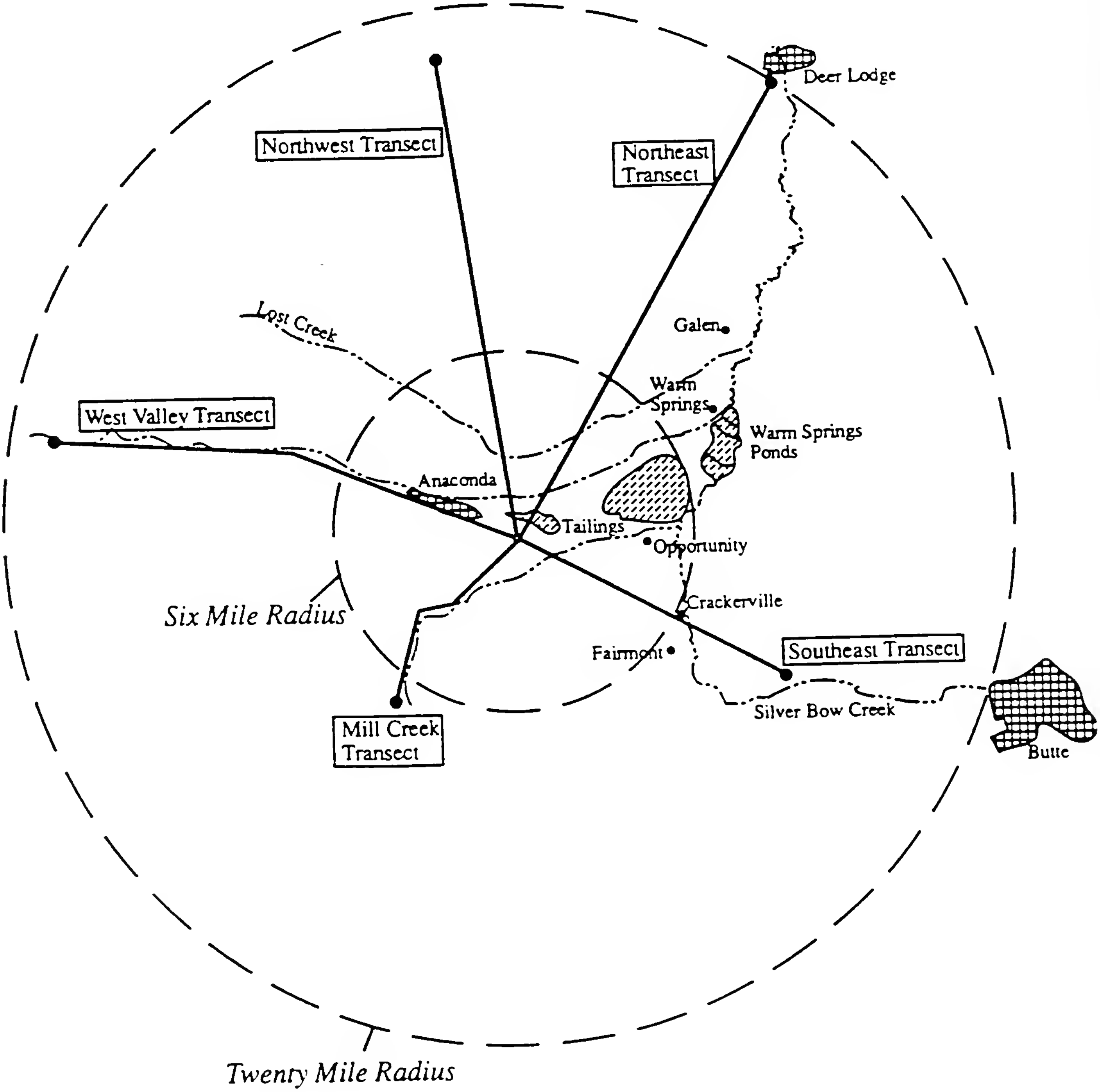
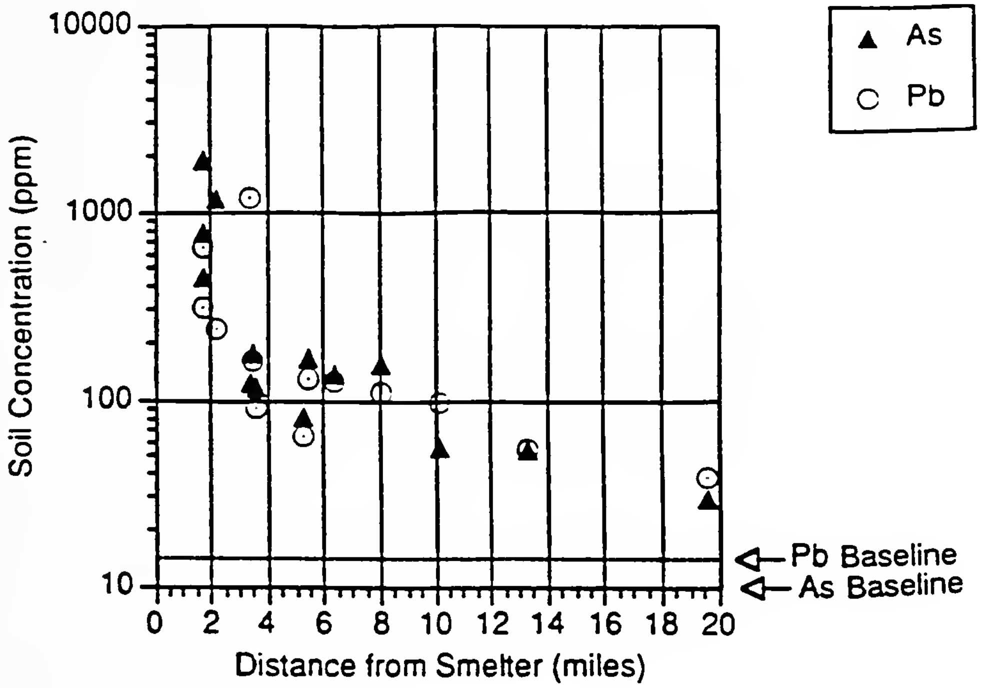


Figure 2-4. Location of Transects in Figures 2-5 through 2-9.



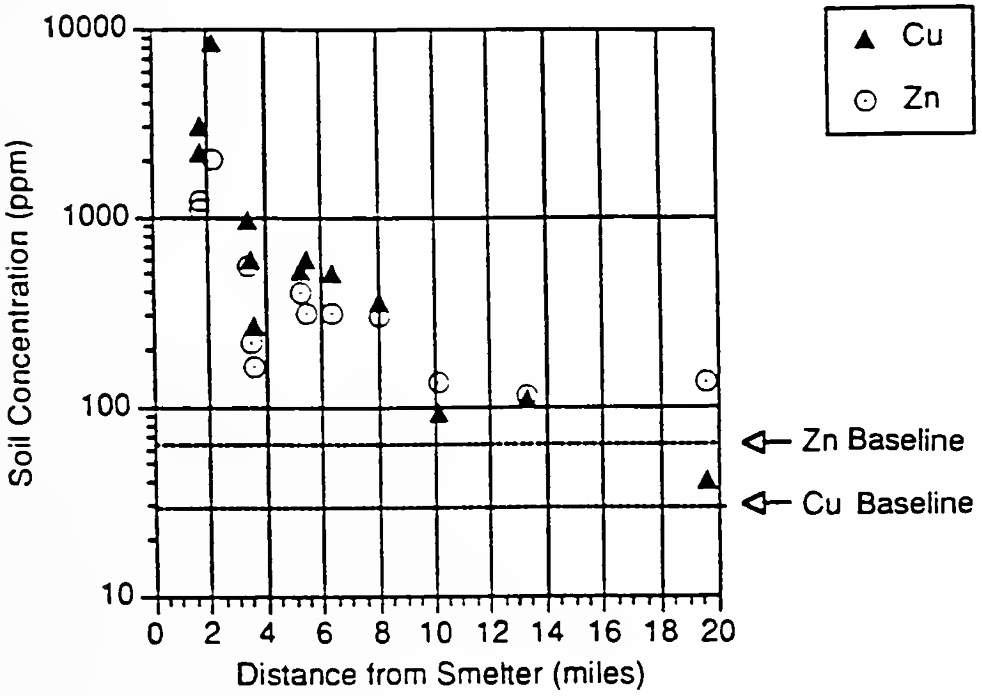


Figure 2-5. **Northwest Transect.** Source: Brick and Moore, 1992.

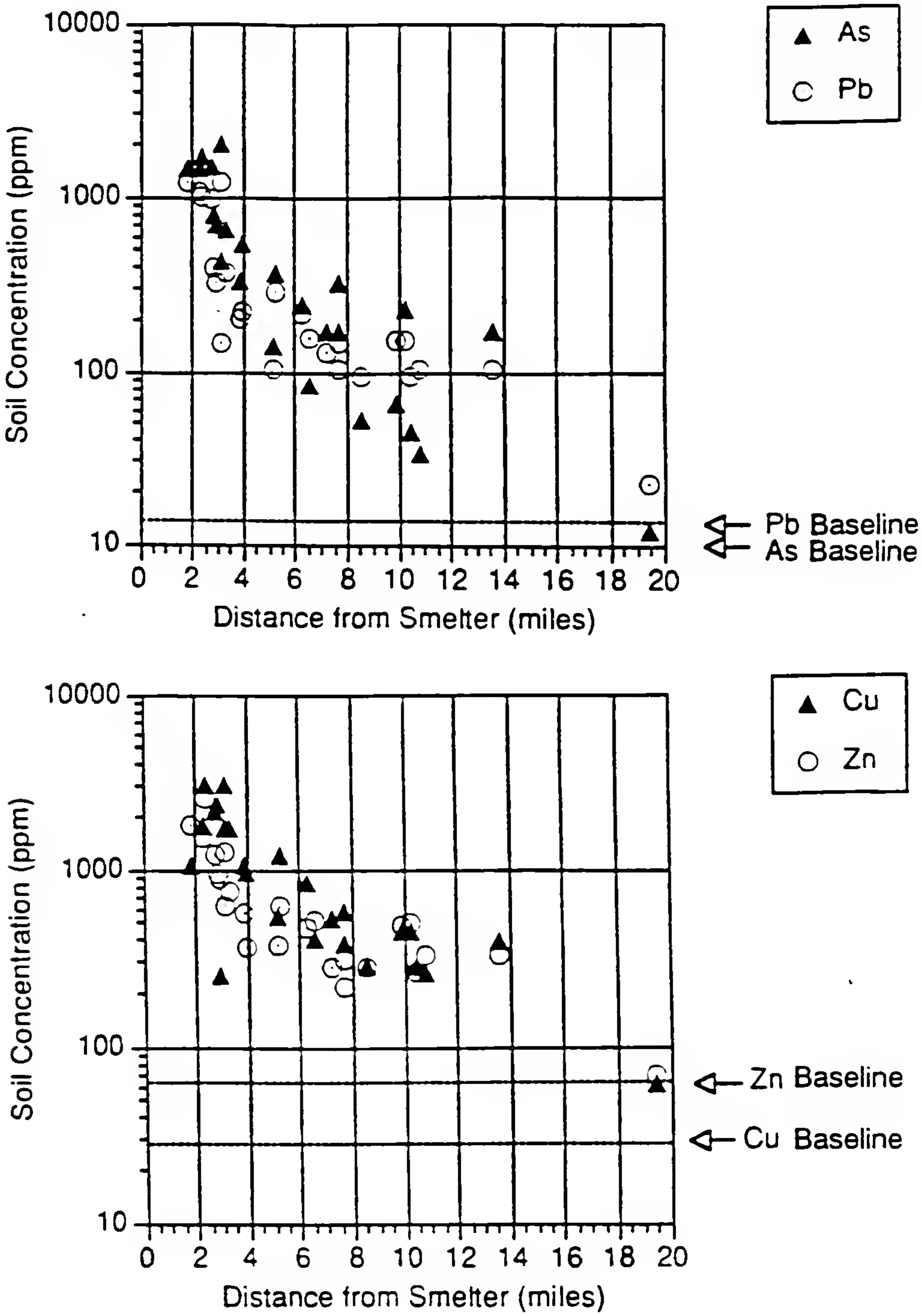


Figure 2-6. Northeast Transect. Source: Brick and Moore, 1992.

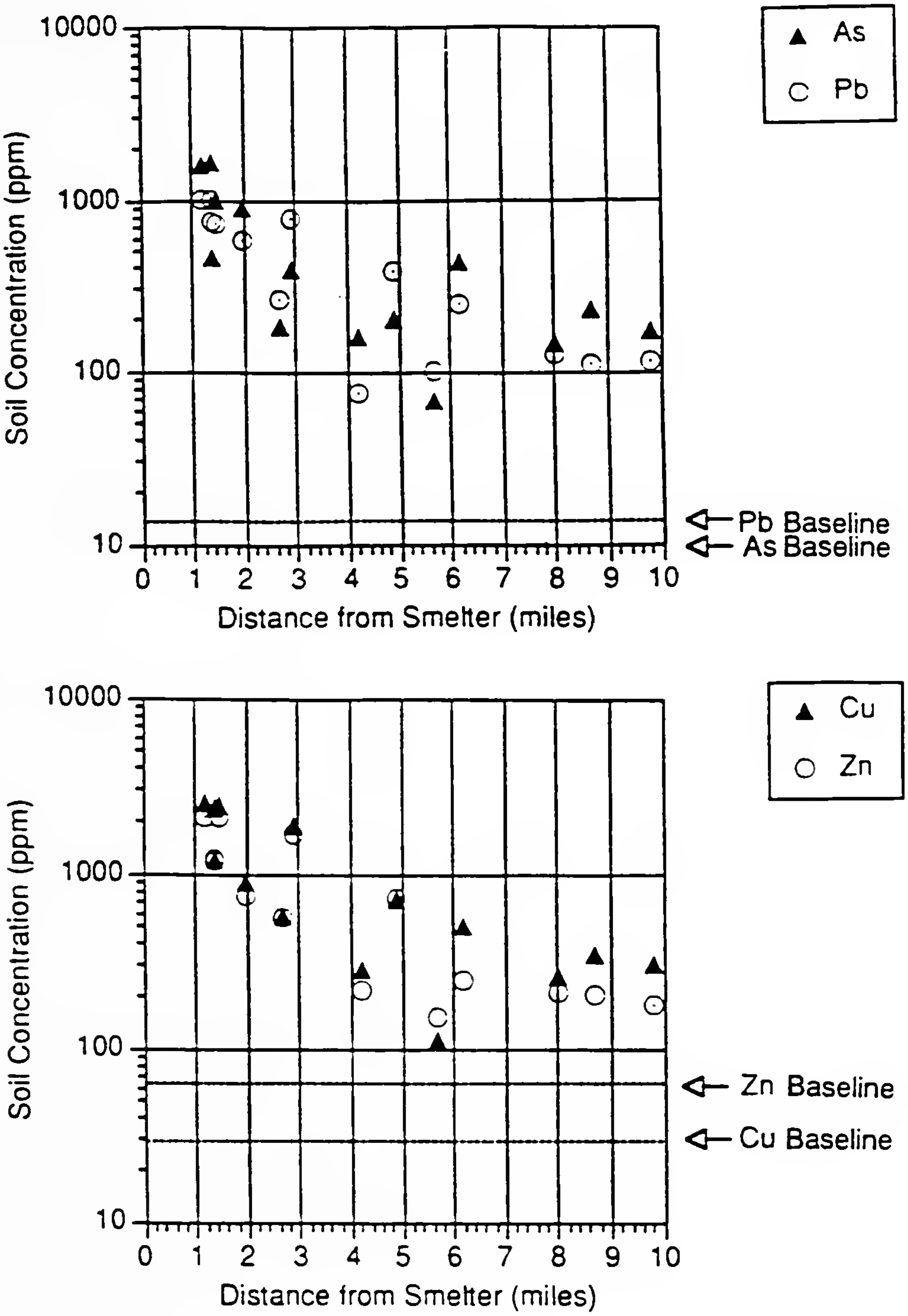


Figure 2-7. Southeast Transect. Source: Brick and Moore, 1992.

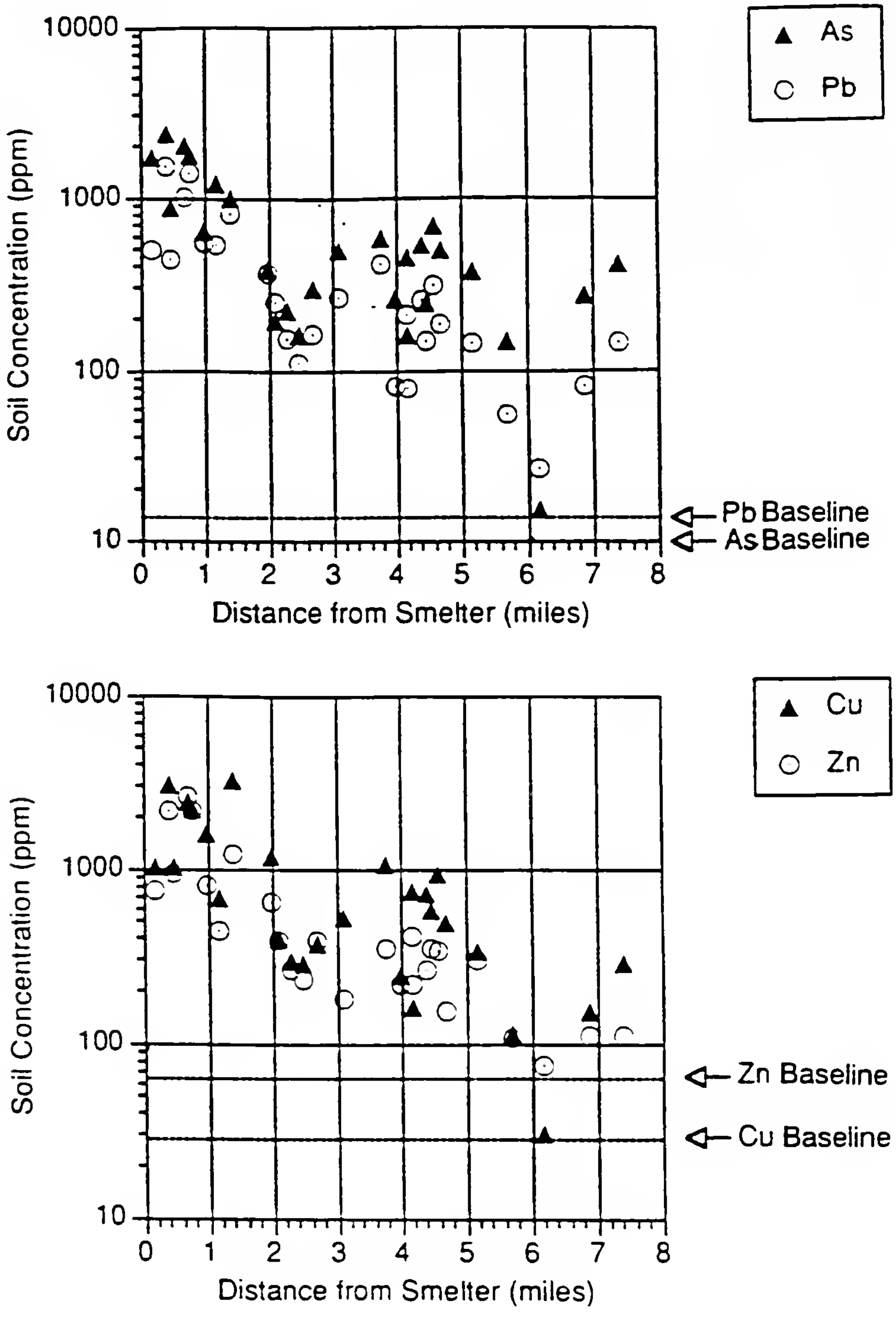


Figure 2-8. Mill Creek Transect. Source: Brick and Moore, 1992.

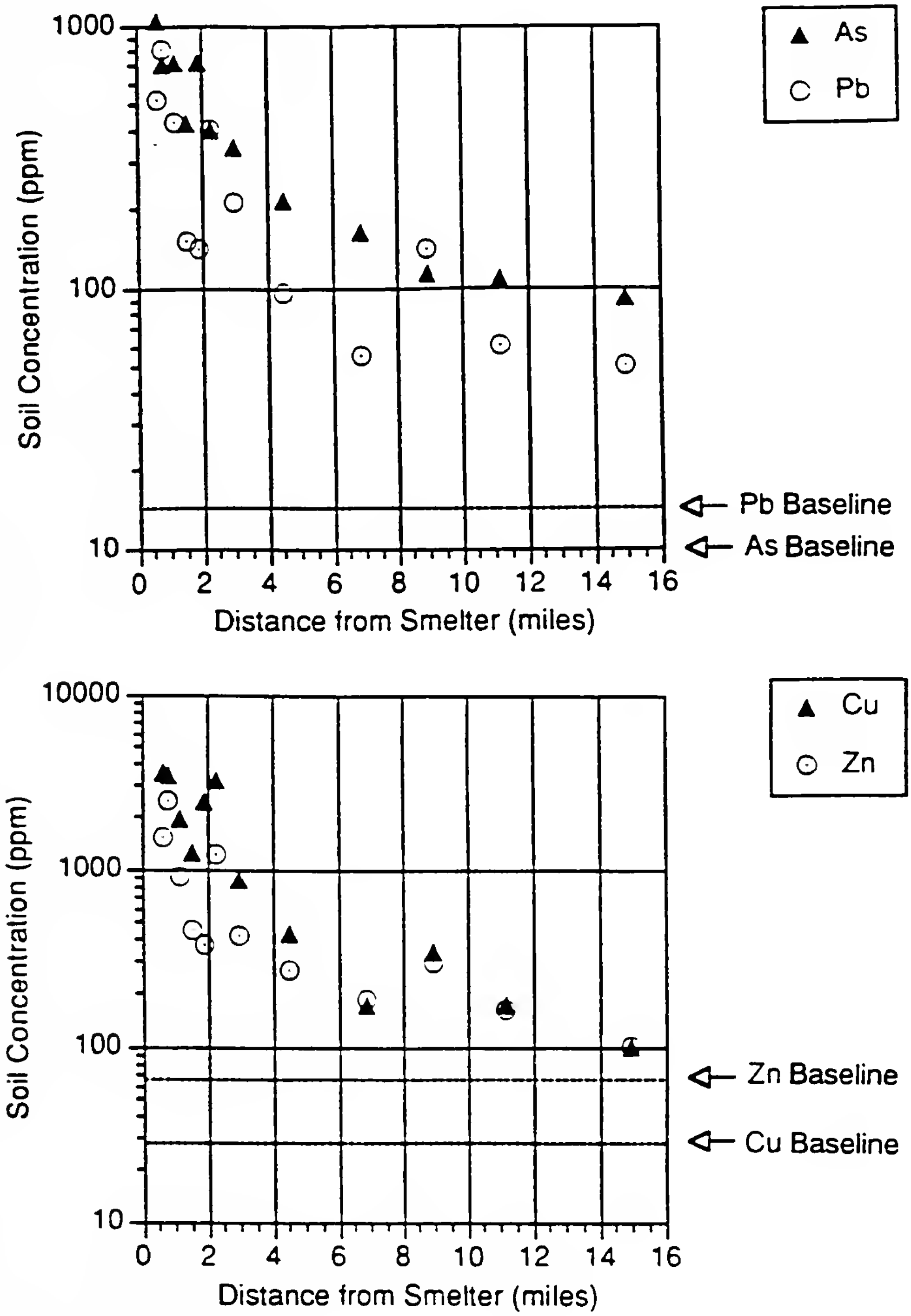


Figure 2-9. West Valley Transect. Source: Brick and Moore, 1992.

Concentrations of arsenic, cadmium, copper, lead, and zinc in surface soils (0-2 inches) collected as part of this assessment (see Chapter 3.0 and Appendix A) were analyzed to assess the relationship between concentration and distance from the stack. Soils were collected from upland, mountainous terrain north (Stucky Ridge), southwest (Smelter Hill and Weather Hill area), and south (Mount Haggin) of the smelter, as well as from matching control areas located south of the smelter in German Gulch. The exponential decline in concentration with distance from the stack for all five elements is illustrated in Figures 2-10 through 2-14. Statistical analyses confirmed that all five relationships exhibit a significantly negative slope ($p = 0.0002$), indicating that soils concentrations decrease with distance from the stack. Such a pattern is typical of contamination emanating from a point source.

The exponential decline with distance illustrated in Figures 2-10 to 2-14 is commonly associated with main point sources of industrial pollution, including metal smelters (Figure 2-15). For example, "halos" of contaminated soils, typically pronounced in a downwind direction, have been observed surrounding a copper smelter in Tacoma, Washington, a gold smelter at Yellowknife, Canada, a zinc smelter in Pennsylvania, and the copper-nickel smelting complex at Sudbury, Ontario, Canada (Kabata-Pendias and Pendias, 1992; Baker, 1990; O'Neill, 1990). At Sudbury, soils enriched with copper extend some 25 miles from the point of release, and within 4 miles of the smelter, soil copper concentrations in excess of 1,000 ppm are common (O'Neill, 1990).

2.3.3 Soil Profile Concentrations Indicative of a Surficial Source

Soils collected from the 0-2 inch and the 0-6 inch layers from exposed upland areas near Anaconda were compared statistically to test for differences in concentrations of hazardous substances (see Chapter 3.0 and Appendix A). The results confirm that concentrations of arsenic, cadmium, copper, lead, and zinc are significantly greater in the upper stratum than in the lower stratum (Table 2-5), indicating that the source of the hazardous substances is surficial rather than attributable to the underlying parent (geologic) material. That even cadmium and zinc (the most mobile of the elements analyzed, and typically rapidly leached from surface soil horizons) are elevated in surface horizons is evidence suggesting a recent and common origin of these hazardous substances.

2.3.4 Fugitive Emissions

Exposure of the air pathway continues through re-releases of hazardous substances via windblown dust. Currently, unvegetated areas in the Anaconda area subject to wind erosion include Smelter Hill, Mount Haggin Wildlife Preserve, the Old Works area, portions of Stucky Ridge, the Anaconda Ponds, the Opportunity Ponds, and the entire flatland between Willow Creek and Lost Creek east of Smelter Hill. The Anaconda Ponds cover approximately 560 acres. The Opportunity Ponds are virtually barren, but in recent years

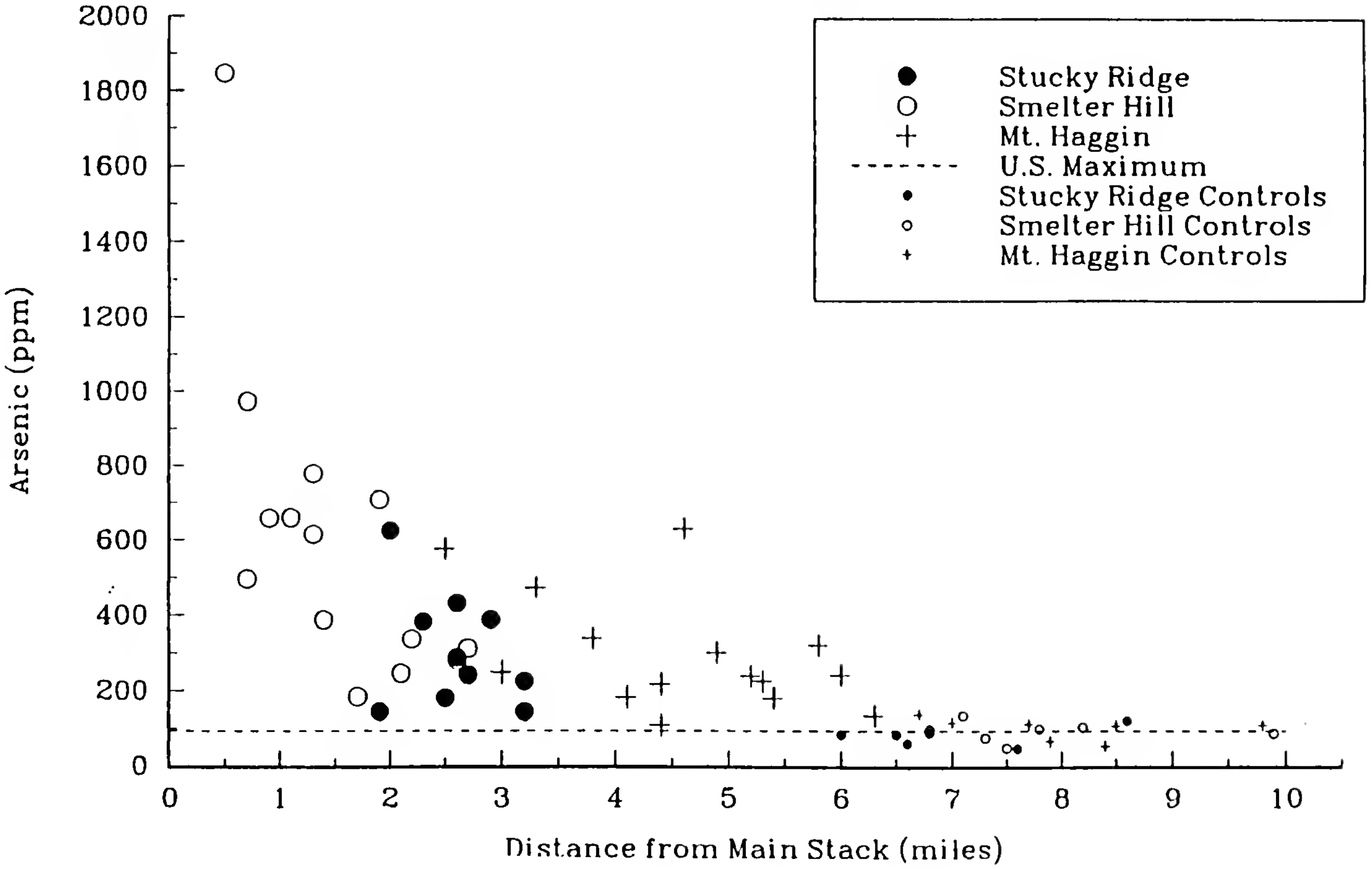


Figure 2-10. Arsenic Concentration in Soils with Distance from the Main Smelter Stack. Data points represent total arsenic (ppm) in 0-2 inch soil samples collected from Stucky Ridge, Smelter Hill, and Mount Haggin impact areas, and from German Gulch control sites. The dashed line indicates the upper end of the range of arsenic concentrations reported for uncontaminated soils of the United States (0.1 to 90.0 ppm) (Kabata-Pendias and Pendias, 1992)

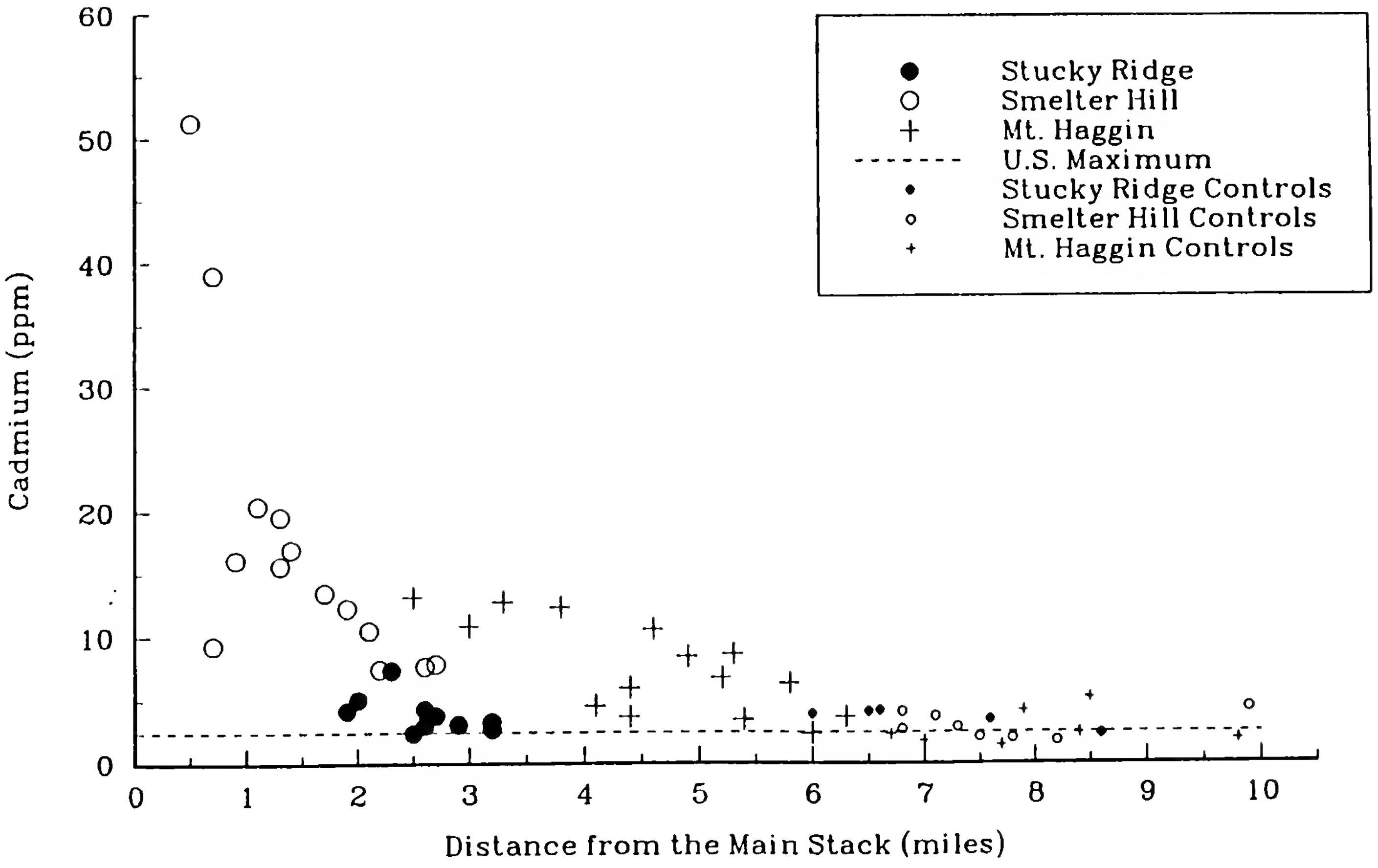


Figure 2-11. Cadmium Concentration in Soils with Distance from the Main Smelter Stack. Data points represent total cadmium (ppm) in 0-2 inch soil samples collected from Stucky Ridge, Smelter Hill, and Mount Haggin impact areas, and from German Gulch control sites. The dashed line indicates the upper end of the range of cadmium concentrations reported for uncontaminated soils of the United States (0.005 to 2.4 ppm) (Alloway, 1990).

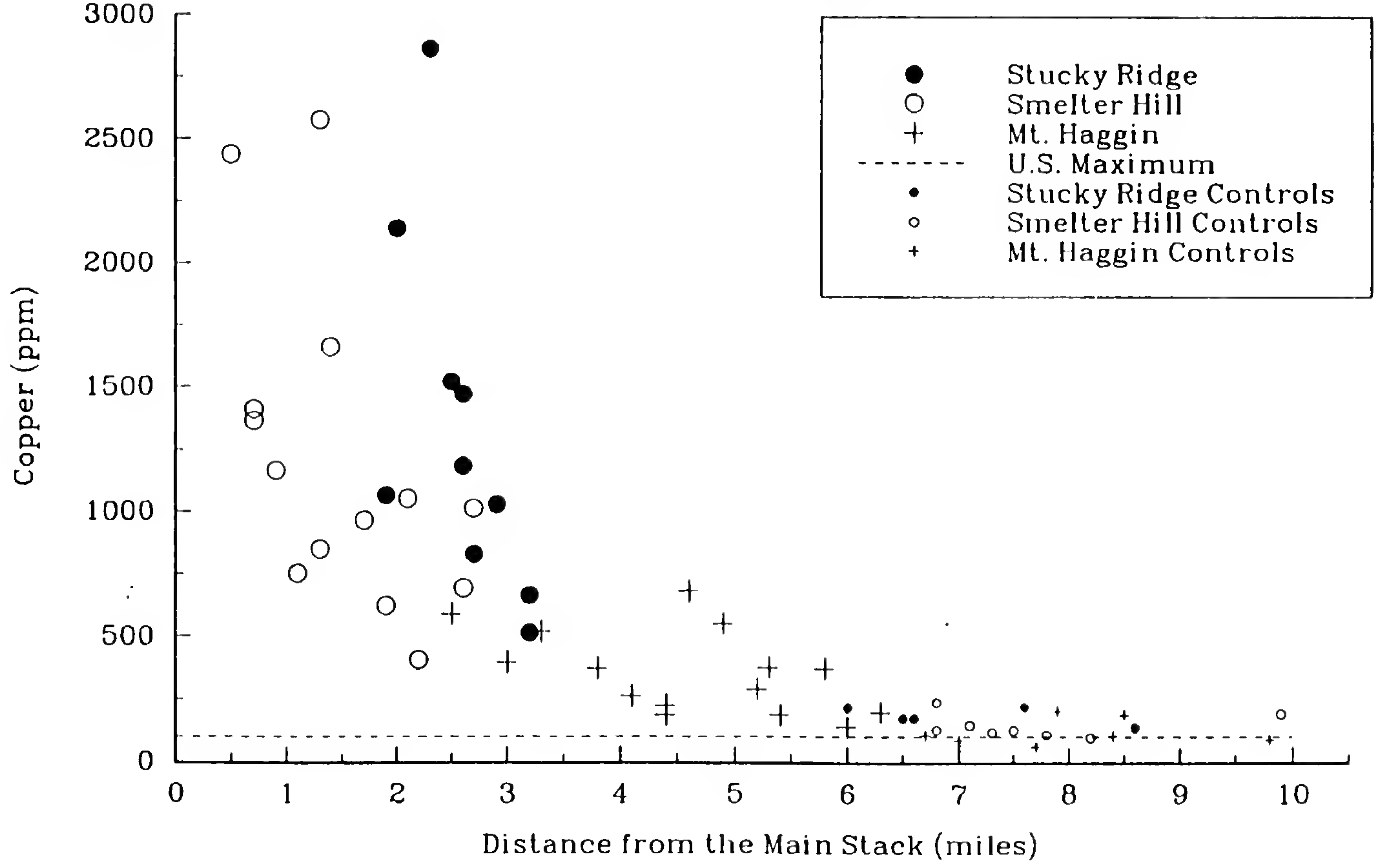


Figure 2-12. Copper Concentration in Soils with Distance from the Main Smelter Stack. Data points represent total copper (ppm) in 0-2 inch soil samples collected from Stucky Ridge, Smelter Hill, and Mount Haggin impact areas, and from German Gulch control sites. The dashed line indicates the upper end of the range of copper concentrations reported for uncontaminated soils of the United States (1 - 100 ppm) (Kabata-Pendias and Pendias, 1992)

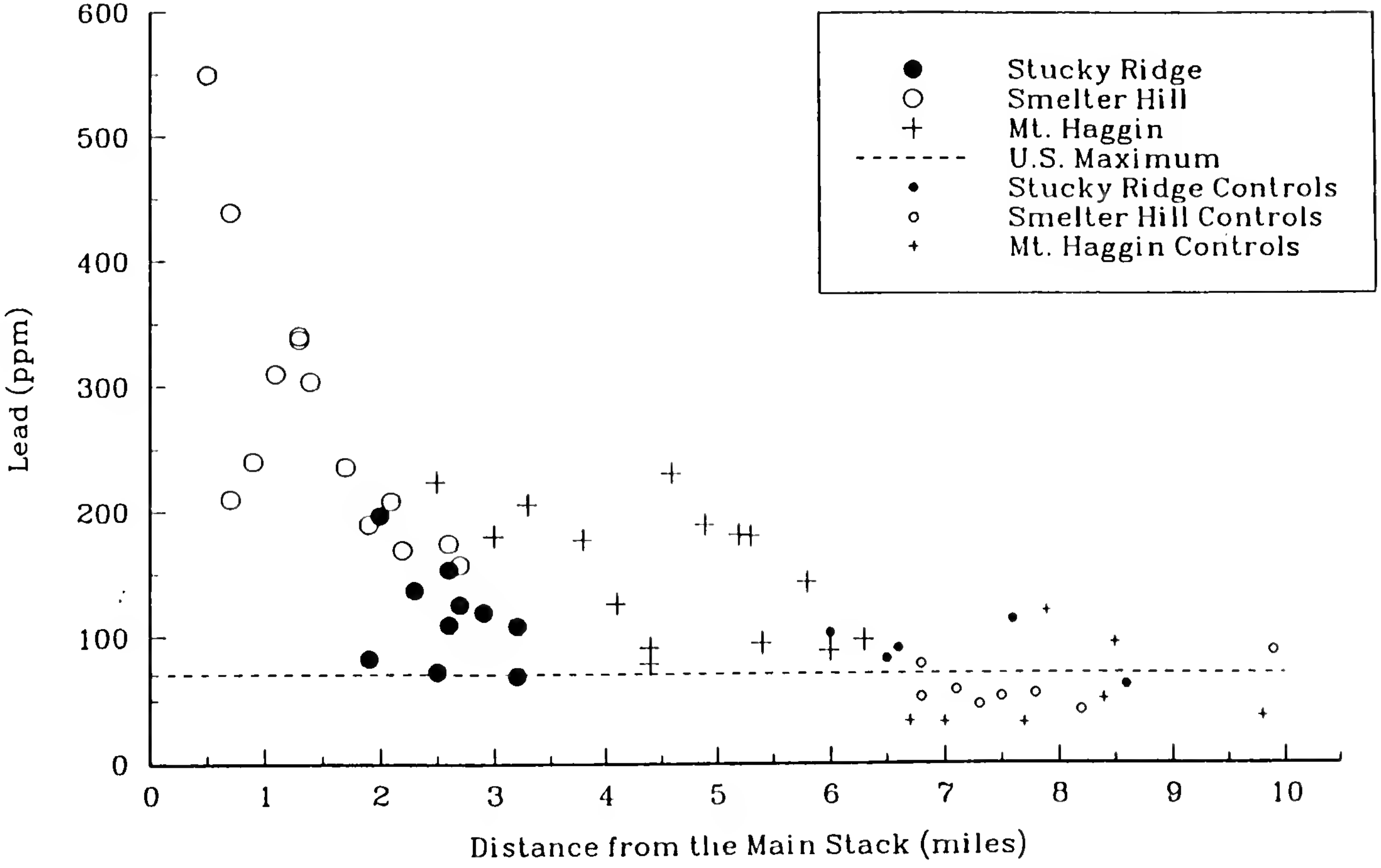


Figure 2-13. Lead Concentration in Soils with Distance from the Main Smelter Stack. Data points represent total lead (ppm) in 0-2 inch soil samples collected from Stucky Ridge, Smelter Hill, and Mount Haggin impact areas, and from German Gulch control sites. The dashed line indicates the highest soil concentration considered to represent naturally occurring lead in soils of the United States (70 ppm) (Kabata-Pendias and Pendias, 1992)

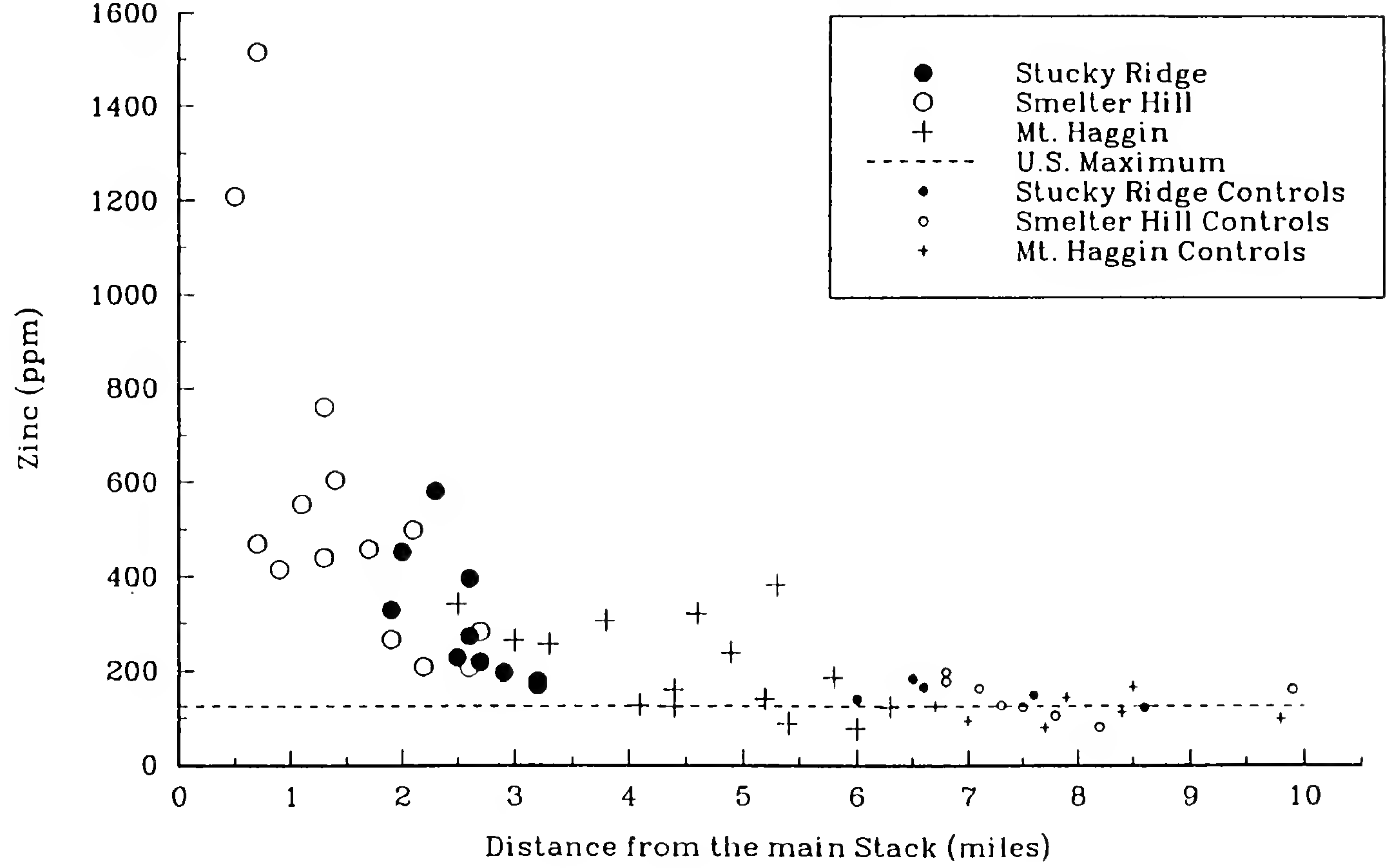


Figure 2-14. Zinc Concentration in Soils with Distance from the Main Smelter Stack. Data points represent total zinc (ppm) in 0-2 inch soil samples collected from Stucky Ridge, Smelter Hill, and Mount Haggin impact areas, and from German Gulch control sites. The dashed line indicates the upper end of the range of mean zinc concentrations reported for uncontaminated soils of the United States (17 - 125 ppm) (Kabata-Pendias and Pendias, 1992)

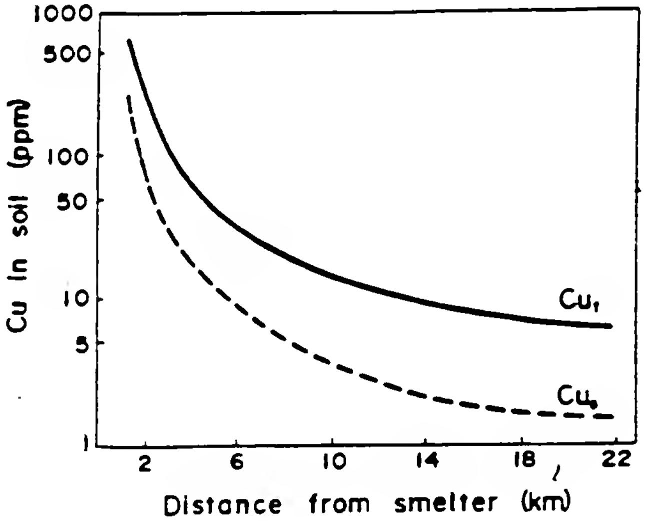


Figure 2-15. Smoothed Patterns for Copper Concentrations in Soils as a Function of Downwind Distance from a Copper Smelter (mean values of 3 years). t = total concentration, s = soluble concentration (Kabata-Pendias and Pendias, 1992).

Table 2-5
Comparison of 0-2 Inch and 0-6 Inch Soil Concentrations:
Upland Areas Near Anaconda (n=12)

Element	p-value[1]
Arsenic	0.0049*
Cadmium	0.00073*
Copper	0.00049*
Lead	0.00024*
Zinc	0.00073*

[1] Compared using Fisher's Paired Permutation Test (Manly, 1991).

* Indicates significantly greater concentrations in the 0-2 inch soil layer at $\alpha = 1\%$.

erosion has been reduced by application of a surfactant. The Opportunity Ponds cover approximately 3,400 acres. There are also 173 acres of slag disposal, 107 acres of nonvegetated rocky barrens, and 498 acres of "industrial disturbance" including former locations of the smelter buildings on Smelter Hill (PTI/MNRIS, 1992).

2.3.5 Areal Extent - Summary

The data described above demonstrates that air in the Deer Lodge Valley has been exposed to smelter and fugitive emissions and has served, and continues to serve, as a pathway of hazardous substances to geologic and biologic resources. Soils exposed by aerial deposition during the 96 years of smelting now are a reservoir of accumulated hazardous substances (Munshower, 1972). The extent of airfall contamination is highest around the Anaconda smelter, as evidenced by soil concentrations within a 6-mile radius (approximately 110 square miles) (Brick and Moore, 1992). In this area, concentrations of metals are approximately 10 times background concentrations, on average. The total area of exposed and contaminated soils is probably closer to 1,260 square miles, which is approximately the area of a 20 mile radius circle around the Anaconda Smelter (Brick and Moore, 1992).

The areal extent of exposed air that historically served as a pathway of hazardous substances, based on elevated concentrations of hazardous substances in surface soils, included air in the Anaconda area, Smelter Hill and the Old Works, Stucky Ridge and the Lost Creek drainage, Mount Haggin Wildlife Refuge and the Mill Creek drainage, and the Deer Lodge Valley to Garrison. Since the emissions and deposition of hazardous substances were prolonged and ubiquitous in the Deer Lodge Valley and uplands to the west, all areas with sparse or no vegetation or other soil covering are potential sources of continuing releases of hazardous substances via fugitive dust.

Surface level winds within at least 1,260 square miles have been exposed to hazardous substances; this represents the extent of transects that have been established to determine soils concentrations, not the extent of contamination. Within a radius of 20 miles, air has been a pathway of smelter emissions to soil, surface water, and vegetation resources.

2.4 MOBILITY AND RATES OF TRANSPORT OF HAZARDOUS SUBSTANCES IN AIR

2.4.1 Main Stack Emissions

Historically, particles emitted in gas streams from flue systems venting smelters and other facilities associated with ore refining in the Anaconda complex were transported by local winds and dispersed. Rates of dispersion of airborne particles depend on the size of the particles and the meteorological conditions. The gravitational settling velocity of a particle

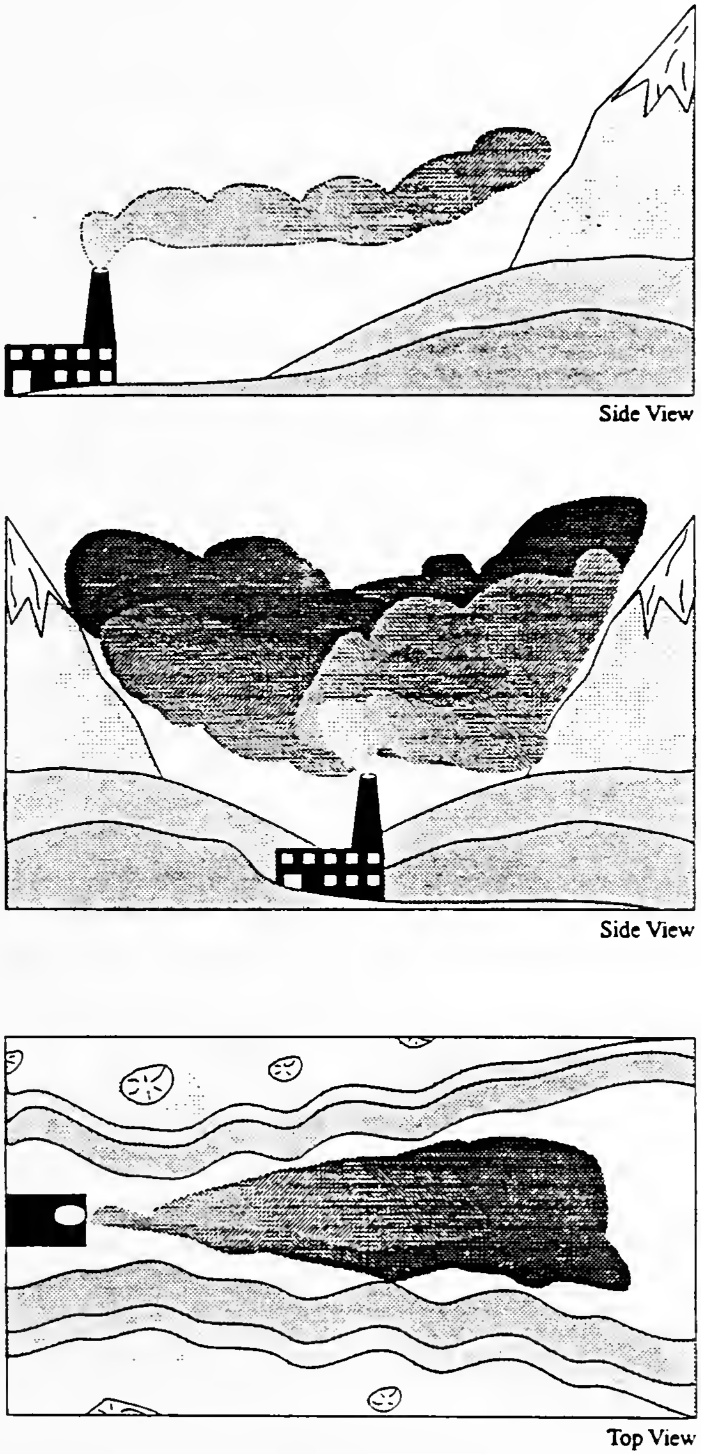
50 µm in diameter is 67.5 cm per second. A particle of this size would fall 133 feet in 1 minute, or the entire 585-foot height of the Washoe Smelter stack in 4.4 minutes. The average Anaconda wind speed at stack height was approximately 5 meters per second (about 11 miles per hour) (Gelhaus et al., 1979); at this windspeed, a particle of this size would be transported 1.3 kilometers (0.6 miles) before it hit the ground. A smaller particle, 10 µm in diameter, has a gravitational settling velocity of 2.7 cm per second, and under the same meteorological conditions would fall to the ground from the top of the stack in 1.8 hours, or approximately 33 kilometers (20 miles) away. Small particles travel with the wind, at the speed of the wind.

The direction of transport of particles from the smelter stack depended on the winds at the top of the stack and at the higher level to which the hot flue gases rose. The rugged terrain surrounding the Anaconda smelter has a dramatic effect on plume transport and dispersion; rugged, complex terrain can cause pooling in valleys, stagnation, drainage channeling along valleys, and plume impingement on elevated terrain (Figure 2-16). Plume impingement occurs when emissions are transported directly toward the side of a mountain or hill so that the high plume concentrations intersect the ground. High concentrations and particle deposition rates would occur under such conditions.

Emissions from the early years of smelting in Anaconda released from shorter stacks, fugitive emissions from waste piles (including flue dust) throughout the years of smelter operation, wind-blown dust from tailings piles, large particles spewn from the stack, and all particulate emissions during precipitation events would have been deposited at greater rates closer to the source than particles emitted from the 585 foot stack in fair weather.

2.4.2 Fugitive Emissions

A model was constructed in 1986 before the release of the Mill Creek ROD to estimate the potential for the continuing contamination of Mill Creek soils by natural wind erosion processes involving resuspension, transport, and deposition of hazardous substances in exposed contaminated soils and wastes (McVehil-Monnet, 1986). Emission rates derived for specific areas within the Smelter Hill Operable Unit site ranged (conservatively) from 1.5 to 5.1 pounds of arsenic per year (McVehil-Monnet, 1986). At that rate, the estimated annual arsenic deposition due to airborne recontamination at Mill Creek is in the range of 0.0022 to 0.061 g/m^2, or an increase of 0.05 to 1.5 ppm arsenic per year in the upper 1 inch of soil (McVehil-Monnet, 1986). In modeling potential ongoing contamination at Mill Creek, McVehil-Monnet (1986) assumed that the deposited arsenic is mixed into the upper 1 inch of soil (density 1.6 g/cm^3). Over a 20-year period, expected increase in soil arsenic where the town of Mill Creek used to stand ranged from 1 to 30 mg/kg (ppm) (McVehil-Monnet, 1986). Predictions of average airborne concentrations of arsenic in Mill Creek were shown to be consistent with observed concentrations in the air at Mill Creek and elsewhere near the smelter (McVehil-Monnet, 1986).



A. Plume Impingement on High Terrain

B. Pooling in Valleys

C. Persistence Due to Channeling

Figure 2-16. Effects of Rugged Terrain on Dispersion. Source: Hanna and Strimaitis, 1990.

2.5 OTHER PATHWAYS

2.5.1 Leaching/Erosion

Waste deposits in the Old Works, Smelter Hill, and tailings ponds areas that contain hazardous substances are sources of hazardous substances to underlying and adjacent soils by leaching and wind and water erosion pathways. Elevated concentrations in native soils beneath the waste/alluvium interface were identified during RI/FS work in the Old Works Operable Unit (PTI, 1991b) and in the Smelter Hill Operable Unit (PTI, 1991a).

Leaching and vertical migration of hazardous substances from Anaconda area waste deposits into the underlying geologic and groundwater resources have been documented in numerous investigations (e.g., Tetra Tech, 1987; PTI, 1991a,b; PTI, 1992a). Evidence of erosion from waste deposits in the Old Works Area, the Opportunity Ponds, and Smelter Hill area has also been documented (PTI, 1991a; Tetra Tech, 1987). Contamination of shallow groundwater is evident on Smelter Hill in the area near the stack; migration of dissolved contaminants is occurring to depths of up to 200 feet (PTI, 1991a). In addition, analyses of drainage channel sediments in the Smelter Hill area have shown that metals concentrations in the handling/process/storage area, and in Geyser Gulch and Weather Hill drainages, are elevated. The concentrations of metals in sediments are similar to concentrations found in surface soils (PTI, 1991a), indicating that runoff erosion is an ongoing pathway of transport of hazardous substances.

These examples are evidence of pathway mechanisms from waste deposits to geologic and hydrologic resources. Evidence of vertical migration is visible as well; vertical sections exposed in backhoe trenches in the Old Works area showed blue-green zones of copper enrichment in the alluvium below the waste (Tetra Tech, 1987). Trace metal data indicate that leaching and re-precipitation in native alluvium have occurred (Tetra Tech, 1987).

2.5.2 Biological Uptake

Upland vegetation and wildlife resources are exposed to sources of hazardous substances in upland soils in the Anaconda area. Investigations conducted for the Smelter Hill RI/FS determined concentrations of hazardous substances in soils and in plant tissue. Total metals concentrations in surface soils (0-2 inches) were significantly correlated with metals concentrations in plant tissue for all metals tested (PTI, 1991a). Additional studies have demonstrated that:

- Arsenic concentrations in plant tissue collected across Smelter Hill averaged 24.6 ± 34.0 ppm. Arsenic content in a wide variety of plants from uncontaminated regions typically averages between 0.02 and 7.0 ppm (Alloway, 1990).

- Plant tissue concentrations of cadmium at the Smelter Hill site averaged 2.35 ± 2.02 ppm. Nationwide levels of cadmium in plants are generally less than 1 ppm (Kabata-Pendias and Pendias, 1984 as cited in PTI, 1991a). Cadmium is generally less toxic to plants than to consumers, thus cadmium accumulation in plants represents a potential pathway to herbivorous wildlife.

- Copper plant tissue concentrations at the Smelter Hill site averaged 91.87 ± 166.5 ppm (ranging as high as 467 ppm in horsebrush). Levels in unimpacted plants generally range between 1.5 and 30 ppm (CH_2M Hill, 1987, as cited in PTI, 1991a).

- Lead plant tissue concentrations across the Smelter Hill site averaged 15.43 ± 29.5 ppm. Nationwide lead levels in a variety of plant tissues generally range from 0.5 to 4 ppm (Kabata-Pendias and Pendias, 1984, as cited in PTI, 1991a).

- Zinc concentrations in plant tissue across the Smelter Hill site averaged 208 ± 173.5 ppm. Most agricultural crops exhibit toxicity when zinc tissue levels reach 200-300 ppm (MacNichol and Beckett, 1985), but the range for reported toxicity is much greater. Toxicity has been reported for tissue levels as low as 60 ppm.

It should be noted that concentrations of arsenic, cadmium, copper, lead, and zinc in upland soils in the Anaconda area are, in places, so elevated that analysis of uptake residues is hardly relevant: rather, the soils are phytotoxic. Chapter 3.0 and Appendix B describe the toxic effects on Smelter Hill soils and vegetation.

2.6 SUMMARY

The data presented in this chapter support the following conclusions:

- Air has been exposed to hazardous substances through smelter emissions and ongoing releases from exposed soils and waste piles.

- Air has served as an ongoing pathway to terrestrial resources.

- Aerial patterns of soil contamination are indicative of a point source located in the Anaconda area.

- The vertical distribution of soil contamination demonstrates that hazardous substances have been released by a surface source rather than reflecting geologic parent material.

- The areal extent of exposure exceeds over 100 square miles.

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3.0 GEOLOGIC RESOURCE — UPLAND SOILS

Geologic resources are solid components of the Earth's crust, including soils, sediments, rocks, and minerals [43 CFR § 11.14]. In this chapter, injuries to upland soil resources near Anaconda are determined and quantified.

Overall, the data presented in this chapter demonstrate that:

- Concentrations of hazardous substances in exposed soils are significantly greater than baseline concentrations.
- Exposed soils are phytotoxic relative to control soils, and hence are injured.
- The degree of phytotoxicity observed in controlled laboratory experiments was correlated with the concentrations of hazardous substances in the soil.
- Concentrations of nitrate-nitrogen, potassium, and phosphorous, cation exchange capacity, pH, and percent sand, silt, and clay in control and impact soils were not significantly different.
- The observed effects on plant growth were consistent with the phytotoxic effects of heavy metals.
- Concentrations of hazardous substances in exposed soils exceed phytotoxic thresholds identified in the literature; the observed phytotoxic response therefore is consistent with scientific literature.
- The areal extent of severe injury to soils is estimated to be approximately 17.8 square miles.

In Chapter 4.0, it is demonstrated that upland soils that have been exposed to elevated concentrations of hazardous substances and that were found in laboratory studies to be phytotoxic, do indeed manifest severe injury to vegetation. Hence, evidence of phytotoxic injury is supported by both controlled laboratory experiments and by field measurements.

3.1 DESCRIPTION OF UPLAND SOIL RESOURCES

Upland soils that have been injured by releases of hazardous substances from smelting and related ore refining operations in Anaconda include the soils of:

- Stucky Ridge
- Smelter Hill, including the A and C hills, Weather Hill, and other unnamed slopes between Mill Creek and Warm Springs Creek to the west of the main smelter stack
- Mt. Haggin Wildlife Management Area, south and east of Mill Creek, extending south as far as the Continental Divide.

These upland areas exhibit extensive loss of native vegetative cover and topsoil. These three areas are referred to as impact areas for simplicity of discussion (Figure 3-1). In reality, they constitute a single, contiguous, injured landscape.

3.1.1 Stucky Ridge

Stucky Ridge (Area A, Figure 3-1) is a glacial moraine that borders the town of Anaconda to the north. Historical stacks and connecting flues were built along the southern flank of the ridge (the Old Works area, Anaconda Smelter NPL Site). Historical photographs of the Old Works (circa 1886) indicate that Stucky Ridge was formerly vegetated by arid grassland and open steppe communities on exposed slopes and forest communities in the moister drainages. Currently, most of Stucky Ridge is either completely devegetated or supports species-poor communities. Extensive soil loss on southern slopes and hilltops has exposed a cobbled surface, or the rocky core of the moraine, and is evident as deep erosion gullies in the northern slopes and eastern end of the ridge.

3.1.2 Smelter Hill

Smelter Hill (Area B, Figure 3-1) refers to the general locale of the former Washoe Smelter (also called the Anaconda Smelter) facilities. The Smelter Hill Operable Unit of the Anaconda Smelter NPL site (located within the boundaries of Area B, Figure 3-1) occupies approximately 4 square miles adjacent to and south of the town of Anaconda (PTI, 1991). The main flue to the main stack was on the north side of Smelter Hill. A brick smoke stack is on the top of Smelter Hill (elevation 5,799 feet above mean sea level). The stack, an equipment garage, and two guard shacks are the only remaining structures of the former industrial facility (PTI, 1991). Weather Hill (elevation 6,372 feet above mean sea level), to the south of the stack, the A and C hills bordering the town of Anaconda to the south, and hillsides to the west of the stack are currently devegetated or support species-poor communities. Extensive soil loss and cobbled, wind-eroded surfaces are prevalent. The site where the main structures of the industrial facility once stood is called the handling/process/storage (HPS) area. The HPS area is on the northern and eastern flanks of Smelter Hill and extends to the large black slag pile and the Anaconda Tailings Ponds that lie just

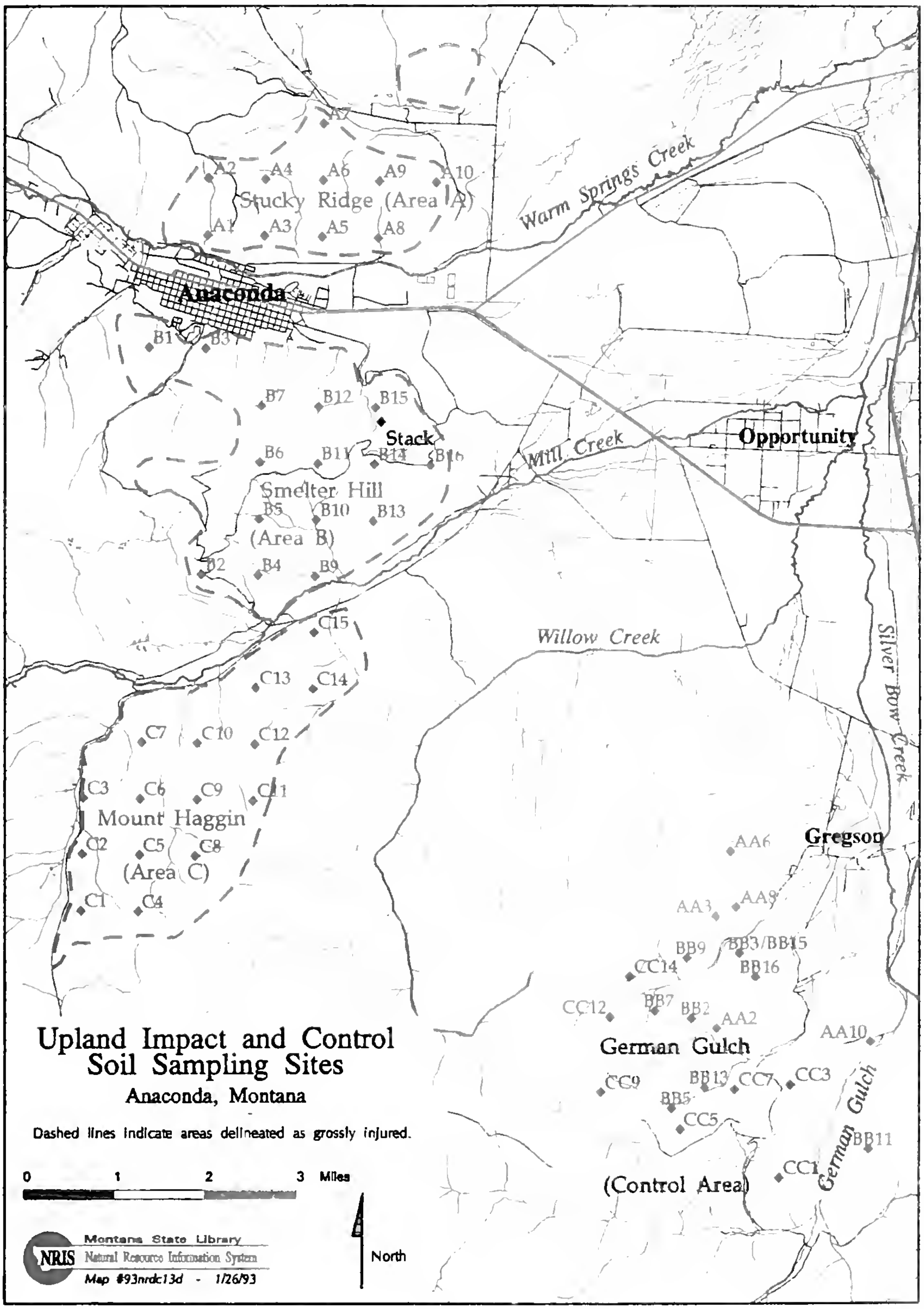

Figure 3-1. Upland Impact and Control Soil Sampling Sites.

outside the operable unit. The soils of the HPS area have been heavily disturbed, both by contamination with hazardous substances and by past construction and current reclamation activities.

Two intermittent streams drain the area. Geyser Gulch flows northeast through the valley between Weather Hill and Smelter Hill. Walker Gulch flows through the northwestern part of the site and drains under the main site entrance road to a ditch north of the black slag pile. Mill Creek, a perennial stream that drains to Silver Bow Creek, borders the NPL site to the southeast (Figure 3-1).

3.1.3 Mount Haggin

The Mount Haggin Wildlife Management Area (23,000 hectares) is owned and managed by the Montana Department of Fish, Wildlife, and Parks. The land was purchased in 1976 from the Mount Haggin Livestock Company through The Nature Conservancy. The Mount Haggin area is characterized by steep mountainous slopes. Portions of the management area (Area C, Figure 3-1), including slopes to the south and west of Mill Creek, at least as distant as the Continental Divide, are barren of vegetation and exhibit signs of extensive soil loss. The Mount Haggin area was logged historically, as evidenced by the remains of old logging camps amidst acres of un-decomposed logs, stumps, and exposed root systems. In addition, extensive areas littered with standing dead or fallen dead trees are visible on slopes within the Mount Haggin area.

3.2 INJURY DEFINITION

For this assessment, injury to soil is defined as:

- 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 have caused injury as defined to surface water, groundwater, air or biological resources when exposed to the substances [43 CFR § 11.62 (e) 11].

3.2.1 Phytotoxicity

All green plants require the same basic set of mineral nutrients and use them for similar purposes (Fitter and Hay, 1987). Trace elements essential to plants at very low concentrations are referred to as plant micronutrients. Copper and zinc are essential to plants at very low concentrations, but become toxic at higher concentrations (Alloway, 1990).

Arsenic, cadmium, and lead have no role in plant metabolism, and their accumulation in plants is toxic (Kabata-Pendias and Pendias, 1984).

For most hazardous substances, there is a concentration range at which no injurious effects are suffered by any species, and one at which all species are vulnerable (Fitter and Hay, 1987). Phytotoxic response stems from an inhibition of enzymatic reactions, metabolic processes, or growth (Fitter and Hay, 1987). Plant toxins generally inhibit either the acquisition or the utilization of nutrients and water by the plants (Alloway, 1990) (see Table 3-1). Stunted growth, yellowing or blanching (chlorosis), localized death of tissue (necrosis), leaf curling or withering (epinasty), and reddish-brown discoloration are visible symptoms of severe metal phytotoxicity (Heale and Olmrod, 1982; Woolhouse, 1983; Van Assche and Clijsters, 1990).

Other characteristic symptoms of metal toxicity include stunted root growth and either browning or death of the root meristem. Plant root growth is controlled by plant hormones; disruption of the concentration gradient by elevated metals concentrations in the root-soil interface will affect hormonal activity and may inhibit root elongation and water and nutrient uptake (Fitter and Hay, 1987; U.S. DOI, 1987). Poorly developed root systems can cause water stress, growth reduction, or early plant aging and death (U.S. DOI, 1987). Phytotoxic response may also be evidenced as an inability of a mature plant to produce viable seeds, or a failure of seeds to germinate (U.S. DOI, 1987). Without annual production of seeds and successful regeneration, most plant species cannot persist in a local environment (U.S. DOI, 1987).

Injury to vegetation grown on soils or sediments contaminated with hazardous substances can be direct or indirect. Direct phytotoxicity is generally observed within days of exposure and results from exposure of the plant to compounds that disrupt ionic balance within the plant or inhibit gas and ion exchange in the plant root zone (U.S. DOI, 1987). Indirect effects resulting from the disruption of biotic processes important to long-term plant growth, survival, and reproduction can occur over an extended period, i.e., months or years (U.S. DOI, 1987). Indirect effects include residual impacts of hazardous substances in the rooting zone and impacts to the soil organisms that contribute to nutrient availability in the plant root system. The response of plants grown on soils containing elevated concentrations of hazardous substances varies widely by species; some may tolerate toxic concentrations by exclusion or excretion of hazardous substances, but more sensitive species are eliminated either by death, indirectly through competitive interactions with resistant species, or by additional stressors such as drought and disease (Newman, 1983).

Table 3-1
A Simple Classification of the Effects of Hazardous Substances on Plants

Effects on the Ability of Plants to Acquire Resources
1. Acquisition of water: a. Osmotic effects arising from excess solute concentrations b. Inhibition of cell division, reducing root growth
2. Acquisition of nutrients: a. Competition between ions b. Damage to membranes c. Effects on symbionts d. Inhibition of cell division
3. Acquisition of carbon dioxide and light energy: a. Stomatal malfunction caused by toxic gases b. Chlorophyll bleaching
Effects on the Ability to Utilize Resources
1. Inhibition of enzyme action 2. Inhibition of cell division 3. Loss of respiratory substrates; oxygen deficiency
Source: Fitter and Hay, 1987.

3.2.2 Assessment of Soils Phytotoxicity

Soil phytotoxicity was assessed through controlled laboratory experiments using soils collected from impact and control areas, and by the assessment of vegetation community integrity in impact and control areas.

3.2.2.1 Laboratory Testing

Phytotoxicity is an adverse response of plants to chemical stressors. Excessive soil concentrations of both essential and nonessential metals result in phytotoxic responses that range from decreased productivity or vigor to death. However, no regulatory criteria exist for soil metals concentrations sufficient to cause phytotoxic responses. In this assessment, phytotoxicity of hazardous substances in soils was determined by laboratory tests of seed germination, seedling growth, and root elongation [43 CFR § 11.64 (e) (6)]. Standard Operating Procedures consistent with the ASTM protocol for early seedling growth studies

(ASTM, 1994[1]) were adapted to evaluate whether site soils cause phytotoxicity (see Appendix B). Screening tests examined the toxicity of 100% site soils to the standard laboratory test species alfalfa, lettuce, and wheat seedlings over a two-week exposure period. Performance of test species in impact site soils was compared to performance of control species grown in control soils. Control soils were collected from control sites previously designated and sampled as representative of baseline conditions (Section 3.3.2.1 and Appendix A).

Determination of phytotoxicity was based on a suite of species-endpoint responses, including:

- Germination (number of seedlings emerged/20 seeds; five replicates of 20 seeds each)
- Shoot height (mm, for each surviving seedling; mean of plants measured)
- Maximum root length (mm, for each surviving seedling; mean of plants measured)
- Shoot mass (g oven dry weight for each seedling; mean of plants measured)
- Root mass (g oven dry weight for each surviving seedling; mean of plants measured)
- Total mass (g oven dry weight for each surviving seedling; mean of plants measured).

Differences between impact and control samples were assessed statistically using randomized t-tests. A soil sample was deemed phytotoxic when plants grown in it displayed significantly lower performance in the endpoints identified above, relative to the control soil. The degree of phytotoxicity was quantified based on (1) the magnitude of the difference from control performance, (2) the number of endpoints exhibiting a phytotoxic response, and (3) the number of species exhibiting a phytotoxic response. Quantitative phytotoxicity scores were then assigned to each soil sample based on the degree of phytotoxic response. These toxicity scores, in turn, were used to classify soils as either:

- Non phytotoxic
- Phytotoxic:

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[1] At the time the laboratory phytotoxicity tests were performed, this standard was available as a working draft. The standard tests incorporated the methods outlined in Greene et al., 1989 and in Gorsuch et al, 1990.

- Mildly toxic
- Moderately toxic
- Highly toxic
- Severely toxic.

3.2.2.2 Vegetation Communities

Soil phytotoxicity was also evaluated by comparing the structure and composition of vegetation communities in impact and control areas. Injury to vegetation communities is defined in terms of community integrity, i.e., as changes in the species composition, diversity, dispersion, or percent cover [43 CFR §11.71 (l)(6)], and was determined by reference to the established baseline area [43 CFR §11.72]. Injury to vegetation is addressed in Chapter 4.0; however, obvious injury to vegetation is indicative of injury to soil, and will be discussed as it pertains to soils in the injury determination and quantification section of this chapter.

3.3 INJURY DETERMINATION AND QUANTIFICATION

This section presents evidence that soils in the Anaconda area contain elevated concentrations of hazardous substances attributable to smelter emissions and fugitive dust (see Chapter 2.0), that these concentrations of hazardous substances are sufficient to cause a phytotoxic response, and, hence, that soils are injured.

3.3.1 Baseline Conditions

Baseline is defined as the condition or conditions that would have existed at the assessment area had the release of hazardous substances not occurred [43 CFR § 11.14 (e)]. Baseline concentrations are not necessarily naturally occurring "background" concentrations; other anthropogenic impacts may have contributed to pre-release conditions, such as releases of lead from leaded gasoline-burning vehicles. However, the naturally occurring "normal" concentrations of trace elements in soils are of interest as background values pertinent to the assessment of the degree of soil contamination in both impact and control areas. Natural background concentrations of arsenic, cadmium, copper, lead, and zinc are primarily controlled by the parent material. Chemical and physical weathering breaks down bedrock, releasing constituent minerals, which become a part of the soil. The natural soil composition is further affected by mobility and activity of the various ions. Thus, the range of naturally occurring concentrations throughout the United States (Table 3-2) is due principally to parent material variability and soil weathering processes and rates.

Table 3-2
Background Concentrations Reported for Uncontaminated Soils of the United States
(total metals in ppm)

	Arsenic	Cadmium	Copper	Lead	Zinc
Range	< 0.1 - 93	0.005 - 2.4	1 - 100	10 - 70	17 - 125
Mean	10	0.53	25	32	64

The range of **arsenic** in U.S. soils is broad, < 0.1 - 93 ppm, but most soils are in the less than 10 ppm range (Kabata-Pendias and Pendias, 1992). Baseline values for arsenic in soils overlying granitic rock typically range from 0.7 to 15 ppm (Kabata-Pendias and Pendias, 1984, as cited in Morrison Knudsen, 1991). The lowest concentrations of arsenic are found in sandy soils, particularly sandy soils derived from granites (means in the range of 2-6 ppm).

Higher As concentrations are found in alluvial soils and soils rich in organic matter (means in the range of 5-25 ppm). Acid sulfate soils are reported to accumulate a high proportion of native As, up to 30 to 50 ppm. An overall mean value for arsenic in U.S. soils is reported to be between 5.8 and 10 ppm (Kabata-Pendias and Pendias, 1992; O'Neill, 1990).

Average soil concentrations of **cadmium** in the United States range between 0.005 and 2.4 ppm (Alloway, 1990). The highest average cadmium content is found in organic soils (0.78 ppm), while the lowest mean is found in highly leached spodosols (0.37 ppm). The calculated worldwide mean of cadmium in surface soils is 0.53 ppm (Kabata-Pendias and Pendias, 1992).

Based on recent compilations of estimates, the average natural **copper** concentration in soil worldwide ranges from 20 to 30 ppm (Baker, 1990). Generally, copper concentrations reported for various soil types (sandy soil and podzols, silty soils, loamy and clay soils, rendzinas, chernozems, histosols, and other organic soils) range from 1 to 100 ppm (Kabata-Pendias and Pendias, 1992). Copper concentrations typically are lowest in soils formed by granitic, igneous, or carbonate parent materials. Kabata-Pendias and Pendias (1992) cite 13-24 ppm as the average copper concentration in soils of the United States, and Adriano (1986) cites 25 ppm as an average value for naturally occurring copper in U.S. soils.

Background values for **lead** in soils of the world rock typically range between 10 and 67 ppm and average 32 ppm (Kabata-Pendias and Pendias, 1992). Over all soil types, a mean value is approximately 32 ppm. An upper limit for the lead content of normal soils has been suggested as 70 ppm; higher values reflect anthropogenic inputs (Kabata-Pendias and Pendias, 1992).

Mean **zinc** content in surface soils ranges from 17 to 125 ppm (Kabata-Pendias and Pendias, 1992). The mean calculated for worldwide soils is 64 ppm (Kabata-Pendias and Pendias, 1992). Kiekens (1990) cites an average content of 50 ppm. Highest naturally occurring mean values are found in alluvial soils; the lowest naturally occurring mean values are in light mineral and organic soils.

Anaconda Baseline

Historical data regarding the baseline conditions specific to Anaconda area soils before releases of hazardous substances are not available since releases have occurred continuously from the late 1800s through the present. In the absence of pre-release data, concentrations in soils in the German Gulch area, approximately 6 to 10 miles south of the Anaconda smelter, have been defined as baseline (see Appendix A).

The German Gulch area was selected as an appropriate control area because of its proximity to the impact area, and its similarity in elevation and overall aspect. Surface soils collected in German Gulch were analyzed for total arsenic, cadmium, copper, lead, and zinc (sampling locations shown in Figure 3-1). Means and ranges for the 20 control soils sampled were in excess of U.S. means, and copper and cadmium concentrations were in excess of reported ranges for uncontaminated U.S. soils. These results, coupled with soils distribution profiles (Chapter 2.0, Section 2.4.3), indicate that soils in the German Gulch area most likely have been exposed to aerial deposition of emissions from the Anaconda smelter. For example:

- Arsenic in German Gulch samples ranged from 47.2 to 136.4 ppm and averaged 89.5 ppm. Overall mean values for arsenic in U.S. soils are reported to be between 5.8 and 10 ppm (range < 0.1-93 ppm).

- Cadmium in German Gulch samples ranged from 1.3 to 5.1 ppm and averaged 3.0 ppm. The calculated worldwide mean value for cadmium in soils is 0.53 ppm (range 0.005-2.4 ppm).

- Copper in German Gulch samples ranged from 58.6 to 236.5 ppm and averaged 148.4 ppm. An average value for copper in U.S. soils is 25 ppm (range 1-100 ppm).

- Lead in German Gulch samples ranged from 31.1 to 119.7 ppm and averaged 68.1 ppm. Mean soil concentration of lead in U.S. soils is approximately 32 ppm (range 10-70 ppm).

- Zinc in German Gulch samples ranged from 78.4 to 196.3 ppm and averaged 135.9 ppm. Baseline zinc concentrations in U.S. soils average 50 ppm (range 17-125 ppm).

Maximum concentrations from the control sites are clearly elevated above what can be considered naturally occurring levels. German Gulch mean values thus represent conservative baseline values (Table 3-3).

Table 3-3
Baseline Concentrations (ppm) of Hazardous Substances in Anaconda Area Soils
(measured in German Gulch area 0-2 inch soils)

	Arsenic	Cadmium	Copper	Lead	Zinc
Range	47.2-136.4	1.3-5.1	58.6-236.5	31.1-119.7	78.4-196.3
Mean	89.5	3.0	148.4	68.1	135.9

3.3.2 Soil Concentrations of Hazardous Substances

3.3.2.1 NRDA Investigations

As a component of the soil resource investigation of this NRDA, a soil sampling study was designed to sample soils from areas identified as grossly impacted. Grossly impacted areas were identified in the field based on the following factors:

- Complete or virtual elimination of the indigenous major plant associations
- Little or no regeneration of the indigenous major plant associations
- Extensive topsoil exposure and erosion associated with vegetation loss.

The following areas were delineated for sampling using a combination of aerial photographs and field observations:

- 3.8 square miles on and immediately adjacent to Stucky Ridge (Area A, Figure 3-1)

- 7.3 square miles on Smelter Hill, including Weather Hill and other slopes to the south and west of the stack (Area B, Figure 3-1)

- 6.7 square miles within the Mount Haggin Wildlife Preserve, south and west of Mill Creek, extending toward the Continental Divide (Area C, Figure 3-1).

Forty surface soil samples were collected from these three impacted areas. Sample site locations were determined based on the Universal Transverse Mercator grid (Figure 3-1). Soil samples were composited along transects centered on the sample site. The sample design allowed statistical comparisons of each impact area, as well as comparison among individual sample locations. For 20 of the impact area sample sites, a paired control site was identified and sampled (German Gulch; Figure 3-1). For a full description of the soils investigations, see Appendix A.

Soils collected from the 0-2 inch and 0-6 inch layers were sent to a laboratory for analysis of arsenic, cadmium, copper, lead, and zinc. A subset of the samples collected was analyzed for pH, texture (percent sand, silt, clay), soil nutrients including nitrate, phosphorous, and potassium, organic matter, and cation exchange capacity (CEC). Field vegetation and wildlife habitat measurements were also recorded at impact and control sites for analysis of injury to biological resources (see Chapter 4.0 and Appendices C and D).

Statistical comparison of the two soil data sets revealed that total concentrations of arsenic, cadmium, copper, lead, and zinc in the impact areas are significantly greater than concentrations of the same elements in paired control sites. A summary of the concentration data is presented in Table 3-4; mean value comparisons between impact and control soils are illustrated in Figure 3-2; raw data are presented as an attachment to Appendix A. Statistical comparisons of ancillary parameters indicated that nutrient concentration, pH, CEC, and soil texture do not differ significantly between control and impact soils, but that control soils have a significantly greater percent organic matter than impact soils (Table 3-5). Specifically, the following statistically significant differences were found:

- Arsenic, cadmium, copper, lead, and zinc occur in significantly greater concentrations in upland impact area soils than in German Gulch control soils ($p = 0.0002$).

- Arsenic, copper, and zinc occur in significantly greater concentrations in Stucky Ridge soils than in paired control soils ($p = 0.03$).

- Arsenic, cadmium, copper, lead, and zinc occur in significantly greater concentrations in Smelter Hill area soils than in paired control soils ($p = 0.00391$).

- Arsenic, cadmium, copper, and lead occur in significantly greater concentrations in Mount Haggin area soils than in paired control soils ($p = 0.008$ (As); $p = 0.015$ (Cd, Cu, Pb)).

- Percent organic matter is significantly greater in control soils than in impact soils ($p = 0.0078$). No differences in pH, CEC, percent sand, silt, or clay, nor concentrations of nitrate, potassium, or phosphorous were detected ($p > 0.05$).

Table 3-4
Summary Statistics for Anaconda Upland Impact and German Gulch Control 2-Inch Soil Samples (total metals in ppm)

Sample Identification	As	Cd	Cu	Pb	Zn
Stucky Ridge n = 10					
Arithmetic mean	303.50	3.83	1,324.23	117.00	300.74
Maximum	624.30	7.30	2,856.00	196.00	580.50
Minimum	142.70	2.30	513.40	68.70	167.40
Standard deviation	144.84	1.39	677.17	36.97	129.56
Stucky Ridge controls n = 5					
Arithmetic mean	78.16	3.50	183.16	89.36	150.88
Maximum	119.6	4.10	220.40	112.70	182.60
Minimum	47.20	2.20	135.50	60.80	121.00
Standard deviation	24.78	0.69	31.42	17.73	21.20
Smelter Hill n = 14					
Arithmetic mean	605.29	17.64	1,229.48	275.59	562.27
Maximum	1,846.70	51.20	2,547.00	548.80	1,515.00
Minimum	183.30	7.40	404.90	156.80	205.10
Standard deviation	410.42	12.16	627.76	108.96	363.18
Smelter Hill controls n = 8					
Arithmetic mean	90.91	2.86	143.41	58.38	140.96
Maximum	132.30	4.30	236.50	88.00	196.30
Minimum	47.30	1.70	96.40	41.00	80.20
Standard deviation	22.82	0.94	43.96	15.07	36.68
Mount Haggin n = 16					
Arithmetic mean	295.83	7.80	356.38	153.26	215.78
Maximum	630.00	14.20	678.70	229.20	379.30
Minimum	107.60	2.30	139.10	78.10	76.60
Standard deviation	144.59	3.70	155.55	49.64	93.69
Mount Haggin controls n = 7					
Arithmetic mean	99.37	2.64	118.73	56.54	115.80
Maximum	136.40	5.10	201.50	119.70	165.40
Minimum	53.00	1.30	58.60	31.10	78.40
Standard deviation	27.17	1.30	49.99	33.10	27.95

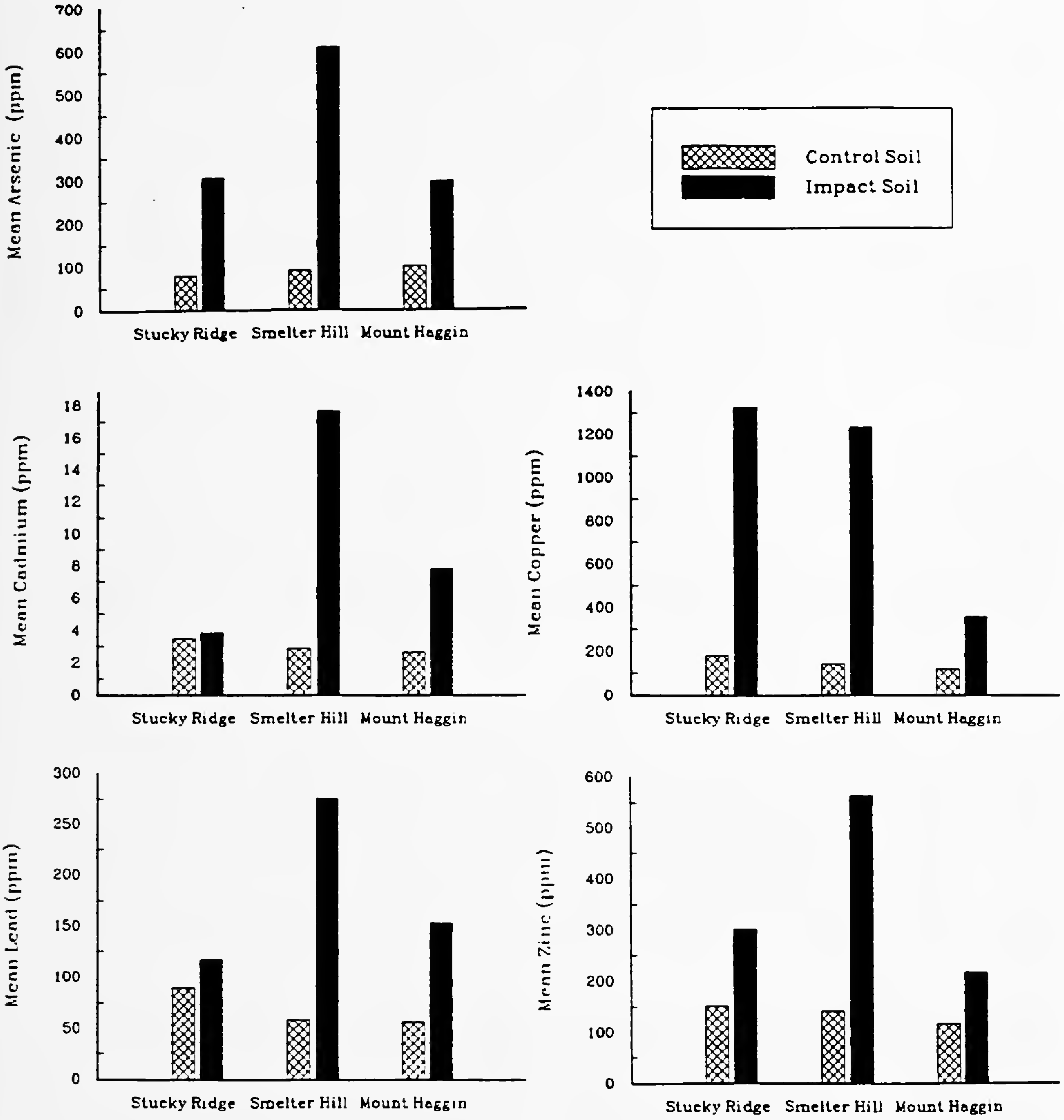

Figure 3-2. Mean Concentrations of Hazardous Substances in Upland Impact and Control Soils.

Table 3-5
Comparisons of Mean Soil Nutrient Concentrations (ppm), pH, CEC (meq/100g), % Organic Matter, and % Particle Size in Impact and Reference Soils (0 to 5 cm)

Variable	Reference Samples	Impact Samples	p-value
Potassium	609.7	501.6	0.4538
NO_3-nitrogen	1.8	4.7	0.0904
Phosphorous	137.1	139.4	0.9358
pH	5.7	5.4	0.2908
CEC	16.4	16.0	0.8888
% Organic matter	6.4	3.9	0.0078*
% Sand	59.6	56.5	0.5124
% Silt	25.2	24.3	0.7562
% Clay	16.1	18.8	0.2310

* indicates a significantly greater amount in reference soils (2-tailed tests).

3.3.2.2 Previous Investigations

The results of this study are consistent with previous studies performed as part of the RI/FS. The soils of the Smelter Hill Operable Unit have been sampled extensively as part of the remedial investigation. The Preliminary Site Characterization Information Report (PSCI) (PTI, 1991) was released in November 1991. In January 1993, the Smelter Hill RI/FS Phase II soils data, collected during summer 1992 in response to data gaps identified in the PSCI, were released (PTI, 1993). The Smelter Hill Operable Unit (Figure 3-3) and the Smelter Hill study area sampled for this NRDA partially overlap. For this reason, soils concentrations of hazardous substances are presented here for comparison to the data presented above.

Hazardous substances are elevated in soils throughout the Smelter Hill Operable Unit (PTI, 1991). Sources of hazardous substances in the Operable Unit (OU) include soils in disturbed areas contaminated with mixed deposits of processing wastes, flue dust piles, soils that received deposition of smelter emissions and have accumulated a reservoir of hazardous substances, surface drainages that transport contaminated sediments, and shallow groundwater beneath the site (PTI, 1991). For the Phase I investigations, the OU was divided for sampling into three areas: (1) the Handling/Process/Storage (HPS) area, where the main structure of the Anaconda Smelter facilities once stood; (2) disturbed soils, where regrading or surface restructuring has occurred, exclusive of HPS areas; and (3) unreclaimed soils — those that have not undergone regrading or major surface restructuring, and where the primary source of

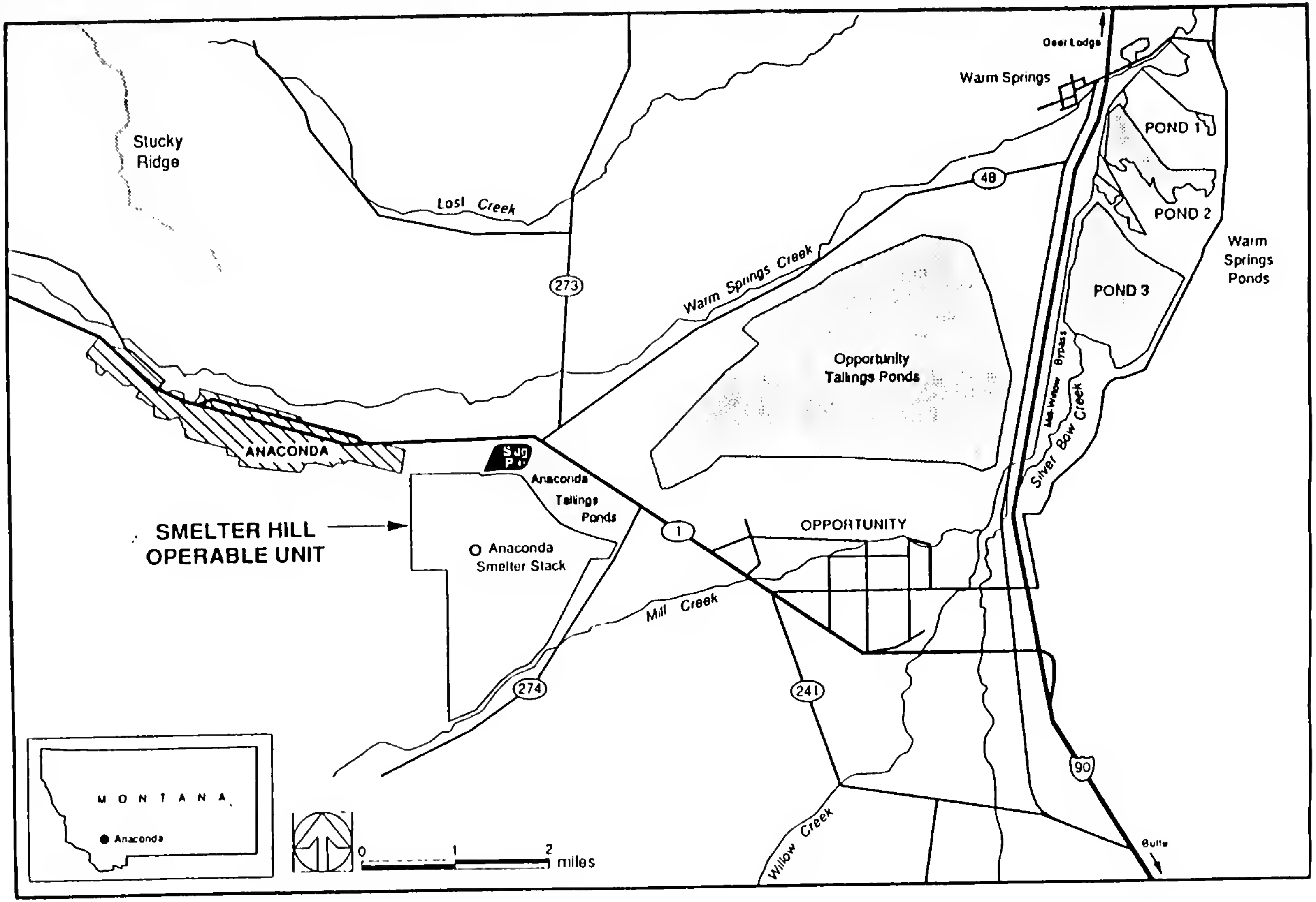

Figure 3-3. Smelter Hill Operable Unit.

RCG/Hagler Bailly

contamination was smelter emissions. Phase II sampling was targeted toward areas that had not been sampled previously and towards "hotspot" sites, where more information was needed to characterize the contamination.

HPS Area

Areas within the HPS area that are of concern are the primary HPS area, the East Anaconda Yard, the coal pile tracks, the railroad beds, and the stack area. In the primary HPS area, concentrations of hazardous substances in disturbed soils are highly variable, but remain extremely elevated to depths exceeding 48 inches. Concentrations of arsenic as high as 567,000 ppm have been detected in buried soils in the HPS area (Table 3-6) (PTI, 1991). In the East Anaconda Yard, hazardous substance concentrations also increase with depth, reaching maximum concentrations at depths > 48 inches. Where reclamation has occurred (covering with 18 inches of imported soils), metals concentrations are lowest.

Soils in the coal pile tracks area contain extremely elevated concentrations of hazardous substances, and the railroad beds exhibit the highest median metals concentrations of all areas sampled on Smelter Hill aside from flue dust (PTI, 1991). Concentrations of hazardous substances in surface and sub-surface soils surrounding the Washoe Smelter stack (approximately 10 acres) are extremely high (PTI, 1991). In the past, smelter emissions were the primary source of hazardous substances to this area, but arsenic concentrations vary with soil matrix type, suggesting a history of deposition of waste material in piles.

Mean concentrations of arsenic reported in HPS area soils are 6 to nearly 60 times greater than baseline, and range between 57 and 6,000 times mean background concentrations (Table 3-6). Mean copper concentrations in the HPS area are 15 to nearly 40 times baseline and 90 to 230 times mean background concentrations. Zinc and lead concentrations reported for HPS area soils exhibit similar exceedences of both background and baseline.

Disturbed Soils

Areas designated as disturbed soils include reclaimed areas on Smelter Hill, reclaimed areas in the East Anaconda Yard, areas around the East Anaconda entrance to Smelter Hill, bulldozed slopes below the stack, and other areas east of the HPS area (PTI, 1991). Additional disturbed soil samples were collected during the Phase II sampling (PTI, 1993), including samples in the vicinity of the drainage area near the southeastern corner of the Anaconda Tailings Pond, in areas adjacent to the hydro-separator, and near two sites sampled previously that had extremely high concentrations of metals.

Concentrations of arsenic, cadmium, copper, lead, and zinc in disturbed area soils (Table 3-6 and 3-7) vary widely, but in general are grossly elevated and exceed concentrations reported for NRDA samples. Mean arsenic concentrations in 0-2 inch disturbed soils exceed baseline by 6 to 30 times, and background by 60 to nearly 300 times. Mean copper 0-2 inch

Table 3-6
Summary Statistics for Smelter Hill OU RI/FS Phase I Soils Data
(all concentrations in ppm; all depths in inches)

Location	Statistic	As	Cd	Cu	Pb	Zn
Primary HPS			NA			
	Mean (all depths, 0- > 48)	5,115		5683	970	982
	Maximum	567,000		67,800	35,100	42,000
East Anaconda yard						
	Mean (all depths, 0-48)	578		2340	1352	1911
	Maximum	6460		65,900	60,000	18,300
Coal pile tracks						
	Mean (all depths, 0- > 48)	833		5193	608	3895
	Maximum	65,800		63,100	15,700	88,100
Railroad beds						
	Mean (all depths, 0-24)	2048		3933	793	4722
	Maximum	19,800		34,900	5520	23,300
Stack area						
	Mean (all depths, 0-7 > 48)	4548		2252	1297	1756
	Maximum	79,700		34,900	28,600	15,550
Disturbed soils						
	Mean (all depths, 0- > 48)	807	22	2877	489	2337
	Mean 0-2	1064	33	4379	714	3320
	Maximum	29,300	584	160,000	22,400	61,600
Unreclaimed soils						
	Mean (all depths, 0-24)	753	21	1561	353	954
	Mean 0-2	1631	53	4143	910	2233
	Maximum	27,200	964	72,400	6430	30,400
Background U.S. concentrations*						
	Mean	10	0.53	25	32	64
	Range	< 0.1-93	0.005-2.4	1-100	10-70	17-125
Baseline concentrations*						
	Mean	89.5	3.0	148.4	68.1	135.9
	Range	47.2-136.4	1.3-5.1	58.6-236.5	31.1-119.7	78.4-196.3

* Background and baseline concentrations are included for comparison.
Source: PTI, 1991.

Table 3-7
Summary Statistics for Smelter Hill OU RI/FS Phase II Soil Samples, Disturbed and Unreclaimed Soils
(all concentrations in ppm)

Location	Statistic	As	Cu	Pb	Zn
Unreclaimed Soils					
Drainage area below the loop					
	Mean (0-2")	724	1,051	376	816
	Mean (all depths, 0-10")	505	683	233	627
	Maximum	971	1,240	462	1,250
Northwest corner of OU					
	Mean (0-2")	605	1,547	313	593
	Mean (all depths, 0-10")	400	1,044	180	442
	Maximum	1,750	5,310	1,150	1,640
Stack area					
	Mean (0-2")	2,315	3,335	930	1,190
	Mean (all depths, 0-10")	1,434	2,181	533	874
	Maximum	3,020	3,490	1,370	1,250
Weather Hill					
	Mean (0-2")	936	1,034	464	810
	Mean (all depths, 0-10")	700	668	293	648
	Maximum	1,890	3,630	2,040	3,520
Disturbed Soils					
Stations D-8 and D-50					
	Mean (0-2")	1,836	7,718	980	4,244
	Mean (all depths, 0-120")	8,351	18,040	1,396	7,688
	Maximum	37,000	93,500	4,870	24,500
Anaconda Ponds drainage area					
	Mean (0-2")	590	1,085	291	1,678
	Mean (all depths, 0-24")	347	490	152	815
	Maximum	1,340	2,070	590	4,710
Hydro separator area					
	Mean (0-2")	2,962	11,913	2,336	12,246
	Mean (all depths, 0-24")	1,133	4,317	833	4,596
	Maximum	5,510	20,700	4,610	22,500
Stack area					
	Mean (0-2")	1,669	1,224	406	738
	Mean (0-10")	1,157	883	274	639
	Maximum	4,330	3,610	1,150	1,440

Source: PTI, 1993.

concentrations in disturbed soils exceed mean baseline by 7 to over 80 times, and background by over 40 to nearly 500 times. Lead and zinc exceedences of baseline and background are similar (Tables 3-6 and 3-7).

Unreclaimed Soils

The other source of concern in the operable unit is unreclaimed soils, where the primary source of contamination was smelter emissions, and continues to be ongoing fugitive emissions. Unreclaimed soils have not undergone regrading or major surface restructuring (PTI, 1991) and, within the operable unit, are west and south of Smelter Hill. Additional samples of unreclaimed soils were collected during the Phase II sampling to refine characterization of the western slope of Weather Hill, drainages to the west of Weather Hill, and localized areas near the stack and below the loop track. Unreclaimed surface soils contain elevated concentrations of hazardous substances, and migration of surface deposited metals has extended to the upper 10-24 inches of soil (PTI, 1991). Mean 0-2 inch concentrations reported for Phase I unreclaimed soils (Table 3-6), and Northwest Corner and Weather Hill 0-2 inch Phase II samples (Table 3-7) are similar to those reported measured in the impact areas for the NRDA investigations (Table 3-4).

3.3.3 Category of Injury: Phytotoxicity - Laboratory Evidence

3.3.3.1 NRDA Phytotoxicity Investigation

Summary of Test Results

To test whether hazardous substances in exposed soils cause a phytotoxic response relative to control soils, laboratory germination and growth tests were conducted. Standard operating procedures consistent with the ASTM protocol for early seedling growth studies (ASTM, 1994) were adapted to compare seed germination and seedling performance of standard laboratory test species (alfalfa, lettuce, and wheat) in impact and control area soils.

Laboratory tests of soils from the upland impact areas confirmed that upland soils are phytotoxic (Appendix B). Eighteen of the 20 soil samples (90%) collected from the impact area exhibited phytotoxicity, including 4 of 5 soils (80%) from Stucky Ridge, 8 of 8 soils from Smelter Hill (100%), and 6 of 7 of soils (86%) from Mount Haggin. These results are consistent with the observed loss of vegetation in the three impact areas (see Chapter 4.0).

Further, it should be noted that these determinations of phytotoxicity were based solely on comparisons to control site soils. As mentioned previously, these control soils are most likely somewhat enriched in hazardous substances from smelter deposition and thus represent a conservative baseline. In addition, the phytotoxicity screening tests were relatively short (2 weeks); the results of such short term tests probably understate the magnitude of phytotoxic responses.

Description of Phytotoxicity Tests

Soils collected from the impact and control sites (0-2 inch layer) were used in upland phytotoxicity tests. Alfalfa, lettuce, or wheat seeds were placed in approximately 100 g of site soil (impact or control). Five replicate tests of 100% impact soil or 100% control soil were conducted. Seeds that germinated were observed over a 14-day post-germination period and, upon harvesting, were measured to determine whether impact and control plants differed in shoot length, shoot mass, root length, root mass, and overall mass (see Appendix B).

The following endpoints were used to evaluate phytotoxicity:

- Germination (number of seedlings emerged/20 seeds; five replicates of 20 seed each)
- Shoot height (mm, for each surviving seedling; mean of plants measured)
- Maximum root length (mm, for each surviving seedling; mean of plants measured)
- Shoot mass (g oven dry weight for each seedling; mean of plants measured)
- Root mass (g oven dry weight for each surviving seedling; mean of plants measured)
- Total mass (g oven dry weight for each surviving seedling; mean of plants measured).

A total of 18 species-endpoint measures were tabulated for all plants that germinated (six endpoints; three species). Plants that did not germinate were (conservatively) not considered in the subsequent analyses of growth parameters. The performance of test species was compared statistically to that of control species. A response was deemed phytotoxic when any of the plants in impact soils exhibited any endpoints that were statistically less than the endpoints exhibited by control plants. Species endpoints were compared for each site, and were pooled and tested by area. T-tests comparing impact response with control response demonstrated statistical differences for each of the three upland areas (Table 3-8).

Mean root length of alfalfa, wheat, and lettuce, mean shoot height and root mass of alfalfa and wheat, and mean shoot mass, total mass, and percent germination of alfalfa were all significantly greater in German Gulch control soils than in Stucky Ridge soils (Table 3-8). Mean root length, root mass, shoot height, and total mass of alfalfa, wheat and lettuce, mean

Table 3-8
Statistical Comparison of Upland Impact Areas to Pooled Control Means

	Endpoint	German Gulch Mean	Stucky Ridge Mean	Smelter Hill Mean	Mount Haggin Mean
Alfalfa	shoot height	36.2	21.0*	17.6*	20.1*
	root length	79.5	23.0*	15.1*	24.0*
	shoot mass	0.326	0.175*	0.146*	0.144*
	root mass	0.245	0.090*	0.061*	0.100*
	total mass	0.571	0.265*	0.207*	0.244*
	% germination	90.2	57.4*	70.6*	59.1*
Lettuce	shoot height	32.9	18.8	18.0*	14.7*
	root length	39.9	16.6*	18.9*	12.1*
	shoot mass	0.064	0.051	0.030*	0.044
	root mass	0.048	0.027	0.012*	0.021*
	total mass	0.111	0.079	0.042*	0.065
	% germination	29.2	36.4	24.8	43.1
Wheat	shoot height	156.0	107.4*	95.4*	113.3*
	root length	162.1	50.6*	48.4*	51.4*
	shoot mass	1.380	1.076	1.026	1.128
	root mass	1.628	0.964*	0.909*	1.183*
	total mass	3.008	1.040	1.935*	2.311*
	% germination	87.6	90.8	90.4	92.0

* indicates that the impact value is significantly less than the control value at $\alpha = 5\%$.

shoot mass of alfalfa and wheat, and mean percent germination of alfalfa were significantly greater in German Gulch control soils than in Smelter Hill soils. Similarly, mean root length, root mass, and shoot height of alfalfa, wheat and lettuce, mean total mass of alfalfa and wheat, and mean shoot mass and percent germination of alfalfa were significantly greater in German Gulch control soils than in Mount Haggin soils. Thus in all three impact areas, growth inhibition of alfalfa was quantified as a significant reduction of all six endpoints. Growth inhibition of wheat was quantified as a significant reduction of up to four of six endpoints (Smelter Hill and Mount Haggin soils), and growth inhibition of lettuce was quantified as a significant reduction of up to five of six endpoints (Smelter Hill soils). The tests demonstrated statistically significant differences for each impact area, for all endpoints, and for all species.

The degree of phytotoxic response was quantified based on (1) the magnitude of the difference between impact and controls, (2) the number of endpoints exhibiting a phytotoxic response, and (3) the number of species exhibiting a phytotoxic response (Appendix B). Sample sites were described as being either:

- Nonphytotoxic
- Mildly phytotoxic
- Moderately phytotoxic
- Highly phytotoxic
- Severely phytotoxic.

Of the 20 upland sites, 18 (90%) were determined to be phytotoxic (Table 3-9). The majority (11 of 20) were found to be highly phytotoxic.

Table 3-9
Summary of Phytotoxicity as Determined by Overall Site Scores
(see Figure 3-1 for site locations)

	Stucky Ridge Site	Smelter Hill Site	Mount Haggin Site
Severely phytotoxic	A-10		
Highly phytotoxic	A-03 A-06	B-02 B-04 B-09 B-11 B-13	C-01 C-05 C-07 C-09
Moderately phytotoxic		B-16	C-12 C-14
Mildly phytotoxic	A-02	B-03 B-05	
Nonphytotoxic	A-08		C-03
Proportion phytotoxic	80%	100%	86%

Root growth was consistently the most affected endpoint (18 of 20 site soils); reduction in both root length and mass was observed. This result is typical of responses to toxic metals (Berry, 1977; Clark et al., 1981; Smith and Brenna, 1983; Atkinson, 1985; Fairley, 1985; Fitter, 1985; Krawczyk et al., 1988; ICF, 1989; Alloway, 1990). Nutrient deficiency, in contrast, typically causes *increased* root length and equivalent or slightly reduced root mass relative to plants grown in nutrient sufficient conditions. The comparison of soil nutrient concentrations indicated no significant differences between nitrate, potassium, or phosphorous concentrations in impact and control soils (Table 3-5); therefore, neither the analytical data nor the observed phytotoxic response is consistent with a conclusion that the response was caused by lack of nutrients in the site soils.

Reduction in root viability, however, does have implications regarding soil restoration and the establishment and maintenance of a complex plant community. Legume and actinorrhizal species (e.g., alfalfa, peas, conifers) form complex associations with soil biota, resulting in root nodule formation (Curtis, 1983; Fitter and Hay, 1987). Root nodules, the loci of nitrogen fixation, can facilitate development of nutrient-rich soil (Ludden and Burris, 1985; Evans et al., 1985; Kapustka, 1987). Nodules (and symbiotic plant-bacterial associations) only form on healthy root systems. The response of test species and the observed absence of cyanobacteria (mosses, lichens, and crusts common to soil surfaces) in the impact areas indicate long-term impairment of the capacity to support nitrogen fixation.

3.3.3.2 Statistical Relationships Between Phytotoxicity and Hazardous Substances

Preceding sections of this chapter have demonstrated that soils collected from impacted areas surrounding the Anaconda Smelter (Smelter Hill, Stucky Ridge, Mt. Haggin) contain significantly elevated concentrations of hazardous substances relative to control soils, and are significantly phytotoxic relative to control soils. Further, these phytotoxic impacted areas have significantly reduced vegetative cover, including percent cover, number of vegetative habitat layers, and presence of dominance types (see Chapter 4.0). The conclusion that hazardous substances in upland soils have *caused* the observed injury is supported by the following observations:

1. **Metals concentrations exceed phytotoxic thresholds observed in other studies.**

   Mean concentrations of arsenic, copper, and zinc from the impact areas are substantially higher than those known to cause phytotoxic responses in controlled laboratory experiments (Table 3-10). For example, the mean concentration of arsenic in impact areas was 7-24 times higher than known phytotoxic concentrations, and the mean copper concentration was 6-14 times higher than known phytotoxic concentrations. Mean concentrations of cadmium and lead were higher than phytotoxic concentrations reported in some studies.

2. **Phytotoxicity is consistent with hazardous substance concentration and pH.**

   Figure 3-4 presents a scatter plot of copper and arsenic concentrations (the hazardous substances with the greatest ratio of concentration to phytotoxic threshold, Table 3-9), and soil pH. For each sample site, the degree of phytotoxicity is indicated with a symbol (e.g., highly toxic sites appear as solid squares; nontoxic impact sites appear as

Table 3-10
Soil Concentrations Reported to Cause Phytotoxicity and Ratios of Mean Impact Area Concentrations to Phytotoxic Levels

Element	Minimum Concentrations Causing Phytotoxicity	Ratio of Mean Impact Area Concentrations to Phytotoxic Threshold[1]
Arsenic	15 - 50	7.3 - 24.6
Copper	60 - 125	6.7 - 14.1
Cadmium	3 - 5	2.3 - 3.0
Lead	100 - 400	0.4 - 1.8
Zinc	70 - 400	0.9 - 5.0

[1] Values > 1 indicate average soils concentrations greater than phytotoxic threshold.
Summarized by Kabata-Pendias and Pendias, 1992.

open triangles; control sites appear as open circles). Control sites have lower concentrations of both arsenic and copper, while highly and severely toxic sites tend to have more elevated concentrations of both hazardous substances. The figure also demonstrates the well-documented mediating influence of soil pH on metal availability and toxicity (Kabata-Pendias and Pendias, 1992): as pH increases (e.g., pH > 7), sites are either mildly toxic or nontoxic (except for a single highly toxic site with extremely elevated copper concentration).

3. Phytotoxicity is correlated with metals concentrations.

Statistically significant relationships were found to exist between *concentrations* of hazardous substances and the *degree* of phytotoxicity measured in impacted soils samples. This dose-response relationship (i.e., degree of phytotoxicity positively correlated with the *concentration* of hazardous substances) provides additional evidence of the causal linkage between the hazardous substances in impacted soils areas, and the observed injury to vegetation. In addition, as described in Chapter 4, injuries to vegetation in upland areas near Anaconda were positively (and statistically significantly) correlated with both the degree of phytotoxicity and concentrations of arsenic and copper. These correlations provide further evidence relating observed injuries in laboratory testing to conditions observed in the field.

Relationships between phytotoxicity scores and metal concentrations were examined using nonparametric correlation (see Appendix B). This approach is not sensitive to departures from normality and does not attempt to measure the degree of linearity of the relationship between two variables. Correlations between phytotoxicity and

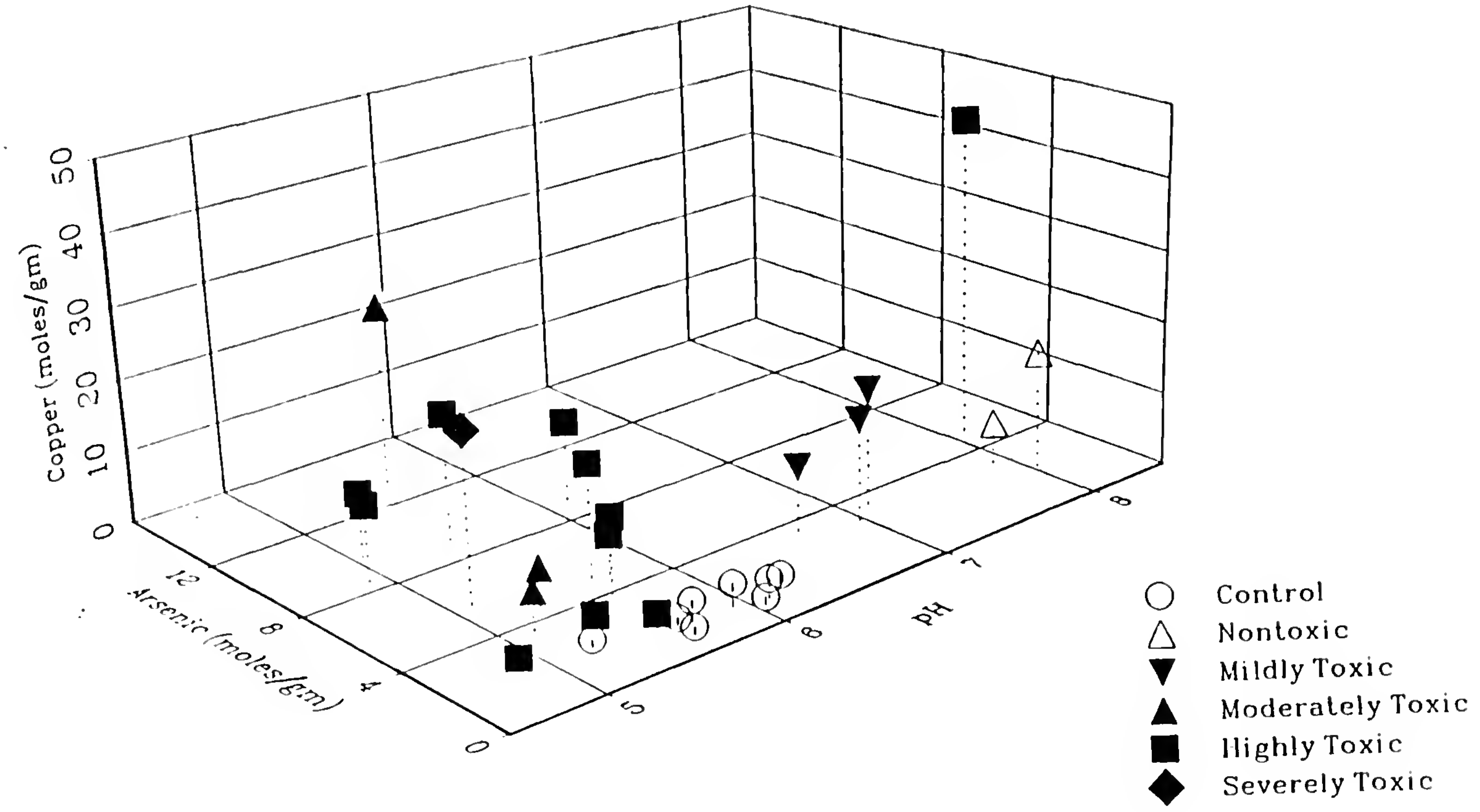

Figure 3-4. Scatter Plot of Total Arsenic and Total Copper (moles/gm), and pH at Sites Tested for Phytotoxicity. Solid symbols indicate toxic sites; open symbols indicate nontoxic impact sites and control sites. Soils that were nontoxic exhibited either high pH or low arsenic and copper concentrations.

biologically available metals (M_b)[2] in impacted and control soils for all five metals were highly significant ($p < 0.005$ in all cases; Table 3-11).[3] The correlation between pH and each metal was negative and highly significant ($p < 0.001$ in all cases).

Since the range of pH measured in impact samples was within the range that is generally tolerable for plants, it is unlikely that pH had a direct influence on phytotoxicity. Rather, the significant negative correlation between pH and phytotoxicity is a by-product of the high degree of correlation between metals concentrations and pH. To be conservative, partial correlations between phytotoxicity and M_b were examined to account for any possible direct effect of pH (Table 3-12). The partial correlations reflect the degree of relationship between metal concentrations and phytotoxicity if pH were held constant. Significant partial correlations ($p < 0.05$) were found between phytotoxicity and four of the five metals (arsenic, copper, lead, and zinc). The partial correlation between phytotoxicity and cadmium was significant at $p < 0.06$.

When impact soil samples only were included in the correlation analysis, correlations between phytotoxicity and pH-adjusted metals concentrations remained positive and highly significant ($p < 0.01$ in all cases except cadmium; Table 3-13). The highest degree of correlation with phytotoxicity was for copper and arsenic; the lowest was for

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[2] A simplified transformation based on solubility relationships (Stumm and Morgan, 1980; Drever, 1982) was adopted to approximate the relationship of the bioavailable fraction of total metal, total metals, and acidity for correlation analysis. Metals concentrations were adjusted for soil pH for each individual site to derive a "surrogate" for bioavailability using the following transformation:

$$[M_b] = [M_t]*[H^+]*10^{12}$$

where M_b represents the metal concentration adjusted for hydrogen ion concentration (pH), or the bioavailability surrogate, and M_t represents the actual measured total metals concentration. Multiplication by the constant 10^{12} is an aid for representational purposes and has no effect on correlation coefficients or significance levels.

[3] A sensitivity analysis was performed on these correlations to determine whether they were robust to variations in the toxicity scoring protocol used. Five alternative scoring protocols were evaluated: (1) use of a binary scoring protocol where non-significant species-endpoint responses received a "0," and all significant responses received a "1"; (2) a linear scoring approach (scores equal to 0, 1, 2, 3, 4 depending on the degree of response); and (3) three scoring systems which used a subset of the 18 species-endpoints (total mass for all species; shoot height and root length for all species; and all six endpoints for wheat only). As with the primary scoring system, correlations using the alternative scoring systems were positive and highly significant ($p < 0.01$ for all elements and all scoring systems).

The results of this sensitivity analysis demonstrate that the significant correlations are robust to variations in the scoring protocol, and are not a function of the specific scoring protocol that was employed.

Table 3-11
Kendall-τ Correlations Between Phytotoxicity Score and [H⁺]-Adjusted Metal Concentration (M_b)

	Phytotoxicity Score	As_b	Cu_b	Cd_b	Pb_b	Zn_b
As_b	0.48					
Cu_b	0.52	0.90				
Cd_b	0.41	0.84	0.83			
Pb_b	0.48	0.90	0.85	0.88		
Zn_b	0.44	0.92	0.87	0.88	0.90	
$[H^+]$	0.39	0.80	0.71	0.73	0.81	0.78

$p < 0.005$ in all cases, under the hypothesis H_o: $\tau \leq 0$ vs. H_a: $\tau > 0$, $n = 28$.

Table 3-12
Kendall-τ Partial Correlation Coefficients Between Phytotoxicity Score and Bioavailable Metal Concentration (M_b), with Partialing Variable $[H^+]$, n=28

Variable	Partial τ
As_b	0.31**
Cu_b	0.38**
Cd_b	0.20
Pb_b	0.30*
Zn_b	0.24*

* and ** indicate $p < 0.05$ and $p < 0.01$, respectively (quantiles approximate; Siegel and Castellan, 1988).

Table 3-13
Kendall-τ Correlations Between Phytotoxicity Score and [H^+]-Adjusted Metal Concentration (M_b)

	Phytotoxicity Score	As_b	Cu_b	Cd_b	Pb_b	Zn_b
As_b	0.51**					
Cu_b	0.52**	0.92**				
Cd_b	0.37*	0.79**	0.75**			
Pb_b	0.47**	0.87**	0.79**	0.83**		
Zn_b	0.46**	0.88**	0.86**	0.84**	0.86**	
[H^+]	0.50**	0.79**	0.70**	0.70**	0.84**	0.73**

* and ** represent $p < 0.05$ and $p < 0.01$, respectively, under the hypothesis H_o: $\tau \leq 0$ vs. H_a: $\tau > 0$, n = 20.

cadmium. Correlations *among* the metals were again all positive and highly significant ($p < 0.001$ in all cases), which is indicative of their common source (the smelter at Anaconda). The partial correlation analysis indicated a significant positive relationship between phytotoxicity and copper ($p < 0.05$) and a slightly weaker relationship with arsenic ($p < 0.10$; Table 3-14).

Thus, even in the more conservative analysis (impact samples only), concentrations of hazardous substances were found to be positively correlated with phytotoxicity, indicating the causal connection between concentration of hazardous substances and injury to vegetation.

3.3.3.3 Previous Phytotoxicity Studies

Earlier greenhouse studies (Taskey, 1972) using soils collected in the Anaconda area determined that growth of both lodgepole pine and Douglas fir were greatly reduced when the combined concentrations of arsenic, copper, lead, and zinc were approximately 1,000 ppm or greater. Taskey demonstrated that the phytotoxicity observed in the greenhouse could be expected in soils within 5 miles of the smelter (Taskey, 1972).

Hartman (1976) sampled soils near the Anaconda smelter, on Weather Hill and near the Old Works to examine the effects of cadmium, copper, lead, and zinc soil contamination on fungal flora. He observed a consistent negative correlation between both fungal species diversity and numbers of fungal propagules (a population count) and soil heavy metal

Table 3-14
Kendall-τ Partial Correlation Coefficients Between Phytotoxicity Score and Bioavailable Metal Concentration (M_b), with Partialing Variable [H^+], n = 20

Variable	Partial τ
Asb	0.21*
Cu_b	0.27**
Cd_b	0.03
Pb_b	0.09
Zn_b	0.15

** and * indicate $p < 0.05$ and $p < 0.10$, respectively (quantiles approximate; Siegel and Castellan, 1988).

concentrations; as metals concentrations increased, the diversity of microfloral species and the number of propagules decreased. Variation in other abiotic growth factors that influence fungal growth and reproduction were assessed and failed to correlate with the observed diversity and population data. In addition, Hartman noticed that conifer roots in the Anaconda area lacked essential symbiotic micorrhizae, and attributed the failure of the Anaconda Company's revegetation attempts (possibly referring to reforestation and sporadic seeding attempts by the Anaconda Minerals Company in the 1960s and 1970s) to reduced fungal diversity and propagule density.

The Hartman (1976) study is additional confirmation that soils in the impact areas were phytotoxic because of elevated concentrations of hazardous substances. Reduced fungal diversity and propagule density have implications for biochemical cycling in soils. Soil microorganisms are ecologically important in that they function in production, consumption, and transportation within the soil ecosystem, and are involved in the flow of energy and in chemical cycling in the soil (Kabata-Pendias and Pendias, 1992). Decomposition of soil organic matter involves numerous enzymatic stages, in which many species of fungi may be required to perform in sequence for optimum organic matter decomposition. The study concluded that high concentrations of cadmium, copper, lead, and zinc caused impoverished microfungal communities and population reductions, which in turn resulted in depressed nutrient cycling and incomplete decomposition of plant and animal residues in Anaconda area soils (Hartman, 1976).

3.3.3.4 Implications of Phytotoxicity

In an ecological context, phytotoxic soils have serious implications regarding species diversity, vegetative structural composition, and the nutritional quality of vegetation (Appendix B). The accumulation of phytotoxic substances in surface soils will continue to affect plant establishment and growth, particularly of native species, indefinitely. Unlike the transient effects of fire, logging, or transient and ephemeral air toxins, metal contamination in soils is virtually permanent (Kabata-Pendias and Pendias, 1992). In addition, preclusion of plant growth and normal decomposition processes further prevents the process of soil formation, which might aid in recovery of soils. Chapter 4.0, Vegetation and Wildlife Resources, discusses vegetation population and community-level effects of phytotoxic soils.

3.3.4 Extent of Injury

3.3.4.1 Areal Extent of Injury

The areal extent of injury to upland soils encompasses 17.8 square miles (46 square km) and includes the following lands:

- 3.8 square miles on and immediately adjacent to Stucky Ridge, a de-vegetated ridge north of the Old Works
- 7.3 square miles on Smelter Hill, including Weather Hill and slopes to the south and west of the stack
- 6.7 square miles in the Mount Haggin Wildlife Preserve, south and west of Mill Creek, extending toward the Continental Divide.

Soils within these upland impact areas were determined to be phytotoxic in comparison to control area soils, and thus injured.

3.3.4.2 Volume of Injured Soils

The volume of injured soil can be estimated using the aerial extent of the impact area (17.8 square miles) and the depth of contamination measured. Based on the results of the sampling described in Section 3.3.1.1 and Appendix A, surface soils (0-2 inches) exhibit the greatest contamination in the Anaconda uplands. Thus the volume of contaminated 0-2 inch soil in the impact areas defined exceeds 3 million cubic yards (2.3 million cubic meters). This volume of soil has been shown to cause injury to biologic resources; this number most likely under-represents the amount of injured soil in the uplands because of the convoluted terrain, the difficulty in determining the true areal extent of the delineated impact areas, and the fact that the study boundaries do not include all injured soils.

If the estimate is extended to soils within a 6-mile radius of the stack that exhibit, on average, concentrations elevated 10 times above baseline, then it may be estimated that 19.5 million cubic yards (14.9 million cubic meters) of 0-2 inch soils have been contaminated with hazardous substances emitted from the Anaconda smelter. If all soils exposed to smelter deposition that are known to exhibit elevated concentrations of hazardous substances are included in the calculation (0-2 inch soils within a 20-mile radius), the volume of contaminated soil becomes 217 million cubic yards (166 million cubic meters).

These estimates fail to account for concomitant injury caused by soil material lost in the past 90 or more years to accelerated erosion (see Section 3.3.4), or the injury to additional areas and resources caused by the redistribution of contaminated eroded soils.

As part of the Anaconda Smelter RI/FS, Tetra Tech (1987) attempted to estimate the mass of soil arsenic attributable to stack emissions using depth-averaged arsenic concentrations. The estimate was based on a 12-inch mixing zone, a dry density of 1.5 g/cm^2, and data from 22 sampling stations where arsenic concentrations had been measured at more that one depth within the top 12 inches of soil. Based on the results, the mass of arsenic in soils attributable to smelter stack emissions was estimated to be within an order of magnitude of 20 million kilograms (22,000 tons) within an affected land area of approximately 68,000 acres (106 square miles). The estimate was limited to the areas sampled, and does not take into account areas where surficial soil arsenic concentrations are above background (about 10 mg/kg, in Tetra Tech, 1987) but below 100 ppm (Tetra Tech, 1987).

3.3.5 Ability of Soil Resource to Recover

Natural recovery of upland soils in the mountainous terrain north, west, and southwest of the smelter will require many hundreds, if not thousands, of years. Estimations of trace metal persistence in soils have indicated that complete removal (to baseline levels) of contaminants from soils through natural recovery processes is nearly impossible (Bowen, 1979; Kabata-Pendias and Pendias, 1992). In addition, though soils are a sink for trace elements, remobilization processes, induced by changes in soil pH or the moisture regime, for example, will ultimately transfer elements into biogeochemical cycles, and consequently disrupt the flow of elements in the soil-plant-animal ecosystem.

Processes by which trace elements are removed from soils include:

- Leaching to subsurface soil horizons

- Erosion (which merely re-distributes the contamination and constitutes a re-release of hazardous substances)
- Plant uptake or adsorption in soil organic matter (a temporary immobilization)
- Dilution of soil through natural chemical weathering and biological soil formation processes.

Leaching of hazardous substances to subsurface layers in the semi-arid montane climate of the Anaconda area is apparently very slow. Taskey (1972) observed that most of the contamination was concentrated in the top 6 to 8 inches of the soil profile. Considering that the loadings had occurred at that time for 88 years, the amount of leaching is relatively small (Taskey, 1972). Similarly, 0-2 inch samples collected in June 1992 exhibited significantly greater concentrations of hazardous substances than 0-6 inch soils (Appendix C), which also suggests that leaching is proceeding slowly. Leaching of contaminants from Anaconda area soils cannot be expected to be a viable mechanism of soil recovery.

Erosion of unvegetated slopes, however, is occurring at tremendous rates. Entire root systems of dead conifers are exposed on hillsides in the Mount Haggin area; erosion gullies 6 to 20 feet deep scar the north and east sides of Stucky Ridge; a cobbled pavement is exposed at the surface of wind-scoured slopes on the south side of Stucky Ridge and on much of Weather Hill. The cobbled surfaces stabilize erosion somewhat, but are not conducive to development of an organic layer, and despite the extensive erosion that has obviously occurred, metals levels in soils underlying the cobble pavement remain significantly elevated relative to baseline.

On the A and C hills adjacent to the smelter stack, the estimated amount of soil eroded in the past 75 years has been calculated as approximately 16 tons/acre/year (Gariglio, 1984, SCS, unpublished letter). The 1984 calculated rate of erosion for the steeper areas of the hills, using the Universal Soil Loss Equation, was 60 tons/acre/year (Gariglio, 1984, SCS, unpublished letter). Soil is normally replaced in similar arid environments by natural weathering and biotic processes at 3 tons/acre/year. In the absence of vegetation establishment to stabilize these soils, erosion will continue to re-distribute contaminated soils and degrade the upland landscape. Therefore, erosion of contaminated soils has not served as a recovery process in the Anaconda uplands.

The final two natural processes by which soils may recover, **uptake** by plants soil organic matter, and **dilution**, will be precluded by the current phytotoxic concentrations. In the more severely contaminated areas, natural re-establishment of vegetation has been inhibited or precluded. Vegetation is slowly re-establishing in parts of the impact area, but at a very slow rate, and community development is impoverished (see Chapter 4.0). Plant species that are recolonizing the area are predominantly noxious weed species, species that have evolved local tolerance to elevated metals concentrations, and species that do not depend on seed germination for regeneration.

In conclusion, natural recovery of the upland soil resource would be highly variable, depending on topography, degree of contamination, the composition of the parent material, and rates of future soil formation, but it is likely that over the entire impact area, recovery periods would range from hundreds to many thousands of years.

3.4 SUMMARY

Overall, the data presented in this chapter demonstrate that:

- Concentrations of hazardous substances in exposed soils are significantly greater than baseline concentrations.
- Concentrations of soil nutrients (nitrate-nitrogen, potassium, and phosphorous), CEC, pH, and percent sand, silt, and clay in control and impact soils are not significantly different.
- Exposed soils are phytotoxic relative to control soils, and hence are injured.
- The degree of phytotoxicity observed in controlled laboratory experiments is correlated with the concentrations of hazardous substances in the soil.
- The observed effects on plant growth are consistent with the phytotoxic effects of heavy metals.
- Concentrations of hazardous substances in exposed soils exceed phytotoxic thresholds identified in the literature; the observed phytotoxic response therefore is consistent with scientific literature.
- The areal extent of severe injury to soils is estimated to be approximately 17.8 square miles.

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4.0 UPLAND BIOLOGICAL RESOURCES — VEGETATION, WILDLIFE, AND WILDLIFE HABITAT

Upland biological resources include vegetation, wildlife, and wildlife habitat. This chapter describes and quantifies injuries to these biological resources in the upland areas adjacent to the town of Anaconda.

Chapters 2.0 and 3.0 demonstrated that the soils of these upland areas are contaminated with hazardous substances at concentrations that are toxic to plants. The results presented in this chapter demonstrate that vegetation, wildlife, and wildlife habitat have been injured in the upland impact areas surrounding Anaconda as a result of exposure to these contaminated soils. Specifically:

- Exposure to phytotoxic soils has resulted in gross modifications to, or the elimination of, vegetation communities at impacted sites. The extent of forest and grassland has been significantly reduced at impact sites relative to matching controls; the extent of bare ground is significantly greater at impacted sites.

- The number of habitat layers has been significantly reduced in the impacted areas.

- Habitat has been significantly reduced in extent and quality for marten (an indicator species for forest habitat) and elk (an indicator species for forest edge/grassland habitat). The viability of wildlife populations that depend on these habitat types therefore has been reduced in the injured areas.

- As a result of habitat loss and degradation, a large number of wildlife species that depend on this habitat are likely to have been lost from the injured area or have undergone population reductions.

- Loss of vegetation and wildlife habitat is caused by exposure to hazardous substances. Lack of vegetative cover is positively correlated with hazardous substance concentrations and the degree of phytotoxicity observed in controlled laboratory tests.

No causal factor other than hazardous substance exposure consistently and plausibly explains conditions in the injured area.

4.1 DESCRIPTION OF UPLAND BIOLOGICAL RESOURCES

Upland biological resources include vegetation, wildlife, and the wildlife habitat provided by vegetation communities in the upland impact areas surrounding Anaconda (i.e., Stucky Ridge, Smelter Hill, and Mount Haggin) that were described in preceding chapters. The native vegetation in the uplands surrounding Anaconda comprises species adapted to semi-arid montane conditions; typical vegetation includes mesic or xeric species of trees, shrubs, forbs, and bunchgrasses (Pfister et al., 1983; Mueggler and Stewart, 1980). Likewise, wildlife species associated with these upland habitats are those adapted to semi-arid montane conditions and the vegetation communities typical of such areas.

4.2 INJURY DEFINITION

Injury to upland biological resources is defined as:

- . . . adverse changes in viability: death, . . . physiological malfunctions (including malfunctions in reproduction), or physiological deformations [43 CFR § 11.62 (f) (i)].

In the Clark Fork Basin, injury to vegetation that resulted from releases of hazardous substances is expressed in the complete elimination of vegetation, or changes in the composition, structure, and/or distribution of vegetation communities. At the level of the individual plants, these community changes have been caused by death and physical deformations (i.e., reduced growth leading to a loss in viability).

Plant death and reduced growth have been found in this assessment to satisfy the four acceptance criteria for biological responses [43 CFR § 11.62 (f) (2) (i-iv)]. Specifically, plant death and reduced growth:

- Are often the result of exposure to hazardous substances, as shown in various scientific studies, including the phytotoxicity studies described in Chapter 3.0 and Appendix B.

- Have been shown to occur in controlled laboratory experiments (see Chapter 3.0 and Appendix B). Death and reduced growth occurred in plants grown on soils collected from the impacted upland areas.

- Are often the result of exposure to hazardous substances among free-ranging organisms, as documented in the literature (see Chapter 3.0), and in the field studies described in this chapter and in Appendix C.

- Are routine measurements that are practical to perform and produce scientifically valid results.

Overall, injury (death, reduced growth relative to controls) to vegetation has been confirmed by the results of phytotoxicity studies and by the observed loss of vegetation in exposed areas (see Section 4.2.3).

The viability of upland wildlife resources in the upper Clark Fork Basin has been reduced by:

- Reductions in habitat quantity and quality for selected indicator species [43 CFR § 11.63 (f)(4)(ii)(A)] relative to uncontaminated control areas [43 CFR § 11.72 (d)(1)].

Since the quality and quantity of upland wildlife habitat are defined largely by vegetative community characteristics, which, in turn, are a function of the relative viability of individual plants, the first three acceptance criteria listed are also pertinent to wildlife injury. The final criterion has also been met: routine measurements of wildlife habitat quality and quantity can be performed using habitat evaluation procedure (HEP) models developed by U.S. Fish and Wildlife Service and identified as appropriate models for use in NRDAs [43 CFR §11.71 (l)(8); U.S. DOI, 1987].

The following sections describe the relationship between vegetation and wildlife habitat, and methods of assessment of injury to wildlife habitat.

4.3 ASSESSMENT METHODOLOGIES

4.3.1 Vegetation Assessment

The soils of the Stucky Ridge, Smelter Hill, and Mount Haggin impact areas have been shown to be phytotoxic (Chapter 3.0); the cumulative result of phytotoxic responses among individual plants has been expressed as changes in community composition and structure (e.g., species composition, dispersion, or percent cover) [43 CFR § 11.71 (l)(6)] of the indigenous upland vegetation communities.

Injury to vegetation communities was assessed by statistically comparing vegetation measurements made at study sites in the area impacted by smelter emissions and at paired control sites. The following vegetation variables were measured:

- Proportional representation of cover types (e.g., coniferous forest, deciduous forest, grasslands)

- Proportional representation of habitat layers (e.g., tree canopy, tree bole, shrub layer, terrestrial subsurface)
- Percent cover of vegetation and individual plant species.

Vegetative cover then was related to the observed phytotoxicity of site soils as well as concentrations of hazardous substances to confirm the causal relationship.

4.3.2 Wildlife Habitat Assessment

The distribution of wildlife species reflects differing habitat requirements, including preferences for thermal and hiding cover, and breeding and foraging sites. Certain species have very restrictive habitat requirements (habitat specialists), while others are less specific (habitat generalists). The difference between habitat specialists and generalists is one of degree, because even the generalist species have well-defined, though less restrictive, preferences for food, water, cover, reproduction, and other needs.

Plant community structure and distribution are generally the primary determinants of whether an area provides habitat suitable for terrestrial wildlife species (Cooperrider et al., 1986). Most species have habitat requirements that specify comparatively narrow ranges of vegetational parameters (e.g., many bird and mammal species require mature conifer forest types). While the vegetational characteristics of an area may not capture all of the environmental parameters important to a particular animal species, vegetation normally defines the baseline quality of the habitat.

At the species level, the value of habitat can be quantified using a set of measurable habitat variables. Measurable information concerning the quality, or suitability, of habitat for a species is often derived from vegetational cover types used by the species (U.S. FWS, 1981). Aspects of a species' habitat preferences that are difficult to measure or quantify can often be approximated using a related vegetation parameter; for example, if food availability for a species is determined by small mammal abundance, and it is known that small mammal abundance can be approximated by the percent herbaceous cover, then herbaceous cover can be measured as an index of food availability (U.S. FWS, 1981).

When comparing habitat integrity and suitability for wildlife at selected study sites, a useful approach is to select indicator species whose habitat requirements are shared by a wide range of species. For example, many avian species are dependent on mature conifer canopy. Evaluating the habitat in an area for one such species gives an indication of its more general suitability for all canopy-dependent species.

Habitat Evaluation Procedure (HEP) models were used to assess injury to upland wildlife habitat in the upper Clark Fork Basin as recommended in 43 CFR § 11.71 (l)(8) and

U.S. DOI (1987). HEP models are based on the relationships between the ecological features of an area and its ability to provide habitat for wildlife. In HEP models, the important features of an area of habitat that influence its suitability for the model species are identified, and quantitative relationships that describe the availability of those features and the suitability of the habitat are established. HEP models provide indices of the potential carrying capacity of an area of habitat for the model species.

The selection of HEP models for this injury assessment was based on the types of habitats that were initially identified as potentially injured. Initial field observations and discussions with local ecologists and wildlife managers indicated that upland plant associations potentially impacted by hazardous substances included coniferous forests [primarily Douglas fir (*Pseudotsuga menziesii*) or lodgepole pine (*Pinus contorta*)], and montane meadow and forest edge (i.e., interspersed grassland and forest patches).

4.3.2.1 Forest Habitat: Indicator Species = Marten

Injury to the forest habitat types was determined using marten (*Martes americana*) as an indicator species. Marten are primarily arboreal mammals and in Montana are confined to forested areas, particularly spruce-fir forests (Koehler and Hornocker, 1977; Hawley and Newby, 1957; Weckwerth and Hawley, 1962) or Douglas fir and lodgepole pine stands (Fager, 1992). A HEP model for marten winter habitat published by the U.S. Fish and Wildlife Service (Allen, 1984) for the boreal forest biome and Rocky Mountain forests of the western United States (Allen *pers. comm.*) was used in this assessment. Much of the data used in the development of the model were obtained during habitat studies in Montana, making it particularly suitable for use in the assessment area

Variables measured to evaluate winter habitat quality for marten included:

- Percent tree canopy closure. Only forested areas are suitable marten habitat.
- Percent of the canopy that is fir or spruce. Coniferous forests, including Douglas fir and lodgepole pine types, are preferred over deciduous forests.
- Successional stage of the forest stand. Mature or old growth stands are preferred over earlier successional stages (Koehler and Hornocker, 1977).
- Percent of the ground surface covered by fallen timber greater than 3 inches in diameter. This parameter serves as a proxy measure for the availability of the marten's rodent prey (Allen, 1984).

The suitability of marten habitat was assessed in impact and control areas, and resulting values were compared statistically to determine whether significant differences exist.

4.3.2.2 Forest Edge and Grassland Habitat: Indicator Species = Elk

Injury to forest edge and grassland habitat was determined using elk (*Cervus elaphus*) as an indicator species. In southwest Montana, elk depend on forests for security, and grassland vegetation provides the mainstay of the elk diet. An elk HEP model describing winter habitat suitability was developed for this assessment (see Appendix C).

Variables measured to evaluate winter habitat suitability for elk included:

- Availability and quality of forest cover
- Availability and quality of food, measured as percent cover of palatable forage species.

4.3.2.3 Habitat Layers

In addition to the individual species models, a third HEP model, the layers of habitat model (Short, 1984), was used to address the relationship between the vertical complexity of vegetation communities and their capacity to provide habitat for a diversity of wildlife. Habitats that are structurally complex (i.e., that have many habitat layers) generally support a more diverse fauna than structurally simple habitats. This relationship has been shown for birds (MacArthur and MacArthur, 1961; Cody, 1975), reptiles (Pianka, 1967), fish (Tonn and Magnuson, 1982), and molluscs (Harman, 1972). The layers of habitat model quantifies this relationship, and habitats that are structurally complex (i.e., able to support diverse wildlife populations) score higher than less structurally complex habitats.

In this assessment, the layers of habitat model was used with information about the habitat preferences of individual species to classify wildlife species by vegetation layer "guilds," or groups of species whose niches occur in the same vegetation layers or groups of vegetation layers (Short, 1984). This, together with vegetation structure measurements made in impact and control areas, allowed the identification of species that are likely to have been become locally extinct or have reduced viability in the impacted areas because of the demonstrated changes in habitat structure.

Using the HEP models described above, measurements of habitat suitability at study sites within the area impacted by smelter emissions were compared with measurements made at paired control sites in German Gulch.

4.3.3 Baseline Conditions

Injury to wildlife habitat was defined relative to control areas [43 CFR § 11.72 (d)(1)]. Baseline conditions are those that would be expected to be present in the Stucky Ridge, Smelter Hill, and Mount Haggin impact areas in the absence of releases of hazardous substances. Baseline conditions are not necessarily pristine, since other nonmining anthropogenic activities (e.g., timber harvesting and livestock grazing) are likely to have occurred in the impacted areas in the absence of mining-related injury. Baseline conditions for the injured areas were evaluated using two methods: historical evidence, and observations made at the German Gulch control areas described in Chapter 3.0.

4.3.3.1 Historical Information

Historical documents describe the high-quality wildlife habitat previously provided by the now-injured uplands adjacent to Anaconda. The mountains south of Anaconda were "thickly timbered with pine and fir trees, the meadows covered with knee-deep bunchgrass . . . deer, elk, mountain goats and mountain lions were so abundant that ranchers did not need to hunt for smaller animals" (in Wolle, 1963); hill "C" (overlooking Anaconda to the south) was "heavily timbered at that time with pine trees some three to four feet in diameter" (Deer Lodge County Historical Group, 1975). A later document states, "Prior to the late 1800s the hills locally referred to as the A and C hills were vegetated by a mosaic of Douglas fir and aspen stands intermixed with grasslands." (USDA, 1986). Historical photographs (USDA, 1986) show that in the 1880s the upper elevations of Smelter Hill and the adjacent hills to the west were covered in conifer forest, which extended as "stringers" down the northern aspects of these hills to the valley floor at 5,000 feet. Stumps and dead standing and fallen trees are evidence of previous forest cover in the Anaconda area uplands. Therefore, the historical documentation indicates that the injured area was vegetated with a mixture of coniferous forest and grasslands.

4.3.3.2 Control Areas

The German Gulch area was selected as the overall control area based on its similarity in elevation and aspect, and its proximity to the impacted area (Figure 4-1). Historical accounts and photographs were consulted to confirm that German Gulch and the Anaconda uplands (before mining-related injury) supported similar vegetation. Like the injured upland areas, the control areas of German Gulch were clear-felled of timber in the early part of this century, and timber harvesting continued until 1991 (M. Frisina, Montana Department of Fish, Wildlife, and Parks, pers. comm.). Grazing by livestock is a continuing land use in the control area, and the presence of fire scars attests that burning has occurred in the past. Based on current land use patterns in the German Gulch area, logging, grazing by livestock, and fires would be expected in the impact area in the absence of mining-related injury.

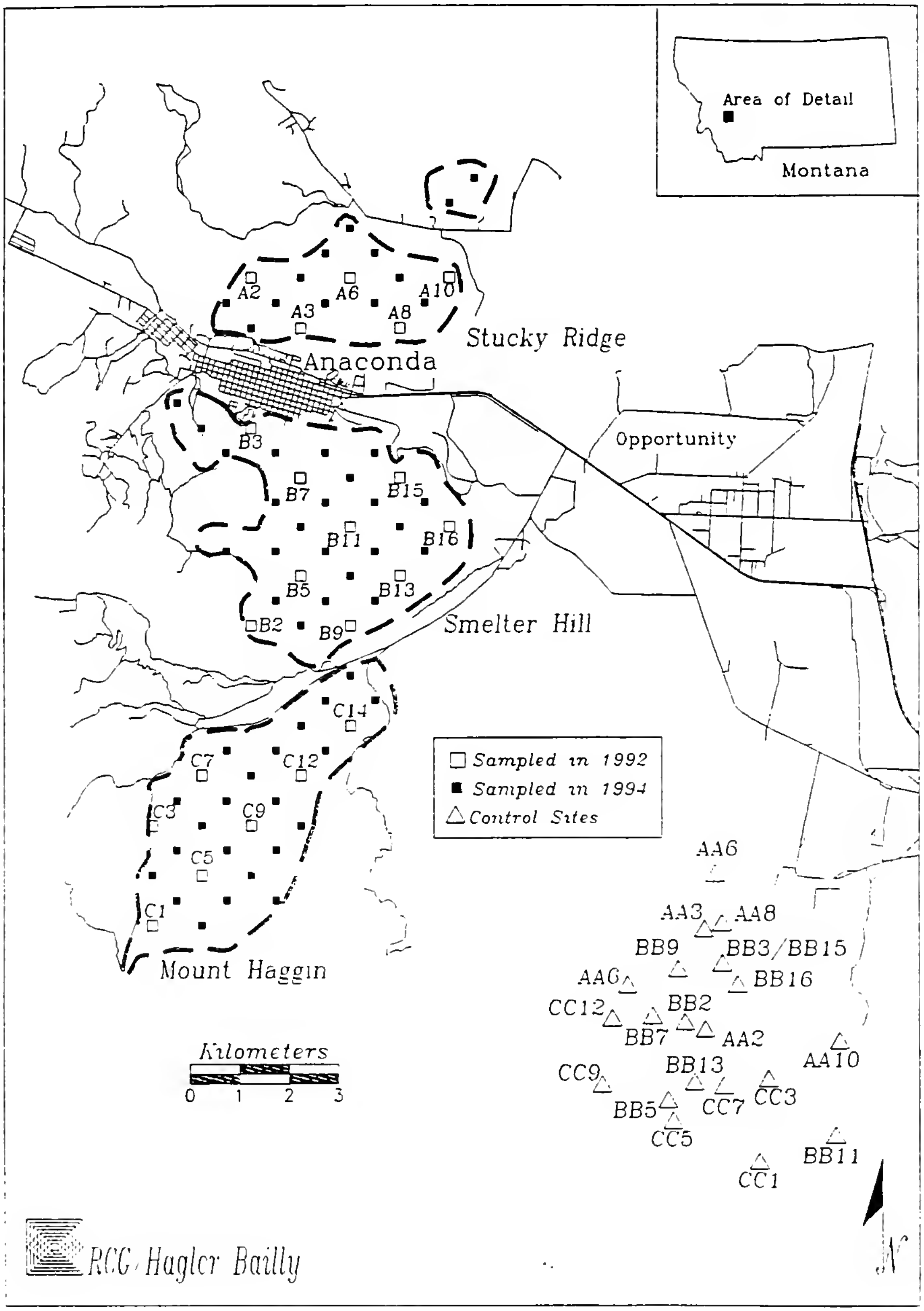

Figure 4-1. Upland Impact and Control Vegetation Sampling Sites.

Within the overall German Gulch area, individual sampling sites were selected as a paired control for each 1992 sampling site in the injured upland area. Each control site was chosen so that it resembled its respective impact sampling site in the environmental features that influence vegetation community structure and composition, and thus habitat (Table 4-1).

Vegetation measurements made at the control sites are consistent with the historical documentation cited previously. Specifically, sites selected as controls for the Stucky Ridge area are dominated by grasslands, intermixed with evergreen forest, shrubland, and deciduous forest (Figure 4-2). Sites selected as controls for the Smelter Hill area are dominated by coniferous forests interspersed with grasslands (Figure 4-3). Sites selected as controls for the Mount Haggin area are dominated by coniferous forests (Figure 4-4).

Vegetation and habitat measurements made in the control area also confirm that the baseline conifer forests and open grasslands continue to provide high quality habitat for a rich diversity of animal species. At least 32 avian species and 10 mammal species are characteristic of conifer forests in southwest Montana (Tables 4-2 and 4-3). The avian species include game birds such as blue and spruce grouse, and birds of prey; the mammal species include elk, marten, black bear, and bobcat. Over 70% of the native species characteristic of the area were observed in the control area during fieldwork conducted in 1992, indicating that current or recent land use practices (logging and livestock grazing) in the control area do not eliminate wildlife habitat quality or availability.

4.4 INJURY DETERMINATION AND QUANTIFICATION

This section provides evidence confirming and quantifying reductions in wildlife habitat quantity and quality in the injured upland areas in the vicinity of Anaconda.

4.4.1 Previous Investigations

Early (1886) photographs of the Smelter Hill area show that, prior to injury, the northern slopes of Smelter Hill were vegetated with forests and grasslands. Sporadic attempts have been made to revegetate limited portions of the impacted area to reduce erosion on the hills south of the town of Anaconda (USDA, 1986; Headwaters RC&D Forester, 1992; NPI, date unknown). Between 1960 and 1967, AMC planted more than 60,000 lodgepole pine and Douglas fir near Mill Creek, on the A Hill, and in Sheep Gulch (NPI, date unknown). Between 1971 and 1977, AMC planted 16,500 lodgepole pine, ponderosa pine (*Pinus ponderosa*), and unspecified "trees" on the A and C Hills and in Sheep Gulch (NPI, date unknown). All locations recorded are vague. Apparently, the attempts by AMC to reforest met with marginal success; subsequent efforts to revegetate the same general areas were initiated in 1985 (Headwaters RC&D Forester, 1992).

Table 4-1
Comparison of Elevation (ft), Aspect, Slope, and Distance to Winter Road (km) for Paired Impact and Control Sites

Site	Elevation (ft)		Aspect		Slope[1]		Distance to Winter Road (km)	
	Impact	Control	Impact	Control	Impact	Control	Impact	Control
Stucky Ridge and Controls								
A2	5800	6000	SE	S	M	M	1.2	1
A3	5400	5500	S	E	M	M	0.5	0.5
A6	5400	5400	NE	ENE	G	G	1.2	1.3
A8	5300	5200	S	E	G	G	0.3	0.5
A10	5200	5300	E	E	M	M	1	1.1
Smelter Hill and Controls								
B2	6000	6000	S	S	M	G	1.5	1.9
B3	5600	5500	NNW	N	M	M	0.2	0.2
B5	5900	6100	E	E	M	S	1.9	1.7
B7	6000	6000	NNE	NNW	S	S	1.2	1.3
B9	5500	5700	S	SE	G	G	0.6	0.6
B11	6300	6400	W	NW	G	G	1.6	1.2
B13	6000	6000	S	S	S	S	1	0.6
B15	5600	5500	NNW	N	M	M	0.4	0.2
B16	5600	5700	ENE	NNE	G	M	0.6	0.6
Mount Haggin and Controls								
C1	6800	6600	WNW	NW	S	M	0.3	0.6
C3	6200	6000	W	W	S	M	0.1	0.2
C5	6800	6600	NNW	N	M	M	1.2	1.2
C7	6200	6000	WNW	NNW	G	G	0.6	0.5
C9	7000	6900	WNW	WNW	S	S	2.1	2.6
C12	6700	6500	NE	NE	M	M	1.4	1.9
C14	5900	6100	ENE	E	G	M	1.2	1.3

[1] S = steep; M = moderate; G = gentle

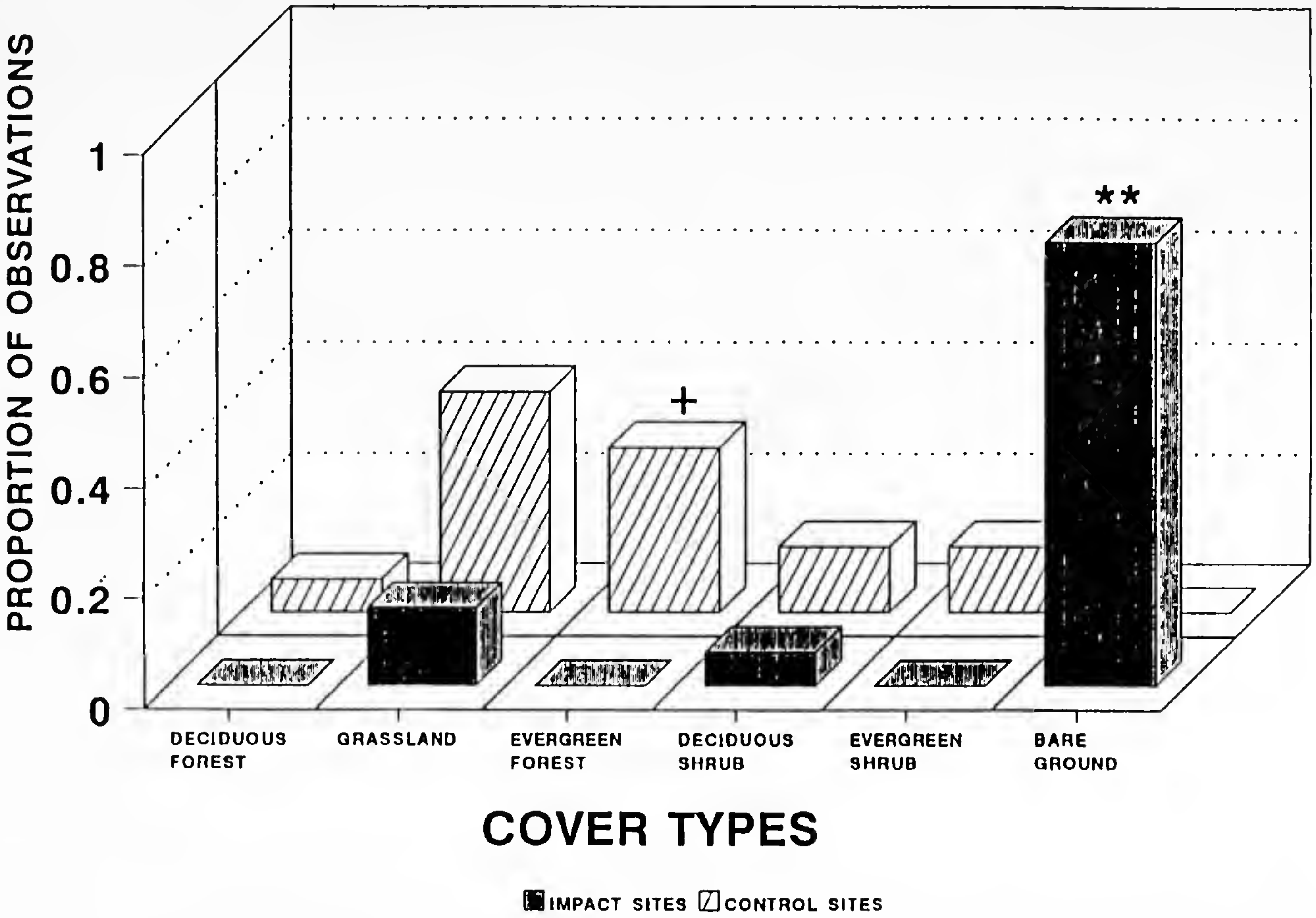

Figure 4-2. **Proportional Representation of the Cover Types of Stucky Ridge (Area A) and Corresponding Control Sites.** + and ** indicate significant differences in the proportional representation at $\alpha = 10\%$ and 3.3%, respectively. Source: Appendix C.

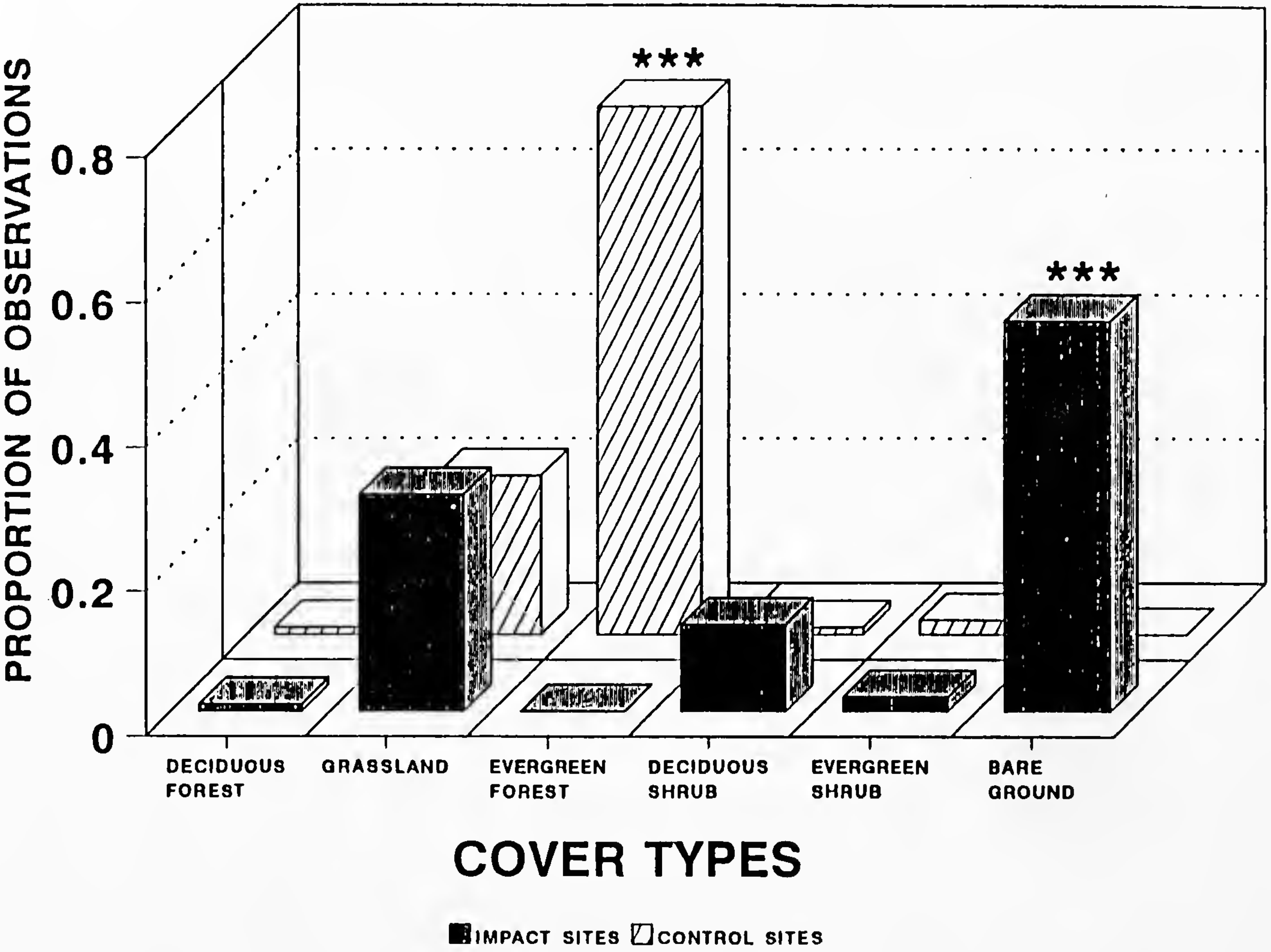

Figure 4-3. Proportional Representation of the Cover Types of Smelter Hill (Area B) and Corresponding Control Sites. *** Indicates a significant difference in proportional representation at $\alpha = 1\%$. Source: Appendix C.

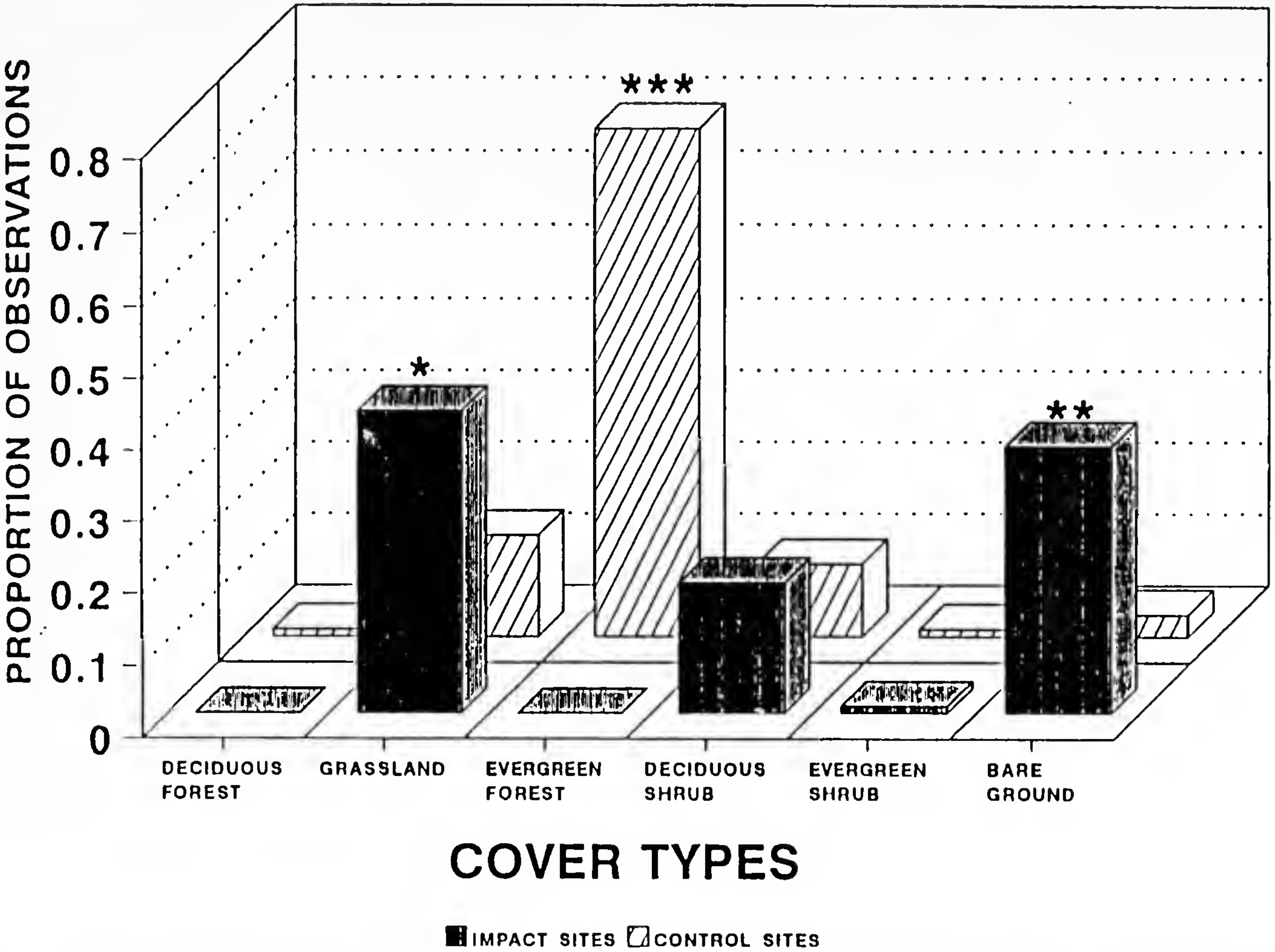

Figure 4-4. **Proportional Representation of the Cover Types of Mount Haggin (Area C) and Corresponding Control Sites.** *, **, and *** indicate significant differences in proportional representation at α = 5%, 3.3%, and 1%, respectively. Source: Appendix C.

Table 4-2
Birds Characteristic of Southwest Montana Lodgepole Pine and Douglas Fir Forests and their Feeding and Nesting Vegetation Layers

Species		Feeding Layers	Nesting Layers
Red-tailed hawk*	*Buteo jamaicensis*	US	TC
Sharp-shinned hawk*	*Accipiter striatus*	TC/SM	TC
Cooper's hawk	*Accipiter cooperii*	TC/SM	TC
Northern goshawk	*Accipiter gentilis*	TC/SM	TC
Blue grouse*+	*Dendragapus obscurus*	TC/SM	-
Spruce grouse	*Dendragapus canadensis*	TC/SM	-
Northern saw-whet owl	*Aegolius acadicus*	TC/SM/US	TB
Downy woodpecker*	*Picoides pubescens*	TB	TB
Hairy woodpecker*	*Picoides villosus*	TB	TB
Olive-sided flycatcher	*Contopus borealis*	-	TC
Western wood-pewee*	*Contopus sordidulus*	-	TC
Grey jay*	*Perisoreus canadensis*	US/SM/TC	TC
Steller's jay*	*Cyanocitta stelleri*	US/SM/TC	TC
Clark's nutcracker*	*Nucifraga columbiana*	TC	TC
Mountain chickadee*	*Parus gambeli*	TC/SM	TB
Red-breasted nuthatch*	*Sitta canadensis*	TB/TC	TB
House wren*	*Troglodytes aedon*	US/SM	TB
Ruby-crowned kinglet*	*Regulus calendula*	TC	TC
Mountain bluebird*+	*Sialia currucoides*	SM/US	TB

Table 4-2 (cont.)
Birds Characteristic of Southwest Montana Lodgepole Pine and Douglas Fir Forests and their Feeding and Nesting Vegetation Layers

Species		Feeding Layers	Nesting Layers
Townsend's solitaire*	*Myadestes townsedii*	TC/SM	US
Swainson's thrush*	*Catharus guttatus*	SM/US	SM
American robin*	*Turdus migratorius*	TC/SM/US	TC/SM
Cedar waxwing*	*Bombycilla cedrorum*	TC/SM	TC
Yellow-rumped warbler*	*Dendroica coronata*	TC	TC
Western tanager*	*Piranga ludoviciana*	TC/SM	TC
Chipping sparrow*	*Spizella passerina*	US	US
White-crowned sparrow*	*Zonotrichia leucophrys*	US	US
Dark-eyed junco*	*Junco hyemalis*	US	US
Pine grosbeak*	*Pinicola enucleator*	TC/SM	TC
Red crossbill*	*Loxia curvirostra*	TC	TC
Pine siskin*	*Carduelis pinus*	TC/SM	TC
Evening grosbeak*	*Coccothraustes vespertinus*	TC	TC

References: Bergeron et al., 1992; Johnsgard, 1992.

TC = tree canopy; TB = tree bole; SM = shrub midstory; US = understory; TS = terrestrial subsurface.

* Indicates species observed in control study sites during June and July 1992.

$^+$ Indicates species observed in impact study sites during June and July 1992.

Table 4-3
Mammals Characteristic of Southwest Montana Lodgepole Pine and Douglas Fir Forests and their Feeding and Cover Vegetation Layers

Species		Feeding Layers	Cover Layers
Snowshoe hare*	*Lepus americanus*	US/SM	US
Red squirrel*	*Tamiasciurus hudsonicus*	TC/US	TC
Porcupine	*Erithezon dorsatum*	TC/SM	TC
Black bear	*Ursus americanus*	SM/US	US
Pine marten	*Martes americana*	TC/US	TC/TS
Ermine	*Mustella erminea*	US	US/TS
Mountain lion	*Felis concolor*	SM/US	TS
Bobcat	*Felis rufus*	SM/US	TS
Lynx	*Felis lynx*	SM/US	TS/SM
Elk*+	*Cervus elaphus*	SM/US	TS/SM

Reference: Chapman and Feldhamer, 1982.

TC = tree canopy; TB = tree bole; SM = shrub midstory; US = understory; TS = terrestrial subsurface.

* Indicates species observed in control study sites during June and July 1992.

+ Indicates species observed in impact study sites during June and July 1992.

The vegetation and phytotoxicity investigation for the Smelter Hill RI/FS Phase I was designed to evaluate the various vegetation types that grow within the physically undisturbed areas (no regrading, restructuring, or reclamation) of the Smelter Hill OU and to evaluate vegetation growing on the reclaimed areas (including the Anaconda and Opportunity Ponds berms and parts of the HPS area) (PTI, 1990a). Unreclaimed areas were those portions of the study area where the original (or remaining) soils have been injured by airborne contamination, but the substrate has not been graded or altered during construction or reclamation activities (see Chapter 3.0). Ninety-three of the 198 sites samples for the RI/FS were unreclaimed soil sites on Smelter Hill (PTI, 1990b).

Smelter Hill was mapped by vegetation type, and types were delineated based on aerial photographs and field verification. The "natural" plant types identified and sampled were Great Basin wild rye (*Elymus cinereus*) grasslands, aspen (*Populus tremuloides*) woodlands/scrub forest, wet meadow, rocky barrens, horsebrush (*Tetradymia canescens*) shrubland, and willow (PTI, 1991). Sample sites consisted of 10 x 10 meter plots (PTI, 1990a). Percent cover, density, and production were measured, and vegetation biomass samples were collected for analysis of acid-extractable metals (PTI, 1990a,b).

All mean values for vegetative percent cover by vegetation type were less than 35%, except for wet meadow vegetation (9% of the total area sampled, located near Mill Creek), which had a mean cover of 65% (PTI, 1991). Nearly 50% of the study area was classified as Great Basin wild rye grasslands. Great Basin wild rye is an invasive weedy species, and monocultures are characteristic of disturbed sites (J. Joy, USDA/Forest Service, pers. comm.). Of the 58 Great Basin wild rye sites sampled, vegetative cover averaged only 27% (range 5-46%) (PTI, 1991). Bare soil cover ranged from 3 to 71% and averaged 26%, and litter and bare rock cover ranged from 23 to 66% and averaged 47% (PTI, 1991). Much of the cover type designated as litter and bare rock is probably the cobbled, eroded surface now characteristic of much of Smelter and Weather Hills and vicinity.

The only vegetation type with trees was the aspen woodland type (PTI, 1990b). Aspen woodlands and scrub forests were less than 2% of the area sampled and were confined to moist drainages or filled-in beaver ponds (PTI, 1991). The clonal nature of aspen and its role as an early successional colonist contribute to its localized presence on Smelter Hill.

Vegetative productivity was negatively correlated with some or all metals in all area soils sampled, except the horsebrush area (PTI, 1991). Horsebrush consistently had the highest maximum and average tissue concentrations of all analytes, indicating its tolerance of metal contamination (PTI, 1991). Total metals concentrations in 0-2 inch unreclaimed soils were significantly correlated with metals concentrations in plant tissue (PTI, 1991) (see Chapter 2.0). In Great Basin wild rye communities, percent vegetative cover was positively correlated with plant tissue concentrations and plant-available metals, which is also indicative of a species with high tolerance to metals contamination. In wet meadow sites, percent cover was negatively correlated with all plant-available metals concentrations (PTI, 1991).

4.4.2 NRDA Investigations

Field studies of vegetation community structure and composition and the wildlife habitat provided by those communities were performed in 1992 and 1994 (see Appendices C and D). Reductions in habitat quality and quantity were assessed within areas delineated as grossly injured based on aerial photographs and preliminary field observations. Grossly injured areas were identified and delineated using the following criteria:

- Complete or virtual elimination of the indigenous major plant associations
- Little or no regeneration of the indigenous major plant associations
- Extensive top-soil exposure and erosion associated with vegetation loss.

The grossly injured areas (Figure 4-1) are:

- The eastern portion of Stucky Ridge and the hills north of Lost Creek (3.8 square miles)
- Smelter Hill, including slopes south and west of the main smelter stack (7.3 square miles)
- The Mount Haggin uplands south and east of Mill Creek (6.7 square miles).

At five sites[1] in the Stucky Ridge area, nine sites in the Smelter Hill area, and seven sites in the Mount Haggin area, and at 21 paired control sites in German Gulch, the following measurements were made in 1992:

- Dominant vegetative cover type
- Number and type of habitat layers present
- Approximate height of each habitat layer in the dominant cover type
- Percent canopy closure of each species in the tree canopy, shrub midstory, and understory layers

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[1] Each site comprised two intersecting 500m transects oriented north-south and east-west. Measurements were made at 10 points at 100m intervals along the transects. Vegetation measurements at each of the 10 points were made using 10m line intercept and visual observation methods.

- Percent canopy closure and percent of ground covered by downfall (within evergreen forest cover type only)
- The presence or absence of evidence of previous afforestation (tree stumps, downed timber, standing dead timber)
- Density of elk pellet groups.

In 1994, the following measurements were made at an additional 13 sites in the Stucky Ridge area, 22 sites in the Smelter Hill area, and 22 sites in the Mount Haggin area:[2]

- Dominant vegetative cover type
- Percent canopy closure of plants, vegetative litter, bare ground, rock, and downed timber in the tree canopy, shrub midstory, and understory layers
- The presence or absence of evidence of previous afforestation (tree stumps, downed timber, standing dead timber).

As in 1992, data collected at each of these sites represent a compilation of 10 individual sampling points per site (see Appendix D).

4.4.2.1 Vegetation Characteristics

During 1992 and 1994, 78 sites were sampled in the Stucky Ridge, Smelter Hill, and Mount Haggin impact areas, and 21 sites were sampled in the German Gulch control area. Each site comprised 10 subsites spaced at 100m intervals along intersecting transects.

1992 Data

Cover Types. Analysis of cover type data revealed that the Stucky Ridge area is predominantly bare ground with some grassland and deciduous shrub; the Smelter Hill area is predominantly bare ground or grassland, with some deciduous and evergreen shrub; and the Mount Haggin area is predominantly bare ground and grassland, with some deciduous and evergreen shrub (see Figures 4-2, 4-3, and 4-4). In contrast, bare ground was rarely observed in the control areas, which were predominantly evergreen forest or grassland. Representative views of control and impact upland sample sites showing these gross differences in vegetative communities are shown in Figures 4-5a through 4-5g.

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[2] No control sites were sampled in 1994.

Cover types were compared statistically between impact and paired control sites. The three impact areas had a significantly greater proportion of bare ground and a significantly smaller proportion of evergreen forest than control areas (Table 4-4).

Grasslands. Further analysis indicated that impact sites dominated by the grassland cover type were significantly sparser (i.e., greater mean percent cover of bare ground) than control area grasslands. Moreover, the mean percent cover of native grassland species in control sites was significantly greater than the mean percent cover of native grassland species in the impact areas (which were dominated to a greater extent by invasive weed species) (Table 4-5).

Habitat Layers. Analysis of habitat layer data revealed that the impact areas lack two of the five vegetation layers (tree canopy and tree bole) characteristic of the control sites (Figures 4-6, 4-7, and 4-8). Furthermore, the control areas support a significantly greater development of the remaining three layers (shrub midstory, understory, and soil) than the impact areas (Table 4-6). The number of habitat layers in control areas ranged between two and five; at most of the control sites, five layers were present. In contrast, the number of layers present at the impact sites ranged from zero to three (Figures 4-9, 4-10, and 4-11). The mean number of layers at each impact site was significantly less than the mean number of layers at the respective control site (Table 4-7).

Thus, injury to upland vegetation in the Stucky Ridge, Smelter Hill, and Mount Haggin impact areas is evident as widespread elimination of indigenous conifer forests, a decrease in the cover of native grassland species, and an increase in bare, devegetated ground. The types of habitat layers lost, primarily tree bole and tree canopy, are indicative of the predominant loss of forest vegetation.

1994 Data

The data obtained during fieldwork in 1994 are presented in Attachments A and B to Appendix D.

Cover Types. There were no significant differences in the proportional representations of cover types between the two years (Table 4-8). As in 1992, the most prevalent cover types in all three impact areas were bare ground and grassland. Whereas bare ground comprised approximately 40% of the cover types on Smelter Hill and Mount Haggin, it comprised almost 68% on Stucky Ridge (Figure 4-12). This greater proportional representation of bare ground on Stucky Ridge is evident in the 1992 data also (Figure 4-12). Conversely, both the 1992 and 1994 data show that grassland had greater proportional representation on Smelter Hill and Mount Haggin than on Stucky Ridge (see below). At all sites combined, bare ground comprised 46% of the cover types and grassland almost 37%. Deciduous shrubland (mainly aspen stands) had only limited cover on all three impact areas, particularly on Stucky Ridge where it had a proportional representation of only about 6% (compared with 14% and 19% on Mount Haggin and Smelter Hill, respectively).

Figure 4-5a. Upland Sample Site A6 on Stucky Ridge Showing Devegetation and Loss of Topsoil.

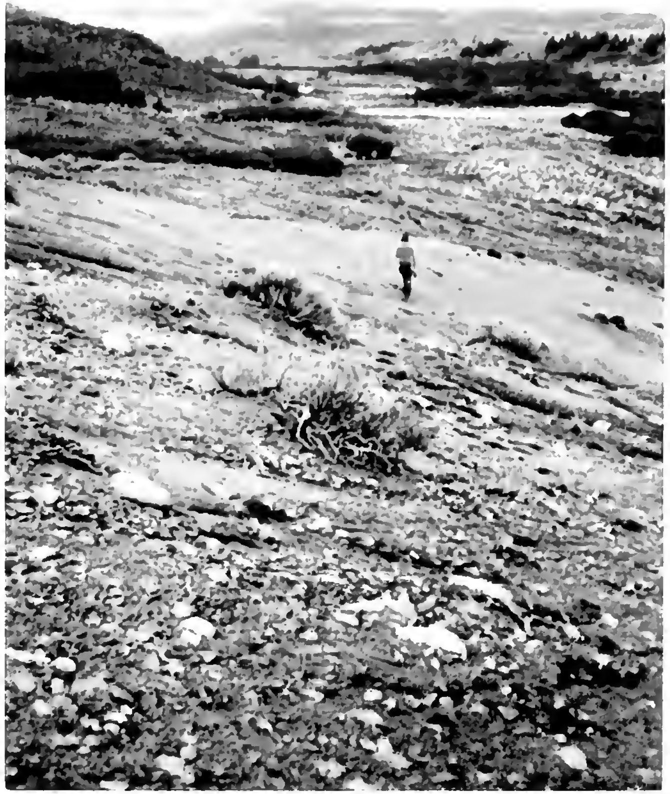

Figure 4-5b. Upland Sample Site B13 on Smelter Hill Showing Devegetation and Dead and Moribund Vegetation.

Figure 4-5c. Upland Sample Site C8 on Mt. Haggin Showing Devegetation and Evidence of Previous Afforestation.

Figure 4-5d. Upland Sample Site C9 on Mt. Haggin Showing Devegetation and Evidence of Previous Afforestation.

Figure 4-5e. German Gulch Upland Control Area Showing Douglas Fir Forest Cover.

Figure 4-5f German gulch Upland Control Area Showing Lodgepole Pine Forest Cover.

Figure 4-5g. Upland Control Sample Sites B13 and C7. Sites located on forested slope facing camera.

Table 4-4
Comparison of the Proportional Representation of Cover Types in Impact and Control Areas

Area	Cover Type	p-value
All impact areas vs. all controls	Evergreen forest Grassland Bare ground	< 0.002*** < 0.23 < 0.0002***
Stucky Ridge vs. controls	Evergreen forest Grassland Bare ground	< 0.06+ < 0.93 < 0.031**
Smelter Hill vs. controls	Evergreen forest Grassland Bare ground	< 0.002*** < 0.31 < 0.002***
Mount Haggin vs. controls	Evergreen forest Grassland Bare ground	< 0.008*** < 0.04* < 0.031*

+, *, **, and *** indicate significantly greater proportional representation in the control site for α = 10%; 5%; 3.3%; and 1%, respectively.

Table 4-5
Comparison of Grasslands in 21 Upland Impact and Control Areas

	% Bare Ground	% Cover of Native Species
Impact	61.7	10.9
Control	11.0	34.5

Table 4-6
Comparison of the Proportional Representation of Habitat Layers in Impact Areas and Control Areas

	Habitat Layer	p-value
All impact areas vs. all controls	Tree canopy Tree bole Shrub midstory Understory Soil	< 0.0002*** < 0.0002*** < 0.0004*** < 0.0002*** < 0.0002***
Stucky Ridge vs. controls (Area A)	Tree canopy Tree bole Shrub midstory	< 0.03125** < 0.03125** < 0.03125**
Smelter Hill vs. controls (Area B)	Tree canopy Tree bole Shrub midstory Understory Soil	< 0.00195*** < 0.00195*** < 0.00977*** < 0.00195*** < 0.00195***
Mount Haggin vs. controls (Area C)	Tree canopy Tree bole Shrub midstory	< 0.00781*** < 0.00781*** < 0.03125**

** and *** indicate significantly greater proportional representation in the control area at $\alpha = 3.3\%$ and 1%, respectively.

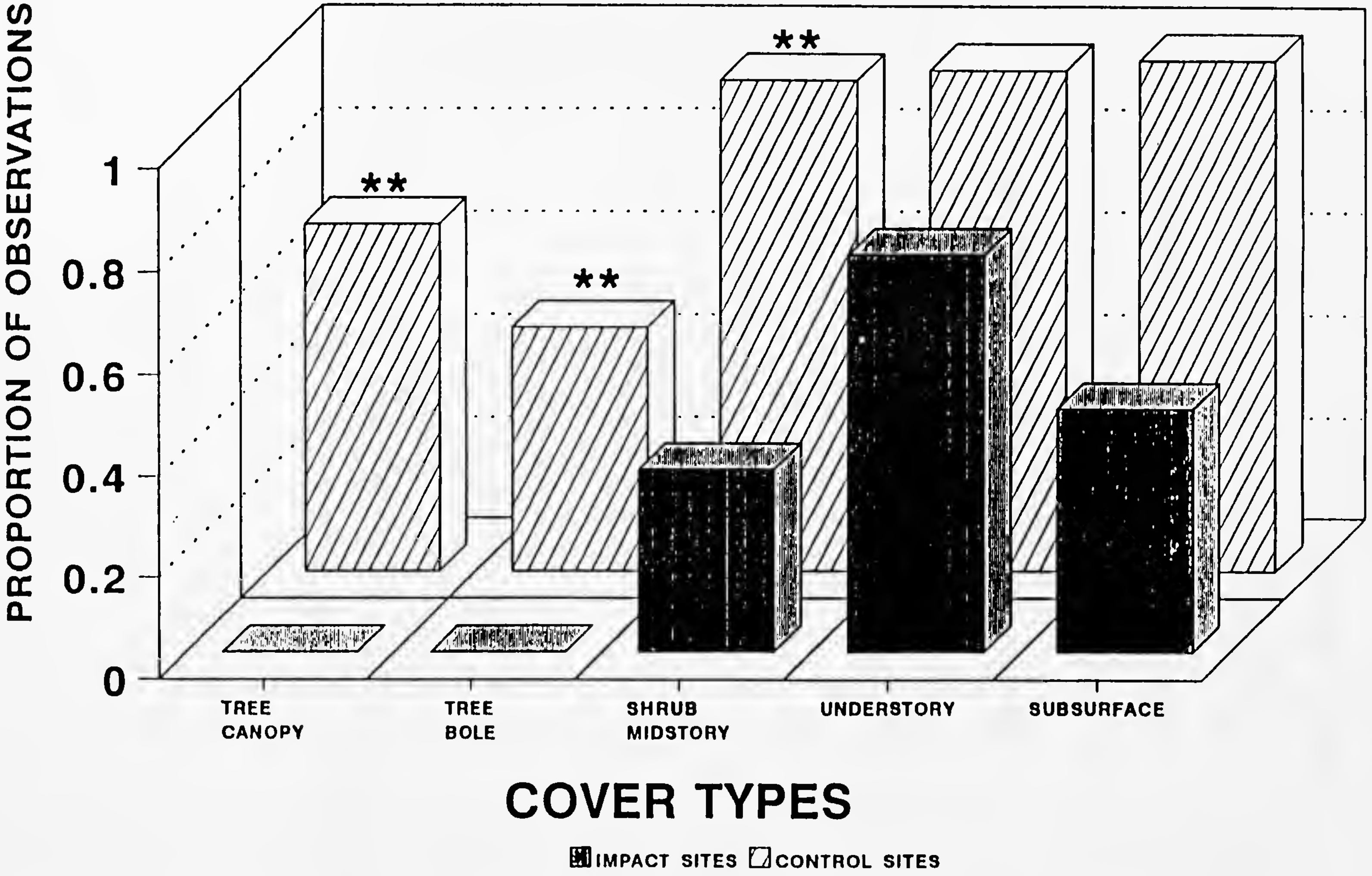

Figure 4-6. **Proportional Representation of the Habitat Layers of Stucky Ridge (Area A) and Corresponding Control Sites.** ** Indicates significant difference in proportional representation at α = 3.3%. Source: Appendix C.

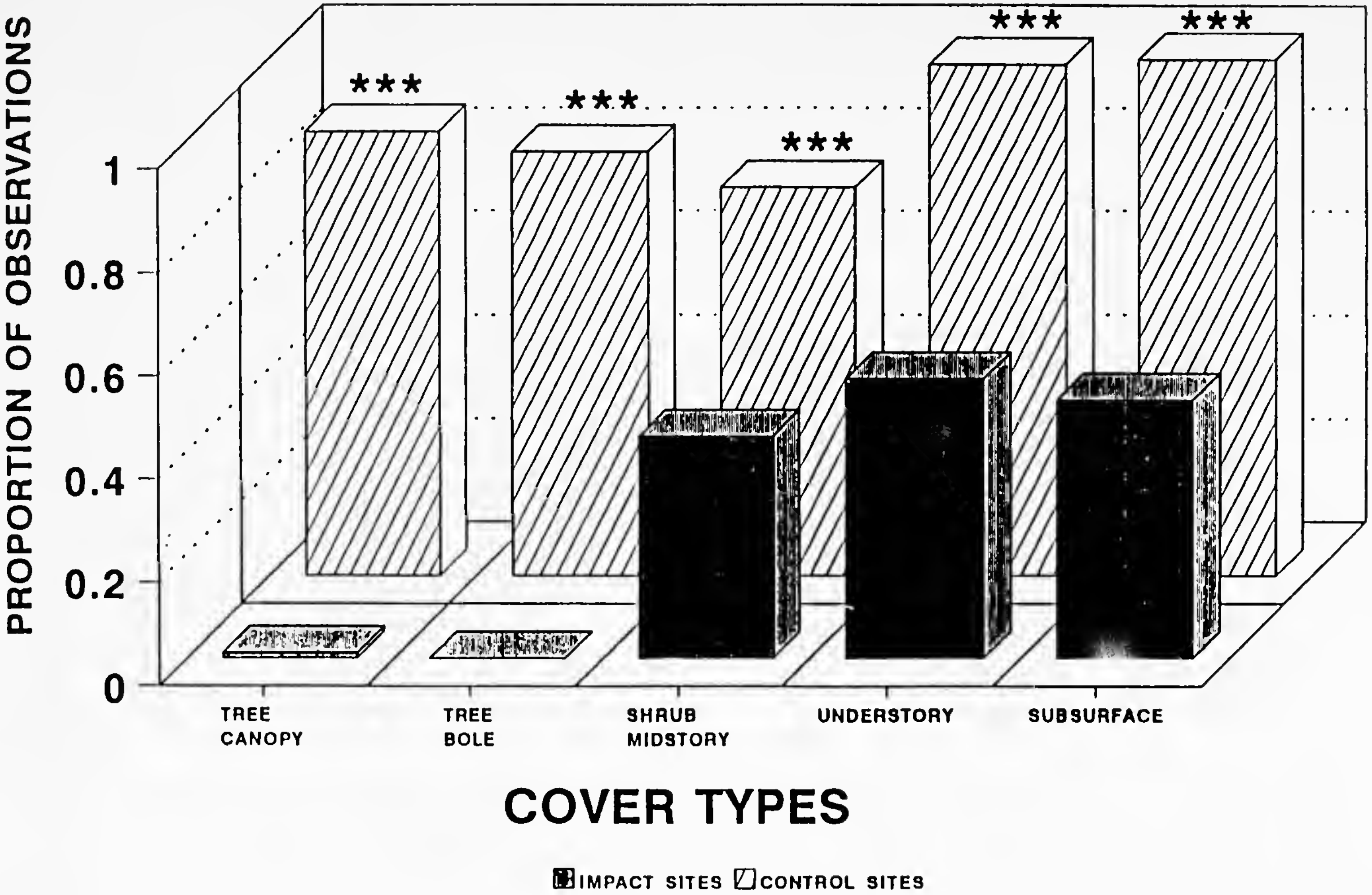

Figure 4-7. Proportional Representation of the Habitat Layers of Smelter Hill (Area B) and Corresponding Control Sites. *** Indicates significant difference in proportional representation at $\alpha = 1\%$. Source: Appendix C.

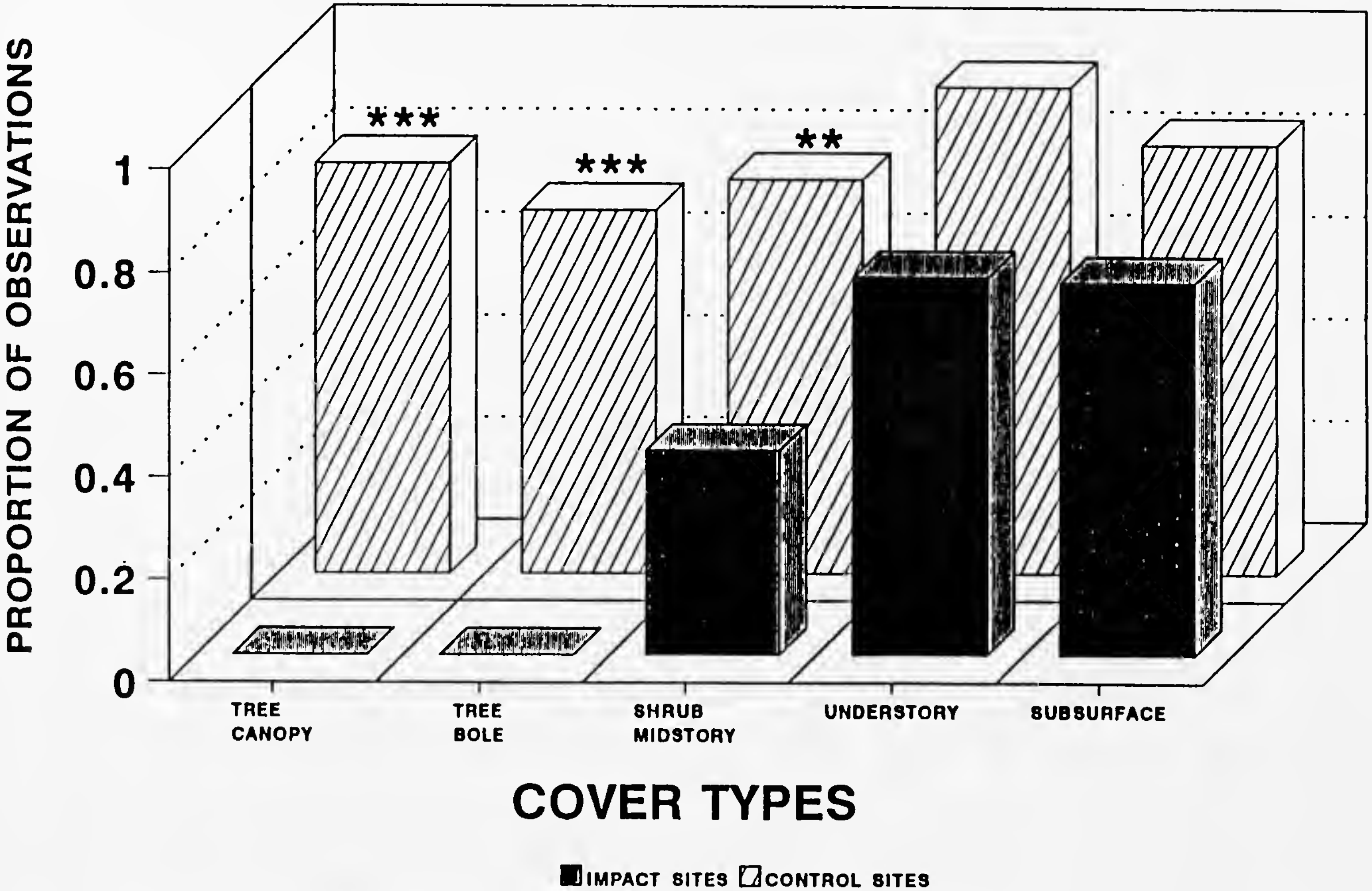

Figure 4-8. **Proportional Representation of the Habitat Layers of Mount Haggin (Area C) and Corresponding Control Sites.** ** and *** indicate significant differences in proportional representation at $\alpha = 3.3\%$ and 1%, respectively. Source: Appendix C.

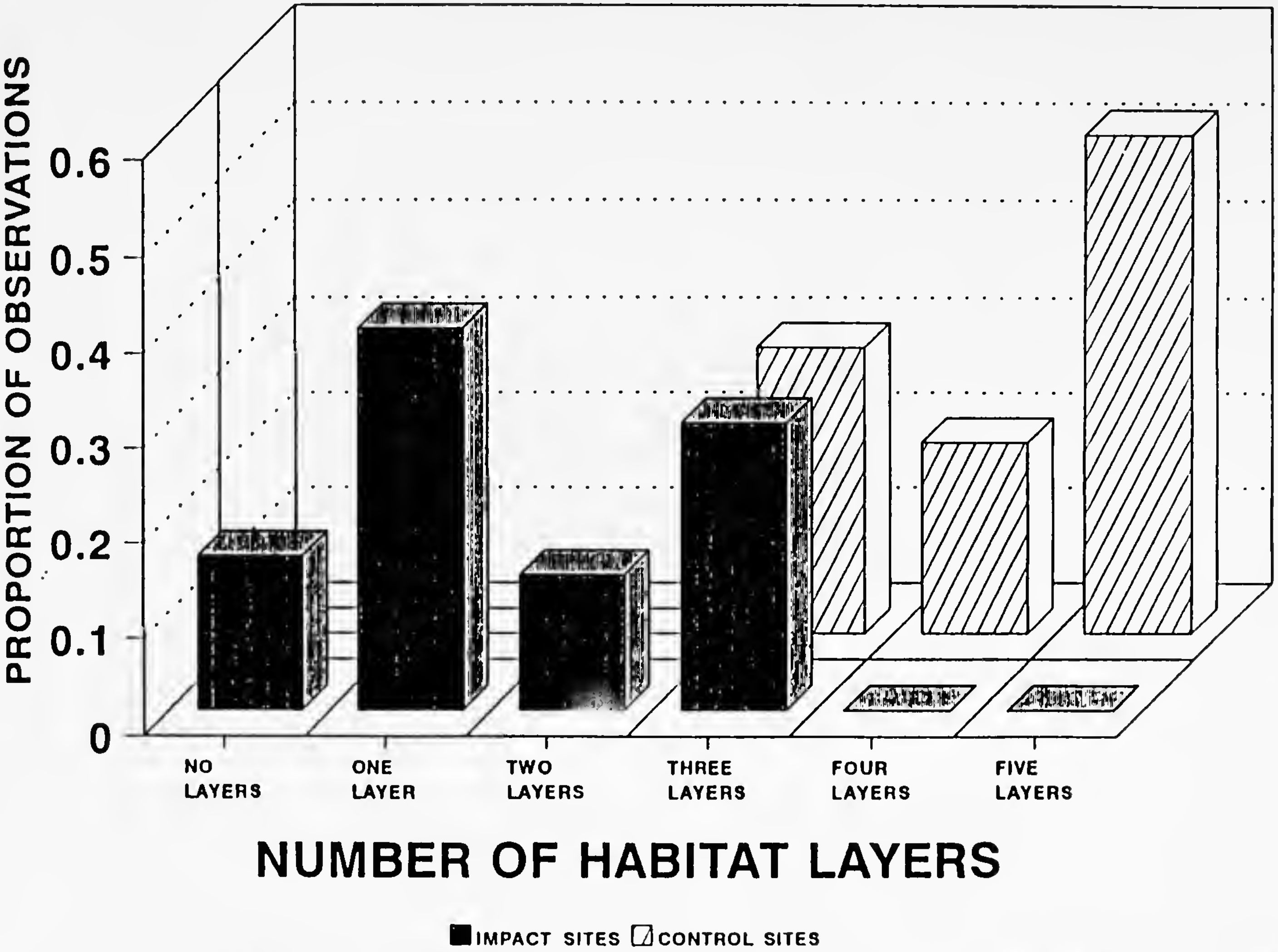

Figure 4-9. Proportional Representation of the Number of Habitat Layers of Stucky Ridge (Area A) and Corresponding Control Sites. Source: Appendix C.

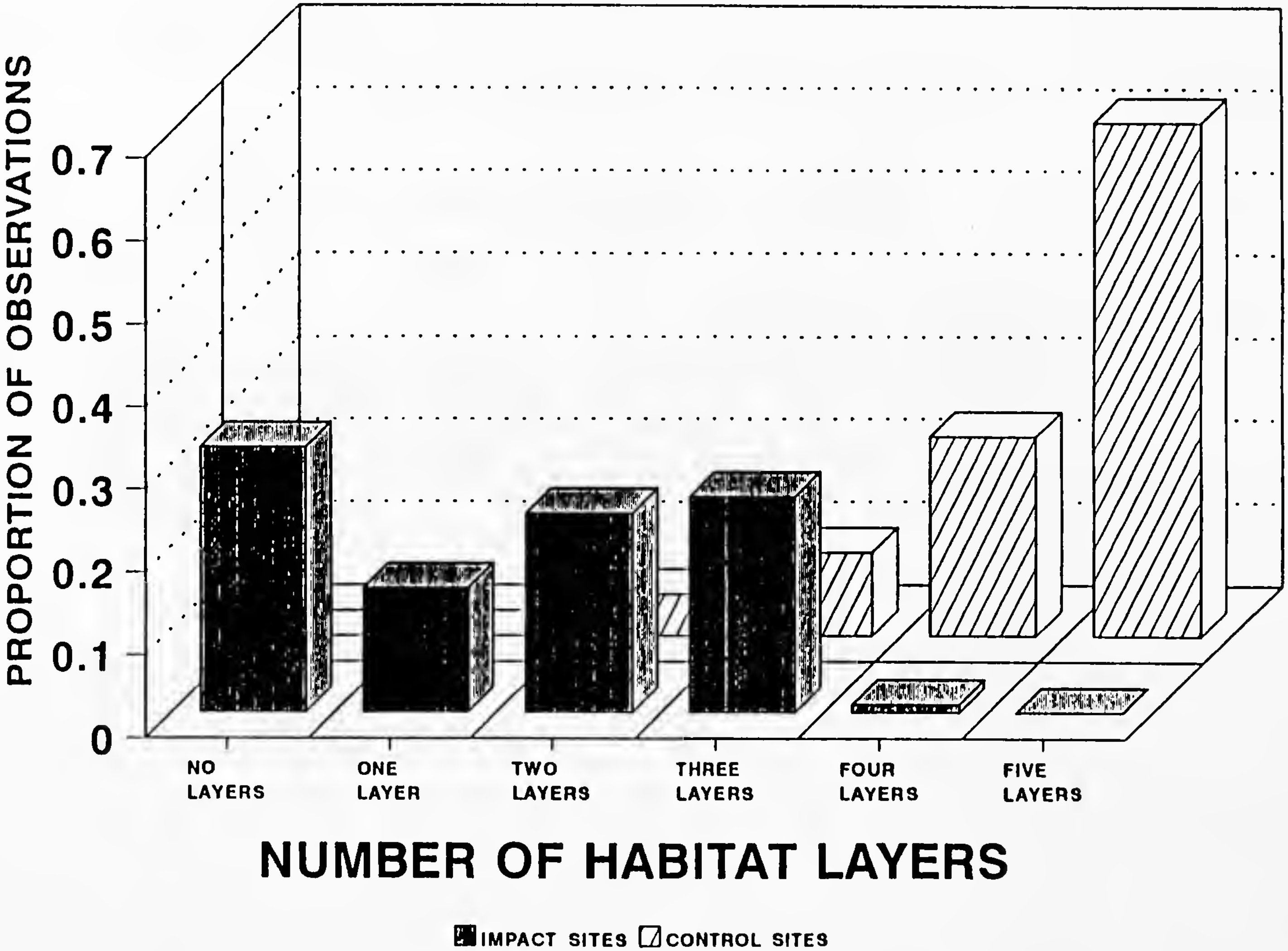

Figure 4-10. Proportional Representation of the Number of Habitat Layers of Smelter Hill (Area B) and Corresponding Control Sites. Source: Appendix C.

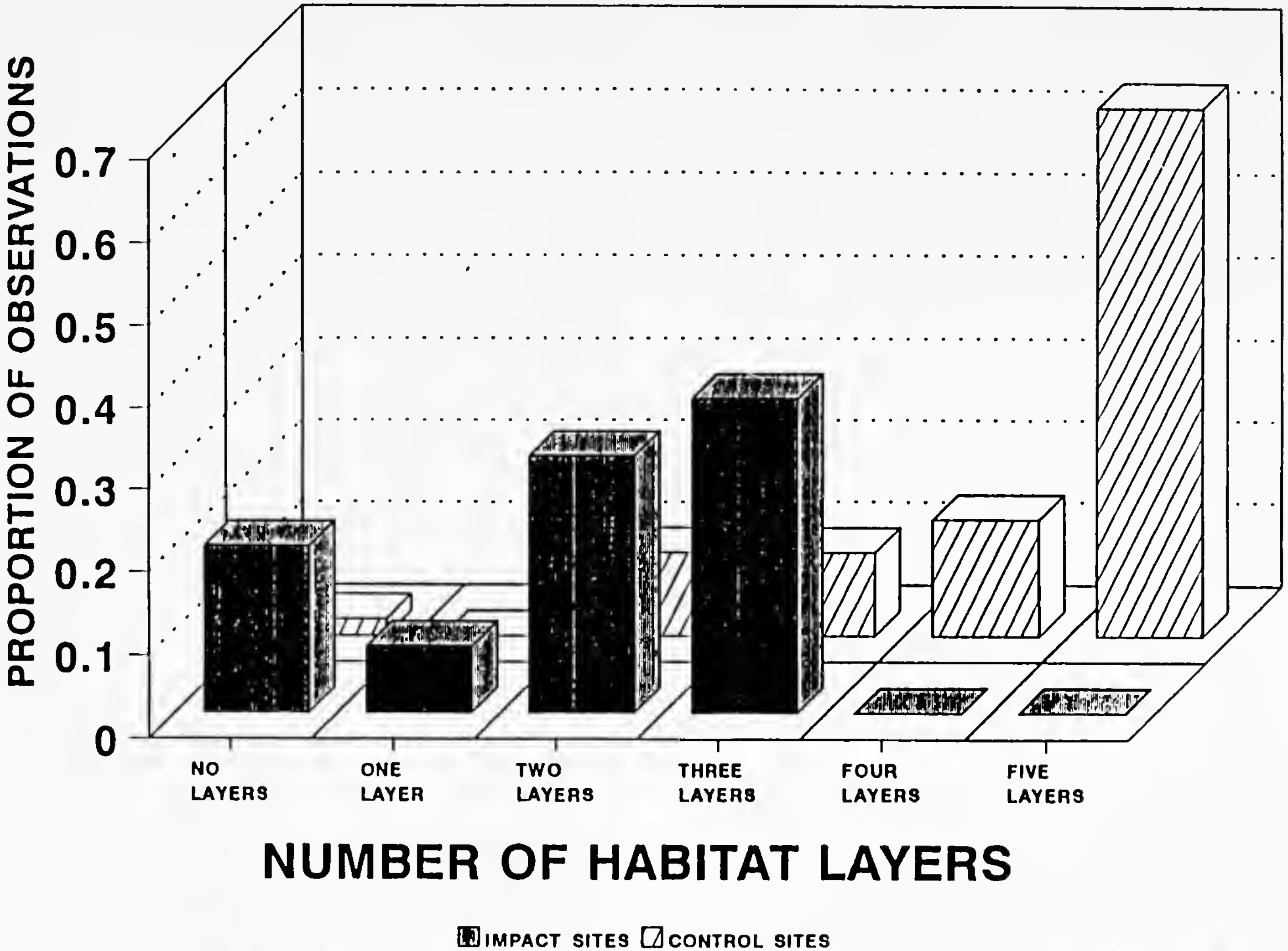

Figure 4-11. **Proportional Representation of the Number of Habitat Layers of Mount Haggin (Area C) and Corresponding Control Sites.** Source: Appendix C.

Table 4-7
Comparison of the Mean Number of Habitat Layers Present in Impact and Control Sites

Area	p-value
All impact vs. all controls	< 0.0002***
Stucky Ridge (Area A) vs. controls	< 0.03125**
Smelter Hill (Area B) vs. controls	< 0.00195***
Mount Haggin (Area C) vs. controls	< 0.00781***

** and *** indicate a significantly greater mean number of layers in the control area at $\alpha = 3.3\%$ and 1%, respectively.

Table 4-8
Results of t-tests Comparing Cover Types Observed at Impact Sites in 1992 and 1994

Cover Types	Stucky Ridge p-Value	Smelter Hill p-Value	Mount Haggin p-Value	Combined p-Value
Evergreen forest	p = 0.3370	*	p = 0.3287	p = 0.1591
Deciduous forest	*	p = 0.8684	*	p = 0.8017
Evergreen shrubland	*	p = 0.4566	p = 0.7348	p = 0.7319
Deciduous shrubland	p = 0.9821	p = 0.3134	p = 0.6528	p = 0.6023
Grassland	p = 0.3664	p = 0.3931	p = 0.8611	p = 0.3388
Bare ground	p = 0.3621	p = 0.2319	p = 0.7004	p = 0.3179

* not observed at either 1992 or 1994 impact sites.

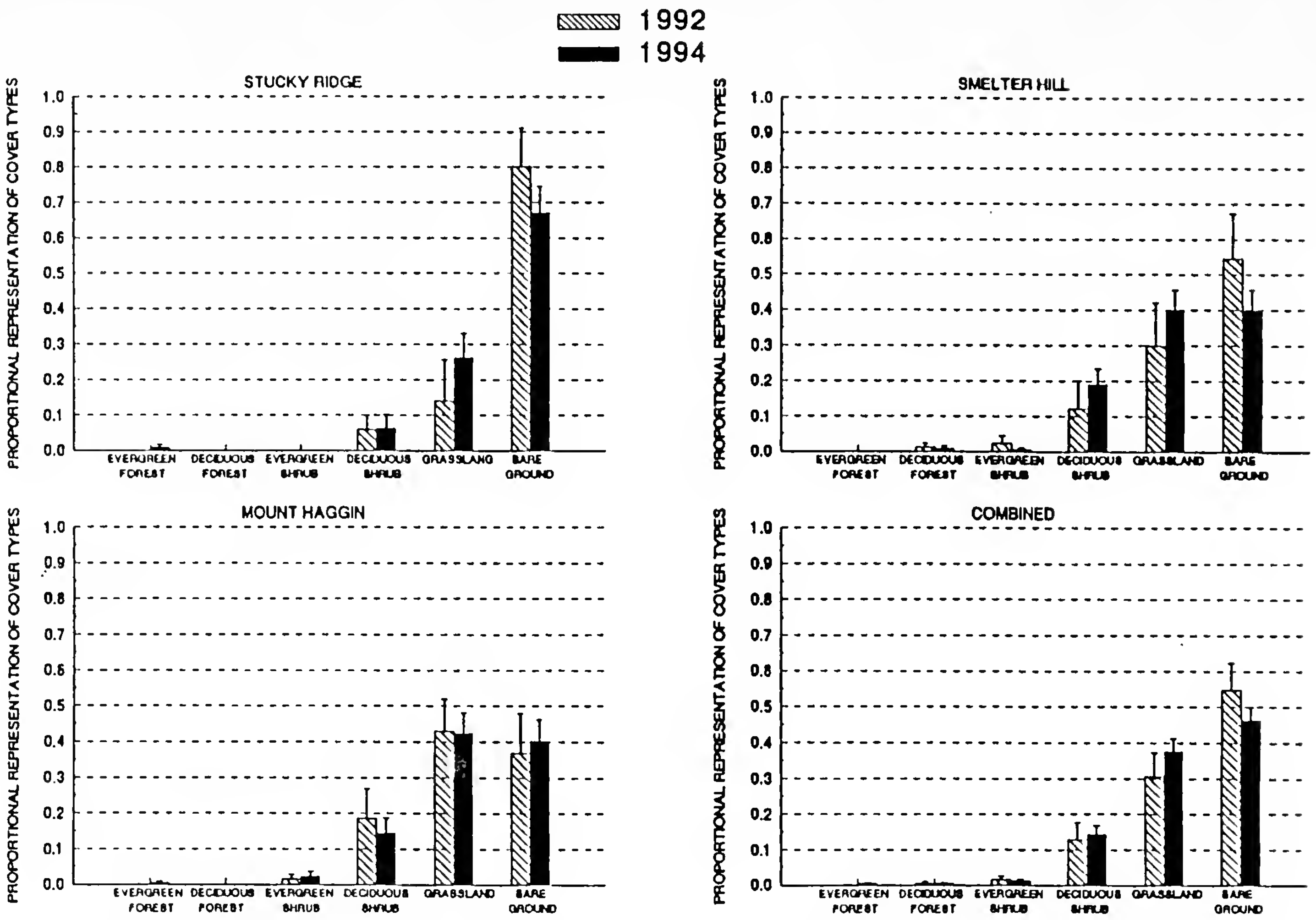

Figure 4-12. **Comparisons of Proportional Representations of Cover Types in 1992 and 1994.** (Mean proportional representation plus one standard error).

Grasslands. As in 1992, the 1994 measurements showed that grasslands were only sparsely vegetated (Figure 4-13). When all sites are combined, only 36% of the line intercepts were actually covered by vegetation, the remainder was mainly vegetative litter (27%), and bare ground (36%). Litter in the impact grassland areas studied did not resemble the deep vegetative litter that is normal for unimpacted grasslands or in forested areas elsewhere in southwest Montana, but was typically a shallow cover of dead plant material overlying bare ground. The extent of bare ground within the grassland community was most marked on Stucky Ridge (46% bare ground), followed by Smelter Hill (37% bare ground), and Mount Haggin (30% bare ground). In addition, measurements made in 1994 showed that the impact area grasslands were dominated by invasive weed species (i.e., early colonists of disturbed or stressed areas), rather than plant species that are indigenous to grasslands in surrounding unimpacted areas (Table 4-9). Only 2.8% of grassland sites in the entire impact area were dominated by indigenous grass species. The remainder were dominated by invasive nongraminoid weeds (26%), or invasive graminoid species (69%), particularly redtop (*Agrostis stolonifera*), or Great Basin wild rye. Most of those invasive species, particularly spotted knapweed (*Centaurea maculosa*), thistle (*Cirsium* spp.), and Great Basin wild rye are relatively unpalatable to grazing animals, hence, of low forage value to wildlife.

Table 4-9
Proportional Representations (% of sites) of Dominant Species in Grassland Cover Type

	Invasive Species						
	Spotted Knapweed	**Thistle**	**Redtop**	**Great Basin Wild Rye**	**Whitetop**	**Total Invasive Species**	**Native Species***
Stucky Ridge	36.6	30.1	21.9	5.2	6.2	100	0
Smelter Hill	26.8	0	42.1	21.9	0	90.8	5.9
Mount Haggin	0	0	84.9	14.3	0	99.2	0.8
Combined	18.8	6.35	53.5	15.6	1.3	95.6	2.8

* Native species include mainly bluebunch wheatgrass, Idaho fescue, and rough fescue.

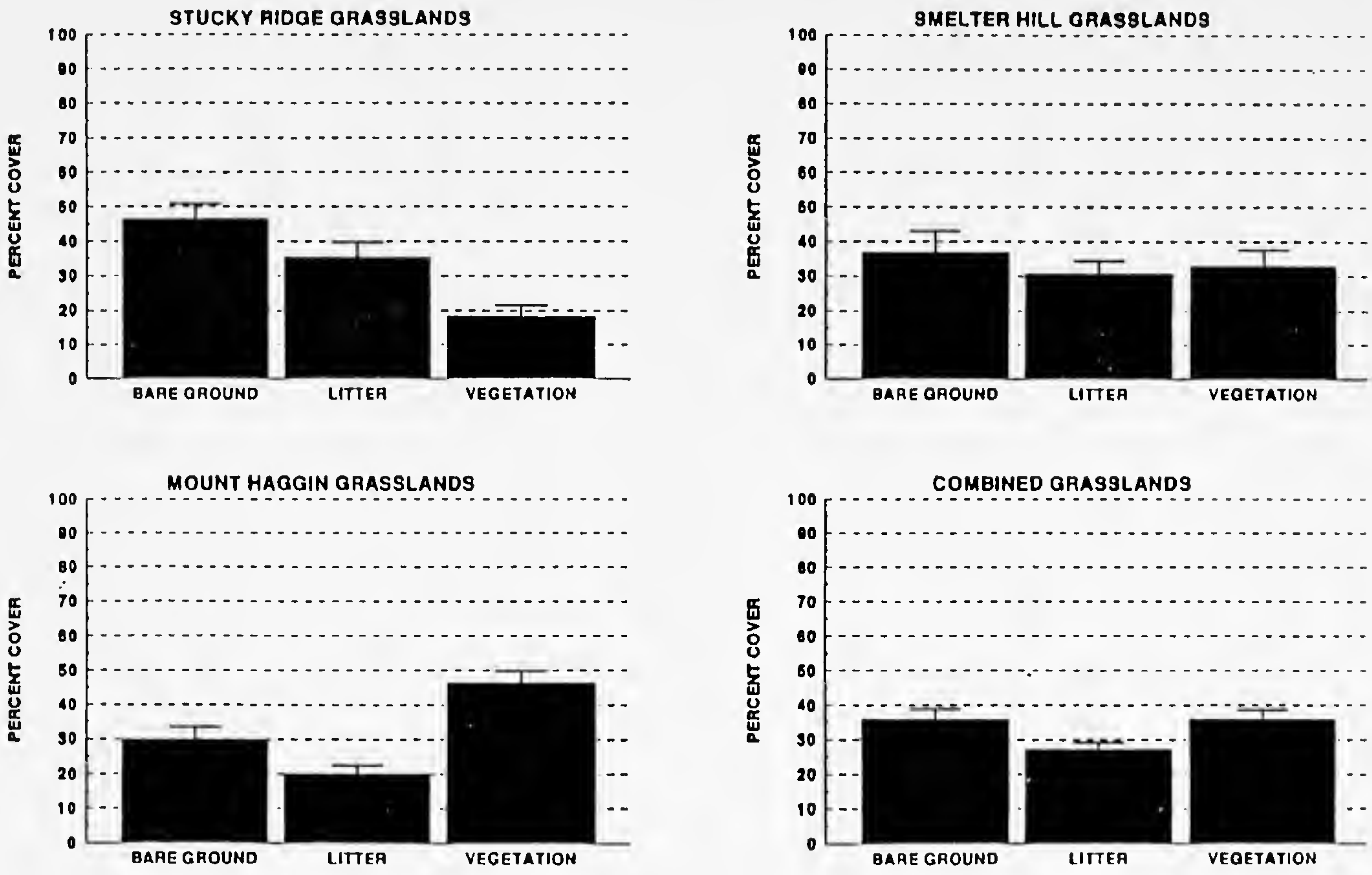

Figure 4-13. Mean Percent Cover (plus one standard error) of Bare Ground, Vegetation, and Plant Litter in Grassland in the Impact Area (1994 data only), as Determined by Line Intercept Measurements.

Evidence of Previous Afforestation

Evidence of previous afforestation (tree stumps and dead timber) was found at 37 (65%) of the 57 sites sampled in 1994, indicating that, at least on the higher ground, much of the area designated as grossly injured once supported extensive conifer forest. No previously afforested sites were found on Stucky Ridge, however, one was found on the injured area to the north of Lost Creek. Figure 4-14 displays all sites (1992 and 1994) at which evidence of previous afforestation was found.

4.4.2.2 Relationships between Observed Vegetation and Phytotoxicity

As described in Chapter 3.0, the results of the phytotoxicity laboratory tests were used to classify impact sites by degree of phytotoxicity using toxicity scores. These toxicity scores were then related to observed vegetation conditions to evaluate whether more toxic sites supported, on average, less vegetation than less toxic sites. Kendall-tau correlations between the percent bare ground measured at sites and the toxicity scores at the same sites were positive[3] (correlation of 0.58) and highly significant ($p = 0.0001$) demonstrating the relationship between phytotoxicity and loss of vegetation.[4]

As further evidence of the causal relationship, percent bare ground was correlated with measured concentrations of hazardous substances. Arsenic (Kendall-tau = 0.59, $p < 0.001$), copper (Kendall-tau = 0.57; $p < 0.001$), cadmium (Kendall-tau = 0.33, $p = 0.018$), lead (Kendall-tau = 0.49, $p < 0.001$), and zinc (Kendall-tau = 0.40, $p < 0.01$) were all significantly correlated with percent bare ground.

Similarly, the mean number of habitat layers at each site was correlated with toxicity score and hazardous substance concentrations. Again, these correlations were statistically significant: the mean number of habitat layers was negatively correlated[5] with toxicity score (Kendall-tau = -0.56, $p < 0.001$), as well as with concentrations of arsenic (Kendall-tau = -0.59, $p < 0.001$), cadmium (Kendall-tau = -0.45, $p < 0.001$), copper (Kendall-tau = -0.51, $p < 0.001$), lead (Kendall-tau = -0.52, $p < 0.001$), and zinc (Kendall-tau, -0.43, $p < 0.005$).

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[3] i.e., as toxicity increases, percent bare ground increases.

[4] As noted in Chapter 3.0, sensitivity analysis was performed on the toxicity scoring system. The results of this analysis demonstrated that the significant positive correlations were robust to variations in the scoring protocol; alternative scoring systems resulted in positive correlations (0.57-0.63) that were all significant ($p < 0.001$).

[5] In this case, the <u>negative</u> correlation indicates that as the toxicity score increases, the number of habitat layers decreases.

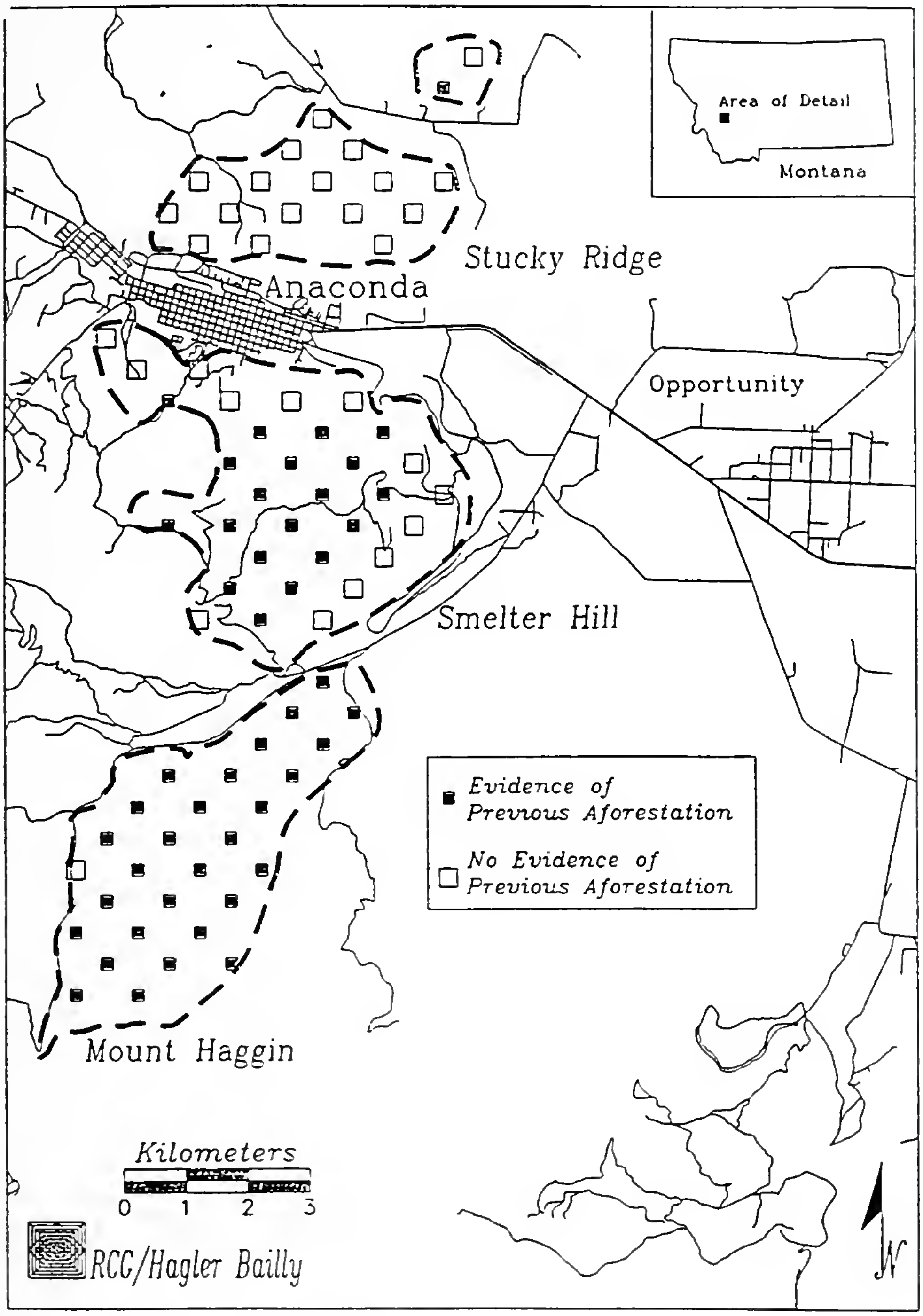

Figure 4-14. Sample Sites at which Evidence of Previous Afforestation was Found (1992 and 1994). (Closed symbols are those with evidence of previous afforestation, while open are those without.)

The results of these correlations (bare ground vs. toxicity, bare ground vs. hazardous substances, number of habitat layers vs. toxicity, number of habitat layers vs. hazardous substances) present clear evidence relating the results of the laboratory toxicity studies and the field vegetation measurements.

4.4.3 Habitat Suitability

The capacities of the injured and control areas to provide wildlife habitat were compared using HEP models.

Marten

Statistical comparisons of marten habitat suitability index (HSI) values calculated for impact and control area sites revealed that Smelter Hill and Mount Haggin provide significantly poorer habitat for martens than respective control areas (Table 4-10). The results confirm injury to marten in the Smelter Hill and Mount Haggin impact areas by demonstrating a significant reduction relative to baseline habitat suitability.

Table 4-10
Comparison of Marten Habitat Suitability in Impact and Control Areas

Area	p-value
All impact areas vs. all controls	< 0.0002*
Stucky Ridge (Area A) vs. controls	< 0.06
Smelter Hill (Area B) vs. controls	< 0.004*
Mount Haggin (Area C) vs. controls	< 0.008*

* Indicates significantly greater marten habitat suitability in the control area at $\alpha = 1\%$.

Optimal marten habitat is provided by coniferous forests composed predominantly of mature fir, spruce, Douglas fir, or lodgepole pine, with ≥ 50% canopy closure and ≥ 25-50% ground cover of deadfall (Allen, 1984). The loss of conifer forests in the Smelter Hill and Mount Haggin areas represents a fundamental reduction in habitat suitability for martens. Stucky Ridge is at a lower elevation and was most likely vegetated primarily by grasslands before injury (approximately 30% of Stucky Ridge would have been forested compared to more than 70% of Smelter Hill and Mount Haggin; see Appendix C). Thus, the results of the marten HEP analysis are consistent with what would be expected based on the probable pre-impact patterns of forestation.

Elk

Statistical comparisons of elk HSI values calculated for impact and control area sites revealed that Stucky Ridge, Smelter Hill, and Mount Haggin, and all impact areas combined, provide significantly poorer habitat for elk than respective control areas (Table 4-11). Significantly lower densities of elk pellet groups at impact sites, relative to controls, confirm the lower use of the injured areas by elk (Appendix C).

Table 4-11
Comparison of Elk Habitat Suitability in Impact and Control Areas

Area	Elk Habitat Effectiveness		
	Cover	Forage	Overall
All impact vs. all control sites	< 0.0002***	< 0.0002***	< 0.0002***
Stucky Ridge (Area A) vs. controls	< 0.03**	< 0.03**	< 0.03**
Smelter Hill (Area B) vs. controls	< 0.002***	< 0.04*	< 0.002***
Mount Haggin (Area C) vs. controls	< 0.0008***	< 0.03**	< 0.008***

*, **, and *** indicate significantly greater suitability in control areas at $\alpha = 5\%$, 3.3%, and 1%, respectively.

Optimal elk habitat is provided in part by coniferous forests of ≥ 50% canopy closure interspersed with grasslands consisting of preferred forage species such as bunchgrasses and bitterbrush. Deforestation and the modification of the grassland community composition have resulted in the virtual elimination of cover and a reduction in forage for elk over all impact areas sampled.

Habitat Layers

The layers of habitat model showed that the loss of forest, shrub, herbaceous, and topsoil cover has resulted in reduced structural complexity for all impact sites. Concomitantly, habitat availability has been reduced significantly relative to baseline. Habitats with five habitat layers (tree canopy, tree bole, shrub midstory, understory, and terrestrial subsurface) define the baseline; the impact areas have been reduced to habitats dominated by bare ground (lacking even a terrestrial subsurface) or grassland. Table 4-12 presents the results of tests comparing the habitat complexity of impact and control sites. Stucky Ridge, Smelter Hill, Mount Haggin, and all impact sites combined exhibited significantly reduced vertical habitat complexity relative to control areas.

Table 4-12
Comparison of Habitat Complexity in Impact and Control Areas

Area	p-value
All impact areas and controls	< 0.0002***
Stucky Ridge (Area A) vs. controls	< 0.03*
Smelter Hill (Area B) vs. controls	< 0.002***
Mount Haggin (Area C) vs. controls	< 0.008***

* and *** indicate significantly greater habitat complexity in the control area at $\alpha = 3.3\%$ and 1% respectively.

Populations of organisms dependent on tree canopy and tree bole are likely to have suffered the greatest loss of viability because of the loss of upland conifer forests. Species that are likely to have been lost from the injured area because of this habitat destruction are listed in Table 4-13. Other organisms less dependent on tree canopy and bole are likely to have suffered reduced population viability due to the reduced extent of shrub, herbaceous, and soil layers in the impact areas.

Twenty-seven of the 32 bird species (84%) characteristic of southwest Montana lodgepole pine and Douglas fir forests are dependent on tree canopy or tree bole layers for nesting or feeding (Table 4-2). These 27 (including birds of prey, woodpeckers, and songbirds) are likely to have been lost from the impacted areas as a result of the loss of these layers. The remaining five species have suffered reduced population viability.

Forty percent of the mammal species listed characteristic of southwest Montana lodgepole pine and Douglas fir forests are strictly arboreal or dependent on dense conifer cover. These species (including squirrels, porcupine, and marten) are likely to have been lost from the impact areas as a result of tree canopy loss (Table 4-3). The remaining six species (including black bear and elk) are likely to have suffered reduced population viability.

Thus, the elimination or modification of upland vegetation communities on Stucky Ridge, Smelter Hill and Mount Haggin has resulted in a severe reduction in the quantity and quality of wildlife habitat. Injured areas that could have supported plant communities, providing important habitat for a diversity of wildlife species, are largely devegetated and extremely limited in their ability to support wildlife populations.

Table 4-13
Bird and Mammal Populations that are Likely to have been Lost or Suffered Reduced Viability Due to Removal of Tree Canopy, Bole, Shrub Midstory, Understory, and Terrestrial Subsurface Habitat Layers in Upland Impact Areas

Reduced Viability	Species Lost	
Swainsons thrush	Red-tailed hawk	Red-breasted nuthatch
American robin	Sharp-shinned hawk	House wren
Chipping sparrow	Cooper's hawk	Ruby-crowned kinglet
White-crowned sparrow	Northern goshawk	Mountain bluebird
Dark-eyed junco	Blue grouse	Townsend's solitaire
Black bear	Spruce grouse	Cedar waxwing
Ermine	Northern saw-whet owl	Yellow-rumped warbler
Snowshoe hare	Downy woodpecker	Western tanager
Mountain lion	Hairy woodpecker	Pine grosbeak
Bobcat	Olive-sided flycatcher	Red crossbill
Elk	Western wood-pewee	Pine siskin
	Grey jay	Evening grosbeak
	Steller's jay	Red squirrel
	Clark's nutcracker	Porcupine
	Mountain chickadee	Pine marten
		Lynx

4.4.4 Causality Evaluation: Vegetation Losses in the Injured Area

The comparisons between control and injured impact areas indicate significant and substantial differences in vegetation community structure and composition. The coniferous forests formerly present in the impact area largely have been replaced by bare ground or sparsely vegetated grasslands. Grasslands in the impact area are vegetatively impoverished and dominated by weed species relative to control area grasslands. Processes other than contamination of soils by hazardous substances can contribute to such effects on vegetation. Potential causes of vegetation loss near Anaconda include fire, logging, and grazing. Evidence indicates that the German Gulch control area has been subject to fires, logging, and grazing pressure; therefore, control sites account for effects of these stressors on vegetation. In addition, while the smelter was in operation, the surrounding landscape was exposed to deposition of sulfur oxides and sulfuric acid, as well as metals and arsenic. This section further evaluates the likelihood, based on characteristic vegetation responses to stress, that factors other than hazardous substances caused the observed injuries in the impact area.

In general, plant species are found where their ecological requirements, growth patterns, and regeneration cycles are compatible with the frequency and regularity of disturbances (Oliver and Larson, 1990). For example, it is possible to predict shifts in species composition and community structure after a fire (e.g., Arno et al., 1985), after clear cutting or selective logging (Arno et al., 1985), and in response to intensive grazing (e.g., "increasers" and "decreasers") (U.S. SCS, 1986). Each of these stressors results in a vegetation community "fingerprint," i.e., a predictable floristic composition and structure. The "fingerprints" of each of fire, logging, grazing, and even acid deposition, are broadly recognizable, and are distinctly inconsistent with the conditions observed currently in the impact area. None of these disturbances precludes regeneration and succession of indigenous plant species. In contrast, the "fingerprint" observed in the impact area is consistent with effects of metal phytotoxicity observed in the laboratory and at other mining/smelting sites, and reported in the literature. In the following paragraphs, we discuss the ecological consequences of fire, logging, grazing, and acid deposition with respect to current conditions observed in the impact and control areas, and the consistency of these expected patterns with empirical data demonstrating injury.

4.4.4.1 Fire

Fire has historically been the primary initiator of succession in northern Rocky Mountain forests and is a regular feature of southwestern Montana forests (Arno and Fischer, 1989). Natural recurrence intervals of fires of varying intensity in Northern Rocky Mountain pine and Douglas fir forests before European settlement ranged from 6 to 120 years (Lemon, 1937; Arno, 1980; Huston, 1973; Davis, 1980; Laven et al, 1980; Martin, 1982; Pyne, 1984; as cited in Oliver and Larson, 1990), and from 100 to 300 years in sub-alpine forests (Romme, 1980; Hawkes, 1980; Pyne, 1984; as cited in Oliver and Larson, 1990).

Post-fire succession in Northern Rocky Mountain forests follows a predictable, sequential development to pre-fire conditions (Arno and Fischer, 1989; Fischer and Bradley, 1987). The composition of seral stages and time required to return to pre-fire conditions may vary, but successional development of community structure and composition to pre-fire conditions is relatively consistent (Lyon and Stickney, 1976). In the absence of fire or other overstory-removing disturbances, shade tolerant conifers will dominate and deciduous forest (aspens) will either revert to shrub and grassland or be replaced by conifers (Brown and DeByle, 1989; Gruell et al., 1986).

Indigenous vegetation communities in the Anaconda uplands (approximately 5,000 to 7,000 feet) comprise a mosaic of cool, dry, Douglas fir habitat types (Pfister et al., 1977) and grassland communities on southwest slopes. Douglas fir habitat types are associated with well-drained mountain slopes and valleys, and extend from lower timberline up to about 7,500 feet on warm aspects in southwestern Montana (Pfister et al., 1977). Undergrowth is variable, but in the Anaconda area, may include huckleberry (*Vaccinium* spp.), snowbush ceanothus (*Ceanothus velutinus*), pinegrass (*Calamagrostis rubescens*), beargrass (*Xerophyllum tenax*), bluebunch wheatgrass (*Agropyron spicatum*), Idaho fescue (*Festuca idahoensis*), ninebark (*Physocarpus malvaceus*), and kinnikinnick (*Arctostaphylos uva-ursi)*, among others (Pfister et al., 1977). Historically, fire maintained the Douglas fir habitat types; estimates of the mean presettlement fire interval range from 35 to 40 years (Arno and Gruell, 1983).

Figure 4-15 depicts generalized forest succession in cool, dry Douglas fir habitat types (Fischer and Clayton, 1983). The seral stages described in this figure are potential vegetation types and successional trajectories expected in the Anaconda area, and observed in the German Gulch area. Frequent fire in cool-dry Douglas fir habitat types can maintain grassland communities. Early successional communities are derived primarily from the pre-disturbance community, and typically establish in the first growing year following the disturbance (Lyon and Stickney, 1976). In the first few years following a stand replacing fire in the Anaconda/German Gulch area, grassland/forb/shrublands dominated by huckleberry-pinegrass, beargrass-pinegrass, or snowbush ceanothus are expected colonizers (Arno et al., 1985). With favorable seedbed conditions, an even-aged stand of lodgepole and Douglas fir usually develops. Any fire in either the seedling or sapling stage reverts the site to grassland. Cool fires during the pole sized stage thin the susceptible stems; a severe fire again reverts the site to grassland. A cool fire in a mature stand will thin the undergrowth and create a park-like forest. At successional climax, Douglas fir will dominate the overstory.

Early successional species that are shade intolerant and adapted either to survive fire or to colonize rapidly following fire, can establish immediately. Species that reproduce vegetatively, such as aspen, are typically stimulated by the removal of overstory vegetation. Rhizomatous species, such as huckleberry, snowberry (*Symphoricarpos albus*) and thimbleberry (*Rubus parviflora*), and bulbs and corms of some herbaceous species can survive all but the hottest fires and develop rapidly post-disturbance. Seeds present before the fire represent another general adaptation to onsite survival; long-term seed storage occurs in the seedbed on the forest floor, and in serotinous cones attached to the crown (lodgepole pine). Northern Rocky Mountain plants with dormant, ground-stored, fire-activated seed comprise predominately shrub and herbaceous growth forms, such as snowbush ceanothus (Lyon and Stickney, 1976). In addition, off-site species demonstrate fire-adaptedness in the ability to introduce disseminules from areas distant from the burn. A review of regional literature reveals that in general, the majority of plant species in Douglas fir habitat types prior to a burn will survive or reestablish on the burn (Lyon and Stickney, 1974; Arno et al., 1985; Fischer and Clayton, 1983), and that in the first decade post-fire, a rapid re-growth of lodgepole pine understory is expected.

Thus, the expected fingerprint of fire on the Anaconda uplands landscape includes patches of fire-maintained grassland/forb/shrubland, patches of even-aged sapling to pole-sized lodgepole pine stands with an understory of beargrass, huckleberry, and/or pinegrass, and patches of mature forest strongly dominated by Douglas fir in the overstory, with pinegrass and huckleberry in the understory (Figure 4-16). In fact, this is what was observed in the German

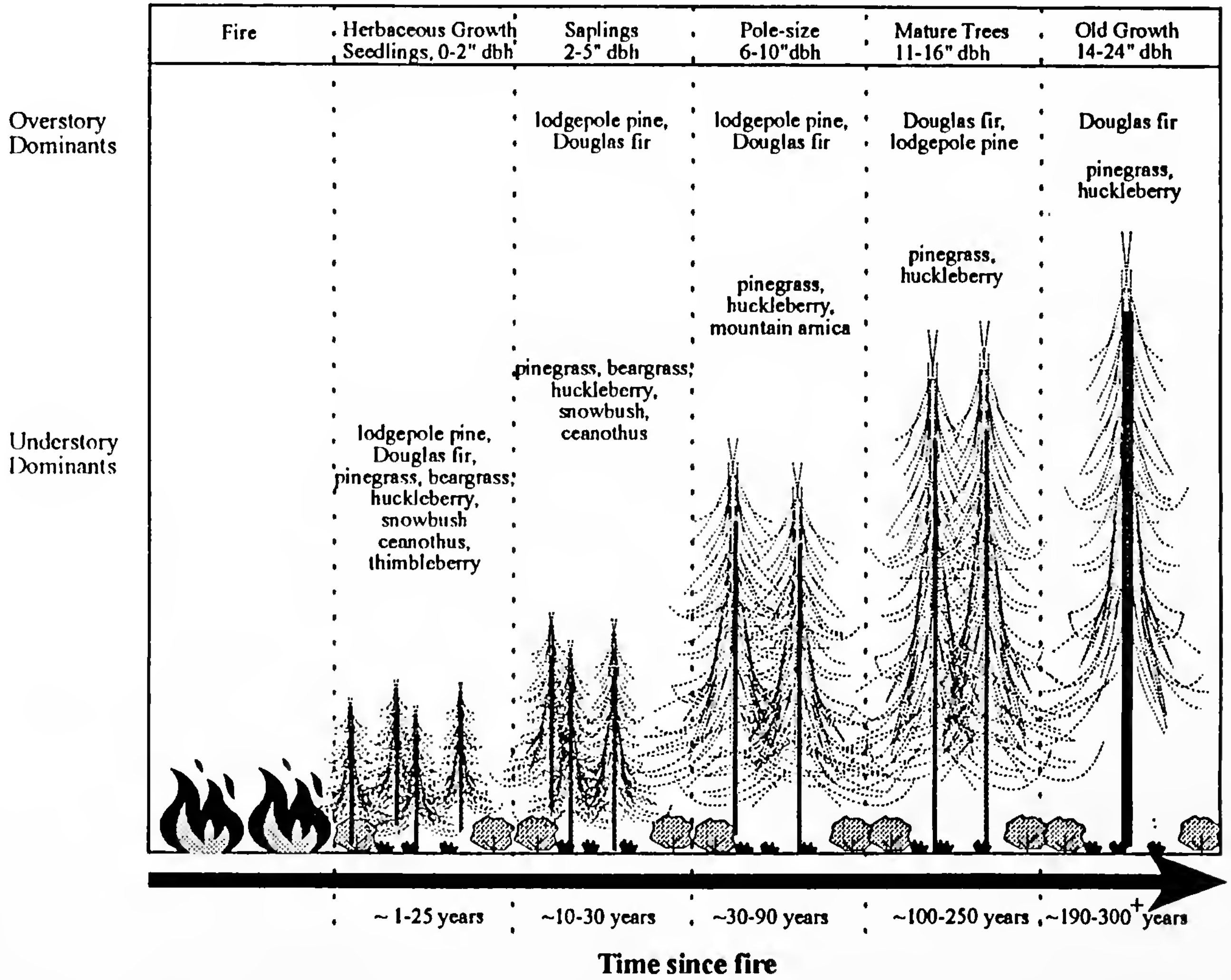

Figure 4-15. Generalized Forest Succession in Cool, Dry Douglas Fir Habitat Types. Seral stages are vegetation types observed in the German Gulch area and expected in the Anaconda Area. Source: Fischer and Clayton, 1983.

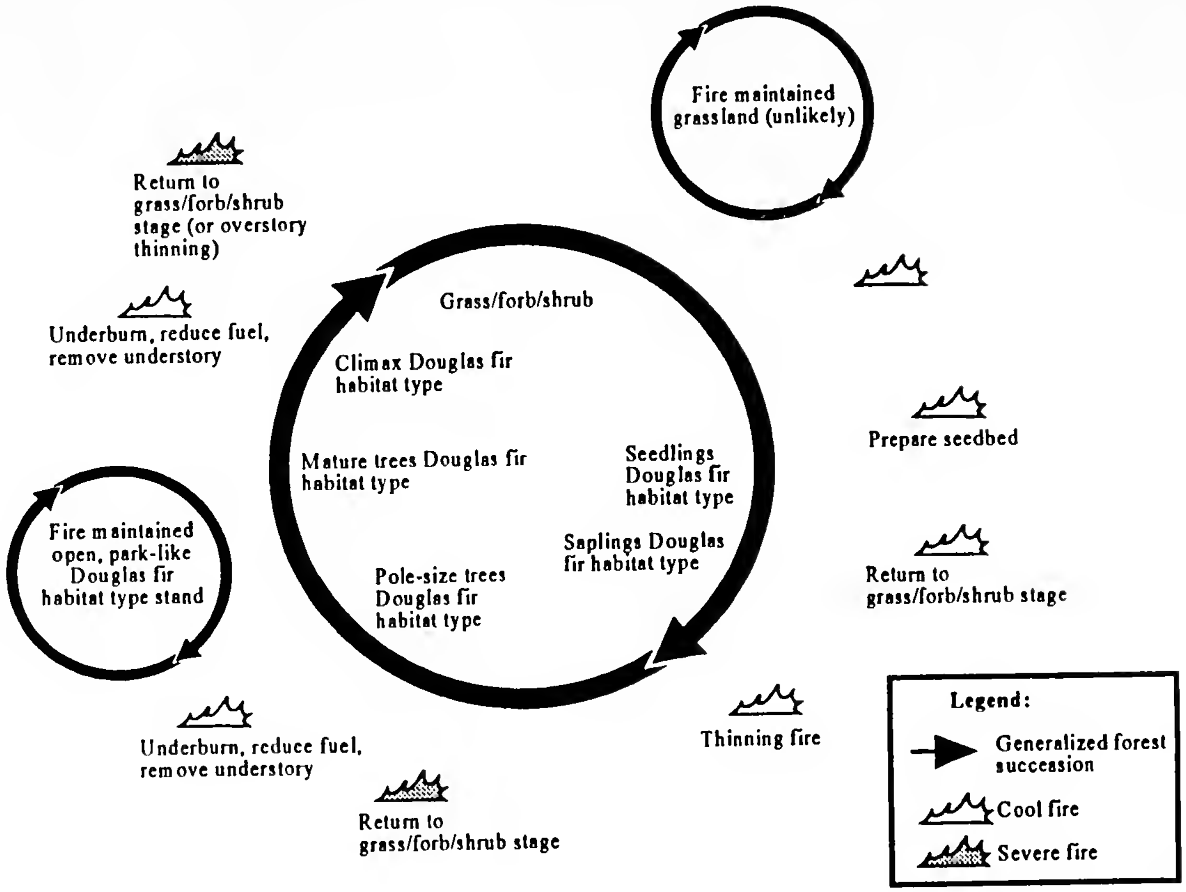

Figure 4-16. **Expected Fingerprint of Fire in the Anaconda Area.** Depending on the time since the fire, vegetation in the Anaconda area should comprise community types similar in composition and structure to those described above. Source: Bradley et al., 1992; Arno et al., 1985.

Gulch area, and is reflected in the number and type of habitat layers and in the species composition observed at the control sites. Vegetation communities in the German Gulch area sampled included mature Douglas fir stands, forest stands representative of the 39-90 years post-disturbance stage, with 6-10 inch dbh Douglas firs and an understory of pinegrass, even-aged sapling-sized lodgepole pine stands, and grassland/shrubland on south facing slopes and in recently burned areas. Evidence of fire in the German Gulch area is apparent in fire scars both on living trees and in ring scars in stumps.

In areas where the potential climax stage is grassland, such as at lower elevations in the control and impact areas and on south facing slopes, the fingerprint of fire would be evident as grassland/shrubland dominated by fire-adapted species. Grasses recover quickly from fire, and while herbage production may be less than pre-burn level during the first year, it typically increases threefold or more by the fifth growing season (Gruell et al., 1986).

In contrast, the fingerprint observed in the vegetation communities in the Anaconda upland comprises abundant bare ground, sparse grasslands, no regeneration of forest communities, and no evidence of the successional stages expected. The fingerprint of fire is inconsistent with that observed, and thus we conclude that it is unlikely that fire, at any frequency or intensity, is the causal agent of the observed injuries in the impact area.

4.4.4.2 Logging

Many turn of the century mining and smelting operations were dependent on a large supply of timber for fuel, shaft supports, and construction. In the arid west climates, denudation of hillsides surrounding mining towns occurred rapidly. Historical photos indicate that logging and land-clearing was typically complete (Gruell, 1983). Likewise, when smelting began in the Anaconda area in the 1890s, the surrounding hillsides were cleared to construct and fuel the smelter. Historical photographs confirm that the German Gulch reference area was also logged extensively in the first half of this century, yet it now supports forest patches of varying age.

Historical photographs of cool-dry Douglas fir habitat types in southwestern Montana compared with more recent photographs indicate that formerly denuded hillsides surrounding many old mining towns have been completely revegetated by now-mature Douglas fir forests (Gruell, 1983; Platts et al., 1987). Historical photographs indicate that even sites where placer mining and logging caused tremendous losses of topsoil from large areas of riparian habitat, Douglas fir, aspen, cottonwood (*Populus trichocarpa*), willow, chokecherry (*Prunus virginiana*), and other understory shrubs have regenerated successfully (Platts et al., 1987).

Disturbance by logging and land clearing can be similar to successional initiation by fire, except that harvest does not favor regeneration of fire-activated seeds, does not return minerals previously stored in biomass to the soils, and may be selective of dominant vigorous trees, leaving the more susceptible and stressed stems. Logging/land clearing can increase erosion rates, but overstory clearing typically releases and stimulates the rapid growth of shade intolerant early successional species (Gruell, 1983). Evidence of recent logging, within the past ten years, was observed during the 1992 field sampling in German Gulch. Removal of the overstory apparently stimulated the growth of shade intolerant understory grasses, forbs, and shrubs.

In the absence of continual physical or chemical disturbance, we expect that the Anaconda uplands would have been rapidly revegetated as shown in Figure 4-17a,b (Gruell, 1983). The expected fingerprint resulting from logging would include evidence of logging as stumps and slash, favored regeneration of Douglas fir over lodgepole pine, and essentially no effects on grasslands. In fact, these characteristics are apparent in German Gulch.

In contrast, the fingerprint observed in the vegetation communities in the Anaconda uplands comprises evidence of stumps and logging camps, but no regeneration of shade intolerant understory species, and no regeneration of Douglas fir. Moreover, large areas of the injured Anaconda uplands have never been logged as attested by the fact that there are no stumps and the trees that previously flourished there are now present as standing- and fallen-dead timber. The vegetation community characteristics observed are inconsistent with the fingerprint expected for logging; thus we conclude that it is unlikely that logging is the causal agent of the observed injuries in the impact area.

4.4.4.3 Grazing

Grasslands in the Anaconda area prior to impact by mining were likely composed of some mix of bluebunch wheatgrass, needlegrass (*Stipa* spp.), rough fescue (*Festuca scabrella*), Idaho fescue, and scattered shrubs and forbs (U.S. SCS, 1986). In response to excessive grazing by cattle, species expected to decrease in abundance, "decreasers", include bluebunch wheatgrass, rough fescue, tufted hairgrass (*Deschampsia cespitosa*), bearded wheatgrass (*Agropyron caninum*), and serviceberry (*Amelanchier alnifolia*). Species expected to increase in abundance in response to grazing, "increasers", include Idaho fescue, needleandthread (*Stipa comata*), prairie junegrass (*Koeleria macrantha*), lupine (*Lupinus* spp.), paintbrushes (*Castilleja* spp.), snowberry, timber danthonia (*Danthonia unispicata*), fringed sagewort (*Artemisia frigida*), phlox (*Phlox* spp.), and other forbs. Noxious/weedy species that invade in response to grazing pressure include spotted knapweed, thistles, dandelion (*Taraxacum officinale*), houndstounge (*Cyroglossum officinale*), annual and biennial forbs, and cheatgrass (*Bromus tectorum*) (U.S. SCS, 1986).

Figure 4-17a. Alder Gulch (a cool, dry Douglas fir habitat type near Virginia City, Montana) in 1871. Gold was discovered in the drainage in 1863 and ensuing placer mining removed much of the native vegetation. In 1871, the dominant herbaceous layer was bluebunch wheatgrass, a few Rocky Mountain juniper (*Juniperus scopulorum*) were evident on the south facing slope at left, and Douglas fir regeneration was present on the north-facing slope at right. Stumps in the area and fire-scars in the stumps indicate that logging occurred and fires were frequent. (Source: Gruell, 1983).

Figure 4-17b. The Same View of Alder Gulch in 1981, 110 Years Later. Douglas fir and Rocky Mountain juniper regeneration has covered the formerly devegetated slopes; the north slope is now densely covered by Douglas fir. Aspen, narrowleaf cottonwood (*Populus angustifolia*), willow, and chokecherry have colonized the canyon bottom. Physical devastation by placer mining has not precluded regeneration of the native riparian and upland communities. (Source: Gruell, 1983).

Vegetation surveys in 1992 and 1994 indicate that the most widespread grassland species in the injured area are Great Basin wild rye and redtop. Both are known to be successful invaders of tailings-contaminated sites (MSU/RRU, 1993a; U.S. SCS, 1993; U.S. BLM, 1992), and neither is an expected increaser or invader resulting from grazing pressure. Moreover, neither Stucky Ridge, Smelter Hill, nor the part of Mount Haggin sampled is currently grazed by domestic livestock. In contrast, grazing by domestic livestock is common and ongoing in German Gulch. Dominant grass species at the control sites included bluebunch wheatgrass, Idaho fescue, tufted hairgrass, and various forbs. In addition, despite grazing pressure, forests stands representative of all age classes persist, vertical structure of the vegetation communities present remains diverse (all habitat layers are represented), and recognizable successional stages are present.

The expected fingerprint, greater abundance of decreaser species and invasive species, with minimal effects on forest community development, is not evident in the impact area. The composition of the grasslands in the impact area, the pervasive absence of forests, and the simple fact that the area is not heavily grazed, are evidence that the cause of the observed injury is not grazing pressure.

4.4.4.4 Sulfur Dioxide

During the period of smelter operation (1884-1980), combustion of sulfide ores likely released sulfur dioxide to the atmosphere, which may have resulted in wet or dry acid deposition. Sulfur oxides released to the atmosphere may be oxidized to sulfate (SO_4^{2-}) and deposited as sulfate or sulfuric acid (H_2SO_4) on plant surfaces and soils. This acid deposition is known to reduce plant productivity by leaching nutrients from leaves and interfering with photosynthesis (U.S. EPA, 1984; Fitter and Hay, 1987). Over extended periods, acid deposition on soils can cause accelerated leaching of soil nutrients and acidification of soils, with effects dependent on soil type, climate, and to a lesser degree, vegetation cover type (Reuss and Jonson, 1986; U.S. EPA, 1984). However, the effect of acid deposition on plants is transient, and on soils, recognizable in the chemistry of the soil. As the following paragraphs describe, neither effect persists in the impact area currently.

Reports prepared for the Anaconda Company in the 1970s indicate that at that time, sulfur dioxide (SO_2) effects on the landscape were minimal (Treshow, 1972). Field investigations conducted to identify the extent of plant injury attributable to sulfur dioxide determined that the vegetation in the vicinity of the smelter was limited to a few species, but the existing plants were free of abnormal markings indicative of SO_2 damage. Further from the stack, aspen, lodgepole pine, limber pine (*Pinus flexilis*), and Douglas fir were reported to be normal and free from markings attributable to SO_2 (Treshow, 1972; Treshow, 1974). Some other investigators, however (e.g., Carlson (1974), Walsh and Bissel (1979), and Bissel (1982)), reported evidence to the contrary: abnormal markings associated with acid deposition, shifts in plant community composition, and reductions in total vegetative cover downwind of the smelter.

Regardless of whether plants were injured by acid deposition during the period of smelter operation, the source has ceased, and acid deposition at the leaf surface is no longer a factor contributing to the poor regeneration and succession in the impact area.

Since the period of releases of sulfur oxides lasted 90 years, there is the potential that sulfate anions deposited on soils may have acidified the soils. Acidification of soils is a natural process, but the deposition of acid anions on soils can potentially accelerate the natural processes by expediting leaching of base cations (Ca^{2+}, Mg^{2+}, K^{+}, or Na^{+}) from the soil. Accelerated leaching of base cations from soil has two primary effects: it reduces the available supply of plant nutrients, and it results in an increase in the concentration of hydrogen ions in the soil solution (reduces the pH).

In general, acid deposition does not produce acid soils unless it is accompanied by slow leaching through the soil column. Runoff water will minimally impact soil chemically, due to its brief contact with soil particles (U.S. EPA, 1984). Acid deposition on dry soils, and even some moist forest soils, may cause no lasting ill effects (U.S. EPA, 1984; Stuanes et al., 1992). However, the literature regarding the effects of acid deposition in the northern Rocky Mountains is sparse, either because the air is relatively clean compared to other parts of the world, or the soils and thus streams are not prone to acidification.

The data collected as part of this assessment indicate no significant acidification of soils either as an increase in the H^{+} concentration in the soil solution (a decrease in pH), or as a reduction of exchangeable cations, relative to the control area. No significant differences in the cation exchange capacity of control and impact soils, the pH of the control and impact soils, nor the potassium concentration (an exchangeable base cation) of control and impact soils were observed (Table 4-14). Soils with a cation exchange capacity exceeding 15 meq/100 g are generally considered insensitive to acid deposition (U.S. EPA, 1984). The mean CEC values for impact and control soils (16.6 meq/100g and 16.4 meq/100g) are both within the range of soils considered to be insensitive to acid deposition (U.S. EPA, 1984), and are comparable to CECs of other soils of the world. Although most soils do not exceed 30 meq/100 g, CEC measured in the impact soils ranged from 35.9 to 7 meq/100 g, and in the control soils, 26.6 to 8.5 meq/100 g. Moreover, it should be noted that, unlike hazardous substance concentrations, pH was <u>not</u> correlated with either bare ground (Kendall-tau = -0.08, p = 0.65) or with the number of habitat layers (Kendall-tau = 0.08, p = 0.57).

It is possible that acidification of the soil solution did occur in the past and that the sulfate anions leached smelter-deposited metals through soils. This process would have made the hazardous substances in the soils more available for plant uptake, as metal solubilization and biological toxicity are pH dependent (Kabata-Pendias and Pendias, 1992; U.S. EPA, 1984).

Table 4-14
Comparisons of Mean Potassium Concentrations (ppm), pH, and CEC (meq/100g) in Impact and Reference Soils (0 to 5 cm)

Variable	Reference Samples n = 8	Impact Samples n = 23	p-value
Potassium	609.7	501.6	0.4538
pH	5.7	5.4	0.2908
CEC	16.4	16.0	0.8888

* p-values (> 0.05) indicate no significant differences between control and impact soils (2-tailed tests).

Thus acidity could have actually increased the phytotoxicity of the metals deposited concurrently (U.S. EPA, 1984). The distribution of metals in the soils currently however, suggests that metals have not leached from the upper soil horizon to lower horizons (Appendix A).

The evidence overall suggests that acid deposition had no discernible lasting effects on soil chemistry in the Anaconda uplands. Despite the facts that soils were not acidified and acid deposition ceased fourteen years ago, vegetation communities show no signs that are indicative of a release from a transient stress. The fingerprint of injury caused by acid deposition is not consistent with the pattern observed, and therefore is unlikely to be the cause of the persistent injury in the Anaconda uplands today.

4.4.4.5 Evidence of Hazardous Substance Causality

The soil chemistry data, the vegetation community measurements, the phytotoxicity tests, and the correlations between phytotoxicity scores and hazardous substance concentrations in soils, phytotoxicity scores and percent bare ground, phytotoxicity scores and the number of habitat layers, concentrations of hazardous substances in soils and percent bare ground, concentrations of hazardous substances and the number of habitat layers, as well as numerous other studies conducted for the RI/FS process, consistently support the conclusion that it is elevated concentrations of hazardous substances in the soils of the impact area that has injured the vegetation communities.

Other vegetation surveys conducted within the Superfund boundaries have also identified metals concentrations in soils as the primary factor limiting plant growth (MSU/RRU, 1993a, 1993b). Vegetation survey results indicate that species present near the former smelter are metals tolerant and drought resistant. These include Great Basin wild rye (seeded in revegetation attempts on Smelter Hill, MSU/RRU, 1993a), a metals-tolerant and drought tolerant grass, spotted knapweed, an invasive metals and drought tolerant noxious weed, and tufted hairgrass and redtop bentgrass, also known to be metals tolerant though less drought tolerant (MSU/RRU, 1993a). Shrubs and trees that have persisted in isolated patches on Smelter Hill and Mount Haggin typically have rooted below the upper layers of contaminated soil; fine roots are observed only in deeper soil horizons (MSU/RRU, 1993a). The aspen groves that persist on parts of Smelter Hill and Mount Haggin assessment areas are reproducing asexually. These colonies likely have survived since pre-mining days. Their persistence is attributable to the fact that the genet (genetic individual) already had roots established below the contamination and could continue to rootsprout despite conditions at the soil surface inhospitable for seedling growth (MSU/RRU, 1993a).

The evidence of hazardous substance causality is supported by the "consistency criteria" of Hill (1965). The results of the upland soils, vegetation, and wildlife habitat investigations demonstrated that:

- The impact soils are contaminated with hazardous substances (Chapter 3.0, Appendix A).
- The concentrations of hazardous substances measured in impact soils exceed phytotoxic thresholds (Chapter 3.0, Appendix B).
- The impact soils are phytotoxic in controlled laboratory studies (Chapter 3.0, Appendix B).
- Degree of phytotoxicity is correlated with concentrations of hazardous substances (Chapter 3.0, Appendix B).
- Degree of phytotoxicity scores is correlated with percent bare ground and with the mean number of habitat layers.
- Concentrations of hazardous substances are correlated with percent bare ground and with the mean number of habitat layers.
- No significant differences between impact and control soil nutrient concentrations, pH, CEC or soil texture are observed (Chapter 3.0, Appendix A).
- Impact area vegetation communities are characterized by an increased percentage of bare ground, absence of forest cover, and reduced indigenous species diversity.

- Impact area wildlife habitat is characterized by a reduced number of habitat layers, particularly tree canopy, tree bole, and terrestrial subsurface, and thus reduced habitat availability and suitability.

All of this evidence is consistent with the conclusion that hazardous substances caused the injury. Metals and arsenic contamination is toxic to vegetation (MSU/RRU, 1993a; Kabata-Pendias and Pendias, 1992; Fitter and Hay, 1987), soil flora (Kabata-Pendias and Pendias, 1992), soil fauna (Kabata-Pendias and Pendias, 1992), is virtually permanent (Kabata-Pendias and Pendias, 1992), and thus is consistent with the conditions observed in the impact area. Metals and arsenic contamination explains the loss of vegetation, the persistence of the injury, the differences observed between the impact and control sites, the laboratory toxicity, the impacts to forest, shrub, and grassland communities, and the uniformity of the impact throughout the assessment area (Table 4-15).

The effects of fire, grazing, logging, and acid deposition are clearly inconsistent with what is observed in the impact areas investigated as part of this NRDA (Table 4-15). Fire and logging can cause initial loss of vegetation, but do not explain impacts across all community types throughout the assessment area, do not explain differences observed between the control and impact sites do not explain the impacts in areas that have not been logged, and do not explain the toxicity of the soils. Grazing can result in loss of vegetation in grasslands and shrublands and understory components of forest communities, but does not explain absence of trees, soil toxicity, or the differences observed between impact and control sites. Soil nutrient depletion can cause long-term loss of vegetation and impacts across all vegetation types, but was not observed in impact area soils relative to control area soils. Acid deposition can cause initial loss of vegetation, but does not explain the persistence of the observed injury, particularly in rapidly regenerating grasslands.

The accumulation of hazardous substances in the soil is the only consistent and plausible cause of the injury observed in the Anaconda uplands.

4.4.5 Extent of Injury

The State's delineation of injured areas showed that 17.8 square miles (11,366 acres) of upland vegetation and wildlife habitat have been grossly injured. Although the degree of injury varies throughout the injured area, significant reductions in habitat quantity and quality relative to uncontaminated control sites has been confirmed over the 17.8 square mile area. This injury extends north from the Washoe Smelter stack to include Stucky Ridge and hillsides north of Lost Creek, and south to Mount Haggin as far as the Continental Divide.

Table 4-15
Evaluation of Causality

	Fire	Logging	Grazing	Nutrients	SO_2	Hazardous Substances
Can cause loss of vegetation?	yes	yes	yes	yes	yes	yes
Long-term impact?	no	no	no	yes	no	yes
Impact site different from controls?	no	no	no	no	?	yes
Can explain laboratory toxicity?	no	no	no	no	no	yes
Explains impacts to forest, shrub, grassland?	no	no	yes	yes	no	yes
Explains impacts to entire assessment area?	no	no	no	no	no	yes

4.5 ABILITY OF RESOURCE TO RECOVER

Plant communities have the capability to recolonize disturbed land and, eventually, re-establish wildlife habitat. The extent to which this may occur and the direction of the recovery (i.e., the resulting composition and structure of the recolonist communities, and the degree to which they resemble the pre-impact communities) are determined by whether residual stress persists, and whether the original stress has not irrevocably altered the abiotic conditions of the site.

Phytotoxicity studies performed by the state during the assessment of injury (see Chapter 3.0) have shown that the ability of the injured upland areas to revegetate and provide wildlife habitat is severely constrained by the current high to severe phytotoxicity of soils caused by elevated concentrations of hazardous substances. Furthermore, the extensive loss of topsoil (including the associated seed bank and nutrients) limits potential recovery. In areas exposed to wind erosion, it is likely that the current vegetative conditions will be virtually permanent. In more sheltered areas where some topsoil persists, limited recovery may take place; however, the natural recovery process will be extremely slow. Furthermore, the concentrations of hazardous substances in the soil and their demonstrated phytotoxic effects render the outcome of this revegetation process uncertain; it is by no means certain that without restoration, the eventual secondary climax community will resemble that which was lost as a result of exposure to hazardous substances.

4.6 SUMMARY

The data presented in this chapter demonstrate that:

- Upland vegetation and wildlife habitat (and, in turn, wildlife population viability) have been injured within a 17.8 mi^2 area in the vicinity of Anaconda, including areas of Stucky Ridge, Smelter Hill, and Mount Haggin.

- Vegetation injuries have resulted in statistically significant reductions in evergreen forest in impact areas, with concomitant significant increases in bare ground.

- Grassland communities in injured areas have significantly reduced vegetative cover and increases in invasive weed species that are less palatable to grazing wildlife.

- Injured areas demonstrated significant reductions in habitat layers, including tree canopy, tree bole, shrub midstory, understory, and soil subsurfaces.

- Wildlife habitat quality was reduced in injured areas, including forests (representative species = marten), forest/grassland (representative species = elk), and lost habitat layers. These reductions in wildlife habitat reduce the viability of wildlife populations in injured areas.

- Vegetation reduction and loss (measured as percent bare ground and the number of habitat layers) were statistically significantly correlated with degree of phytotoxicity and hazardous substance concentrations.

- Exposure to hazardous substances in soils provides the only consistent and plausible explanation for the injuries observed in the impact area.

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5.0 SOURCES AND PATHWAYS OF HAZARDOUS SUBSTANCES TO RIPARIAN RESOURCES

Pathway determination establishes the route or media by which hazardous substances have been transported from their sources to riparian soils and floodplain sediments of Silver Bow Creek, the upper Clark Fork River, and the Opportunity Ponds area [43 CFR § 11.63 (b)]. This chapter identifies sources of hazardous substances, pathways by which hazardous substances have been and continue to be transported from sources to riparian resources of the upper Clark Fork Basin, and the areal extent of the exposed pathways.

5.1 SILVER BOW CREEK

5.1.1 Identification of Sources of Hazardous Substances — Silver Bow Creek

Surface water resources have historically served as the primary pathway by which riparian soils have been exposed to hazardous substances. Numerous sources of hazardous substances have historically contributed to contamination of Silver Bow Creek. Although direct discharge of mining and mineral-processing wastes to Silver Bow Creek has ceased, re-releases of hazardous substances into the creek are ongoing, resulting in continued exposure of floodplain soils and sediments.

Historical and current sources of hazardous substances to Silver Bow Creek are described in detail in Lipton et al. (1995). These sources are summarized briefly in Table 5-1.

5.1.2 Identification of Transport Pathway — Silver Bow Creek

Pathways of transport of hazardous substances from sources to the floodplains of Silver Bow Creek include direct disposal and surface water pathways. Contaminated sediments transported in Silver Bow Creek have been deposited on Silver Bow Creek floodplains as a result of increased sediment loading and channel aggradation[1] during seasonal high water, and as a result of downstream erosion and redeposition of contaminated material.

The addition of large quantities of sediment in the wastes discharged to Silver Bow Creek resulted in aggradation of the river channel. The decreased riverbed volume initially caused increased flooding frequency (GCM Services, Inc., 1983, as cited in MultiTech, 1987a) and accelerated river meandering as the increased sediment load clogged the channel. As a result of clogged channels, a braided stream pattern developed and progressed downstream. Former

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[1] Modification of the channel bed in the direction of uniformity of grade by deposition; in this case, filling in of the channel.

Table 5-1
Sources of Hazardous Substances to Silver Bow Creek

Historical Discharge of Raw Mining and Mineral-Processing Wastes Directly into Silver Bow Creek

- Discharges occurred from the inception of mining in the Butte area in approximately 1878, until 1976, when the Weed Concentrator treatment process was expanded to include mill wastewater (MultiTech, 1987a).
- Tailings, waste rock, smelter slag, process water, and minewater were discharged directly to Silver Bow Creek (MultiTech, 1987a).

Smelting Waste Deposits

- At least six major smelters were built along Silver Bow Creek between 1879 and 1885 between Meaderville and Williamsburg (Freeman, 1900; Meinzer, 1914; Smith, 1952; Historical Research Associates, 1983; all as cited in MultiTech, 1987a).
- Smelters operated continuously until 1920 (except for the Pittsmont Smelter, which operated until 1930).
- Tailings and slag waste products were deposited on the Silver Bow Creek floodplain or sluiced to tributaries of Silver Bow Creek (Flynn, 1937, as cited in MultiTech, 1987a; CH$_2$M Hill and Chen-Northern, 1990).

Waste Rock Deposits

- Waste rock dumps identified in the Butte area include the Belmont and other inactive mines; waste rock dumps in the Warren Avenue drainage basin; numerous inactive mines and associated waste dumps outside the MRI boundary fence; eroded mine wastes in the Anaconda Road-Butte Brewery Basin; heavily eroded waste rock dumps in Buffalo Gulch basin; and waste rock dumps in Missoula Gulch (Camp Dresser and McKee, 1991).

Tailings Deposits

- Tailings deposits that have been identified as significant sources of hazardous substances include the Parrot Smelter Tailings, the Butte Reduction Works tailings, and the Colorado Tailings.
- Historically, tailings were deposited on the Silver Bow Creek floodplain. Photographs (1955) show extensive exposed tailings and slag deposits in the upper Metro Storm Drain area (CH$_2$M Hill and Chen-Northern, 1990).
- An estimated 3.7-7.8 million cubic yards of contaminated tailings and waste material have been deposited along the Silver Bow Creek floodplain and serve as sources of re-released hazardous substances (Canonie, 1992).

stream channels are evident in aerial photographs as deposits of fine-grained sediment devoid of vegetation.

Exposed tailings, waste rock piles, contaminated soils, and the large expanses of exposed streamside tailings along Silver Bow Creek are subject to erosion and entrainment during high water, snowmelt, and precipitation-induced runoff (CH_2M Hill and Chen-Northern, 1990). Streams at high water stage carry increased suspended sediment loads, and as high waters recede, the sediment load is deposited on the floodplains. Tremendous amounts of material containing hazardous substances may be moved during seasonal high water events. Currently, the entire Silver Bow Creek floodplain is contaminated with fluvially deposited pure and mixed tailings (Hydrometrics, 1983; MultiTech, 1987b; PTI, 1989a; CH_2M Hill and Chen-Northern, 1990). Re-entrainment and transport of streamside tailings constitute a continuing release and transport of hazardous substances; hazardous substances in floodplain sediments will be gradually transported downstream.

During warm dry periods, moisture in the tailings moves upward and evaporates, leaving a metal-salts precipitate on the tailings surface that forms a crust up to several centimeters thick (MultiTech, 1987b; Nimick, 1990). The crusts dissolve easily in rainwater, and runoff becomes very acidic and metal-rich (see Lipton et al., 1995). Since the tailings have low permeability, very little precipitation infiltrates below the surface; most of the runoff discharges into the stream (Nimick, 1990). These pathways contribute to additional metals loadings in surface water resources of Silver Bow Creek.

Riparian soils and floodplain sediments of Silver Bow Creek themselves serve as a pathway of contamination to surface water resources of Silver Bow Creek. Silver Bow Creek redistributes streambank and floodplain sediments by entraining and redepositing them in bed, bank, and overbank deposits. Through mass wasting, bank erosion, and slumping, and by way of surface runoff over easily dissolved metals salts that form on tailings deposits, hazardous substances are re-released to surface water resources (MultiTech, 1987b).

5.1.3 Extent of Pathway Contamination — Silver Bow Creek

As a result of hazardous substance releases to and transport within Silver Bow Creek, suspended, bank, and bed sediments throughout the creek are contaminated with hazardous substances relative to baseline (see Chapter 6.0). The entire floodplain of Silver Bow Creek is contaminated with hazardous substances and is a continuing source of hazardous substances to Silver Bow Creek surface water resources. Therefore, the surface water pathway to riparian soils and sediments extends the length of Silver Bow Creek.

Chemical analysis of floodplain materials from Silver Bow Creek indicates that tailings materials contain elevated concentrations of hazardous substances and low pH. The presence of hazardous substances in slickens and mixed tailings deposits and riparian soils has been confirmed by many studies through chemical analysis of deposited tailings and mixed tailings and soil material (e.g., Peckham, 1979; Hydrometrics, 1983, 1987; Rice and Ray, 1984, 1985; MultiTech, 1987a,b; MSU et al., 1989; PTI, 1989a,b; CH_2M Hill and Chen-Northern, 1989, 1990; CH_2M Hill et al., 1991; Appendix A). All data indicate that the tailings deposits and soils impacted by tailings have concentrations of arsenic, cadmium, copper, lead, and zinc well in excess of expected (baseline) concentrations in native riparian soils.

Average concentrations in tailings and floodplain sediments for the length of Silver Bow Creek and the Opportunity Ponds compiled from previous investigations are presented in Table 5-2. Additional data are presented in Chapter 6.0.

Table 5-2
Average Total Metals and Arsenic Concentrations in Tailings and Floodplain Sediments of Silver Bow Creek (in ppm)

Location on Silver Bow Creek	As	Cd	Cu	Pb	Zn	(n)
Montana Street to the Upper Metro Storm Drain[1]						
► Exposed tailings	601	9	1523	644	2854	14
► Flue dust	761	15	477	2645	4510	2
► Floodplain sediments/mixed alluvium and tailings	306	10	1936	773	4217	26
► Waste rock - railway roadbed fill	298	3	1389	421	857	8
► Waste rock - transported fill and alluvium	113	4	552	265	1571	11
► Soil	97	1	570	565	1101	4
Below Colorado Tailings to Miles Crossing[2]	485	6.5	220	1280	3970	21
Below Colorado Tailings to Miles Crossing[3]	854	4.6	1230	370	842	41
Miles Crossing to Warm Springs Ponds[2]	371	6.2	2030	1040	2920	28
Butte to the Mill-Willow Bypass[4]	678	17.3	2520	1480	3790	35
Opportunity Ponds[5]	210	4.9	2030	474	1200	42
Baseline[6]	27.8	1.2	34.2	35.9	102.2	12

[1] CH_2M Hill and Chen-Northern, 1990.
[2] Canonie, 1992.
[3] MultiTech, 1987b.
[4] MSU et al., 1989.
[5] Tetra Tech, 1987.
[6] Chapter 6.0, this report.

5.2 CLARK FORK RIVER

5.2.1 Identification of Sources of Hazardous Substances — Clark Fork River

The historical sources of contamination in the Clark Fork River pathways and resources are the same as those described for Silver Bow Creek (see Lipton et al., 1995). Before 1918, discharged wastes were neither treated nor impounded, and raw mining and mineral-processing wastes were transported unobstructed downstream to the Clark Fork River. The three Warm Springs Ponds, constructed in 1918, 1919, and 1959, were built to settle out mining wastes, but it is estimated that by 1959, more than 110 million tons of metals-contaminated wastes had been released directly to the Clark Fork River from Warm Springs Ponds and Silver Bow Creek (Andrews, 1987). In addition, though the Warm Springs Ponds were effective in settling a fraction of the suspended sediments transported by Silver Bow Creek, large amounts of tailings and other mine waste material continued to be discharged to the Clark Fork River, particularly during high flows, which by-passed the Warm Spring Ponds, and during labor strikes when the ponds were not in full operation (Phillips, 1985; Johnson and Schmidt, 1988).

Additional sources of hazardous substances to the Clark Fork River include historical discharges from the Anaconda Smelter via outflow from the Opportunity Ponds, erosion and transport via Mill Creek of soils contaminated by stack emissions, and erosion and transport of tailings dumps or other waste deposits along Warm Springs Creek (see Lipton et al., 1995). A continuing source of hazardous substances to the surface water pathway in the Clark Fork River is erosion and re-entrainment of contaminated riverbanks and floodplains. Through mass wasting, bank slumping, and surface runoff over exposed tailings deposits, hazardous substances are re-released to the Clark Fork River.

5.2.2 Identification of Transport Pathways — Clark Fork River

Hazardous substances have been transported from sources to the floodplains of the Clark Fork River via Silver Bow Creek surface water resources and, to a lesser extent, Mill Creek and Warm Springs Creek. The uppermost sediment layer along much of the Clark Fork River lies above the native, pre-mining, floodplain, and consists of tailings and mixed alluvium and tailings. Old, barren meander channels within the upper Clark Fork floodplain are evidence of the fluvial transport of hazardous substances.

The thick overbank deposits along the Clark Fork River resulting from large sediment releases of mining wastes ensure persistent contamination of water and bed sediments of the Clark Fork River through continual release of contaminated floodplain soils and sediments caused by surface water runoff following snowmelt or precipitation, mass movement during floods, and riverbank wasting and slumping (Moore, 1985; Rice and Ray, 1985; Andrews, 1987; Moore et al., 1989; Axtmann and Luoma, 1991). The mass of contaminated floodplain sediments and soils will continue to serve as a storage-and-release pathway of hazardous substances to surface water and bed sediments, and through river flooding cycles and under the influence of gravity, hazardous substances will continue to move downstream at a very slow rate (Nimick, 1990).

5.2.3 Extent of Pathway Contamination — Clark Fork River

As a result of hazardous substance releases to and transport within Silver Bow Creek and the Clark Fork River, particularly before the construction of the Warm Springs Ponds, bed sediments throughout the river are contaminated with hazardous substances relative to baseline conditions (see Lipton et al., 1995).

The original, pre-mining floodplain of at least the first 10 kilometers (6 miles) of the Clark Fork River is buried by tailings and mixed tailings and alluvium (Nimick, 1990). Mixtures of cleaner fluvial sediments have been deposited on top of tailings, and tailings are continually cycled between the channel and the floodplain. Average metals and arsenic concentrations in floodplain sediments are listed in Table 5-3 and illustrate the extent of soil resources exposed by the surface water pathway.

Table 5-3
Concentrations in Tailings and Floodplain Sediments of the Clark Fork River (ppm)

Location on the Clark Fork River	As	Cd	Cu	Pb	Zn	(n)
Below Warm Springs Ponds extending 10 km north[1]	769	3.64	4532	712	1839	83
North of Warm Springs Ponds[2]	600	5.7	3662	547.3	2206	67
Warm Springs Ponds to Deer Lodge[3]	634	8.8	1760	461	1160	8
Warm Springs ponds to Drummond[4]	292	NA	2183	262	1298	240
Warm Springs Ponds to Turah[5]	NA	9.3	1147	164	2529	17
North of Deer Lodge[6]	176	5.0	1630	NA	NA	40
Deer Lodge to Drummond[3]	610	8.4	1090	398	1120	9
Drummond to Milltown[3]	116	10	783	87	2660	9
Baseline[7]	27.8	1.2	34.2	35.9	102.2	12

[1] Nimick, 1990.
[2] Brooks, 1988.
[3] Moore, 1985.
[4] CH_2M Hill et al., 1991.
[5] Axtmann and Luoma, 1991.
[6] Rice and Ray, 1984.
[7] Chapter 6.0, this report.
NA = Not analyzed.

5.3 OPPORTUNITY PONDS

Historical sources of hazardous substances to the riparian soils in the Opportunity Ponds area included Anaconda mill tailings, plant effluents, discharges from smaller ponds, and, between 1932 and 1947, Silver Bow Creek water. The ponds were constructed to receive smelting-related wastes, and to clarify process wastewater before discharge to the Warm Springs Ponds or the Clark Fork River.

According to a report prepared by the Anaconda Minerals Company in the mid-1970s (AMC, date unknown), Pond A (approximately 215 acres) was constructed in 1914, and by 1919 was filled and abandoned. Ponds B and C were constructed concurrently, and discharges to the B Ponds (approximately 925 acres) began in 1918. During the 1950s, Pond B was dredged, and the wastes transported to the Butte mines for fill. Pond B-2 later received fine-grained tailings from the electric furnace slag project. The C Ponds (approximately 1180 acres) received effluent from the B Ponds, and discharged to the D ponds. The D Ponds (approximately 810 acres) were filled with tailings deposited in the 1960s and 1970s. The D-2 Pond was built on top of 100 acres of slime ponds built in 1910 and abandoned in 1918 (Tetra Tech, 1987).

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6.0 GEOLOGIC RESOURCE — RIPARIAN SOILS

This chapter described injuries to riparian soils along Silver Bow Creek, along the upper Clark Fork River (from Warm Springs Ponds to Deer Lodge), and in the Opportunity Ponds. Overall, the data presented in this chapter demonstrate that:

- Concentrations of hazardous substances in riparian soils of Silver Bow Creek, the upper Clark Fork River, and the Opportunity Ponds are significantly greater than baseline conditions.
- Riparian soils of Silver Bow Creek, the upper Clark Fork River, and the Opportunity Ponds are severely phytotoxic, as demonstrated in controlled laboratory tests, and hence are injured.
- Riparian soils of Silver Bow Creek, the upper Clark Fork River, and the Opportunity Ponds have pH values less than 4.0, and hence are injured.
- Injury to riparian soils of Silver Bow Creek, the upper Clark Fork River, and the Opportunity Ponds is further confirmed by field studies quantifying a significant reduction in vegetation.
- The areal extent of injury, delineated by the area of riparian soils effectively devoid of vegetation, covers approximately 800 acres along Silver Bow Creek, 215 acres along the upper Clark Fork River, and some 3,400 acres in the Opportunity Ponds area.

6.1 DESCRIPTION OF RIPARIAN SOIL RESOURCE

Geologic resources that have been injured by releases of hazardous substances from mining and mineral processing operations in Butte and Anaconda include the riparian soils and floodplain sediments adjacent to Silver Bow Creek and the upper Clark Fork River from Warm Springs Ponds to Deer Lodge, and former low-lying soils associated with Mill and Willow Creeks and minor drainages and springs in the Opportunity Ponds area.

6.1.1 Silver Bow Creek

Silver Bow Creek is a perennial stream that begins at the confluence of the Metro Storm Drain and Blacktail Creek in Butte, and flows approximately 24 miles (40 kilometers) west and north to discharge into the Warm Springs Ponds (Canonie, 1992a). Approximately 22 miles of Silver Bow Creek, from below the Colorado Tailings to the Warm Springs Ponds, constitute the Streamside Tailings Operable Unit of the Silver Bow Creek/Butte Area NPL Site.

The uppermost sediment layer along Silver Bow Creek lies above the naturally formed (pre-mining) floodplain (MultiTech, 1987a). The natural floodplain soils contain dead vegetation partially buried by deposited tailings and tailings-contaminated alluvium, indicating the recent and common origin of the sediment layer (MultiTech, 1987a). Evidence compiled during the Lower Area I Remedial Investigation (CH_2M Hill and Chen-Northern, 1990) indicates that soils within the operable unit were originally developed on upland slopes under coniferous forests, or in valley-fill sediments under grassland vegetation. Historical maps show that Silver Bow Creek and Blacktail Creek riparian areas supported extensive marshy areas and lowland swamps (CH_2M Hill and Chen-Northern, 1990).

6.1.2 Clark Fork River

The headwaters of the Clark Fork River are formed by the discharge of the Warm Springs Ponds, and the confluences of the Mill-Willow Bypass and Warm Springs Creek. The upper Clark Fork flows north and west to the Milltown Reservoir, a distance of approximately 120 miles (195 kilometers). Between the Warm Springs Ponds discharge and Deer Lodge, approximately 17 river miles, concentrations of hazardous substances are elevated and hundreds of acres of unvegetated tailings deposits occur intermittently.

The uppermost sediment layer along much of the Clark Fork River lies above the naturally formed floodplain (Moore, 1985) and it is estimated that visible slickens areas constitute approximately 18% of the tailings material stored in the floodplain (Nimick, 1990).

6.1.3 Opportunity Ponds

The Opportunity Ponds are a series of tailings ponds constructed incrementally between 1914 and the late 1950s to treat mill tailings and wastes from the Anaconda smelter (MultiTech, 1983). Current drainage patterns suggest that portions of the approximately 3,400 acres now covered by the Opportunity Ponds in the past supported wetland communities associated with Warm Springs Creek, Mill Creek, Willow Creek, and additional minor drainages and springs. Approximately 50 acres in Pond D-1 of the Opportunity Pond complex remains damp most of the year because of groundwater seepage (AMC, date unknown); the natural groundwater seepage most likely supported a wetland community before the deposition of tailings.

Inflows to the Opportunity Ponds included Anaconda mill tailings, plant effluents, and discharges from smaller ponds. Between 1937 and 1942, a dam near Gregson diverted water from Silver Bow Creek to the Opportunity Ponds (MultiTech, 1987a). Estimates of the smelter waste stream volume vary, but approximately 10-30 cubic feet per second (6-19 million gallons per day) of wastes containing tailings slurry were discharged to the ponds (Tetra Tech, 1987).

6.2 INJURY DEFINITION

In this assessment, injury to riparian soil is defined as:

- 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].

These environmental responses are described in Chapter 3.0 and in Section 6.2.2, respectively.

6.2.1 Assessment of Phytotoxicity

As described in Chapter 3.0, controlled laboratory tests were used to evaluate phytotoxicity based on standard operating procedures consistent with the ASTM protocol for early seedling growth studies (ASTM, 1994; Appendix B of this report). Screening tests examined the toxicity of 100% impact site soils (Silver Bow Creek, the Clark Fork River, and Opportunity Ponds) to the standard laboratory test species alfalfa, lettuce, and wheat over a two-week exposure period. Extended tests examined the performance of hybrid poplar cuttings (a representative taxonomic surrogate for willow and cottonwood species) exposed to 100% impact site soils for four weeks. Performance of test species in impact site soils was compared to performance of control species grown in control soils. Control soils were collected from control sites previously designated and sampled as representative of baseline conditions (see Appendix A).

As described in Chapter 3.0, determination of phytotoxicity was based on a suite of species-endpoint responses, including:

- Germination (number of seedlings emerged/20 seeds; five replicates of 20 seed each)
- Shoot height (mm, for each surviving seedling; mean of plants measured)

- Maximum root length (mm, for each surviving seedling; mean of plants measured)
- Shoot mass (g oven dry weight for each seedling; mean of plants measured)
- Root mass (g oven dry weight for each surviving seedling; mean of plants measured)
- Total mass (g oven dry weight for each surviving seedling; mean of plants measured).

A response was deemed phytotoxic when plants in impact soil exhibited any of the above endpoints that was statistically less than the corresponding response of plants grown in control soils. The degree of phytotoxicity was quantified based on (1) the magnitude of the difference from control performance, (2) the number of endpoints exhibiting a phytotoxic response, and (3) the number of species exhibiting a phytotoxic response. Quantitative phytotoxicity scores were then assigned to each soil sample based on the degree of phytotoxic response. These toxicity "scores," in turn, were used to classify soils as either:

- Nontoxic
- Phytotoxic:
  - Mildly toxic
  - Moderately toxic
  - Highly toxic
  - Severely toxic.

Differences between impact and control samples were assessed statistically using randomized t-tests.

Secondary Effects of Phytotoxicity/Implications

The presence of phytotoxic concentrations in soils results in injury to vegetation communities. Phytotoxic injury to vegetation communities is manifested as a change in the plant population density, species composition, diversity, dispersion, or percent cover [43 CFR §11.71 (6)], and can be determined by reference to an established baseline area. Injuries to riparian vegetation resources are addressed in Chapter 7.0; however, obvious phytotoxic injuries in the form of devegetated riparian zones are indicative of injury to soil and will be discussed in the injury determination and quantification section of this report.

6.2.2 Changes in pH

Soil pH, the negative logarithm of the hydrogen ion concentration, is a measure of the acidity of a soil. Soil pH reflects the mineral content of the parent material and the degree of soil weathering, and is typically an indicator of soil contamination (Hassett, 1992). Soil pH values below 4.0 suggest that oxidation of reduced sulfur compounds has occurred or is occurring in the soil (Hassett, 1992). The effect of low pH in soils contaminated with metal and metalloid hazardous substances, in general, is increased mobility and plant availability of soil contaminants (Figure 6-1). Soil pH of less than 4.0 resulting from the release of hazardous substances constitutes an injury to the soil resource [43 CFR § 11.62 (e)(2)].

6.3 INJURY DETERMINATION AND QUANTIFICATION

6.3.1 Baseline Conditions

Baseline is defined as the condition or conditions that would have existed absent the releases of hazardous substances [43 CFR § 11.14 (e)]. Historical data regarding the baseline conditions of Silver Bow Creek and the Clark Fork River riparian soils and floodplain sediments before releases of hazardous substances are not available because releases have occurred since the late 1800s. Nor are adequate upstream control areas available, because Silver Bow Creek has been drastically disturbed by mining nearly to its headwaters. Therefore, baseline conditions were quantified using comparable streams in southwestern Montana that have not been exposed to hazardous substances.

Control areas against which Silver Bow Creek and the upper Clark Fork River riparian soils and floodplain sediments have been compared to determine injury include Divide Creek, Little Blackfoot River, and Flint Creek (see Appendices A and C). Reaches of each of these streams were identified as comparable in geomorphology and hydrology to specific reaches of Silver Bow Creek and the Clark Fork River, and each was sampled to determine representative concentrations of arsenic, cadmium, copper, lead, and zinc in riparian soils and floodplain sediments (see Appendix A). Arsenic, lead, and zinc concentrations measured in Flint Creek floodplain soils confirm that mining operations and associated releases to Flint Creek have contaminated the floodplains with elevated concentrations of hazardous substances (see Appendices A and C). Therefore, Flint Creek does not reflect baseline conditions for floodplain soils and is not used in calculating the baseline for Silver Bow Creek, the Clark Fork River, and Opportunity Ponds soils. Baseline conditions (arsenic = 27.8 ppm, cadmium = 1.2 ppm, copper = 34.2 ppm, lead = 35.9 ppm, and zinc = 102.2 ppm) were established as the averaged concentrations of six samples from Divide Creek and six samples from Little Blackfoot River, each a composite of five sub-samples (see Table 6-1 and Appendix A).

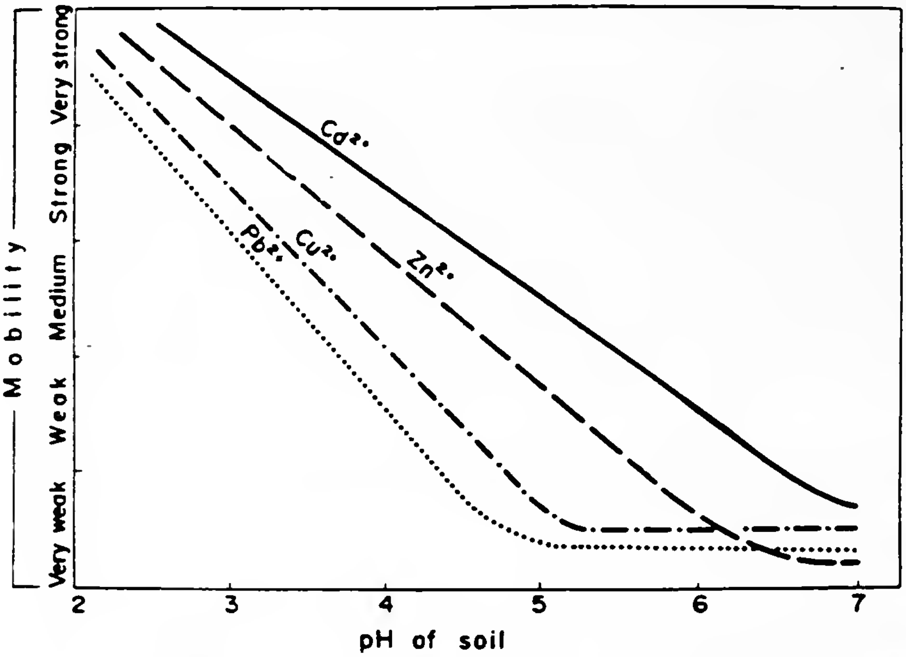


Figure 6-1. Trends in the Mobility of Metals as Influenced by Soil pH; Data for Light Mineral Soil (Kabata-Pendias and Pendias, 1992).

Table 6-1
Baseline and Background Concentrations (ppm) in Riparian Soils and Baseline Conditions for this NRDA (bold) are the Mean of Divide Creek and Little Blackfoot River Samples

Location	Arsenic	Cadmium	Copper	Lead	Zinc
Divide Creek Little Blackfoot River	27.45 28.13	1.7 0.7	43.4 25.0	26.2 45.6	92.3 112.0
Silver Bow Creek[1] (native floodplain)	11.1	NA	26.6	19.5	98.5
Tin Cup Joe Creek[2] Blackfoot River	26 4	1.3 < 0.03	53 13	NA NA	NA NA
Clark Fork tributaries[3]	26.5	< 2.5	27.0	24.0	94.0
Baseline	**27.8**	**1.2**	**34.2**	**35.9**	**102.2**

[1] Canonie, 1992a. [2] Rice and Ray, 1984. [3] Moore et al., 1989.

Previous investigations have identified background concentrations for specific sections of Silver Bow Creek and the Clark Fork River. Table 6-1 presents results of three studies that agree with the baseline concentrations of hazardous substances in floodplain soils determined for this NRDA.

Silver Bow Creek RI/FS boreholes (Canonie, 1992a) drilled to sample the depth of contamination along Silver Bow Creek floodplains indicate that concentrations stabilized at minimum background values more than 10 feet below the surface. Figure 6-2 illustrates the exponential decrease in concentration with depth for arsenic, copper, lead, and zinc. These background values presumably provide pre-release concentrations for comparison.

As part of a study of arsenic, cadmium, and copper contamination of the Grant-Kohrs Ranch near Deer Lodge, Rice and Ray (1984) compared observed concentrations in the Clark Fork River floodplain soils to concentrations in soils collected from Tin Cup Joe Creek, 5 miles southwest of the Grant-Kohrs ranch, and in soils from another control site on the Blackfoot River, 60 miles northwest of Grant-Kohrs. Neither of the two sampling sites had been exposed to contaminated over-bank sediments; background concentrations determined from them are presented in Table 6-1. In addition, background concentrations of total metals in 24 floodplain sediment samples taken from the Clark Fork tributaries are presented in Table 6-1 as average concentration in ppm (Moore et al., 1989).

Overall, the results of these studies confirm the baseline concentrations shown in Table 6-1. Indeed, these baseline conditions are somewhat conservative when compared to the Silver Bow Creek native floodplain.

6.3.2 Injury Determination

6.3.2.1 NRDA Riparian Soil Sampling

As a component of the soil resource investigation of this NRDA, soil samples were collected from three riparian areas in the upper Clark Fork River Basin: Silver Bow Creek from downstream of the Colorado Tailings to the Warm Springs Ponds, the upper Clark Fork River from the Warm Springs Ponds discharge to Deer Lodge, and the Opportunity Ponds. Silver Bow Creek and the upper Clark Fork River had been previously subdivided into four reaches during the work to determine injury to fish habitat and populations (Lipton et al., 1995). Three reaches, defined by geomorphology and hydrology, were also used for the riparian soils, vegetation, and wildlife sampling (see Appendix A). These reaches, referred to as impact reaches, were:

- Silver Bow Creek from below the Colorado Tailings in Butte to the upstream end of the Durant Canyon (Upper Silver Bow Creek)

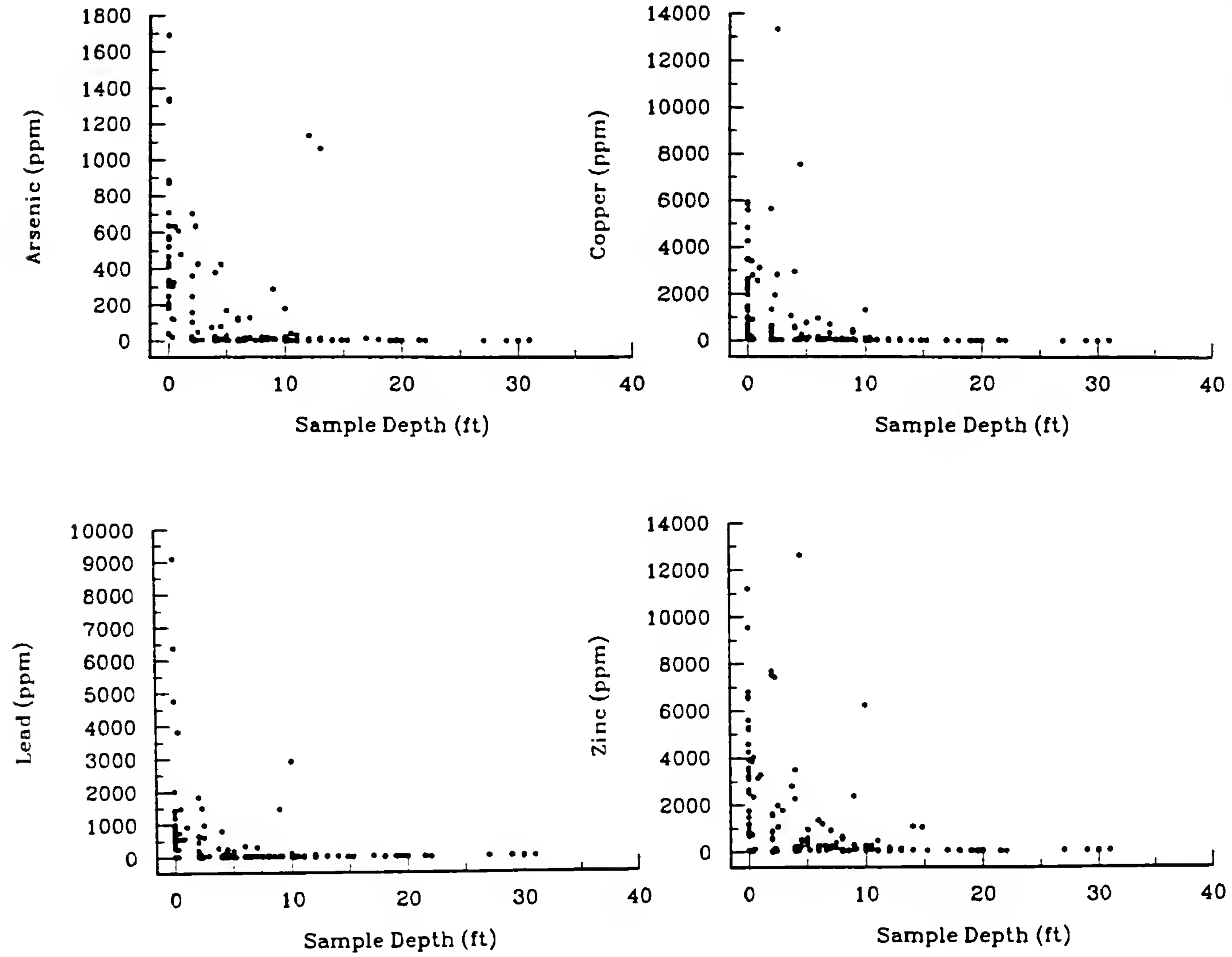


Figure 6-2. Concentrations of Hazardous Substances in the Silver Bow Creek Floodplain. Concentrations decrease with depth to approximately 10 feet below the surface. The asymptotic region of each graph indicates approximate pre-mining concentrations in floodplain soils and sediments. Source: Canonie, 1992a.

- Silver Bow Creek from the downstream end of the Durant Canyon to the Warm Springs Ponds (Lower Silver Bow Creek)

- The Clark Fork River from the Warm Springs Ponds discharge to Deer Lodge (the upper Clark Fork River).

The location of sampling transects is shown in Figure 6-3.

The Opportunity Ponds were also sampled as an impacted riparian area.

Sample sites on Silver Bow Creek and the Clark Fork River floodplains were located randomly within unvegetated slickens to obtain a representative sample of slickens chemical composition. Since there is no comparable reach upstream of the impacts, control streams were selected for comparison of soils and riparian vegetation. Criteria used to select control reaches were based on vegetation characteristics and the factors that control potential riparian vegetation composition and adjacent upland vegetation composition: valley bottom type, stream and valley gradient, channel sinuosity, elevation, and stream basin orientation (see Appendix A).

Three stream reaches were identified as potential control sites for the three impact reaches. Each was ground-truthed to ensure comparability. Divide Creek from the confluence of the North and East Forks was selected as the control for upper Silver Bow Creek. The Little Blackfoot River from Elliston to Avon was selected as the control reach for lower Silver Bow Creek, and Flint Creek from Sheryl to the Clark Fork River confluence was selected as the control for the upper Clark Fork River. The Opportunity Ponds were compared to the mean of the sites sampled as controls for the other riparian impact reaches.

Seventeen composited impact soil samples were collected from unvegetated slickens on Silver Bow Creek and the Clark Fork River, and 18 soil samples were composited from control sites. Samples were dried, mixed, and split for analyses. All samples were analyzed for total metals. Measured values of hazardous substances (total metals) in riparian impact and control soils were compared by reach. Two sample randomization tests (5,000 randomizations) (Manly, 1991) comparing impact and control reaches showed that concentrations of arsenic, cadmium, copper, lead, and zinc were significantly higher in the riparian impact soils than in their respective controls (Table 6-2). Concentrations of arsenic, copper, lead, and zinc in Opportunity Ponds samples were significantly greater than in riparian control samples (Table 6-3).

Summary statistics for riparian impact and control reaches are presented in Table 6-4 and Figure 6-4. Means for arsenic in each impact reach exceeded means in the control reaches by 4.5 to 13.7 times. Cadmium means in the control streams were exceeded by 3.8 to 7.2 times in the impact reaches, copper by 10 to 40 times, lead by 2.2 to 22.5 times, and zinc by 3.5 to 30.5. The comparisons confirm that samples collected from unvegetated slickens along Silver

Bow Creek, the Clark Fork River, and the Opportunity Ponds contain extremely elevated concentrations of arsenic, cadmium, copper, lead, and zinc relative to baseline concentrations (Table 6-4). In addition, the impact data are comparable to data collected in previous investigations of slickens (Tables 6-5 to 6-8).

6.3.2.2 NRDA Phytotoxicity Tests

To assess phytotoxic responses, controlled laboratory experiments were conducted to test seedling germination and plant growth performance in impact soils relative to control soils. Phytotoxicity was defined as a statistically significant decrement in plant growth (germination, shoot length, root length, shoot mass, root mass, and total mass) relative to control plants. The results of phytotoxicity tests of riparian soils and floodplain sediments of Silver Bow Creek and the Clark Fork River, and soil material in the Opportunity Ponds, indicate that these soils are extremely phytotoxic (Appendix B).

Four soil samples collected from slickens along Silver Bow Creek and the Clark Fork River and one from the Opportunity Ponds were used as substrate for the screening tests. Standard reference plants (alfalfa, lettuce, and wheat) were used in the screening tests. Germination/emergence, the first toxicity endpoint, was assessed as the number of seedlings visible above the soil surface after 7 days and at the end of the 14-day exposure period. For each riparian impact site, the mean emergence of five trials (20 seeds each) per species was compared to the emergence determined in the control sample using a t-test. Alfalfa and wheat emergence were significantly less than controls for sites R-04, R-08, and R-14 (Table 6-9). Lettuce emergence was significantly less than controls for all impact samples (R-04, R-08, R-13, and R-14).

Alfalfa, lettuce, and wheat shoot height and root length for all six impact sites tested, including the Opportunity Ponds, were significantly less than those measured for the control soils. Shoot and root mass of alfalfa and lettuce were significantly less than masses determined for the control samples in all six impact site soils tested, and wheat shoot and root mass were significantly less than the control in five of the site soils tested. Based on the results of seedling emergence and growth of alfalfa, lettuce, and wheat, Silver Bow Creek, the Clark Fork River, and Opportunity Ponds soils were classified as severely phytotoxic.

Four soil samples collected from slickens along Silver Bow Creek and the Clark Fork River were used as substrate for the extended impact tests (R-04, R-08, R-13, and R-14). Five hybrid poplar stems were planted in each of the four impact soil samples, for an initial total of 20 test plants. A composite of soil collected from the Little Blackfoot River and Flint Creek was used as control soil for the extended tests. Five hybrid poplar stems were planted in the control soil.

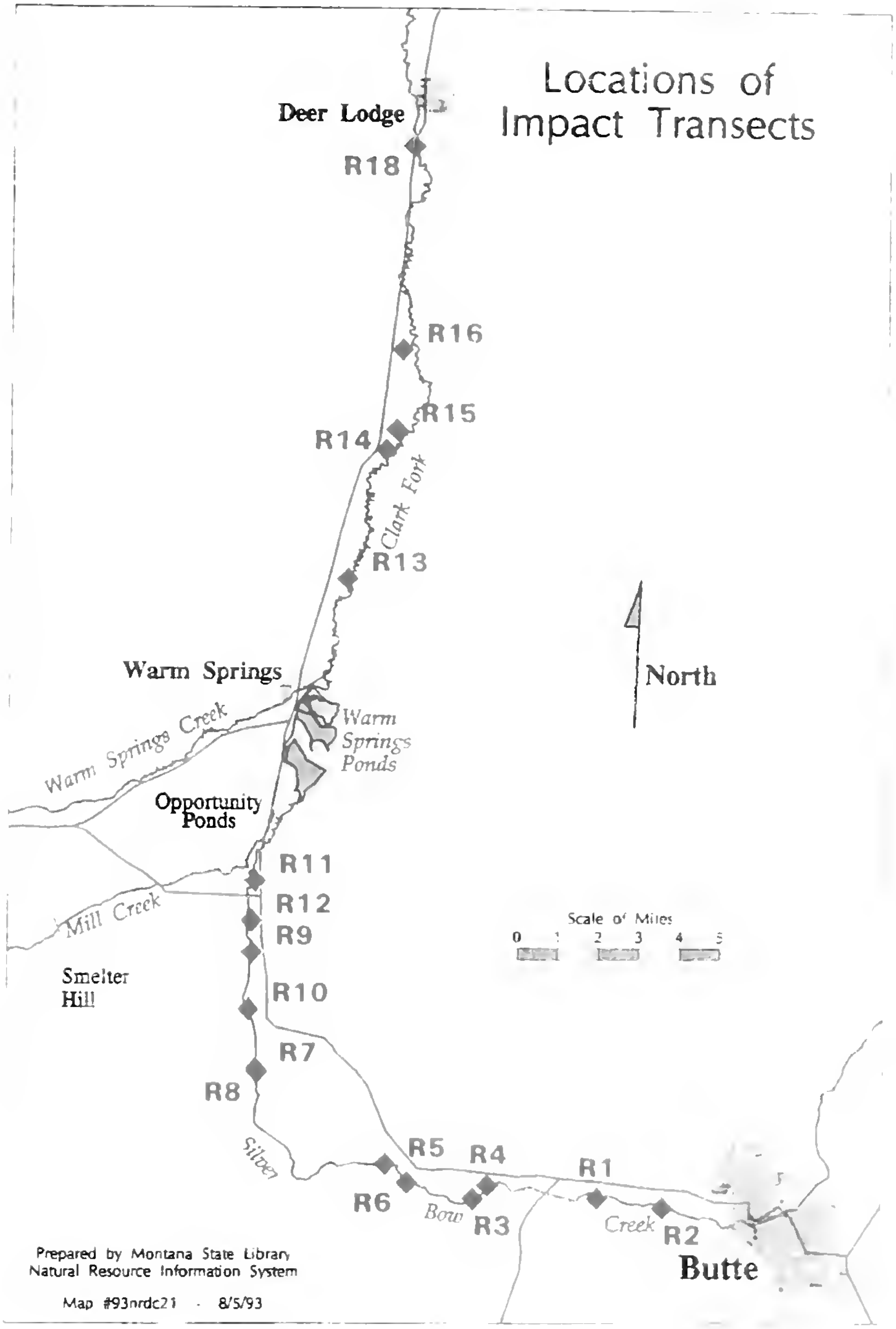


Figure 6-3. Location of Riparian Soil, Vegetation, and Wildlife Sampling Reaches: Silver Bow Creek and the Clark Fork River.

Table 6-2
Two-Sample Randomization Test of the Mean Difference Between Impact and Control Soil Concentrations (ppm)

Test	Upper Silver Bow Creek vs. Divide Creek n = 6 pairs		Lower Silver Bow Creek vs. Little Blackfoot n = 6 pairs		Upper Clark Fork River vs. Flint Creek n = 5 pairs	
Hazardous Substance	**Mean Difference**	**p-value <**	**Mean Difference**	**p-value <**	**Mean Difference**	**p-value <**
Arsenic	347.68	0.001*	235.97	0.0012*	303.66	0.0034*
Cadmium	7.18	0.0042*	4.32	0.0012*	3.42	0.0178*
Copper	1317.28	0.0014*	880.43	0.0014*	1962.7	0.0038*
Lead	564.87	0.0002*	431.88	0.0012*	166.6	0.0046*
Zinc	2725.25	0.001*	1392.33	0.0006*	880.6	0.001*

* indicates significantly greater concentration in the impact samples at $\alpha = 3.3\%$.

Table 6-3
Results of the Two-Sample Randomization Test Comparing Concentrations in Opportunity Ponds Soils and Riparian Control Reach Soils

Hazardous Substance	Mean Difference	p-value <
Arsenic	351.02	0.0014*
Cadmium	13.53	0.056 **
Copper	2314.55	0.0002*
Lead	238.95	0.0064*
Zinc	563.39	0.0358*

* and ** indicate greater concentration in the Opportunity Ponds at $\alpha = 5\%$ and $\alpha = 6\%$, respectively.

Table 6-4
Summary Statistics for Riparian Impact and Control Reach 2-Inch Soils Samples (total metals in ppm)

Sample Identification		As	Cd	Cu	Pb	Zn
Upper Silver Bow Creek	n = 6					
Arithmetic mean		374.6	8.8	1361.0	591.1	2816.6
Maximum		509.0	17.8	4014.0	885.8	5108.0
Minimum		274.3	3.7	478.0	392.0	1460.9
Standard deviation		81.1	5.1	1252.3	178.5	1399.3
Divide Creek (control)	n = 6					
Arithmetic mean		27.5	1.7	43.4	26.2	92.3
Maximum		76.4	5.8	56.4	40.0	136.0
Minimum		10.0	0.5	28.7	17.3	67.3
Standard deviation		22.2	1.9	12.3	8.2	25.8
Lower Silver Bow Creek	n = 6					
Arithmetic mean		264.1	5.0	905.5	477.5	1504.3
Maximum		425.6	8.3	1414.5	836.6	2152.0
Minimum		163.6	1.7	407.5	307.3	720.5
Standard deviation		110.5	2.5	408.3	195.6	590.5
Little Blackfoot (control)	n = 5					
Arithmetic mean		28.1	0.7	25.0	45.6	111.9
Maximum		44.1	1.4	43.6	100.1	169.7
Minimum		12.5	0.3	13.8	19.1	62.4
Standard deviation		12.9	0.4	10.5	26.6	39.3
Upper Clark Fork River	n = 5					
Arithmetic mean		391.3	4.7	2012.6	292.6	1230.3
Maximum		525.5	8.5	3644.0	360.0	1607.2
Minimum		291.8	1.1	566.5	236.8	549.5
Standard deviation		92.1	2.4	987.8	49.3	359.9
Flint Creek (control)	n = 5					
Arithmetic mean		87.6	1.2	49.9	127.8	349.7
Maximum		145.4	1.9	72.8	205.7	523.8
Minimum		36.6	0.6	28.2	51.2	194.4
Standard deviation		39.7	0.6	17.3	60.3	134.6
Opportunity Ponds	n = 5					
Arithmetic mean		396.4	14.7	2353.4	301.9	738.3
Maximum		1398.1	68.1	9980.0	722.6	2676.0
Minimum		18.5	0.7	301.6	54.2	68.0
Standard deviation		506.5	26.7	3816.3	257.2	977.7

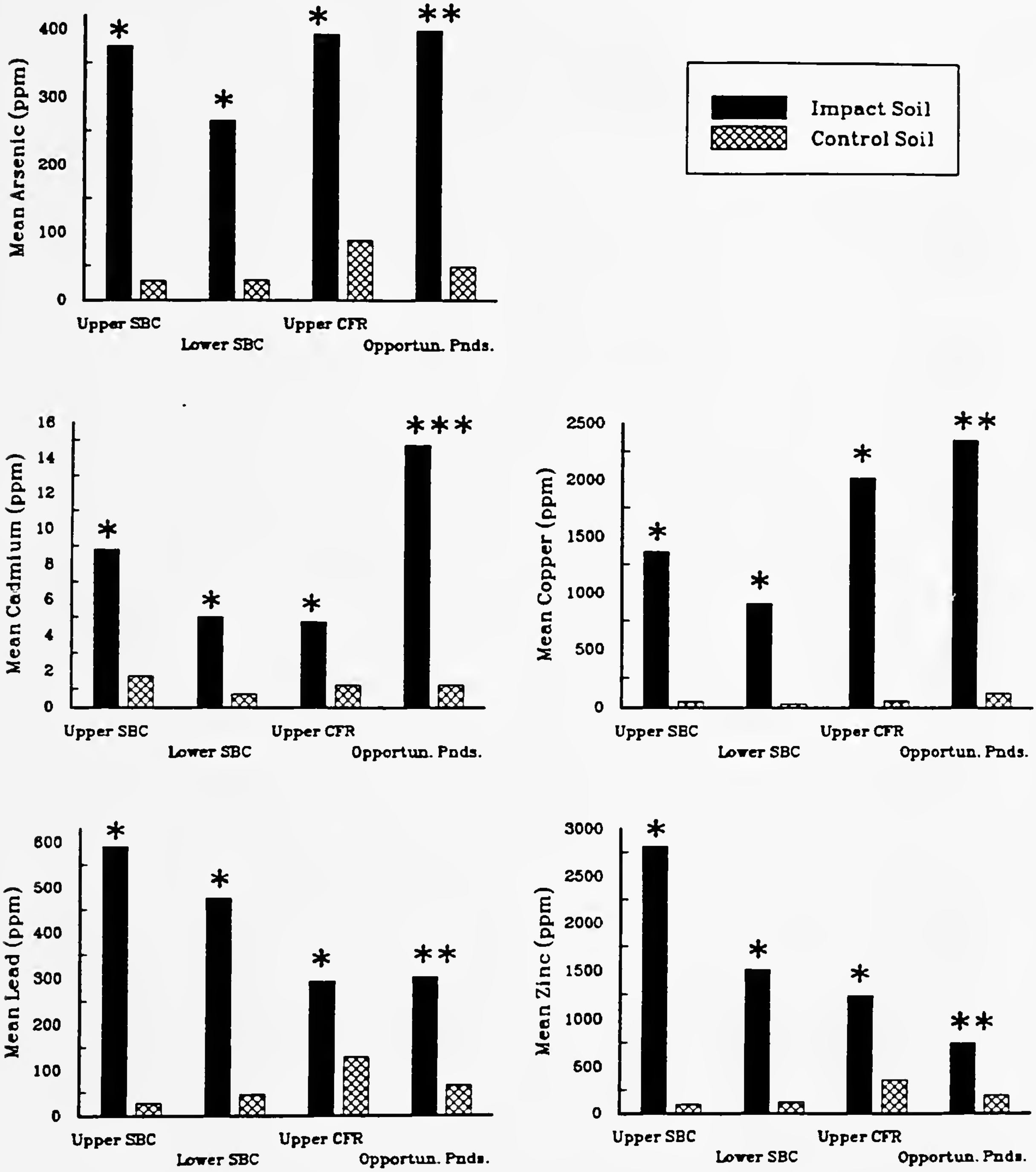


Figure 6-4. Mean Concentrations of Hazardous Substances at Impact and Control Reaches. * indicates significant difference at α = 3.3%; ** indicates significant difference at α = 5%; *** indicates significant difference at α = 6%.

Table 6–5
Streambank Tailings and Revegetation Study (STARS) Data Collected from Unvegetated Streamside Tailings along Silver Bow Creek

Sample	As	Cd	Cu	Pb	Zn	pH	Depth(in)
1	1003.0	13.2	2150.0	1490.0	3940.0	4.2	0 – 15
(TEST) 2	1745.0	108.0	11200.0	1960.0	22000.0	3.8	5 – 15
3	354.0	26.9	208.0	908.0	5580.0	2.7	0 – 15
4	146.0	4.5	2150.0	398.0	2970.0	4.3	0 – 15
5	975.0	32.2	8620.0	3100.0	7490.0	4.4	0 – 13
(TEST) 7	83.6	13.7	461.0	341.0	3840.0	3.3	0 – 15
6	212.0	15.7	6160.0	4920.0	7860.0	6.6	13 – 28
8	491.0	8.4	456.0	1160.0	2480.0	4.1	0 – 15
(TEST) 9	928.0	19.5	4040.0	6477.0	10200.0	5.8	20 – 35
10	51.2	3.6	811.0	312.0	814.0	2.3	0 – 8
11	2544.0	38.6	1600.0	1672.0	2040.0	3.4	0 – 6
12	38.9	15.0	3920.0	264.0	3900.0	6.8	2 – 17
13	285.0	2.8	374.0	578.0	1380.0	3.8	0 – 15
14	3140.0	36.4	5530.0	3380.0	5290.0	3.6	0 – 15
15	352.0	9.4	391.0	504.0	2670.0	3.8	0 – 15
16	1040.0	32.1	7430.0	2720.0	49.4	6.1	0 – 13
17	204.0	4.7	260.0	273.0	1190.0	3.1	2 – 12
18	1755.0	23.1	4070.0	1986.0	4460.0	3.2	0 – 15
19	1530.0	22.6	2430.0	1560.0	4120.0	3.5	0 – 15
20	341.0	8.9	685.0	682.0	5020.0	3.6	0 – 15
(TEST) 21	2560.0	37.0	3900.0	2980.0	7430.0	3.7	0 – 15
22	1050.0	21.9	4650.0	2730.0	4150.0	4.6	34 – 49
23	651.0	20.5	5080.0	1840.0	5500.0	4.5	0 –12
24	414.0	16.6	1550.0	1350.0	5580.0	3.7	0 – 15
25	93.5	4.1	390.0	442.0	937.0	2.5	0 – 8
26	261.0	6.4	868.0	635.0	1760.0	3.5	0 – 15
(TEST) 27	235.0	12.6	1980.0	2520.0	19.2	4.4	0 – 6
28	203.0	14.4	779.0	2180.0	2500.0	4.6	0 – 8
29	83.9	5.7	329.0	125.0	476.0	5.3	0 – 8
30	216.0	2.6	470.0	563.0	938.0	3.4	0 – 15
31	114.0	4.1	1290.0	367.0	559.0	2.8	0 – 15
(TEST) 32	19.3	8.8	1930.0	82.6	2240.0	7.4	12 – 27
33	209.0	1.8	871.0	467.0	1110.0	3.4	0
34	195.0	5.6	761.0	375.0	1440.0	2.7	0
35	779.0	196.0	3.6	534.0	456.0	NR	0

Concentrations reported are total metals in ppm. TEST indicates that the sample was used in greenhouse phytotoxicity tests; in all six soils tested, plants were unable to establish, indicating severe phytotoxicity. Shading indicates pH below 4.0, a criterion for injury determination in soil.

Source: MSU et al., 1989a,b

Table 6–6
Tailings Data Collected for the Silver Bow Creek RI from Ramsay Flats Tailings Material

Site #	Horizon	Soil Type	pH	As	Cd	Cu	Pb	Zn
S1	C1	T	3.7	610.0				
	C2	T	4.2	488.0				
	C3	T	6.0	153.0				
S2	C2	T	3.2	430.0				
	C3	T	2.9	392.0				
	C4	T	4.4	59.2				
S3	C1	T	3.1	2950.0				
	C2	T	3.8	497.0				
	C3	T	5.0	52.6				
	C4	T	7.0	55.2	11.7	1330.0	371.0	4160.0
S4	C1	T	2.6	109.0				
	C2	T	2.4	88.6				
	C3	T	2.8	297.0				
	C4	T	4.4	255.0				
S5	C1	T	3.6	1800.0				
	C2	T	3.7	1910.0				
	C3	T	6.0	350.0				
	C4	T	7.2	56.2				
S6	C1	T	3.7	1020.0	13.7	2410.0	1530.0	5000.0
	C2	T	3.6	2240.0				
	C3	T	3.8	1830.0				
	C3/2	T	3.5	1510.0				
S7	C1	T	4.3	418.0				
	C2	T	3.7	544.0				
S8	C1	T	3.6	1860.0				
	C2	T	5.3	754.0				
	C3	T	5.6	422.0	12.3	4280.0	684.0	2710.0
	C4	T	6.1	−88.6				
S9	C1	T	4.0	1260.0				
	C2	T	6.2	922.0				
	C3	T	5.8	175.0				
	C4	T	6.3	155.0				
S10	C1	T	7.2	1940.0				
	C2	T	7.7	39.7				
S11	C1	T	3.8	592.0	20.0	1220.0	1300.0	7550.0
	C2	T	5.9	564.0	17.0	5150.0	3250.0	8220.0
S18	C1	T	4.4	1210.0	15.8	1910.0	1550.0	3780.0
S20	C1	T	5.1	176.0	2.5	384.0	90.4	198.0
S21	C1	T	4.7	522.0	7.4	4380.0	315.0	2320.0
S22	C1	T	4.7	290.0	14.0	4940.0	112.0	2030.0
S23	C1	T	7.7	424.0	12.0	2290.0	356.0	2440.0
S25	C1	T	4.3	2520.0	26.6	2930.0	2070.0	7170.0
	C1	T	3.6	2680.0	21.8	3330.0	2800.0	6890.0
S26	SURFACE	X	2.8	0.0	86.5	65500.0	81.5	31200.0
S27	SURFACE	X	3.3	0.0	48.3	98500.0	149.0	22200.0
S28	C1	T	4.8	2130.0	21.4	3460.0	4840.0	8350.0
	C2	T	7.0	88.0	21.6	6000.0	7350.0	16000.0
	C3	T	7.6	182.0	9.0	600.0	1380.0	2240.0
S29	SURFACE	X	3.9	0.0	120.0	73000.0	25.8	30900.0

Forty–six samples were analyzed for pH and arsenic (ppm); 15 samples were analyzed for total cadmium, copper, lead, and zinc (ppm). Negative numbers may represent samples below detection; no explanation was provided in the original. Shading indicates pH below 4.0, a criterion for injury determination in soil.

Source: MultiTech, 1987b.

Table 6–7
Tailings Samples Collected from Streamside Tailings along Silver Bow Creek for the Tailings Investigation

Sample	Depth (in)	Borehole	pH	As	Cu	Pb	Zn	Surface Vegetation
SS1	0–2	1850–5	4.7	291	3006	630	3896	no vegetation
SS2	6–10	1850–5	5	674	1967	3785	4769	
SS3	20–28	1850–5	6.9	1460	999	9999	2984	
SS4	28–30	1850–5	7.3	444	207	2912	4743	
SS5	34	1850–5	5.6	0	0	30	1159	
SS6	6–8	1850–6	6.8	847	4828	1604	7245	25% cover
SS7	0–9	1810–5	5.2	91	1010	687	1261	buried willows near
SS8	9–16	1810–5	4.9	169	4044	2782	4630	
SS9	16–40	1810–5	3.2	1091	160	1604	5114	
SS10	40	1810–5	3.2	555	136	837	1332	
SS11	0–1	1750–1	4.1	4434	1287	2513	2521	sparse grass clumps
SS12	3–8	1750–1	5.3	322	2305	480	1879	
SS13	8–16	1750–1	5.3	472	2500	347	1353	
SS14	16–40	1750–1	6	0	0	187	1235	
SS15	0–10	1750–2	4	353	370	1450	3561	no vegetation
SS16	10–24	1750–2	5.1	140	6884	1221	7929	
SS17	24–30	1750–2	3.7	223	60	170	1264	
SS18	30–	1750–2	6.1	313	855	279	3430	
SS19	0–2	1750–0	2.6	163	186	379	773	NR
SS20	0–2	1750–0	2.7	124	494	935	0	
SS21	0–4	1640–5	2.7	157	0	370	0	no vegetation
SS22	4–7	1640–5	3.2	110	579	378	100	
SS23	7–17	1640–5	3.1	4621	106	0	533	
SS24	0–2	1630–2	4.3	1638	1711	1407	2914	no vegetation
SS25	2–5	1630–2	4.1	704	437	1112	2326	
SS26	5–24	1630–2	4	362	319	1029	2162	
SS27	0–1	1630–3	2.3	77	1615	1276	0	dead grass clumps
SS28	0–3	1560–2	3.1	169	0	118	343	no vegetation
SS29	3–8	1560–2	3.1	123	0	498	0	
SS30	8–12	1560–2	6.2	0	0	268	3350	
SS31	0–2	1540–2	2.4	183	935	806	708	dead streambank vegetation
SS32	9–10	1540–2	4.6	212	9999	41	1380	
SS33	10–18	1540–2	4.8	251	9999	0	1761	
SS34	18–24	1540–2	6.2	0	0	271	7825	
SS35	24–28	1540–2	5.7	0	77	2046	9999	
SS36	0–1	1460–1	2.1	61	416	623	0	no vegetation
SS37	1–5	1460–1	2	108	401	454	0	
SS38	5–10	1460–1	2.7	436	241	1501	182	
SS39	10–23	1460–1	2.8	0	182	3858	0	
SS40	23–31	1460–1	3.7	0	0	441	7958	
SS41	0–2	1440–2	4.1	816	1416	2992	8884	no vegetation
SS42	2–6	1440–2	3.9	619	535	1126	2226	
SS43	36	1440–2	7.5	0	0	85	0	
SS44	23–28	1440–2	5.3	4	1449	105	2441	
SS45	2–8	1370–2	4.1	1826	1808	4248	3698	no vegetation
SS46	25–30	1370–2	7.8	0	0	225	4016	
SS47	44–50	1370–2	7.9	0	0	0	0	

Table 6–7 (cont.)
Tailings Samples Collected from Streamside Tailings along Silver Bow Creek for the Tailings Investigation

Sample	Interval (in)	Borehole	pH	As	Cu	Pb	Zn	Surface Vegetation
SS48	0–7	1350–2	4.4	1522	2792	3022	5164	no vegetation
SS49	7–14	1350–2	4.8	245	1154	551	2116	
SS50	14–22	1350–2	5.2	75	7551	28	2605	
SS51	22–26	1350–2	4.9	29	3414	3414	2542	
SS52	0–14	1330–3	3.9	945	4031	4031	999	no vegetation
SS53	14–17	1330–3	3.6	341	1033	1033	3035	
SS54	35	1330–3	3	488	1385	1385	3189	
SS55	41–45	1330–3	5.6	211	9540	9542	9999	
SS56	0–1	1330–1	3.7	952	7004	7004	9158	no vegetation
SS57	2–5	1330–1	3.7	1755	4324	4324	5890	
SS58	8–11	1330–1	3.9	1057	4471	4471	2208	
SS59	0–2	1300–2	3.7	536	2823	2823	9999	no vegetation
SS60	4–6	1300–2	3.6	145	15	15	4546	
SS61	18–24	1300–2	3.7	338	727	727	3599	
SS62	50	1300–2	5.5	276	3343	3343	6690	
SS63	75	1300–2	4.8	254	1639	1639	5003	
SS64	84	1300–2	6.5	0	0	0	9999	
SS65A	102	1300–2	6.7	0	0	0	441	
SS65B	0–2	1280–2	3.6	1220	5354	5354	9594	no vegetation
SS66	5–8	1280–2	3.4	2114	3394	3394	7302	
SS67	29–31	1280–2	4.6	1565	9999	9999	7491	
SS68	41–44	1280–2	6	453	2292	2292	9999	
SS69	59–63	1280–2	6.5	0	0	0	426	
SS70	0–4	1260–3	3.7	1793	3773	3773	6819	willow in vicinity
SS71	8–10	1260–3	3.7	1044	2698	2698	4960	
SS72	10–16	1260–3	3.5	595	1527	1527	2957	
SS73	18–24	1260–3	3.7	1550	5377	5377	8236	
SS74	24–30	1260–3	5.5	1123	9999	9999	9999	
SS75	30–34	1260–3	5.9	633	9290	9290	9999	
SS76	36–40	1260–3	5.9	665	1829	1829	9999	
SS77	49–54	1260–3	6.5	191	1604	1604	9999	
SS78	57–64	1260–3	5.9	56	0	0	1229	
SS79	70–74	1260–3	5.7	0	0	0	91	
SS80	0–4	1220–3	3.9	1753	1646	1646	8631	next to willow
SS81	12–17	1220–3	5.7	941	9999	9999	9999	
SS82	20–23	1220–3	6	876	8064	8064	9999	
SS83	36–40	1220–3	7.5	0	585	585	5243	
SS84	41–45	1220–3	7.2	0	0	0	0	
SS85	46–50	1220–3	6.8	0	0	0	253	
SS86	61–65	1220–3	7.5	0	0	0	232	
SS87	0–9	1160–3	4.6	1404	5356	5356	5579	willows in vicinity
SS88	9–16	1160–3	8.1	249	2524	2524	9999	
SS89	0–5	130–1	4.9	464	1786	1786	3427	willow in vicinity
SS90	5–6	130–1	4.7	556	2400	2400	2788	
SS91	6–8	130–1	5	302	930	930	2449	
SS92	8–15	130–1	5.5	1166	2497	2497	6402	
SS93	15–20	130–1	6.4	68	4868	4868	6233	
SS94	27–31	130–1	8	0	0	0	1353	

Table 6-7 (cont.)
Tailings Samples Collected from Streamside Tailings along Silver Bow Creek for the Tailings Investigation

Sample	Interval (in)	Borehole	pH	As	Cu	Pb	Zn	surface vegetation
SS95	0-5	170-1	4	123	9	9	573	dead willows
SS96	5-7	170-1	4	210	249	249	0	
SS97	7-8	170-1	4	379	336	336	0	
SS98	8-12	170-1	4	0	3611	3611	4253	
SS99	12-22	170-1	6.2	4	408	408	1169	
SS100	0-2	220-2	7	240	774	774	587	dead willows
SS101	2-3	220-2	4.1	613	1966	1966	0	
SS102	3-19	220-2	4	187	1022	1022	1901	
SS103	19-25	220-2	4.6	132	2974	1087	3719	
SS104	25-30	220-2	5.6	35	2699	0	3480	
SS105	0-5	320-2	5.5	422	369	1265	2321	grasses, dead willows in vicinity
SS106	5-16	320-2	5.1	294	0	253	444	
SS107	16-22	320-2	5.3	317	3254	7738	3190	
SS108	0-2	320-3	4.8	467	1896	2653	9999	dead willows
SS109	2-12	320-3	4.3	1419	1260	2424	6686	
SS110	12-20	320-3	4.5	220	196	623	2096	
SS111	25-29	320-3	4.5	383	5221	5485	2406	
SS112	37-41	320-3	4.4	0	1647	0	1903	
SS113	0-5	430-1	4.7	427	715	918	3180	dense willows in vicinity
SS114	5-9	430-1	4.4	73	903	555	1962	
SS115	0-7	1080-1	3.6	198	1201	1346	1999	no vegetation
SS116	7-12	1080-1	3	399	0	685	3847	
SS117	21-27	1080-1	3.2	289	0	296	758	
SS118	0-1	1040-1	3.5	80	154	367	1159	no vegetation
SS119	1-11	1040-1	3.3	34	0	79	0	
SS120	11-16	1040-1	2.8	42	0	88	0	
SS121	0-10	510-1	4.3	324	1826	1708	3930	dead willows
SS122	10-14	510-1	4.3	344	1438	1662	3675	
SS123	21-25	510-1	6.1	429	2777	1195	7059	
SS124	34-38	510-1	6.2	358	3042	961	2758	

Concentrations reported are total metals determined by x-ray fluorescence (XRF) in ppm.
Values reported as 9999 ppm exceeded the instrument detection limit. Shaded pH values are less than 4.0 and constitute an injury to soil.
Source: PTI, 1989.

Table 6–8
Data Collected from Three Bare Tailings Sites in the Clark Fork River Floodplain for the Upper Clark Fork River Screening Study

Station	Depth (in)	Material	pH	As	Cu	Pb	Zn
Site 10							
175S –175E	0–2	T/S	6.9	420	2370	354	2670
175S–120E	0.5–1.5	OM	6.8	470	2230	338	1810
175S –175E	2–4	T/S	4.9	270	2650	280	2640
0N – 60E	1–4	OM	5	550	5920	443	2360
60S –60W	0–1.5	T	3.9	320	1490	258	541
60S – 60E	0–1.5	T	3.8	210	1500	217	813
60S – 175E	0–1.5	T	3.7	340	3830	304	1360
175N 60E	0–1.5	T/S	7.3	560	3490	520	3160
175N – 60W	0–1.5	T/S	4.3	563	1370	377	695
420N – 75E	0–1.5	T/S	5	350	710	389	506
420N – 75E	0–1.5	T	5.4	1340	7720	991	2330
300N – 175W	12–16	T	6.3	440	1410	367	886
175N – 175W	0–1.5	T	3.8	1310	2060	1030	433
60N – 420E	0–1.5	T/S	5.7	500	3810	461	2070
120S – 175E	0–1.5	T/S	7.2	590	2930	485	2436
120S – 0E	9–11	T	3.5	1770	1950	637	1740
120S – 60W	0–1.5	T/S	4.6	460	1020	320	400
0N –175W	0–1.5	T	4.8	640	2760	381	1030
60N –175W	0–1.5	T/S	5.9	570	1670	359	702
120N – 175W	0–1.5	NR	NR	320	6140	337	2920
Site 12							
800N – 100W	16–20	T	6	23.6	96	18	627
800N – 100E	0–1.5	T	4.7	780	7940	473	5540
700N – 100E	0–1.5	T	4.6	370	3050	310	1390
700N – 200E	0–1.5	T	4.9	280	4550	241	4630
700N – 300E	0–1.5	OM	7.6	370	1330	384	1440
600N – 0E	0–1.5	T	5.4	740	2250	730	975
600N – 100W	0–1.5	T	4.5	480	2670	449	1040
400N – 200W	0–1.5	T/S	7.1	610	8160	1170	2490
400N – 0E	5–8	T/S	6.6	180	183	178	515
400N – 100E	0–1.5	T	4.9	370	4090	292	1860
500N – 200E	0–1.5	T/S	5.8	330	1490	251	802
300N – 200E	0–1.5	T	6.2	500	5600	457	2720
400N – 200E	0–1.5	T	4.7	1100	2530	684	2350
300N – 100E	0–1.5	T	4.8	290	1970	245	1790
300N – 0E	0–1.5	T/S	6.5	870	6730	1330	2670
200N – 170W	0–1.5	T	5.1	366	1820	390	827
200N – 200E	0–1.5	T/S	5.3	320	2140	400	815
100N – 0E	0–1.5	T	4.7	320	2260	341	973
0N – 100E	2–3	T	5.3	115	87100	188	13300
100N – 190W	0–1.5	T/S	5.4	230	383	393	1360

Table 6–8 (cont.)
Data Collected from Three Bare Tailings Sites in the Clark Fork River Floodplain for the Upper Clark Fork River Screening Study

Station	Depth (in)	Material	pH	As	Cu	Pb	Zn
Site 24							
0S – 200W	0–2	T	4.2	1620	2070	870	2270
0S – 100W	0–2	T/S	6	320	1630	241	1440
65S – 0W	0–2	T	4	290	916	293	426
150S – 0W	0–2	T	4.3	520	1320	417	1160
150S – 0W	9–11	T	4.3	900	2980	1380	1780
150S – 0W	11–13	T	5.7	38	6660	85	1270
200S – 100W	0–2	T	4	520	863	373	755
200S – 100W	10–13	T	3.5	1950	1010	840	968
100S – 200W	0–2	S	7.5	120	1510	247	1120
100S – 300W	0–2	T/S	5.1	470	897	306	868
200S – 300W	0–2	S	7.1	140	1020	161	1600
100S – 400W	0–4	T	4.6	110	2540	85	713
0S – 400W	0–2	S	5.7	290	2010	266	834
0S – 400W	7–9	S	7.7	63	10900	102	5400
0S – 400W	11–14	S	8	15	138	16	168
0S – 600W	5–10	S	3.8	920	1270	688	680
150S – 600W	0–2	T/S	7.3	160	887	165	1360
150S – 500W	12–14	T/S	3.8	1280	664	640	1710
150S – 500W	14–17	T/S	5.2	40	10200	58	2420
200S – 195W	0–2	T/S	3	1030	19400	540	8150

Concentrations reported are total metals (XRF) in ppm. Material types are designated as: T = tailings; T/S = mixed tailings and soil; OM = organic matter; and NR = not recorded.
Shaded pH values are less than 4.0 and constitute an injury to soil.
Source: CH_2M et al., 1991.

Table 6-9
Screening Tests: Total Number of Germinating/Emergent Seedlings
(out of 20)

Sample	Alfalfa	Lettuce	Wheat
Riparian control	20	9	19
Riparian impact			
R-04	0	0	0
R-08	2 ± 1	0 ± 0	4 ± 3
R-13	8 ± 2	1 ± 1	16 ± 2
R-14	0	0	0
Opportunity Ponds	1 ± 1	0 ± 1	3 ± 1

Note: Values are mean ± standard deviation of five replicates. Each replicate had 20 seeds.

Ten of the initial 20 poplars in 100% impact soil (five each from sites R-04 and R-14) wilted and died within 24 hours of transplanting; two of the five poplars in control soils died. As a precaution against misinterpretation of transplanting stress versus toxicity, these three treatments were repeated (five more poplars were planted in each of R-04 soil, R-14 soil and control soil). Again, all 10 impact soil plants in the repeat trials died (all five in each of R-04 and R-14 soils). All five plants in the repeat control soil tests remained normal in appearance (Figures 6-5 and 6-6). No plants died during the remainder of the test in either control soils or 50% mixed soils. All five plants in impact soil R-08 were dead at the conclusion of the 4-week test.

Thus, mortality was 100% in three of the four impact soils (R-04_1, R-04_2, R-08, R-14_1, and R-14_2) and 40% in the fourth (R-13). Roots of plants grown in the impact soils were poorly developed, and in many instances, were black and brittle. Growth of the poplars in impact samples was substantially less than in control soil. Using new shoot height growth as the baseline, hybrid poplar growth inhibition was 72% in R-08 soil and 76% in R-13 soils, and can be considered 100% (due to mortality) in the remaining impact soils. Shoot height, root length, shoot mass, and root mass for all 100% site-soil impact samples (R-04, R-08, R-13, and R-14) were significantly less than corresponding values determined for the control sample (RR-07). Blending of impact soil with control soil (50% site-soil, 50% control soil) alleviated much of the inhibition; assessment endpoints (shoot length and mass, and root length and mass) of mixed soils were not statistically different from those of the control soils.

In both screening tests (involving alfalfa, lettuce, and wheat) and extended tests (hybrid poplars) in 100% impact soil, phytotoxic responses relative to controls were consistently observed. This phytotoxic response is confirmation of injury to these soils.

6.3.2.3 STARS Phytotoxicity Tests

The only other greenhouse phytotoxicity study that has been conducted using Silver Bow Creek soils reached similar conclusions. As a component of the Silver Bow Creek RI/FS, the Streambank Tailings and Revegetation Study (STARS) was initiated to develop remedies for in situ treatment of tailings deposited along Silver Bow Creek (MSU et al., 1989a). The STARS project consisted of three phases; the first phase involved collection of bulk samples from Silver Bow Creek floodplains, characterization of the soil material, and greenhouse growth studies to identify suitable amendments to neutralize acidity and reduce contaminant mobility. Thirty-five bulk samples were collected along Silver Bow Creek, all from unvegetated tailings deposits. The soils were analyzed for chemical and physical parameters, which included total, soluble, and extractable arsenic, cadmium, copper, lead, and zinc, and pH. Total metals and pH results were presented in Table 6-5. The mean total concentrations (ppm) determined were: arsenic — 694.35 (25 times baseline); cadmium — 22.78 (19 times baseline); copper — 2,508.5 (73 times baseline); lead — 1,482.1 (41 times baseline); and zinc — 3,782.5 (37 times baseline). Mean pH was 4.09.

Six of the 35 soils (indicated as TEST in Table 6-5) were selected for greenhouse growth trials. Species chosen for the growth studies were selected based on tolerance to acid conditions and high concentrations of metals (MSU et al., 1989a). In all repetitions, control plants (plants grown in 100% impact soil, unamended with lime or other treatments) failed to germinate or died shortly after germination. No statistical comparisons between plant response in 100% impact soil and plant response in amended soil were made, and the controls were not discussed further in the report (MSU et al., 1989a). The inability of even the most tolerant plant species to survive in streamside tailings material is further confirmation of injury to soils in the Silver Bow Creek floodplain.

6.3.2.4 Field Evidence

Gross evidence of phytotoxicity is prevalent throughout the floodplains of Silver Bow Creek, and in patches along the Clark Fork River between its headwaters and Deer Lodge. The Silver Bow Creek RI Groundwater and Tailings Investigation (MultiTech, 1987b) sampled tailings and underlying soil in the Ramsay Flats area. The Ramsay Flats tailings deposit covers approximately 160 acres, most of it completely devoid of vegetation, and has been determined to be a source of hazardous substances to Silver Bow Creek (MultiTech, 1987b). Total arsenic and pH were determined for 46 tailings samples from 18 boreholes (Table 6-6). Total cadmium, copper, lead, and zinc were determined for 15 of the 46 tailings samples.

Figure 6-5. **Hybrid Poplar Plants After 28 Days Exposure to Riparian Soil.** Plants in the center group were exposed to riparian control soil Plants on the left of the photograph were exposed to R-04 site soil Plants on the right of the photograph were in R-14 site soil

Figure 6-6. Representative Hybrid Poplar Plants Excavated from Riparian Soil After 28 Days Exposure. The plant on the left was exposed to riparian control soil The plant on the right was exposed to R-04 site soil

Mean values for the analytes listed in Table 6-6 are as follows: pH — 4.78; arsenic — 806.72 ppm (29 times baseline); cadmium — 15.2 ppm (12 times baseline); copper — 2974.27 ppm (87 times baseline); lead — 1866.56 ppm (52 times baseline); and zinc 5270.53 ppm (52 times baseline). Three samples of metal salts, which form as a crust on streamside tailings deposits, were analyzed for metals. The following mean concentrations were determined: cadmium — 84.93 ppm; copper — 79,000 ppm; lead — 85.4 ppm; and zinc — 28,100 ppm. The extremely elevated concentrations in the readily soluble salts constitute a major pathway of hazardous substance transport.

The Silver Bow Creek Tailings Investigation (PTI, 1989) was conducted to quantify the areal and volumetric extent of contamination between the Colorado Tailings and the Warm Springs Ponds. Concentrations of As, Cu, Pb, and Zn, determined using an x-ray fluorescence (XRF) spectrometer, and pH for 124 samples from 31 boreholes are presented in Table 6-7. The surface vegetation was noted in the field. One borehole was sampled "next to [a] willow"; the remainder were collected from areas devoid of vegetation or in the vicinity of willows. No definition of "willow in vicinity" was recorded. Average total metals concentrations determined in the 0-6 inch soil layer were: arsenic — 560 ppm (20 times baseline); copper — 1,550 ppm (45 times baseline); lead — 1,420 ppm (40 times baseline); and zinc — 3,110 (30 times baseline). Concentrations increased with depth, but the depth of greatest mean-concentration varied by substance. Mean arsenic was greatest in the 6-12 inch interval (780 ppm); mean copper was greatest in the 18-24 and 24-36 inch intervals (3,540 and 3,660 ppm, respectively); mean lead was greatest in the 18-24 and 36-48 inch intervals (3,460 and 3,630 ppm, respectively); and mean zinc was elevated relatively consistently in all depth intervals below 6 inches (Table 6-7). Concentrations reported are substantially greater than baseline (Table 6-4), but may not be truly representative because numerous samples were recorded at the maximum detection limit of 9,999 ppm.

The Upper Clark Fork River Screening Study (CH_2M Hill et al., 1991) was designed to determine the magnitude of contamination at sites representative of the degree of contamination present between Warm Springs and Drummond. A total of 12 sites were sampled; sites were categorized as bare tailings, buried tailings, historically irrigated, and good plant growth sites. Each site ranged from 5 to 10 acres, and was described in terms of geomorphology, dominant soils, landform, aspect, degree of contamination, noticeable metals effects on vegetation, proximity to the Clark Fork River channel, land use history, and vegetation type and productivity. The data presented in Table 6-8 include concentrations of As, Cu, Pb, and Zn determined in samples from the three bare tailings sites sampled along the Clark Fork River (10, 12, and 24). Site 10 was 2.5 miles north of the Warm Springs Ponds; Site 12 was 1 mile south of Deer Lodge; and Site 24 was approximately 2 miles southeast of Garrison. Average concentrations in Sites 10, 12 and 24 were, respectively: arsenic — 600, 432, and 540 ppm; copper — 2852, 7317, and 3444 ppm; lead — 442, 446, and 389 ppm; and zinc — 1575, 2406, and 1912 ppm. Mean values over the three sites exceeded baseline as follows: arsenic, 19 times; copper, 133 times; lead, 12 times; and zinc, 19 times. Average pH for each site was 5.2, 5.5, and 5.2. Percent bare ground at each of the bare tailings sites was estimated as 62%, 86.2%, and 38.6%.

6.3.2.5 Reduction of Soil pH

Soil pH of less than 4.0 resulting from the release of hazardous substances constitutes an injury to the soil resource [43 CFR § 11.62 (e)(2)]. Tables 6-5 to 6-8 present soil pH measured in unvegetated floodplain soil samples from Silver Bow Creek and the Clark Fork River. Soil pH values less than 4.0 are indicated by shading.

Of the 35 samples collected for the STARS project, 22 (63%) had a pH of less than 4.0 (MSU et al., 1989a,b). Of the 31 boreholes sampled for the Silver Bow Creek Tailings Investigation (PTI, 1989), 17 (55%) had pH values less than 4.0, and of the 29 boreholes and surface samples analyzed for the SBC/RI Groundwater and Tailings Investigation (MultiTech, 1987b), 13 (62%) had a pH of less than 4.0.

Of the nine samples used in the NRDA phytotoxicity testing, four (44%) had a pH less than 4.0 (3.5-3.8), one sample had exactly 4.0, and the remaining four ranged between 4.4 and 6.2. No control soils had pH values less than 4.0. All of these studies confirm injury to riparian soils.

6.3.3 Injury Quantification

6.3.3.1 Areal Extent of Unvegetated Slickens

Slickens locations have been mapped through inspection of aerial photographs (MultiTech, 1987c; Hydrometrics, 1983; MultiTech, 1986; Nimick, 1990; U.S. EPA, 1992). Fluvially deposited tailings and tailings waste piles dominate the 23-mile floodplain of Silver Bow Creek (Canonie, 1992a). The Colorado Tailings cover approximately 40 unvegetated acres (CH_2M Hill and Chen-Northern, 1990), and the slickens in the Ramsay Flats vicinity cover approximately 160 unvegetated acres (MultiTech, 1987b). In total, along Silver Bow Creek from the upstream end of the Colorado Tailings to the Warm Springs Ponds, there are approximately 1,270 acres of unvegetated fluvially deposited tailings (Hydrometrics, Inc., 1983).

In addition to areas of unvegetated tailings deposits determined from maps and aerial photographs, there are hundreds of acres in the Silver Bow Creek floodplain where historically deposited tailings are partially covered with un-decomposed willows that died when the tailings were deposited. MultiTech (1987a) estimated 1,133 acres of unvegetated tailings deposits between the Metro Storm Drain confluence in Butte and the Kohrs Bridge near Deer Lodge, and considered that estimate of impacted soils to be conservative because extensive stands of dead willow were grouped as living vegetation. Hydrometrics, Inc. (1983) estimated a total areal coverage of tailings from below the Colorado Tailings to the Warm Springs Ponds of 1,270 acres. It is likely that the 1,270 acres identified by Hydrometrics included some areas covered by dead, undecomposed willows, such as the extensive stands between the Gregson Bridge and Opportunity. The inclusion of areas of dead willow stands alone would dramatically increase the areal extent of measurable injury from surface tailings.

The total areal extent of floodplain contamination in the Clark Fork riparian corridor is not well defined. The extent of injured soils is difficult to determine because injured soils may be buried, and therefore would not exhibit visible signs of injury such as devegetation. In addition, as Silver Bow Creek and the Clark Fork River meander periodically and erode parts of the mining terrace of tailings sediments, new mixtures of eroded tailings, original bank material, and channel sediment are created and deposited, creating a changing mosaic of slickens (Nimick, 1990). Currently, estimates of extent of contamination are bounded by limits of studies rather than actual limits of contamination; however, buried and mixed tailings deposits enriched with hazardous substances by as much as four to five orders of magnitude above baseline do occur along the Clark Fork River (Nimick, 1990). Soils containing concentrations of that magnitude do not support vegetation (see Section 6.3.2.2).

In the upper 10 kilometers (6.2 miles) of the Clark Fork River, there are approximately 98.5 acres of unvegetated fluvially deposited tailings (MultiTech, 1987c). Nimick (1990) mapped tailings distribution, including buried tailings, in the upper 10 kilometers (6.2 miles) of the Clark Fork River, and identified 678 acres. Nimick's estimate includes vegetated mixed tailings/alluvium, re-worked tailings, and buried tailings, thus the discrepancy between the MultiTech and Nimick estimates. Below Garrison, slickens deposits exist but constitute a lesser percentage of the floodplain area. No reliable maps of slickens locations exist for the section of river below Deer Lodge to Milltown.

The width of the flood-contaminated land in the upper 10 kilometers (6.2 miles) of the Clark Fork River is generally between 180 and 490 meters (590-1,600 feet), but ranges between 90 and 900 meters (295-2,950 feet) (Nimick, 1990). The thickest tailings deposits sampled are either near the river or near the course of the late 1800s channel (Nimick, 1990). The band of thick deposits usually lies within the meander belt of the current channel. Tailings 10 to 30 centimeters (4-12 inches) thick are extensive in areas where the floodplain was wide.

6.3.3.2 Volume of Contaminated Material

The total volume of tailings and soil material in Lower Area One that is enriched with hazardous substances is approximately 2.2 million cubic yards (0.6 million in the Colorado Tailings area, and 1.6 million cubic yards of wastes associated with the former Butte Reduction Works site) (Camp Dresser and McKee, 1991). Large quantities of fill material have been deposited in the upper Metro Storm Drain area covering extensive, previously exposed tailings deposits generated by the Parrott Smelter. As much as 20 feet of fill material overlies tailings deposits as thick as 14 feet in the upper Metro Storm Drain area (CH_2M Hill and Chen-Northern, 1990). Estimated volumes of 190,000 cubic yards of tailings and mixed alluvium and tailings, 300,000 cubic yards of slag, slag-sand, and gravel, 525,000 cubic yards of waste rock, and 840,000 cubic yards of fill material overly native sand and gravel in the upper Metro Storm Drain area (CH_2M Hill and Chen-Northern, 1990).

Native silts and clays in the lower Metro Storm Drain area are covered by mixed alluvium and tailings averaging approximately 2 feet deep and landfill material ranging from 4 to 11 feet deep. The area south of the drain area was apparently used as a landfill/dump, on top of mixed tailings and alluvium. Approximately 0.2 million cubic yards of tailings and mixed tailings and alluvium, and 0.57 million cubic yards of demolition debris and landfill debris, cover native silts and clays in the lower Metro Storm Drain area (CH_2M Hill and Chen-Northern, 1990).

Between Montana Street and the Colorado Tailings, slag walls presumably built to contain tailings waste generated by the Butte Reduction Works were constructed on the Silver Bow Creek floodplain. Materials now overlying the former floodplain consist of approximately 0.43 million cubic yards of tailings and mixed tailings and alluvium, and 1.63 million cubic yards of various types of waste, including manganese flue dust, railroad bed fill, and transported fill (CH_2M Hill and Chen-Northern, 1990). Source materials in the Butte Reduction Works area extend to a depth of 10 to 15 feet, and contamination has been detected to a depth of 2 feet in overlain native soils (Camp Dresser and McKee, 1991).

The Colorado Tailings resulted from the deposition of tailings and mine and mill waste from the Colorado Smelter. The extensive tailings deposit, approximately 40 acres, consists of relatively continuous tailings material, up to 4.5 feet deep, and additional transported fill material. The approximate thickness of all material units overlying native sediment is 18 feet. Approximately 230,000 cubic yards of tailings and mixed tailings and alluvium, and 580,000 cubic yards of additional fill material, are present in the deposit (CH_2M Hill and Chen-Northern, 1990). In the Colorado Tailings, source areas of hazardous substances include the tailings and the underlying peat layer.

The Rocker Operable Unit of the Silver Bow Creek/Butte Area NPL site is approximately 7 miles west of Butte and is bordered to the north by Silver Bow Creek (Keystone, 1992). The former Rocker Timber Framing and Treating Plant, which treated mine timbers with a preservative containing arsenic, was operated by the Anaconda Company until 1957, when operations ceased. Extensive quantities of waste material from the treatment plant were dumped on the banks of Silver Bow Creek; in 1989, approximately 1,021 cubic yards of arsenic-contaminated wood chips and soils were removed from areas in the site where arsenic concentrations exceeded 10,000 ppm (Keystone, 1992).

Extensive deposits of mill tailings, mine waste material, and precipitates, sometimes mixed with native sediments, occur within the entire floodplain from Butte to the Warm Springs Ponds. Within the Streamside Tailings Operable Unit, which extends from downstream of Colorado Tailings to the Warm Springs Ponds and excludes the Rocker area, the estimated volume of tailings and tailings-impacted material is 3.7 to 7.8 million cubic yards (Canonie, 1992a).

Between the downstream end of the Colorado Tailings and the upstream end of the Durant Canyon, approximately 1.7 to 4.1 million cubic yards of tailings and mixed tailings and alluvium overlie native fluvially deposited sands, silty sands, and gravels. Among the most prominent features of this reach of river are the 160-acre tailings deposit at Ramsay Flats and extensive tailings deposits downstream of Miles Crossing. Downstream of Miles Crossing to Finlen, Silver Bow Creek cuts through a volcanic canyon. In the canyon, approximately 0.733 million to 0.965 million cubic yards of tailings and mixed tailings and alluvium overlie native sands, silts, and clay. From Finlen to the Warm Springs Ponds, estimates of the amount of overlying tailings and mixed tailings and alluvium range from 1.27 to 2.8 million cubic yards (Canonie, 1992b).

Downstream of Warm Springs Ponds, visible deposits are sporadic, occurring along inside bends of the Clark Fork River (MultiTech, 1987c). Stratigraphic evidence of the Clark Fork River floodplains indicates that sediments consisting of essentially pure tailings were deposited on the pre-mining floodplain to a depth of 1 to 2 meters above the current channel elevation (Nimick, 1990). Numerous studies have identified extensive deposits of metal-enriched sediment deposits on the banks and floodplains of the Clark Fork River (Moore, 1985; Hydrometrics, Inc., 1983). The high metal concentrations, physical attributes, and evidence of recent sedimentation indicate that the sediments contain mill tailings along with variable quantities of mine waste rock, flocculated metals, and natural sediment.

In the floodplain of the Clark Fork River, an estimated 2 million cubic meters (2.6 million cubic yards) of contaminated sediment have been deposited (Moore and Luoma, 1990; Axtmann and Luoma, 1991). Nimick (1990) identified flood-deposited tailings up to 120 cm thick overlying the pre-mining floodplain. He estimated 0.92 million cubic yards (0.704 million cubic meters) of tailings cover 678 acres (275 hectares). The highest metal concentrations are no longer in near-surface tailings because of downward migration of metals (Nimick, 1990). Studies that have quantified extent of contamination of floodplain soils by visual examination alone have grossly underestimated the true extent.

In the Opportunity Ponds, there are an estimated 435 million cubic yards (333 million cubic meters) of wastes (Tetra Tech, 1987). Borehole investigation indicate that the average depth of tailings in the Ponds ranges from 14.3 to 35.0 feet (Tetra Tech, 1987).

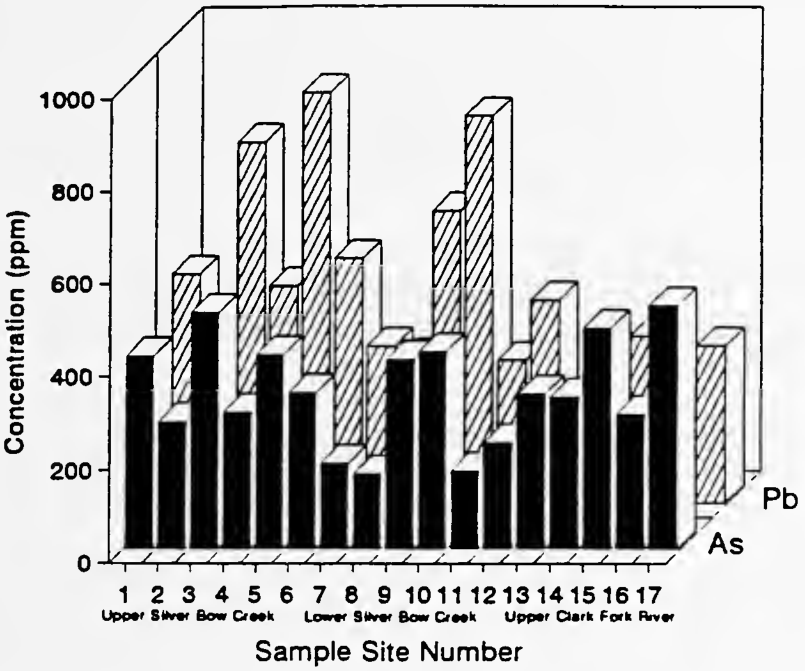
6.3.4 Ability of Resource to Recover

Natural recovery of the riparian soils and floodplain sediments of Silver Bow Creek and the Clark Fork River will require many hundreds, if not thousands of years, for the following reasons:

- The total volume of tailings and soil material in Lower Area One that is enriched with hazardous substances is approximately 2.2 million cubic yards (0.6 million in the Colorado Tailings area, and 1.6 million cubic yards of wastes associated with the former Butte Reduction Works site) (Camp Dresser and McKee, 1991). Within the approximately 23 miles of the Streamside Tailings Operable Unit (downstream of the Colorado Tailings to the Warm Springs Ponds), the estimated volume of tailings and impacted soils is 3.7 to 7.8 million cubic yards (Canonie, 1992a). In the floodplain of the Clark Fork River, an estimated 2 million cubic meters (2.6 million cubic yards) of contaminated sediment have been deposited (Moore and Luoma, 1990; Axtmann and Luoma, 1991). In the Opportunity Ponds, there are an estimated 435 million cubic yards (333 million cubic meters) of wastes (Tetra Tech, 1987). The sheer volume of hazardous materials insures that biological, surface water, and groundwater resources will be exposed to hazardous substances for many years to come.

- The persistence of contamination in soils, particularly by heavy metals, is virtually permanent (Kabata-Pendias and Pendias, 1992). Metals accumulated in soils are depleted slowly by leaching, plant uptake, erosion, or deflation. Estimations of removal rates indicate that the complete removal of metallic contaminants from soils is nearly impossible (Kabata-Pendias and Pendias, 1992).

- Studies of downstream metal trends in bank sediments (Moore, 1985; Moore et al., 1989, Axtmann and Luoma, 1987) found considerable variability in metals concentrations and little evidence of downstream decreases in metals levels, particularly between Warm Springs and Garrison (Nimick, 1990). Data collected during the 1992 NRDA field sampling (Figure 6-7) identify similar variability and absence of trends of decreasing metals and arsenic concentrations downstream. Therefore, dilution of slickens and floodplain sediments is not occurring at a rate sufficient to anticipate recovery of Silver Bow Creek and the Clark Fork River riparian zones.



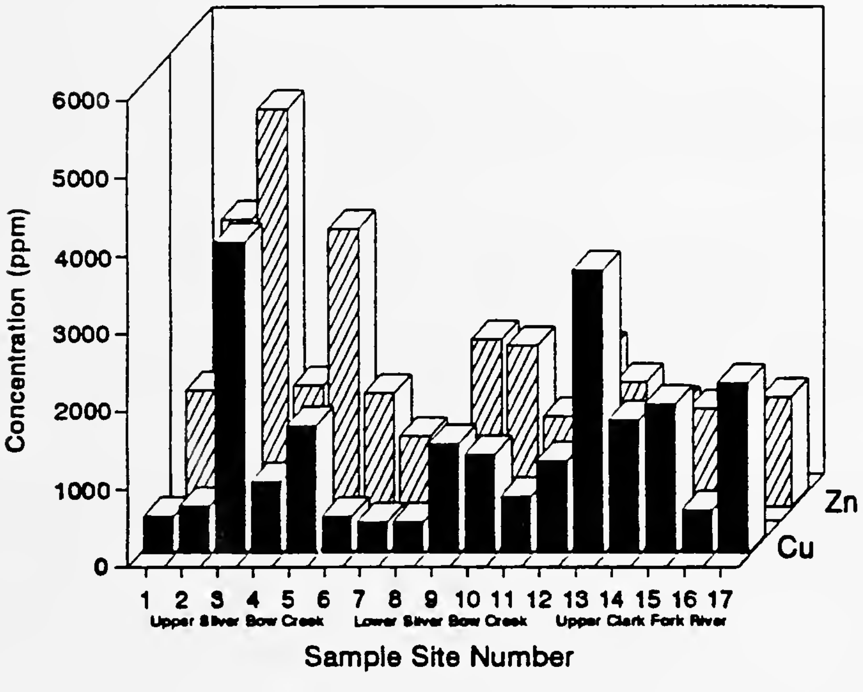


Figure 6-7. Concentrations of Each Element at Sample Points Collected Within Each Impact Reach. Sample point concentrations are plotted in a downstream direction; the axis is not scaled to show linear distance. The figures illustrate the absence of trend in concentration of hazardous substances with distance

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7.0 BIOLOGICAL RESOURCES — RIPARIAN VEGETATION, WILDLIFE, AND WILDLIFE HABITAT

Riparian biological resources include vegetation, wildlife, and wildlife habitat. This chapter describes and quantifies injuries to these resources in the riparian corridor along Silver Bow Creek, from the Colorado Tailings to the Warm Springs Ponds, along the upper Clark Fork River, from the Warm Springs Ponds to Deer Lodge, and in the Opportunity Ponds area. Overall, the results presented in the chapter demonstrate that vegetation, wildlife, and wildlife habitat have been injured in riparian assessment areas. Specifically:

- Riparian slickens areas along Silver Bow Creek and the upper Clark Fork River — shown to be phytotoxic in Chapter 6.0 — are virtually devoid of vegetation. Matching control sites contain a mixture of riparian forest/shrub communities and agricultural land uses.

- The number of habitat layers has been significantly reduced in impacted areas.

- Habitat has been significantly reduced for white-tailed deer (an indicator species for riparian forest/shrub ecosystems). The viability of wildlife species that depend on this habitat type has been reduced.

- As a result of habitat loss, a large number of wildlife species are likely to have been lost to the injured areas or have undergone reduced population viability.

7.1 DESCRIPTION OF RIPARIAN BIOLOGICAL RESOURCES

Riparian biological resources include terrestrial wildlife populations and the terrestrial wildlife habitat provided by vegetation communities associated with Silver Bow Creek, the upper Clark Fork River, and the Opportunity Ponds. Riparian vegetation in southwest Montana generally comprises associations of species adapted to hydric or semi-hydric conditions and regular disturbance, particularly cottonwoods, willows, rushes, and sedges (Hansen et al., 1989). In southwest Montana, many wildlife species are characteristic of riparian areas and are dependent on the existence of riparian vegetation communities.

The riparian soils of Silver Bow Creek and the upper Clark Fork River from the Warm Springs Ponds to Deer Lodge, and the Opportunity Ponds areas have been injured by releases of hazardous substances (see Chapter 6.0). The preceding chapters have traced the pathways of hazardous substances from the sources in Butte to surface water, sediments, aquatic biota, and floodplain soils of Silver Bow Creek and the Clark Fork River. The banks and floodplains, including native riparian soils, have been injured by the deposition of tailings material transported in surface water (Chapter 6.0). Floodplain soils contain elevated concentrations of hazardous substances relative to baseline, and are severely phytotoxic.

Vegetation establishment and growth are precluded along much of Silver Bow Creek and along the upper Clark Fork River by the phytotoxic condition of the soils; wildlife populations dependent on the habitat provided by riparian vegetation have been concomitantly reduced or lost within the injured areas.

The Opportunity Ponds area was formerly a low-lying area that most likely supported wetland communities associated with Mill and Willow Creeks, and other minor drainages and springs. Current hydrological and geomorphological patterns, historical anecdotes, and the rationale for locating the settling ponds where they are suggest that the Opportunity Ponds area was naturally wet and, in the absence of mining-related impacts, would probably have supported diverse riparian and possibly mixed-meadow vegetation community types. Currently, the Opportunity Ponds area is devoid of vegetation and supports no wildlife habitat.

7.2 INJURY DEFINITION

Injury to riparian biological resources is defined as:

- . . . adverse changes in viability: death, . . . physiological malfunctions (including malfunctions in reproduction), or physiological deformations [43 CFR § 11.62 (f) (i)].

In the Clark Fork Basin, injury to vegetation that resulted from releases of hazardous substances is expressed in the complete eradication of vegetation, or changes in the composition, structure, and/or distribution of vegetation communities. At the level of the individual plant, these community changes have been caused by death and physical deformations (i.e., reduced growth leading to a loss in viability).

As described in Chapter 4.0, plant death and reduced growth satisfy the four acceptance criteria for biological responses [43 CFR § 11.62 (f) (2) (i-iv)].

Overall, injury to vegetation has been confirmed by the results of the phytotoxicity studies (death, reduced growth relative to controls), and by the observed loss of vegetation in exposed areas (see Section 7.3).

The viability of riparian wildlife populations in the upper Clark Fork Basin has been reduced by:

- Reductions in habitat quantity and quality for selected indicator species [43 CFR § 11.63 (f)(4)(ii)(A)] relative to uncontaminated control areas [43 CFR § 11.72 (d)(1)].

The following sections describe the relationship between vegetation and wildlife habitat, and methods of assessment of injury to wildlife habitat (described in detail in Chapter 4.0).

7.2.1 Methods of Measuring Injury to Wildlife Habitat Quantity and Quality

Injury to wildlife and wildlife habitat in the impacted riparian areas was determined using a combination of wildlife habitat models, surveys of selected organisms, and field investigations of vegetation.

7.2.1.1 HEP Models

Assessment of injury to vegetation, as a supporting means of quantifying the extent of both soil injury and wildlife habitat injury, is discussed in Chapter 4.0. HEP models were used to assess injury to riparian wildlife habitat along Silver Bow Creek, along the upper Clark Fork River, and in the Opportunity Ponds.

The selection of HEP models for use in this injury assessment was based on the types of habitats initially identified as potentially injured. Initial field observations and studies performed by the Montana Riparian Association (MRA, 1992) indicated that riparian plant associations impacted by the deposition of hazardous substances include riparian shrub and riparian forest communities. Two HEP models were selected to determine injury to these riparian wildlife habitats.

Riparian Forest/Shrub Habitat: Indicator Species = White-Tailed Deer

Determination of injury to riparian forest and shrub habitat types was performed using white-tailed deer as an indicator species. An existing HEP model for assessing white-tailed deer winter habitat (Short, 1986) was modified for use in Montana by incorporating northern Rocky Mountain regional browse species as a nutritional parameter.

Variables measured to evaluate winter habitat quality for white-tailed deer included:

- Water availability. Free water must be available within 1.6 km (1 mile) of the habitat block being evaluated.
- Habitat block area. The area of evaluation must be at least 40 hectares (100 acres).
- Cover availability. Overstory or midstory cover must provide protective or thermal cover on at least 20% of the area being evaluated.

- Forage availability. A sample site is categorized by whether or not it provides suitable white-tailed deer forage.

Since the habitat evaluated was riparian, water was close to all impact and control areas, and thus the first parameter was satisfied for all sample sites. Likewise, all areas evaluated exceeded the 40 ha (100 acre) area requirement. Habitat suitability indices were calculated for impacted areas along Silver Bow Creek, the upper Clark Fork River, and in the Opportunity Ponds and statistically compared to baseline habitat values determined for control sites (Divide Creek, Little Blackfoot River, Flint Creek).

Habitat Layers HEP Model

In addition to the white-tailed deer model, the layers of habitat (Short, 1984) HEP model was used to address the relationship between the vertical complexity of vegetation communities and their capacity to provide habitat for a diversity of wildlife. The layers of habitat model is described in detail in Chapter 4.0.

7.2.1.2 Wildlife Population Surveys

Riparian avian populations were surveyed to determine whether differences exist in the population densities on Silver Bow Creek relative to a control stream. Two surveys of riparian bird species characteristic of southwestern Montana (common merganser, belted kingfisher, great blue heron, dipper, and spotted sandpiper), chosen because of their conspicuousness and the relative ease with which they can be counted, were conducted on Silver Bow Creek between the downstream end of Durant Canyon and Warm Springs Ponds in late June 1992, and on a paired control reach on the Little Blackfoot River. On each survey, an observer experienced in surveying riparian bird populations walked the study reach of the river and recorded the numbers of individual birds encountered.

7.2.1.3 Vegetation Assessment

The floodplain soils and sediments of Silver Bow Creek, the upper Clark Fork River, and the Opportunity Ponds have been shown to be phytotoxic (Appendix B and Chapter 6.0); a phytotoxic response is reflected in the vegetation community as a change in the plant population density, species composition, dispersion, or percent cover [43 CFR § 11.71 (l)(6)].

Injury to vegetation communities was assessed by comparing the proportional representation of native cover types (e.g., deciduous forest and deciduous shrubland) and agricultural cover types (e.g., hayfields, pasture), proportional representation of numbers and types of habitat layers (e.g., tree canopy, tree bole, shrub layer, understory, soil), and percent cover of individual forage species and bare ground or slickens in impact and control areas. Statistical comparisons were made between impact and control areas to identify and quantify reductions in vegetation abundance and compositional quality (Appendix C).

7.2.2 Baseline Conditions

No historical records describe the composition or structure of the wildlife habitat provided by the riparian vegetation communities associated with Silver Bow Creek, the Clark Fork River, and the Opportunity Ponds before mining-related impacts. However, baseline conditions have been determined from information contained in USGS maps, from aerial photographs, and by measurements of vegetation communities and wildlife populations made on control rivers. These procedures are in accordance with the methods recommended for establishing baseline conditions in the DOI regulations [43 CFR § 11.72 (d)].

Divide Creek, the Little Blackfoot River, and Flint Creek were selected as controls for the injured riparian reaches of Silver Bow Creek, Opportunity Ponds and the upper Clark Fork River because they are comparable in the important topographical, hydrogeological, and climatic factors that influence the distribution and composition of plant communities (see Appendix A). The control reaches are not undisturbed by human activities because agriculture is a major land use on all three.

Vegetation measurements made on the control reaches showed that baseline for the injured reaches of Silver Bow Creek and the upper Clark Fork River and for Opportunity Ponds consists of a mixture of natural and agricultural plant communities. Baseline natural plant communities include (1) riparian forest, with an overstory of tall cottonwoods, a shrub midstory of willow and dogwoods, and an understory rich in grasses and herbs; and (2) riparian shrub communities that resemble the riparian forest but lack an arboreal layer (Appendix C). Baseline agricultural plant communities comprise pasture grazed by livestock and hay meadows (Appendix C). Although these communities lack an overstory of shrubs or forest trees, they support a diverse understory of grasses and herbs.

These baseline riparian plant communities provide many ecological niches for wildlife species. In general, the more complex the horizontal and vertical structure of the habitat, the more potential niches in that habitat. Baseline riparian forest is a complex habitat. Measurements made on the control streams showed that riparian forest displayed up to five distinct vertical habitat layers (tree canopy, tree bole, shrub midstory, herbaceous layer, and soil; Appendix C). Furthermore, because the riparian zone is a linear habitat near other habitat types (e.g., agricultural land and/or upland community types), it also has horizontal diversity in the form of extensive "edge" habitat.

Riparian forests of Montana are important islands of biodiversity; despite their relatively small percentage of the landscape (approximately 1%), riparian zones in Montana provide habitat for many mammalian and avian species (Ohmart and Anderson, 1986). Eighty-nine percent of the terrestrial bird species in Montana exploit riparian habitats during breeding season, and 36% breed only in riparian areas (Mosconi and Hutto, 1982). At least 38 bird and mammal species are characteristic of southwestern Montana riparian habitats, including waterfowl, songbirds, birds of prey, white-tailed deer, fox, and mink (Tables 7-1 and 7-2).

7.3 INJURY DETERMINATION AND QUANTIFICATION

This section confirms and quantifies reductions in habitat quantity and quality (suitability) in riparian assessment areas.

7.3.1 NRDA Investigations

Reductions in habitat quality and quantity were assessed within areas delineated as grossly injured based on aerial photographs, existing maps of tailings deposits, and preliminary field observations. Grossly injured areas, or slickens, were identified and delineated using the following criteria:

- Complete or virtual elimination of the indigenous major plant associations
- Little or no regeneration of the indigenous major plant association.

Riparian areas expected to support riparian vegetation and wildlife habitat in the absence of mining-related impacts were identified and sampled on the following stream reaches:

- Silver Bow Creek from downstream of the Colorado Tailings in Butte to the upstream end of the Durant Canyon (upper Silver Bow Creek)
- Silver Bow Creek from the downstream end of the Durant Canyon to the Warm Springs Ponds (lower Silver Bow Creek)
- The Clark Fork River from the Warm Springs Ponds discharge to Deer Lodge.

The Opportunity Ponds were also sampled as an impacted riparian area. The Durant Canyon of Silver Bow Creek was not sampled because of time constraints; however, since the Durant Canyon lies between the upper and lower Silver Bow Creek reaches sampled, pathways and sources to the canyon are identical, existing slickens composition are expected to be identical, and thus injury to vegetation and wildlife habitat is mechanistically similar to those found upstream and downstream.

Measurements of the following were recorded along transects at 17 sites within slickens along Silver Bow Creek and the upper Clark Fork River (Figure 7-1):

Table 7-1
Birds Characteristic of Southwest Montana Riparian Shrub/Forest and their Feeding and Nesting Vegetation Layers

Species		Feeding Layers	Nesting Layers
Great blue heron	*Ardea herodias*	-	TC
Mallard	*Anas platyrhynchos*	-	US
Common merganser	*Mergus merganser*	-	TB/US
Wood duck	*Aix sponsa*	-	TB
Osprey	*Pandion haliaetus*	-	TC
Bald eagle	*Haliaeetus leucocephalus*	-	TC
American kestrel	*Falco sparverius*	US	TC
Great-horned owl	*Bubo virginianus*	US/SM	TC/TB
Belted kingfisher	*Ceryle alcyon*	-	TS
Northern flicker	*Colaptes auratus*	TS/US	TB
Mourning dove	*Zenaida macroura*	US	TC/SM
Western wood-pewee	*Contopus sordidulus*	TC	TC
Willow flycatcher	*Empidonax traillii*	SM	SM
Eastern kingbird	*Tyrannus tyrannus*	TC	TC
Tree swallow	*Tachycineta bicolor*	-	TB
Bank swallow	*Riparia riparia*	-	TS
Black-billed magpie	*Pica pica*	US	TC/SM
Black-capped chickadee	*Parus atricapillus*	TC/US	TB
House wren	*Troglodytes aedon*	SM/US	TB
American robin	*Turdus migratorius*	US	TC/SM
Veery	*Catharus fuscescens*	SM	SM
European starling	*Sturnus vulgaris*	US	TB
Warbling vireo	*Vireo gilvus*	SM	SM
Yellow warbler	*Dendroica petechia*	SM	SM
American redstart	*Setophaga ruticilla*	SM/TC	SM/TC
Common yellowthroat	*Geothlypis trichas*	SM/US	SM/US
Song sparrow	*Melospiza melodia*	SM/US	SM/US
Red-winged blackbird	*Agelaius phoeniceus*	SM/US	SM
Brewer's blackbird	*Euphagus cyanocephalus*	US	SM
Black-headed grosbeak	*Pheucticus melanocephalus*	TC	SM
Brown-headed cowbird	*Molothrus ater*	US	TC/SM/US
Northern oriole	*Icterus galbula*	TC	TC

TC = tree canopy; TB = tree bole; SM = shrub midstory; US = understory; TS = terrestrial subsurface.
References: Bergeron et al., 1992; Johnsgard, 1992.

Table 7-2
Mammals Characteristic of Southwest Montana Riparian Shrub/Forest and their Feeding and Cover Vegetation Layers

Species		Feeding Layers	Cover Layers
Little brown bat	*Myotis lucifragus*	-	TB
Red fox	*Vulpes vulpes*	US	US/TS
Raccoon	*Procyon lotor*	US	TB/TC
Mink	*Mustela vison*	US	US
White-tailed deer	*Odocoileus virginianus*	SM/US	SM
Moose	*Alces alces*	SM/US	SM

TC = tree canopy; TB = tree bole; SM = shrub midstory; US = understory; TS = terrestrial subsurface.
Reference: Chapman and Feldhamer, 1982.

- Dominant vegetative cover type
- Number and type of habitat layers present
- Approximate height of each habitat layer in the dominant cover type
- Percent canopy closure of each species in the tree canopy, shrub midstory, and understory layers
- Presence of white-tailed deer browse.

Data collected at each of the 17 sites represent a compilation of multiple sampling points; the number of sampling points per site was determined by the width of the slickens. Sample points were spaced at 10-meter intervals (see Appendix C).

7.3.1.1 Vegetation Characteristics

Analysis of cover type data revealed that the impact transects were dominated by one main cover type, slickens, which constituted approximately 80% of observations (Figures 7-2 and 7-3). Control sites were predominantly shrub/forest (shrub and forest combined), hayfields, or pasture. The one cover type observed on both impact and control reaches, riparian shrub/forest, was more prevalent on the control sites (Figure 7-4). Representative views of riparian impact and control sample sites are shown in Figures 7-5a through 7-5e.

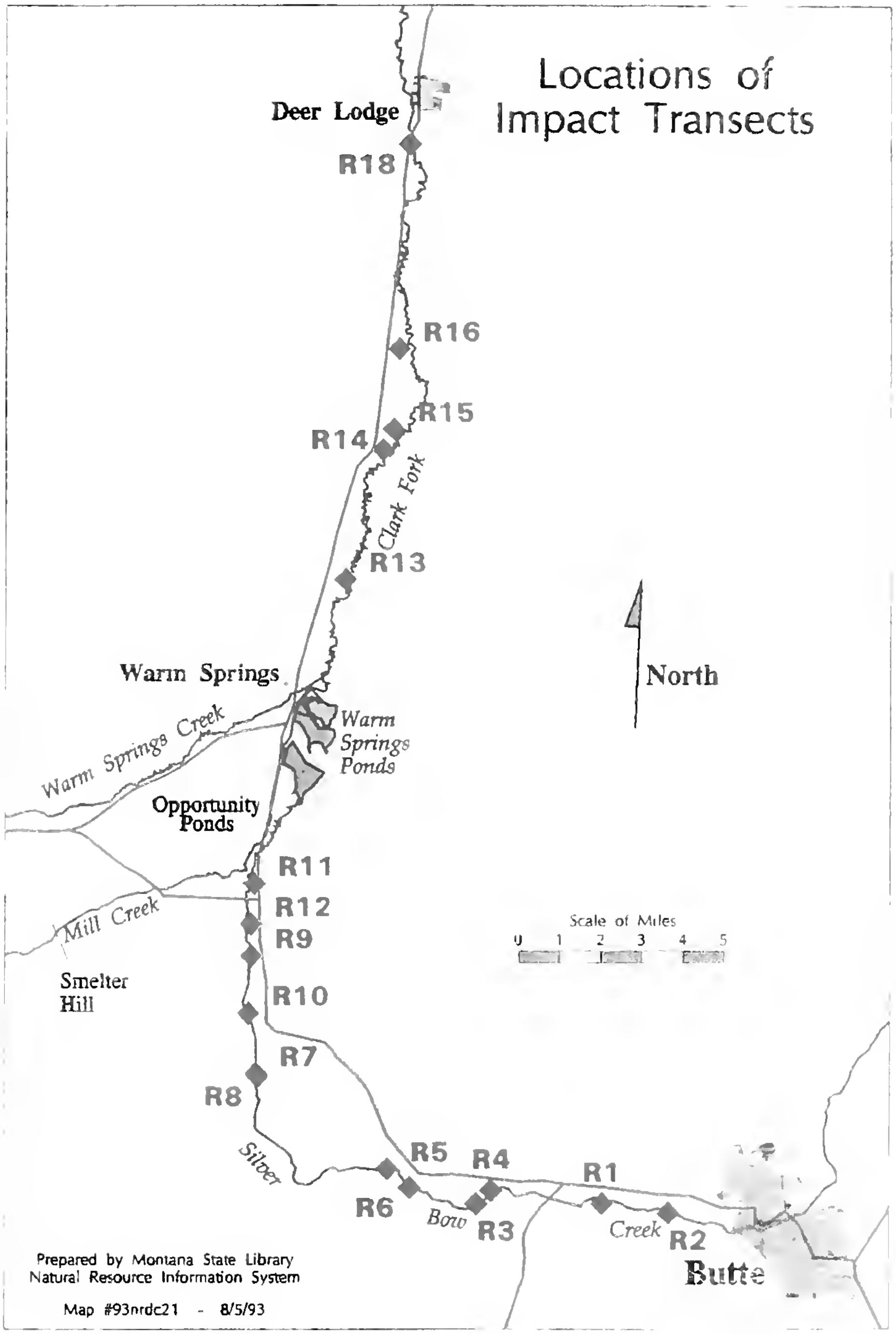


Figure 7-1. **Location of Riparian Sampling Sites: Silver Bow Creek and the Clark Fork River.**

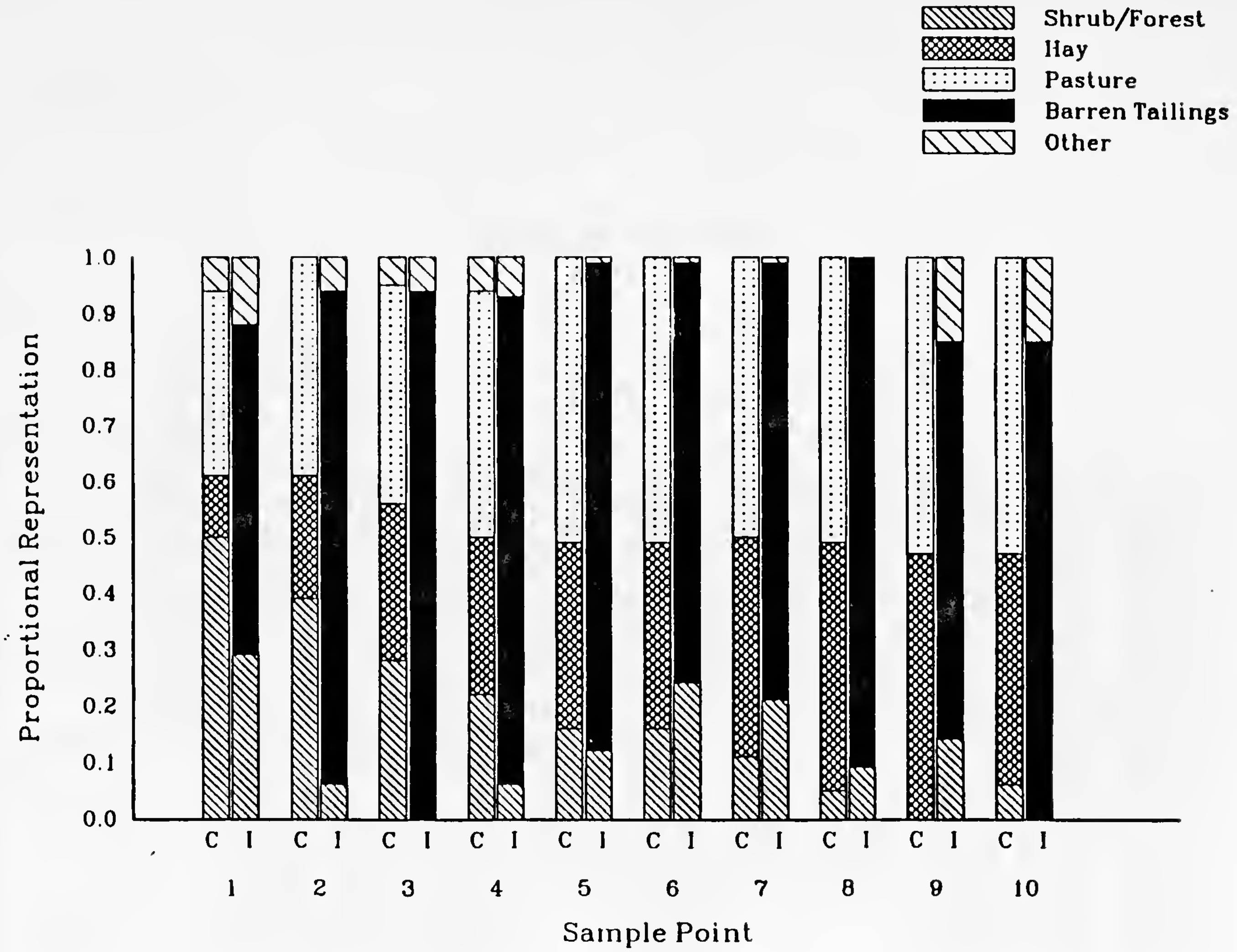


Figure 7-2. Proportional Representation of the Dominant Cover Types Encountered on Riparian Control (C) and Impact (I) Reaches. Sample points represent distance from the river at 10 meter intervals. Source: Appendix C.

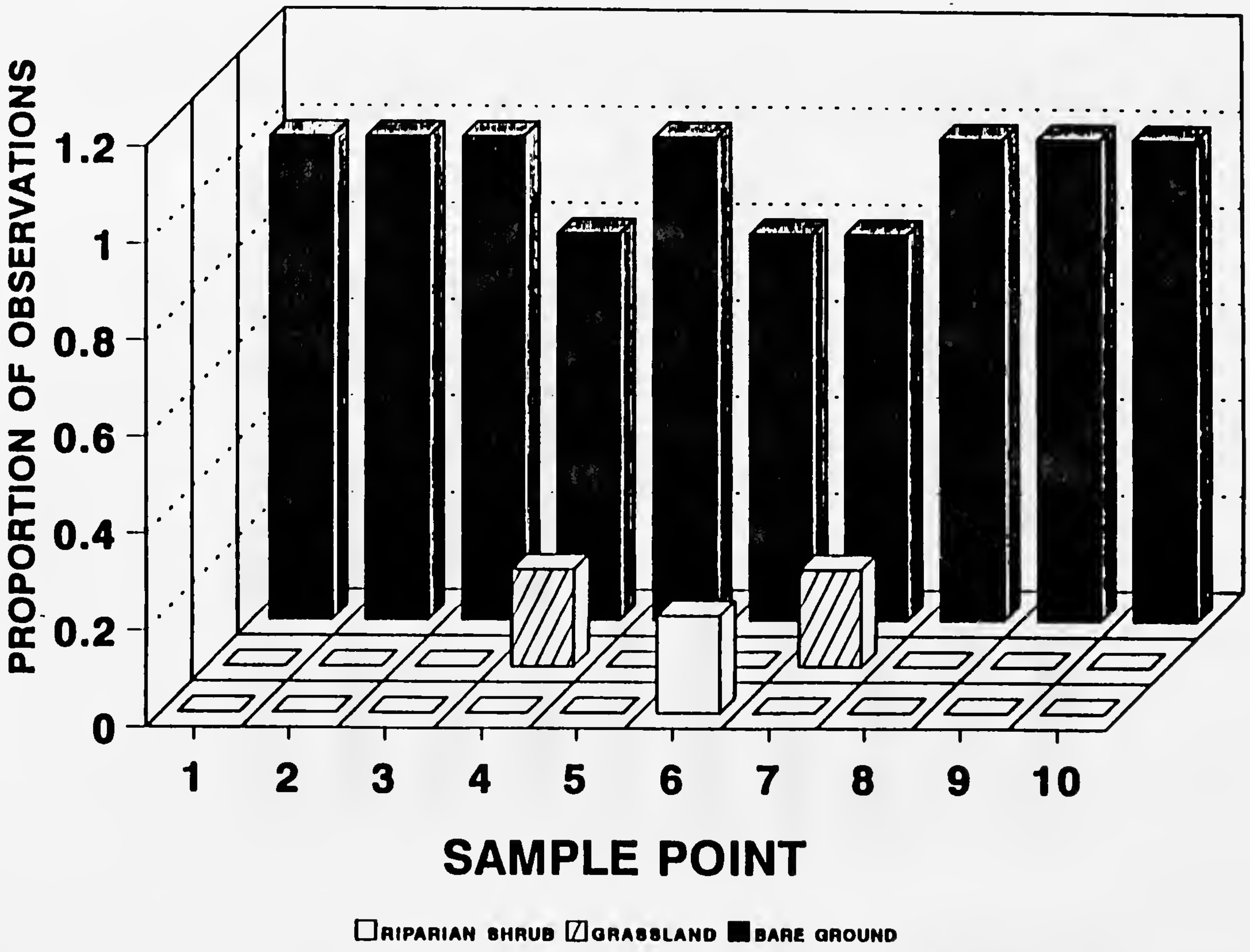


Figure 7-3. **Proportional Representation of the Cover Types Encountered on the Opportunity Ponds.** Source: Appendix C.

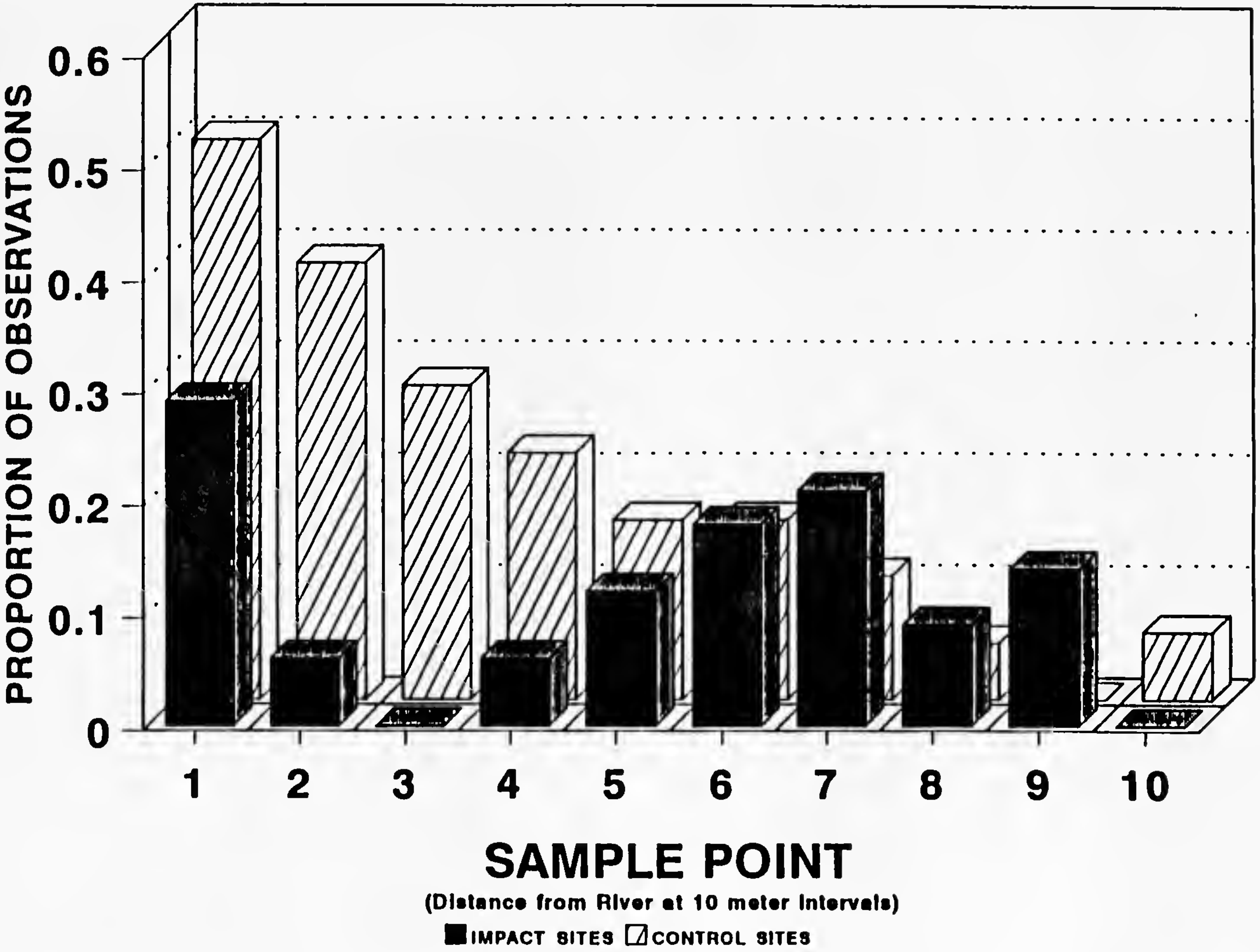


Figure 7-4. **Comparison of the Proportional Representation of Riparian Shrub/Forest on Control and Impact Reaches.** Source: Appendix C.

Impact site cover types were compared statistically to control sites. The proportional representation of barren slickens was significantly greater on impact streams than on control streams; the proportional representation of hay, pasture, and riparian forest was significantly higher on control streams than on impact streams. Results of comparisons of all impact and control streams, and of comparisons of paired control and impact streams, are presented in Table 7-3. Each impact reach exhibited significantly greater proportional representation of slickens than its paired control reach. The Little Blackfoot control reach exhibited significantly greater proportion of riparian forest, hay, and pasture than the lower Silver Bow Creek, and Flint Creek exhibited a significantly greater proportional representation of hay and riparian shrub than the upper Clark Fork River.

Analysis of habitat layers data revealed that the impact reaches were lacking in three of the five habitat layers observed consistently on control reaches (Figures 7-6 and 7-7). Tree canopy and terrestrial subsurface layers were represented only sporadically on impact reaches, and the tree bole layer was entirely absent. Absence of all habitat layers was recorded at more than 60% of the impact sample points, and most layers that were recorded were present at less than 30% of the impact sample points. The control reaches exhibited significantly greater proportional representation of tree canopy, tree bole, understory, and terrestrial subsurface layers than did impact reaches ($p = 0.12$, 0.03, 0.0002, and 0.0002, respectively).

The proportional representation of habitat layers was compared individually by paired impact and control reaches (Table 7-4). All three control reaches had significantly higher proportions of understory and terrestrial subsurface than corresponding impact reaches. The Little Blackfoot had a significantly higher proportion of sites at which shrub midstory, tree canopy, and tree bole were present than did the corresponding impact reach, lower Silver Bow Creek. None of the impact reaches had significantly higher proportions of any habitat layer than the control reaches.

The number of habitat layers on control reaches ranged between two and five (Figures 7-8 and 7-9). The range was a function of distance from the river; the near-bank riparian shrub/forest is a vertically diverse habitat, whereas hayfields and pastures, which dominated at distances greater than 60 meters from the bank, are less diverse, exhibiting only understory and terrestrial subsurface layers (Figure 7-10). In contrast, for the impact areas, the most common observation was absence of all habitat layers, and the greatest number of habitat layers recorded at any point was three (Table 7-5).

Within the Opportunity Ponds, the most prevalent cover type, and almost the only cover type, was bare ground (Figure 7-4). No site had more than two habitat layers, and approximately 80% of the sites sampled had no habitat layers. No tree canopy, tree bole, or terrestrial subsurface, and limited representation of shrub midstory, and understory was observed in the Opportunity Ponds. The observations were compared statistically to all of the control reaches; the control areas exhibited significantly greater proportions of shrub/forest ($p < 0.05$),

Figure 7-5a. Riparian Impact Sample Site R7 Showing Slickens, Devegetation, and Dead Willows.

Figure 7-5b. Riparian Impact Sample Site R8 Showing Slickens, Devegetation, and Dead Vegetation.

Figure 7-5c. Riparian Impact Sample Site R10 Showing Slickens, Devegetation, and Dead Willow Shrub.

Figure 7-5d. Riparian Control Sample Site on Little Blackfoot River Showing Riparian Forest and Dense Shrub and Herb Layers.

Figure 7-5e. Riparian Control Sample Site on Little Blackfoot River Showing Riparian Forest and Dense Shrub and Herb Layers.

Table 7-3
Comparison of the Proportional Representation of Cover Types in Impact and Control Reaches

Area	Cover Type	p-value <
All impact reaches vs. all control reaches	Barren slickens Hay Pasture Riparian forest	0.0002*** 0.002*** 0.0002*** 0.009***
Upper Silver Bow Creek vs. Divide Creek	Barren slickens Pasture	0.0014*** 0.031*
Lower Silver Bow Creek vs. Little Blackfoot	Barren slickens Hay Pasture Riparian forest	0.0014*** 0.036* 0.046* 0.028**
Upper Clark Fork River vs. Flint Creek	Barren slickens Hay Riparian shrub	0.002*** 0.018** 0.03**

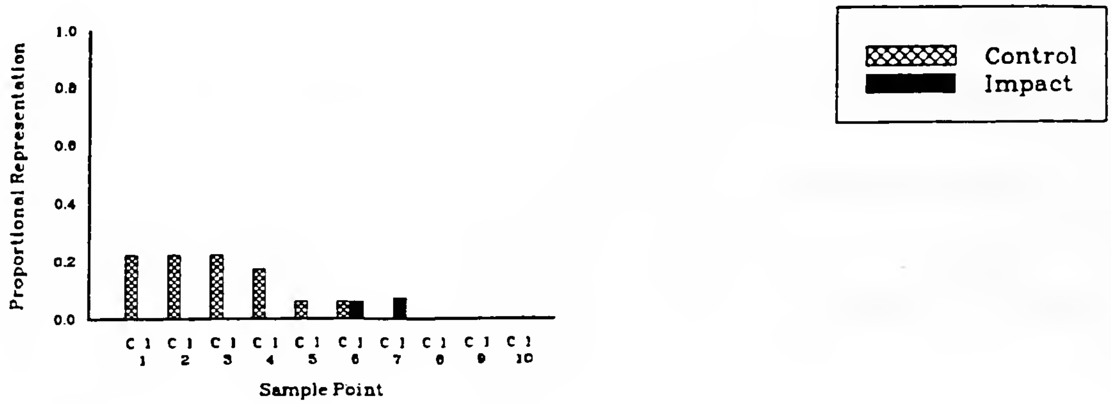
*, **, and *** indicate significant differences in the proportional representation at $\alpha = 5\%$, 3.3%, and 1%, respectively. Slickens representation was significantly greater on all impact streams; the remaining cover types were significantly more abundant on control streams.

hay ($p < 0.08$), and pasture ($p < 0.06$), and mean number of habitat layers ($p < 0.0002$). The Opportunity Ponds showed a significantly greater proportion of bare tailings ($p < 0.0002$).

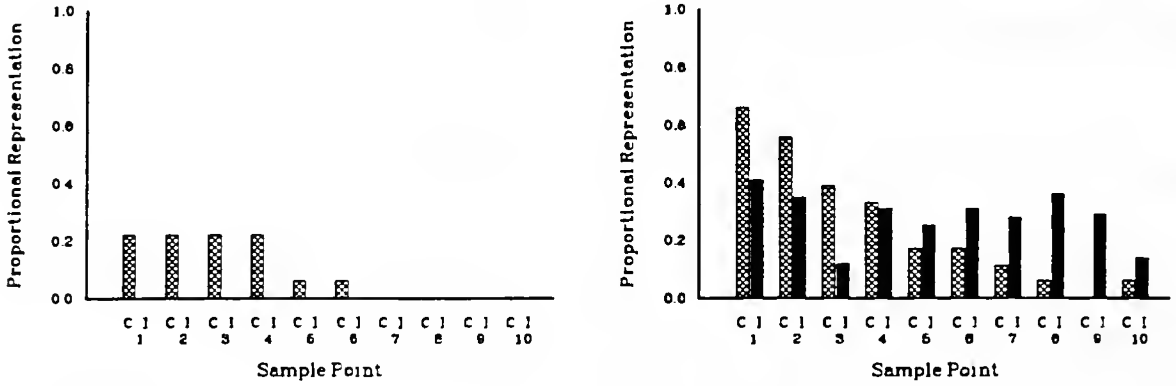
Thus injury to the riparian vegetation of Silver Bow Creek, the upper Clark Fork River, and the Opportunity Ponds is evident as a virtual elimination of the riparian forest, shrub, agricultural grassland cover types, and the tree canopy, tree bole, and soil layers, in areas of slickens or tailings deposition. In areas where mixed agricultural and native plant communities consisting of trees, shrubs, forbs, and grasses are expected, slickens and tailings are bare, unvegetated landscapes.

7.3.1.2 Habitat Suitability

The capacities of the injured and control areas to provide wildlife habitat were compared using HEP models.

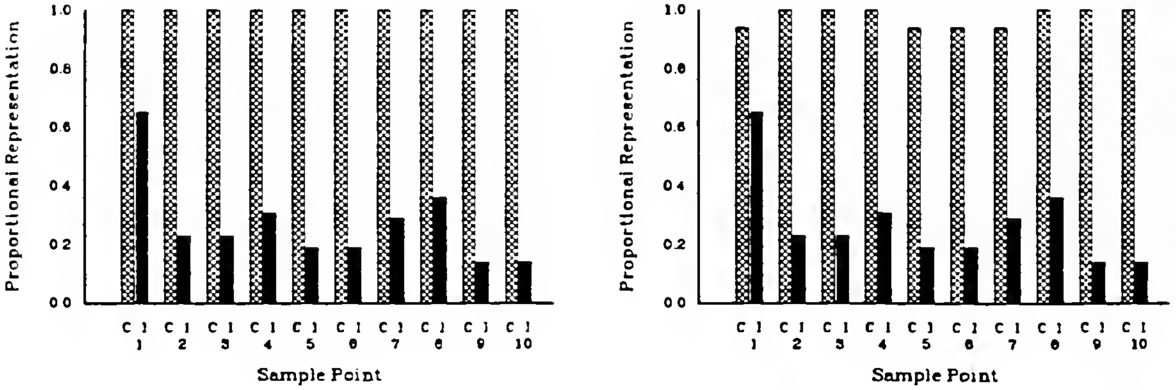


a. Tree Canopy



b. Tree Bole

c. Shrub Midstory



d. Understory

e. Subsurface

Figure 7-6. **Proportional Representation of the Habitat Layers on Riparian Control (C) and Impact (I) Reaches.** Sample points represent distance from the river at 10 meter intervals. Source: Appendix C.

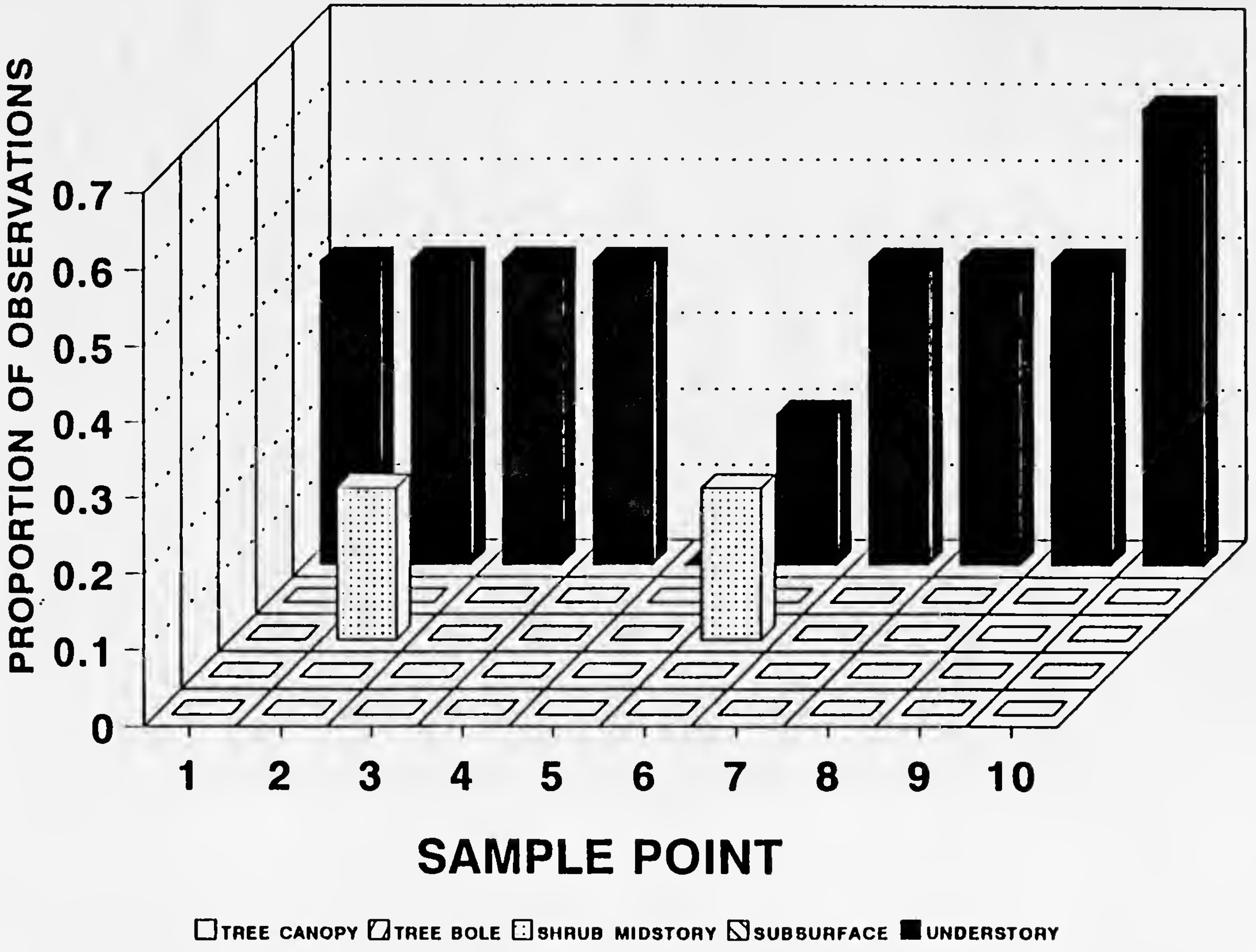


Figure 7-7. **Proportional Representation of Habitat Layers on the Opportunity Ponds.** Source: Appendix C.

Table 7-4
Comparison of the Proportional Representation of Habitat Layers on Impact and Control Streams

Area	Habitat Layer	p-value <
All impact reaches vs. all control reaches	Tree canopy	0.12
	Tree bole	0.03**
	Understory	0.0002***
	Terrestrial subsurface	0.0002***
Upper Silver Bow Creek vs. Divide Creek	Understory	0.0012***
	Terrestrial subsurface	0.0012***
Lower Silver Bow Creek vs. Little Blackfoot River	Tree canopy	0.03**
	Tree bole	0.03**
	Shrub midstory	0.038*
	Understory	0.0012***
	Terrestrial subsurface	0.0018***
Upper Clark Fork River vs. Flint Creek	Understory	0.002***
	Terrestrial subsurface	0.002***

*, **, and *** indicate significantly greater representation on the control streams at $\alpha = 5\%$, 3.3%, and 1%, respectively.

White-Tailed Deer

Statistical comparison of white-tailed deer habitat suitability index (HSI) values calculated for impact reaches with HSI values calculated for control reaches revealed that slickens greater than 100 meters wide provide significantly reduced habitat suitability (presence of cover and browse) relative to the control reaches (Appendix C). In this assessment, white-tailed deer is an indicator species in that it represents a broader component of the ecosystem, or all those organisms dependent upon the integrity of the riparian forest and shrub.

Habitat Layers

The layers of habitat models showed that slickens are significantly less vertically diverse than control areas, both when all control areas were compared with all impact areas and when paired impact and control reaches were compared (Table 7-6). The results of this assessment, which addressed the relationship between habitat vertical complexity and the capacity to provide a diversity of wildlife habitat, showed that slickens and tailings provide significantly less diverse wildlife habitat relative to the control areas.

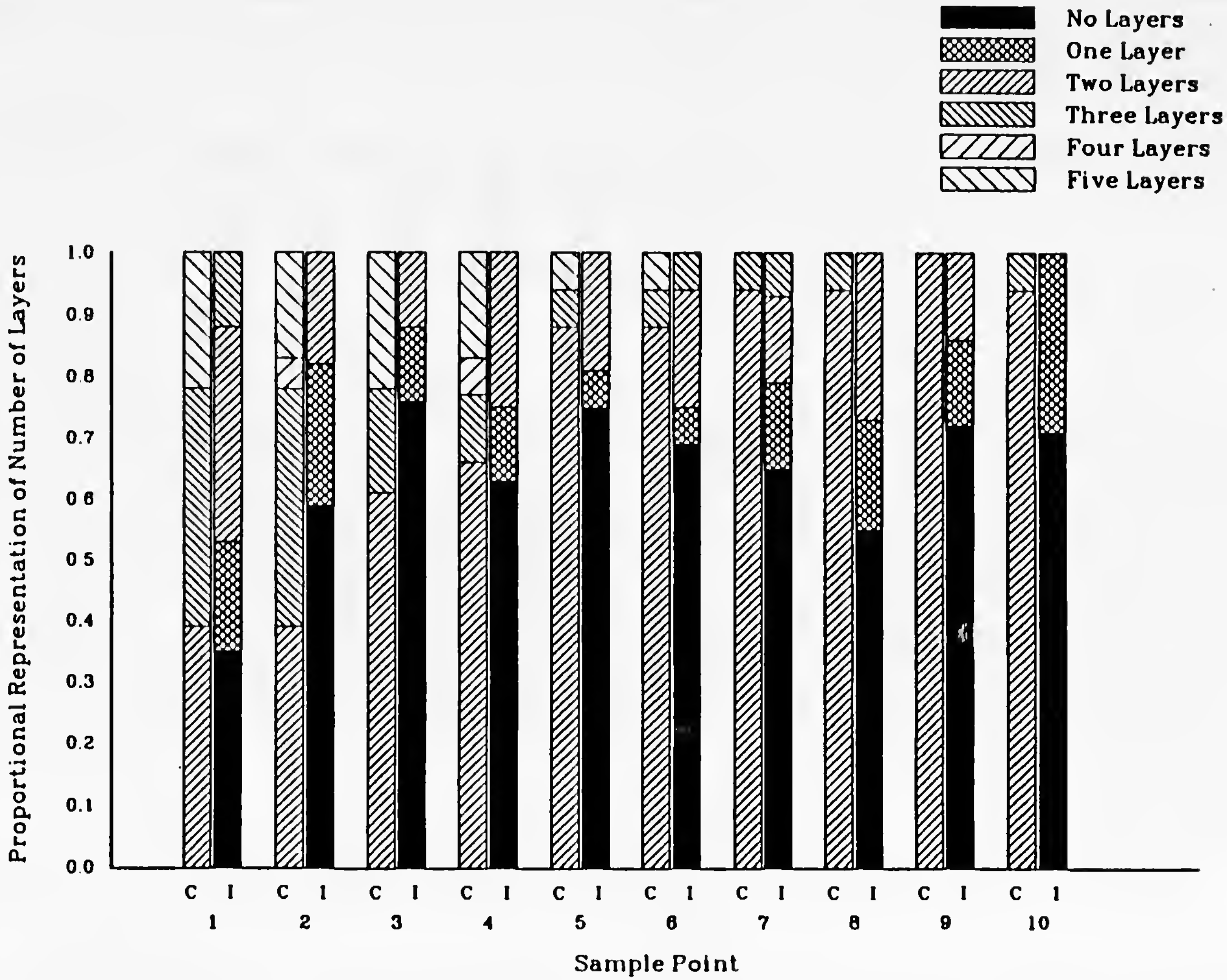


Figure 7-8. **Proportional Representation of the Mean Number of Habitat Layers on Riparian Control (C) and Impact (I) Reaches.** Sample points represent distance from the river at 10 meter intervals. Source: Appendix C.

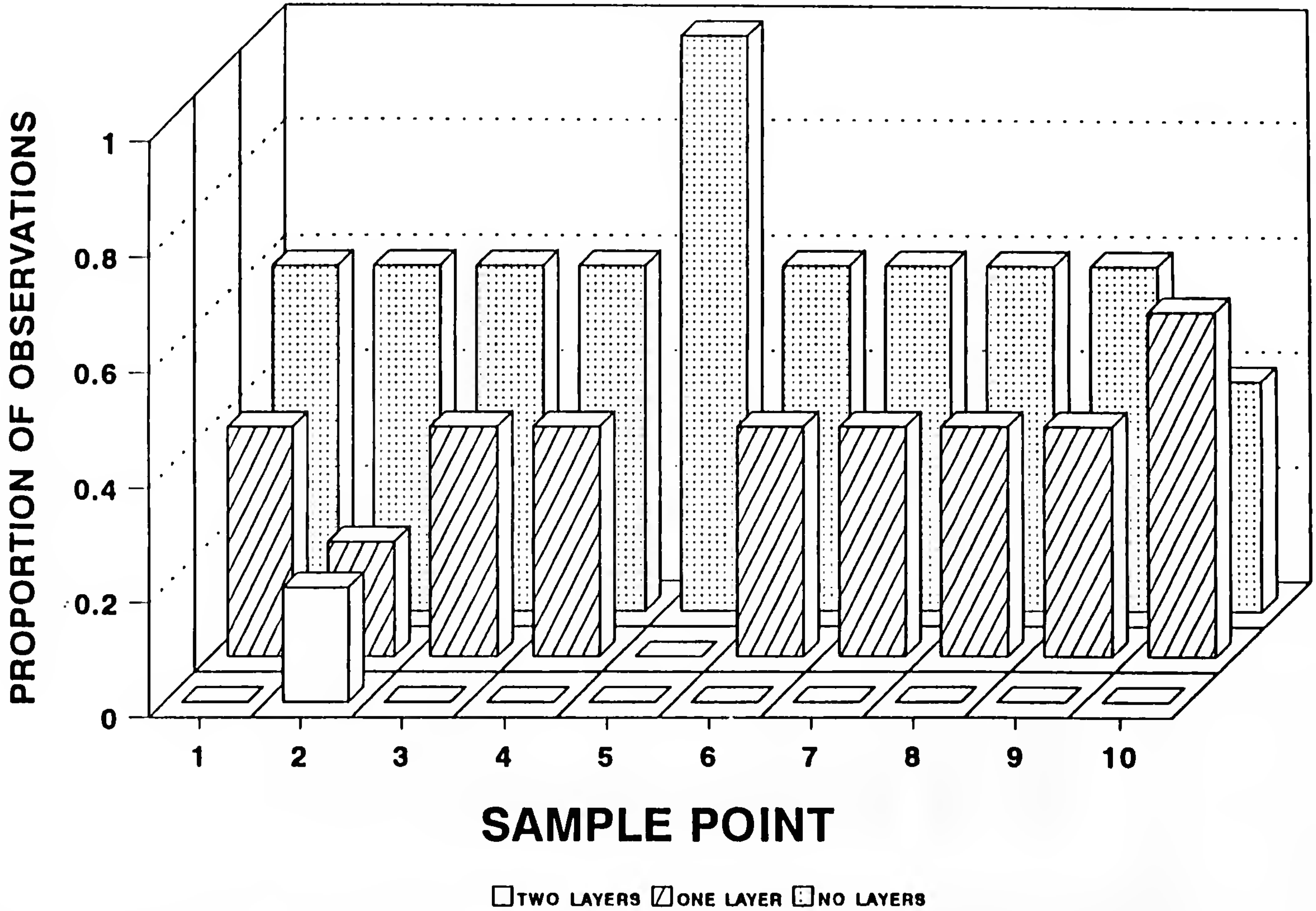


Figure 7-9. **Proportional Representation of the Mean Number of Habitat Layers on the Opportunity Ponds.** Source: Appendix C.

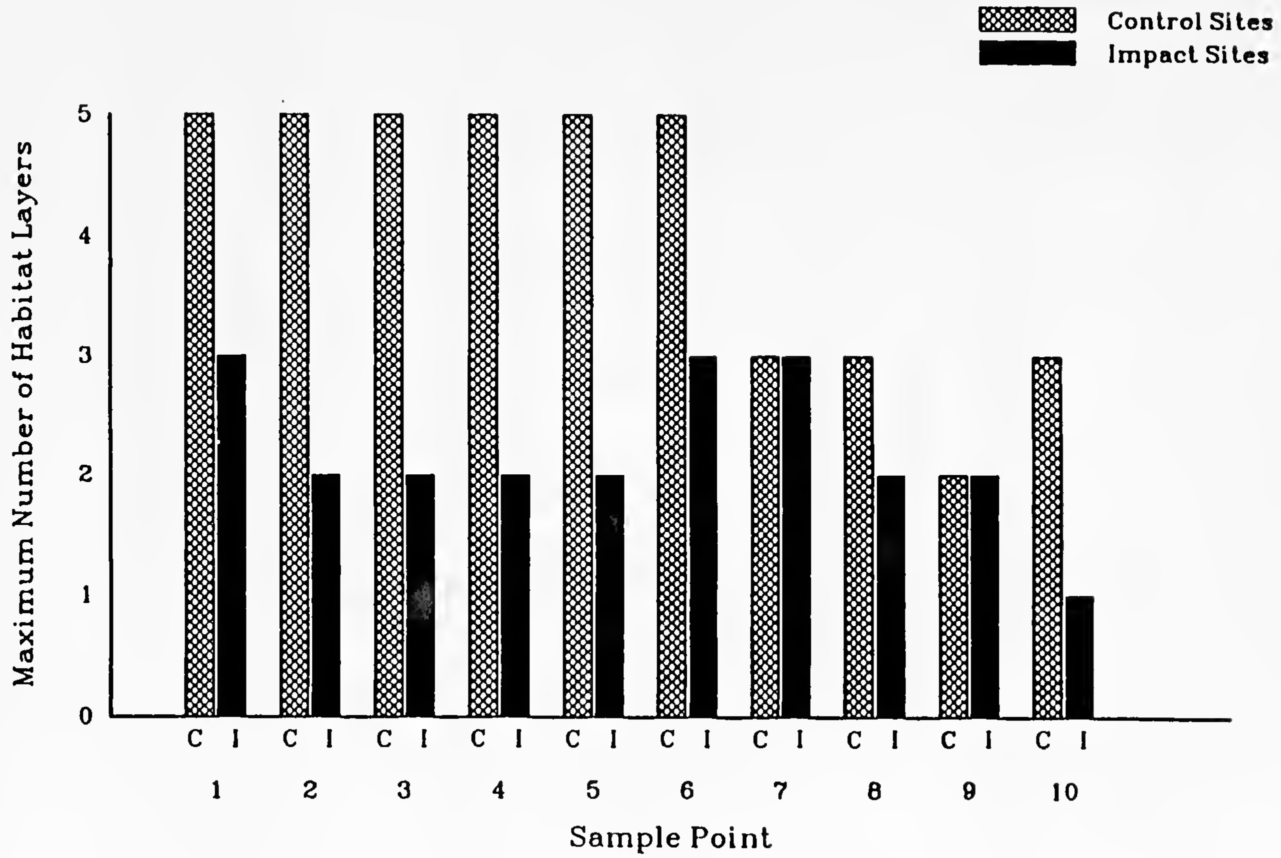


Figure 7-10. Maximum Number of Habitat Layers Observed on Control (C) and Impact (I) Riparian Reaches. Sample points represent distance from the river at 10 meter intervals. Near-bank shrub/forest is vertically diverse; hayfields and pastures dominate at distances greater than 60 meters from the bank.

Table 7-5
Comparison of the Mean Number of Cover Types Observed on Impact and Control Reaches

Reach	p-value
All impact reaches vs. all control reaches	0.0002***
Upper Silver Bow Creek vs. Divide Creek	0.0012***
Lower Silver Bow Creek vs. Little Blackfoot River	0.001***
Upper Clark Fork River vs. Flint Creek	0.0028***

*** Indicates significantly greater number of habitat layers in the control reach at $\alpha = 1\%$.

Table 7-6
Comparison of Vertical Diversity and Habitat Complexity in Impact and Control Reaches

Reach	p-value <
All impact reaches vs. all control reaches	0.0002***
Upper Silver Bow Creek vs. Divide Creek	0.001***
Lower Silver Bow Creek vs. Little Blackfoot River	0.001***
Upper Clark Fork River vs. Flint Creek	0.001***
Opportunity Ponds vs. all controls	0.0002***

*** indicates significantly greater diversity in the control area at $\alpha = 1\%$.

Wildlife Populations

Populations of organisms dependent on the tree canopy and tree bole are likely to have suffered the greatest loss of viability from the almost complete removal of riparian forest that has occurred in the impact area. Species likely to have been lost to the injured areas as a result of habitat loss are listed in Table 7-7. Other populations of riparian shrub and forest organisms less dependent on tree canopy and bole are likely to have suffered reductions in population viability because of the diminished representation of riparian shrub in the impact areas.

The two surveys of bird populations showed that the densities of mergansers, great blue herons, belted kingfishers, and dippers on the unimpacted Little Blackfoot River were approximately 14 times greater than on Silver Bow Creek (Table 7-8). The densities of spotted sandpipers were approximately similar on both reaches. Great blue herons, mergansers, and belted kingfishers are piscivores and dippers are benthivores (they obtain

Table 7-7
Bird and Mammal Populations that are Likely to have been Lost or Suffered Reduced Viability because of Reductions of Tree Canopy, Bole, Shrub Midstory, Understory, and Terrestrial Subsurface Habitat Layers in Riparian Impact Areas

Reduced Viability	Lost Species
Mallard	Great blue heron
Common merganser	Wood duck
Willow flycatcher	American kestrel
Black-billed magpie	Osprey
American robin	Bald eagle
Warbling vireo	Tree swallow
Yellow warbler	Great horned owl
Veery	Belted kingfisher
Song sparrow	Northern flicker
Red-winged blackbird	Bank swallow
Brewer's blackbird	Western wood-pewee
Brown-headed cowbird	Eastern kingbird
Red fox	Black-capped chickadee
Raccoon	House wren
White-tailed deer	European starling
Mink	American redstart
Moose	Northern oriole
	Black-headed grosbeak
	Little brown bat

their food from either the water column or the river bottom). Spotted sandpipers, however, obtain much of their invertebrate prey from the river bank. This dietary difference explains why spotted sandpipers are able to maintain population viability along a river reach that (because of the impacts of hazardous substances to the fish and benthos) is unable to support healthy populations of the other species surveyed.

Implications

The habitat degradation described above reduces the viability of wildlife populations dependent on the tree canopy and tree bole layers of riparian forest (which has been entirely lost from the injured areas). Of the 38 bird and mammal species characteristic of riparian forest in southwest Montana, 50% are dependent on one or more of these layers and are likely to have been lost within the injured areas. Thus, the deposition of slickens and tailings along

Table 7-8
Mean Numbers and Densities (Birds/River Kilometer) of Birds Seen during Two Avian Surveys on Silver Bow Creek and the Little Blackfoot River between Elliston and Avon

	Little Blackfoot		Silver Bow Creek	
Species	Mean Number	Mean Density	Mean Number	Mean Density
Common merganser	1*	0.2	0	0
Belted kingfisher	1	0.2	0	0
Great blue heron	1.5	0.2	1	0.1
Spotted sandpiper	7.5	1.5	7.5	1.1
Dipper	4.5	0.6	0	0
All species	15.5	2.7	8.5	1.2

* The merganser observation was of an adult female bird with a brood of seven ducklings.

Silver Bow Creek, along the upper Clark Fork River, and on Opportunity Ponds has resulted in a significant reduction in wildlife habitat and habitat viability. Injured areas, that could have supported natural and agricultural plant communities providing important habitat for a diversity of wildlife species, are currently largely devegetated and extremely limited in their ability to support viable wildlife populations.

7.3.2 Extent of Injury

Riparian vegetation and wildlife habitat have been injured by releases of hazardous substances from mining-related activities along approximately 34 miles of river from Colorado Tailings on Silver Bow Creek downstream to Deer Lodge on the Clark Fork River. Eight hundred acres of riparian habitat along Silver Bow Creek, 215 acres along the upper Clark Fork River, and some 5 square miles (3,400 acres) at Opportunity Ponds have been injured by the deposition of slickens and tailings.

7.3.3 Ability of the Resource to Recover

In the absence of stress, plant communities have the capability to recolonize disturbed land. The extent to which this may occur and the direction of the recovery (i.e., the resulting composition and structure of the recolonist communities, and the degree to which they resemble the pre-impact communities) are determined by whether residual stress persists, and whether the original stress has not irrevocably altered the abiotic conditions of the site.

Phytotoxicity studies performed during the assessment of injury (see Appendix B) have shown that the ability of the riparian areas to revegetate and provide wildlife habitat is severely constrained by the current high to severe phytotoxicity of soils caused by elevated concentrations of hazardous substances. The existing contamination has prevented much of the slickens from undergoing any substantial revegetation. Redistribution of tailings material during high water events further spreads tailings material and hazardous substances to additional areas. Evidence of the redistribution of phytotoxic substances can be seen where previously vegetated floodplains now support only dead, undecomposed willow stands. The only areas where revegetation has occurred are where a slickens deposit has been removed or has been overlain with uncontaminated soil material.

Without restoration, these constraints on revegetation will persist in the future, and it is extremely unlikely that substantial revegetation would occur except over a time scale of centuries. In addition, it is highly unlikely that natural restoration would result in riparian species assemblages that resemble those lost as a result of exposure to hazardous substances, because none of the pre-impact species have evolved tolerances and or persisted despite contamination.

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8.0 BIOLOGICAL RESOURCES — OTTER, MINK, RACCOON

This chapter summarizes the results of injury determination and quantification studies for semi-aquatic furbearers, specifically river otter (*Lutra canadensis*), mink (*Mustela vison*) and raccoon (*Procyon lotor*).[1] Otter and mink rely heavily (entirely, for otter) on a diet of fish and aquatic macroinvertebrates (Melquist and Dronkert, 1987; Eagle and Whitman, 1987); raccoons (*Procyon lotor*) feed primarily on aquatic macroinvertebrates (Sanderson, 1987). It was reported previously (Lipton et al., 1995) that Silver Bow Creek is almost entirely devoid of fish. Hence, Silver Bow Creek cannot support viable populations of species that rely on fish in their diets. This, alone, is sufficient to conclude that otter, mink, and other fish-eating wildlife are injured throughout Silver Bow Creek. These injures are caused by exposure to hazardous substances released from multiple sources in the Butte area.

Overall, the results of the injury determination and quantification studies demonstrate that otter, mink, and raccoon have been injured throughout the lengths of Silver Bow Creek and the Clark Fork River (from Warm Springs Ponds to Milltown). Specifically:

- Silver Bow Creek is almost entirely devoid of fish (see Lipton et al., 1995). It cannot, therefore, support viable populations of otter or other fish-eating wildlife.

- Populations of otters, mink, and raccoons are significantly reduced relative to baseline conditions. Otter are completely absent from Silver Bow Creek and the Clark Fork River from Warm Springs Ponds to Milltown as shown in field surveys, trapping records, and anecdotal accounts. In contrast, otter were found at control sites along the Big Hole River. Population densities of mink, raccoon, and otter were found to be higher at the control sites than at sites along the Clark Fork River. These population reductions (elimination, in the case of otter) are not caused by human disturbance, trapping, land-use, or other anthropogenic impacts.

- Hazardous metals and arsenic are known to cause adverse effects on mink and otter, including death and local population reductions, as shown in the scientific literature. Dietary exposure concentrations of lead measured in fish sampled from the Clark Fork River were found to exceed a safe tissue residue criterion.

- These three species have been, and continue to be, exposed to elevated concentrations of hazardous substances in their diets — as demonstrated by

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[1] These studies are described in Appendix E: "Exposure to and injury from environmental metal contamination on semi-aquatic mammals in the Upper Clark Fork River, Montana" by H.L. Bergman and M.J. Szumski.

tissue analysis of representative prey items and by significantly elevated tissue concentrations in mink trapped from the Clark Fork River relative to control sites.

8.1 INTRODUCTION

River otter, mink, and raccoon collected from areas exposed to anthropogenic inputs of metals have been shown to contain elevated concentrations of lead (Blus and Henny, 1990; Valentine et al., 1988; Wren et al., 1988), cadmium (Wren et al., 1988; Blus et al., 1987), and copper (Wren et al., 1988; Everett and Anthony, 1976) compared to animals from uncontaminated areas. Adverse effects on wildlife, including death (Wren, 1985; Diters and Nielsen, 1978; Benson et al., 1976; Wobeser, 1976) and reduced local population (Blus and Henny, 1990; Eisler, 1988; Eisler, 1985), have been attributed to metal contamination from anthropogenic sources. Otter and mink are now considered by United States, Canadian, and European experts the two mammalian species most sensitive to aquatic pollutants in streams and lakes because of their position at the top of the aquatic food chain, and because of their known sensitivities to contaminants (Addison et al., 1991).

As reported in Lipton et al. (1995), Silver Bow Creek is almost entirely devoid of fish because of elevated concentrations of the hazardous substances arsenic, cadmium, copper, lead and zinc. Therefore, Silver Bow Creek cannot now (nor has it been able to in the past decades) support a viable population of otters because of hazardous substance exposures. Similarly, the Clark Fork River was devoid of fish until the 1970s because of hazardous substances released from Butte and Anaconda (Lipton et al., 1995); the Clark Fork River could not have supported viable otter populations when devoid of fish.

Based on recent trapping records, and confirmed by field studies of population abundance (see Section 8.5.1), river otter currently are absent from the upper Clark Fork River. Since there are effectively no otter on the upper Clark Fork River, determining the effects of hazardous substances on this species was based on a review of the scientific literature and on comparisons of population densities with a nearby control river not exposed to elevated concentrations of hazardous substances (the Big Hole River).

Evaluation of hazardous substance exposures to otter was based on use of a surrogate species that is found in the Clark Fork River. Mink were selected as the surrogate species because they occupy a similar piscivorous, upper trophic position as otter, and are still present on the upper Clark Fork River. Mink, however, because of their dietary preferences (they consume less fish in their diets than otter) are less exposed to hazardous substances than otter. Therefore, they represent a lower-bound estimate of contaminant exposure and should not be construed as being fully reflective of injury to otter.

A study performed as part of the terrestrial resources injury assessment (Appendix E) quantified the extent of exposure to hazardous substances in prey of mink, otter, and raccoons in the upper Clark Fork River, and evaluated whether food-chain exposures to these hazardous substances are sufficient to result in injury. This was accomplished by:

- Identifying the principal aquatic foods of mink inhabiting the upper Clark Fork River and control sites
- Determining metal concentrations in the principal aquatic foods of mink collected from the Clark Fork River and control sites
- Comparing metal concentrations in the Clark Fork River mink and mink from control sites
- Determining whether the Clark Fork River fish tissue metal concentrations exceed the safe limit for consumption by mink and otter
- Determining whether morphological and histological injuries associated with metal toxicity occur in mink collected from the upper Clark Fork River and control sites.

In addition, the study evaluated whether populations of piscivorous mammals have been reduced in the Clark Fork River relative to control sites. This quantification was accomplished by:

- Determining the relative abundance of otter, mink, and raccoon on the upper Clark Fork River and control sites
- Comparing the relative quality of streamside mink and otter habitat on the upper Clark Fork River and control sites to determine whether potential differences in animal abundance are related to differences in streamside habitat quality
- Comparing the relative trapping pressure, numbers of humans and livestock, irrigation demands, and average distance to the nearest highway along the upper Clark Fork River and control sites to determine whether potential differences in animal abundance are related to anthropogenic disturbance
- Examining trapping records to quantify the number of otter trapped from the Clark Fork River and from control sites.

8.2 PATHWAY DETERMINATION

There are two main exposure pathways for mink, otter, and raccoons:

- The principal exposure pathway to mink and otter is via ingestion of fish exposed to hazardous substances from water and from benthic macroinvertebrates (see Lipton et al., 1995). Aquatic biota make up the entire diet of otter and a substantial component of mink diet.

- The principal exposure pathway to raccoons is via ingestion of aquatic macroinvertebrates exposed to hazardous substances from water and streambed sediments (see Lipton et al., 1995). Aquatic macroinvertebrates are a substantial component of the diet of raccoons (Sanderson, 1987).

Confirmation that these resources have bioaccumulated metals (and, therefore, act as an exposure pathway to raccoons, mink, and otter) is presented below for fish and in Lipton et al. (1995) for benthic macroinvertebrates and fish.

In addition, as described previously, injuries caused by hazardous substances to fish and invertebrates that serve as prey to semi-aquatic mammals represent an indirect cause of injury.

8.2.1 Mink and Otter Dietary Exposure to Hazardous Substances

As described in Appendix E, stomach and intestinal analyses carried out on 26 of 27 mink trapped on the Clark Fork and reference sites during the 1991-1992 trapping season showed that fish, including mountain whitefish, sucker, and trout species, was the greater part of mink diet (Table 8-1).

Whole-body metal concentrations in brown trout collected from the Clark Fork River and from control sites were reported in Lipton et al. (1995). Trout from the upper Clark Fork River were found to have significantly higher levels of copper, cadmium, lead, and arsenic than trout from control areas.

Whole-body metal concentration means and standard errors from whitefish and sucker collected on the Clark Fork and reference sites are given in Tables 8-2 and 8-3, respectively. Whitefish caught downstream from Warm Springs Ponds in 1991, and downstream from Warm Springs Ponds and upstream from Turah Bridge in 1992, had significantly higher whole-body concentrations of Cd and Pb compared to fish from reference sites (Table 8-2). Whole-body Cu concentrations were significantly greater in 1992 fish from Warm Springs and Turah Bridge; As concentrations were significantly greater in 1991 fish downstream from Warm Springs as compared to fish from reference sites.

Table 8-1
Frequency of Occurrence of Food in Intestine and Stomach of Mink Collected from All Clark Fork River and Reference Sites during 1991-1992 Trapping Season

Intestine Samples (N = 26)[a]

Food Item	Percent Frequency of Occurrence in Samples
Unidentified Fish	30.8
Sucker	15.4
Trout	11.5
Whitefish	3.8
Overall Fish	61.5[b]
Small Rodent	11.5
Muskrat	7.7
Aquatic Invertebrates	26.9
Empty	26.9

Stomach Samples (N = 26)[a]

Food Item	Percent Frequency of Occurrence in Samples
Unidentified Fish	7.7
Trout	3.8
Overall Fish	11.5[c]
Small Rodent	3.8
Muskrat	3.8
Empty	80.8

[a] Intestinal and stomach contents were not determined in one of the 27 mink trapped; thus N = 26 for this analysis.

[b] 84 percent of intestines with food present

[c] 60 percent of stomachs with food present

Source: Appendix E.

Table 8-2
Whitefish Mean Body Weight and Mean Whole Body Metal Concentrations (and Standard Errors of the Means) for Fish Collected from the Clark Fork River and Reference Sites in 1991 and 1992

		Mean (SEM)					
Year Location	N	Fish Wt (g)	Cadmium ng/g dw	Lead ng/g dw	Copper ug/g dw	Zinc ug/g dw	Arsenic ng/g dw
1991							
Warm Springs	4	316 (67)	87[a] (27)	203[a] (49)	4.0 (0.2)	64.6 (1.0)	930[a] (137)
Reference Sites	5	313 (23)	34 (10)	64 (10)	3.2 (0.6)	88.3 (9.3)	546 (110)
1992							
Warm Springs	4	270 (37)	234[a] (24)	468[a] (90)	6.1[a] (0.6)	66.1 (3.6)	386 (40)
Turah Bridge	4	324 (23)	183[a] (37)	558[a] (251)	8.0[a] (1.8)	71.5 (3.9)	338 (193)
Reference Sites	7	296 (28)	43 (7)	106 (23)	3.0 (0.1)	75.7 (4.1)	537 (111)

[a] Significantly higher than control at $\alpha = 0.05$

Source: Appendix E.

Table 8-3
Sucker Mean Body Weight and Mean Whole Body Metal Concentrations (and Standard Errors of the Means) for Fish Collected from the Clark Fork River and Reference Sites in 1992

		Mean (SEM)					
Year, Location	N	Fish Wt (g)	Cadmium ng/g dw	Lead ng/g dw	Copper ug/g dw	Zinc ug/g dw	Arsenic ng/g dw
1991	Inadequate number of fish for statistical comparisons						
1992							
Warm Springs	5	883 (61)	345[a] (42)	357[a] (46)	8.2[a] (0.7)	65.8 (4.8)	584 (82)
Turah Bridge	4	588 (66)	166[a] (10)	408[a] (77)	10.6[a] (0.8)	77.5 (3.9)	277 (53)
Reference Sites	4	607 (112)	72 (28)	172 (84)	4.5 (0.1)	72.6 (1.6)	1807 (1252)

[a] Significantly higher than control at $\alpha = 0.05$

Source: Appendix E.

Suckers collected downstream from Warm Springs Ponds and upstream from Turah Bridge in 1992 had significantly higher whole-body concentrations of Cd, Pb, and Cu compared to suckers collected from reference sites (Table 8-3).

Overall, the results of these studies demonstrate that three main fish prey of mink and otter had elevated tissue levels of hazardous substances at the Clark Fork River sites, as compared with fish from control locations. Fish, therefore, represent a pathway of these hazardous substances to these furbearers.

8.2.2 Mink Tissue Concentrations of Hazardous Substances

In addition to confirming the presence of hazardous substances in pathway resources, exposure to furbearers was confirmed by analysis of tissue samples for mink, as described below.

Cadmium

Adult liver and kidney Cd concentrations were found to be significantly higher in mink from Warm Springs Ponds and in pooled adult samples from the Clark Fork sites, compared to reference sites (Tables 8-4 and 8-5). Liver Cd concentrations in juveniles from the pooled Clark Fork sites are higher than from reference sites. Juvenile mink brain Cd concentrations from Warm Springs Ponds were elevated compared to mink from reference sites (Table 8-6).

Lead

The Clark Fork mink liver and kidney Pb concentrations are significantly greater than those from reference sites in both age classes, and across all the Clark Fork site comparisons (Tables 8-4 and 8-5). Brain Pb is significantly higher in adult mink from Warm Springs Ponds and in adult mink from the pooled Clark Fork sites than in adult mink from reference sites (Table 8-6).

Copper

The Clark Fork mink liver Cu concentrations are significantly greater than reference sites in both age classes and across all site comparisons (Table 8-4). Kidney Cu is significantly higher in the Warm Springs Ponds juveniles than in reference juveniles (Table 8-5), and significantly higher in the comparison between the pooled Clark Fork sites and reference sites for juveniles at the 10% level ($p = 0.0649$). Brain Cu is significantly higher in juvenile mink from Warm Springs Ponds than from reference sites, and this difference is significant at the 10% level ($p = 0.0608$) in the comparison of juveniles from pooled Clark Fork sites (Table 8-6).

Table 8-4
Mink Mean (and Standard Error of the Mean) Liver Metal Concentrations by Trapping Location for Mink Collected on the Clark Fork River and Reference Sites During the 1991-92 Trapping Season

		Mean (SEM)				
Location	N	Cadmium ng/g dw	Lead ng/g dw	Copper ug/g dw	Zinc ug/g dw	Arsenic ng/g dw
Juveniles						
Warm Springs Ponds	3	676 (379)	506[a] (80)	54[a] (12)	117[a] (12)	221[a] (91)
Deer Lodge[b]	2	646 (326)	1093 (237)	56 (15)	111 (16)	308 (137)
Clinton	5	359 (37)	600[a] (63)	43[a] (2)	88 (3)	406[a] (137)
Combined CFR Sites	10	512 (122)	670[a] (88)	49[a] (4)	101 (6)	331[a] (76)
Combined Reference	5	275 (68)	212 (74)	28 (3)	89 (9)	24 (29)
Adults						
Warm Springs Ponds	5	1014[a] (187)	994[a] (132)	35[a] (4)	103[a] (6)	1092 (846)
Deer Lodge[b]	1	1394	826	47	72	189
Clinton	0	NO ADULT MINK CAPTURED				
Combined CFR Sites	6	1078[a] (166)	966[a] (112)	37[a] (4)	98 (7)	942 (706)
Combined Reference	6	434 (78)	187 (104)	19 (2)	85 (5)	269 (178)

[a] Significantly higher than control at $\alpha = 0.05$

[b] No statistical comparison made due to small sample size.

Source: Appendix E.

Table 8-5
Mink Mean (and Standard Error of the Mean) Kidney Metal Concentrations by Trapping Location for Mink Collected on the Clark Fork River and Reference Sites During the 1991-92 Trapping Season

		Mean (SEM)				
Location	N	Cadmium ng/g dw	Lead ng/g dw	Copper ug/g dw	Zinc ug/g dw	Arsenic ng/g dw
Juveniles						
Warm Springs Ponds	3	1735	463[a]	23[a]	86	341
		(1040)	(45)	(2)	(10)	(91)
Deer Lodge[b]	2	875	944	24	89	1263
		(357)	(111)	(1)	(10)	(886)
Clinton	5	605	613[a]	18	75	196
		(145)	(70)	(1)	(3)	(63)
Combined CFR Sites	10	998	634[a]	21	81	453
		(326)	(68)	(1)	(4)	(194)
Combined Reference	5	566	252	17	92	274
		(131)	(83)	(1)	(13)	(168)
Adults						
Warm Springs Ponds	5	2604[a]	756[a]	18	78	1122
		(718)	(105)	(2)	(4)	(792)
Deer Lodge[b]	1	3491	996	19	73	413
Clinton	0	NO ADULT MINK CAPTURED				
Combined CFR Sites	6	2752[a]	796[a]	18	78	1004
		(604)	(95)	(1)	(3)	(657)
Combined Reference	6	1114	211	15	69	180
		(326)	(113)	(1)	(3)	(107)

[a] Significantly higher than control at $\alpha = 0.05$

[b] No statistical comparison made due to small sample size.

Source: Appendix E.

Table 8-6
Mink Mean (and Standard Error of the Mean) Brain Metal Concentrations by Trapping Location for Mink Collected on the Clark Fork River and Reference Sites During the 1991-92 Trapping Season

		Mean (SEM)				
Location	N	Cadmium ng/g dw	Lead ng/g dw	Copper ug/g dw	Zinc ug/g dw	Arsenic ng/g dw
Juveniles						
Warm Springs Ponds	3	194 (118)	111 (96)	20[a] (1)	67 (10)	267[c] (161)
Deer Lodge[b]	2	18 (22)	268 (126)	15 (2)	58 (0)	145 (31)
Clinton	5	1 (3)	28 (24)	15 (1)	50 (2)	164 (31)
Combined CFR Sites	10	62 (42)	28 (45)	16 (1)	57[a] (4)	183 (36)
Combined Reference	5	4 (5)	19 (13)	14 (1)	48 (2)	118 (58)
Adults						
Warm Springs Ponds	5	7 (3)	159[a] (26)	12 (1)	46 (2)	589 (316)
Deer Lodge[b]	1	8	350	10	47	124
Clinton	0		NO ADULT MINK CAPTURED			
Combined CFR Sites	6	7 (3)	191[a] (38)	11 (1)	47 (1)	511 (270)
Combined Reference	6	41 (19)	58 (20)	10 (0)	45 (4)	138 (44)

[a] Significantly higher than control at $\alpha = 0.05$

[b] No statistical comparison made due to small sample size.

[c] N = 2

Source: Appendix E.

Zinc

Liver Zn concentrations are significantly higher in both adult and juvenile mink from Warm Springs compared to reference sites (Table 8-4). Brain Zn concentrations in juveniles from the pooled Clark Fork sites were significantly elevated compared to reference sites (Table 8-6).

Arsenic

Liver As concentrations are significantly elevated in juvenile mink from all the Clark Fork sites compared to reference sites (Table 8-4).

Thus, there is a clear pattern of elevated levels of metals and arsenic in the tissues of mink trapped on the Clark Fork, as compared to mink from control rivers. This further confirms exposure to furbearers.

8.3 INJURY DEFINITION

An injury to mink, otter, or raccoons has occurred if they or their offspring "have undergone one of the following adverse changes in viability: death . . . physiological; malfunctions (including malfunctions in reproduction), or physical deformations" [43 CFR § 11.62 (f)(1)].

In the Clark Fork Basin, injury to mink, otter, and raccoons is expressed in population reductions relative to control sites. At the level of the individual animal, these population changes have been caused by death and reproductive impairment. Injuries to mink, otter, and raccoons have been found in this assessment to satisfy the four acceptance criteria for biological responses [43 CFR § 11.62 (f) (2) (i-iv)]. Specifically, these injuries:

- Are often the result of exposure to hazardous substances, as shown in various scientific studies, including the studies described in Appendix E
- Have been shown to occur in controlled laboratory experiments (see Appendix E)
- Are often the result of exposure to hazardous substances among free-ranging organisms, as documented in the literature (see Appendix E), and in the field studies described in this chapter and in Appendix E
- Are routine measurements that are practical to perform and produce scientifically valid results.

8.4 INJURY DETERMINATION: RESULTS OF STUDIES

As described previously, Silver Bow Creek cannot support viable populations of otter because it is devoid of fish. As outlined in Lipton et al. (1995), fish are not found in Silver Bow Creek as a result of releases of hazardous substances. Therefore, otter have been injured throughout Silver Bow Creek. Determination of injury to otter, mink, and raccoon in the Clark Fork River was based on a review of the scientific literature (see Sections 8.4.1 and 8.4.2) and on comparisons of population densities (Section 8.5.1).

Evaluation of Whether Dietary Exposure Poses Risks to Mink and Otter on the Clark Fork River

Models have been developed to estimate the maximum safe dietary exposure, or Tissue Residue Criterion (TRC), of hazardous substances to piscivorous mammals. The model employed by the New York State Department of Environmental Conservation (Newell et al., 1987) was chosen for this assessment because it has been widely accepted by the scientific community, and because it serves as the basis for other similar models such as the Canadian Tissue Residue Guidelines (U.S. EPA, 1992) (Appendix E). The model generates a TRC, which is the maximum acceptable exposure concentration for each metal (in µg of metal/kg diet) of a contaminant (Pb or Cd) in the diet.

Table 8-7 shows the Cd and Pb TRC values obtained from the model. TRC values were slightly higher for otter than for mink for both Pb (89 and 67 µg/kg diet for otter and mink, respectively) and Cd (533 and 400 µg/kg diet for otter and mink, respectively).

These criteria were then compared to the *mean* dietary exposure concentration in fish downstream from Warm Springs Ponds and from reference sites in Table 8-8. The Pb dietary exposure to mink consuming 50% trophic level three fish from the Warm Springs Ponds site (51 µg Pb/kg diet) approaches the Pb criterion (67 µg Pb/kg diet) (Table 8-8). Lead exposure to mink consuming a diet of 100% trophic level three fish from the Warm Springs Ponds site (102 µg Pb/kg diet), and to otter consuming a diet of 50% trophic level three and 50% trophic level four fish from the Warm Springs Ponds site (157 µg Pb/kg diet), exceeds the respective Pb criterion. Hence, this model predicts adverse impacts on otter and mink given these exposures. Dietary cadmium exposures to Warm Springs Ponds and reference site fish did not exceed the respective criteria for either mink or otter (Table 8-8).

Based on the results of this comparison, otter and, to a lesser extent, mink are exposed to concentrations of hazardous substances sufficient to cause injury.

Table 8-7
TRC for Pb and Cd in the Diet of Mink and Otter

	Toxicity Data				Uncertainty Factors[a]			Tissue Residue Criteria (ug/kg diet)	
Chemical	Test Species	Endpoint	LOAEL (ug/kg/d)	Reference	UF_E	UF_S	UF_C	Mink	Otter
Lead	Monkey	Behavior	100	Rice, 1985	10	1	1	67	89
Cadmium	Rats	Birth Defects	6000	Ferm & Layton 1981	10	1	10	400	533

[a] Uncertainty factors defined in text

Source: Appendix E.

Table 8-8

TRC Values and Dietary Exposure Concentrations for Cd and Pb for Mink and Otter Consuming Fish Collected from below Warm Springs Ponds and Reference Sites

	Cadmium			Lead		
		Dietary Exposure Concentration (ug/kg diet)[a]			Dietary Exposure Concentration (ug/kg diet)[a]	
Species (Trophic Level)[b]	Tissue Residue Criteria (ug/kg diet)	Warm Springs	Reference Site	Tissue Residue Criteria (ug/kg diet)	Warm Springs	Reference Site
Mink 50% Trophic Level 3 Fish	400	49	10	67	51	25
Mink 100% Trophic Level 3 Fish	400	99	21	67	102	49
Otter 50% Trophic Level 3 and 50% Trophic Level 4 Fish	533	70	36	89	157	76

[a] Dietary exposure presented as ug metal/kg expressed as wet weight, calculated from dry weight metal concentrations for suckers (trophic level 3 fish) presented in Table 3 and from dry weight concentrations for brown trout (trophic level 4 fish) presented by Bergman (1993).

[b] Based on dietary composition of trophic level 3 and 4 fish in mink and otter as specified by USEPA (1993), as discussed in the text.

Source: Appendix E.

8.5 INJURY QUANTIFICATION

Because of their secretive natures, mink, otter, and raccoon populations cannot be readily determined by direct counts of animals. The most reliable ways of assessing their population status is by carrying out sign surveys (surveys of tracks, scat), or by analyzing trapping records. These approaches were used to compare mink, otter, and raccoon populations on the Clark Fork River and at control rivers (Appendix E).

8.5.1 Population Reductions among Mink, Otter, and Raccoons on the Upper Clark Fork

The populations of mink, otters, and raccoons on the Clark Fork and control rivers were assessed using sign surveys as indices of population levels, and by analyzing trapping records.

Trapping Records

Analysis of trapping records kept by Montana Department of Fish, Wildlife, and Parks (MDFWP) indicates that there appears to be a "hole" in the map showing otter trapping records for western Montana in the area corresponding to the upper Clark Fork and its tributaries (Appendix E; Figure 8-1). This could be explained either by reduced otter populations on the Clark Fork, or by disparities in the amount of trapping effort between the upper Clark Fork and the surrounding drainages.

As described in Appendix E, in virtually all cases, otters are not actively pursued by trappers in Montana, but are trapped incidentally in beaver sets. The number of otter trapped in a given area, therefore, is a reflection of effort in beaver trapping in that area. One would therefore expect two areas with similar numbers of beaver trapped to also produce a similar number of incidental otter captures, if there were no differences in otter numbers between the two areas.

Analysis of the trapping records for administrative regions two (which contains the Clark Fork) and three (which lies immediately south of the Clark Fork valley) showed that the two areas have similar beaver harvests, based on the number of animals caught over the 5 years examined. Thus, the beaver trapping effort in the region that includes the Clark Fork was not less than in the area that contains the Bitterroot.

This review of MDFWP trapping records was further focused to examine the number of otter captured per river mile between the upper Clark Fork and two adjacent river systems: the Bitterroot River immediately west of the Clark Fork, and the Big Hole River drainage immediately south. Significantly fewer otter were trapped on the upper Clark Fork than on the Big Hole and Bitterroot rivers. No statistical difference was seen between the numbers of

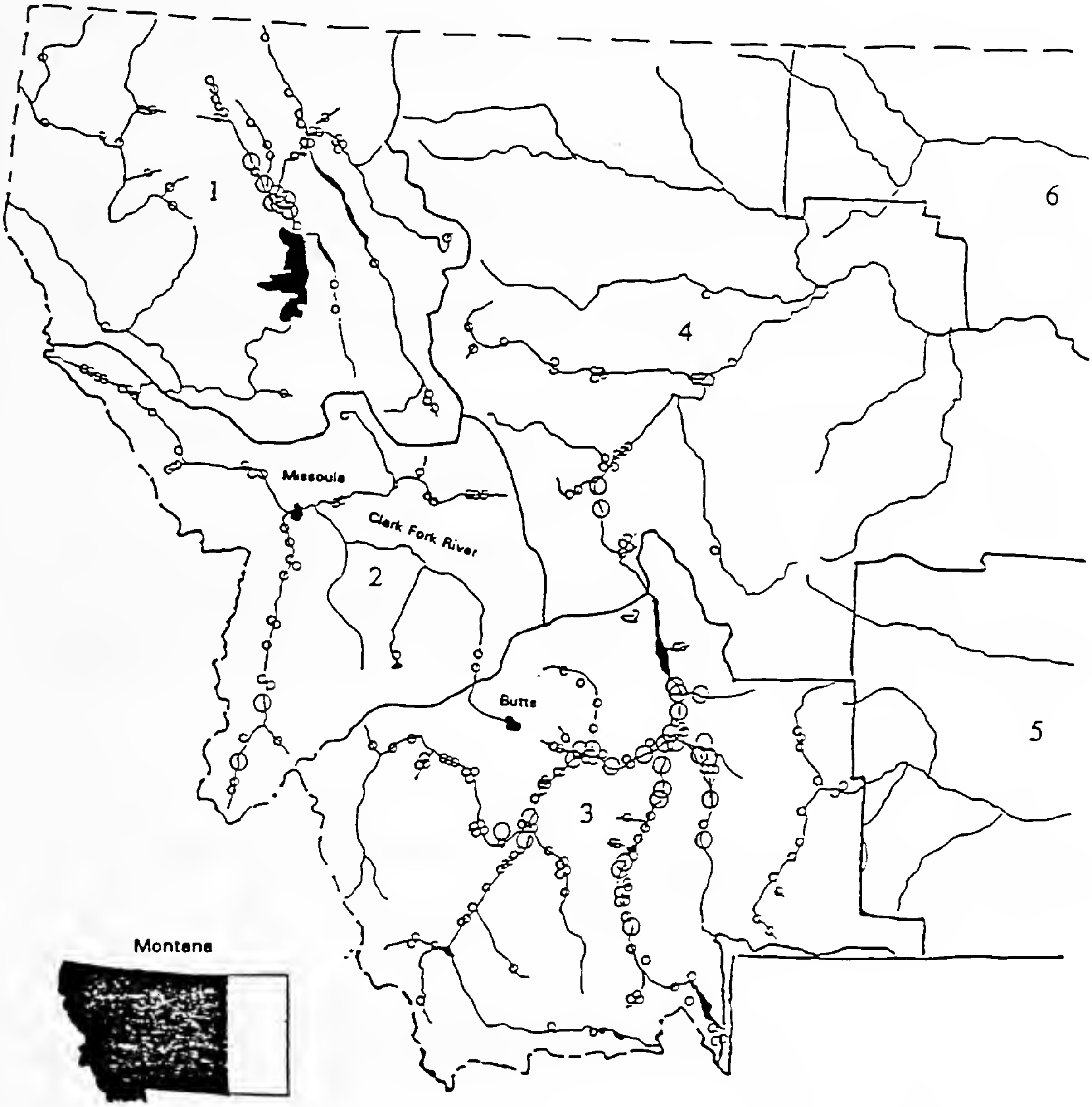

Figure 8-1. **Map of Western Montana Showing the Numbers and Locations of Otter Trapped in each Montana Department of Fish, Wildlife, and Parks Administrative Region (numbers) during the 1977-78 through 1989-90 Trapping Seasons.** (Adapted from Zackheim 1982); small circles indicated single otter, large circles indicate five otter. Note that only two otters were trapped on the upper Clark Fork River during this time period. Source: Appendix E.

otter trapped on the Bitterroot and Big Hole rivers. Thus, the reason fewer otter are trapped on the upper Clark Fork is most likely a reduced or eliminated river otter population.

Sign Surveys

Field studies were used to quantify otter sign at the Clark Fork River and a control river (the Big Hole River). Significant differences were found in the amount of furbearer sign found between the paired Clark Fork River and control sites (Figure 8-2). In the fall 1992 sign survey, no otter sign was found on any of the Clark Fork River sites, whereas sign was found on four of the six reference sites. Otter, mink, and raccoon sign were significantly more common on reference sites than on the paired Clark Fork River sites (Figure 8-2).

Thus, the sign surveys demonstrated that mink, otter, and raccoon population densities are lower on the Clark Fork than on control rivers. Otter have apparently been entirely eliminated from the Clark Fork River between Butte and Missoula.

The differences in mink and otter population levels between the Clark Fork and control rivers are not due to habitat differences or human disturbance (grazing pressure, proximity of highways, trapping pressure, irrigation demands, or human population density); there were no significant differences between the Clark Fork and control rivers in the habitat representation or in human use patterns (Appendix E).

8.6 CONCLUSIONS

As described in Appendix E, the following conclusions can be supported by the injury determination and quantification studies:

- Otter are injured throughout Silver Bow Creek.
- Whole-body concentrations of Pb, Cd, and Cu are significantly elevated in the prey of otters and mink from the upper Clark Fork River, as compared to fish from control sites.
- Metal residue concentrations for Pb, as well as Cd, Cu, Zn, and As, are significantly elevated in liver, kidney, and brain tissues from mink trapped on the upper Clark Fork River as compared to tissues from mink trapped on control sites.
- For mink on the Clark Fork River, dietary exposure concentrations of Pb exceed the Pb tissue residue criterion (a safe dietary intake concentration of Pb), assuming that more than about 65% of their diet is suckers from below Warm Springs Ponds.

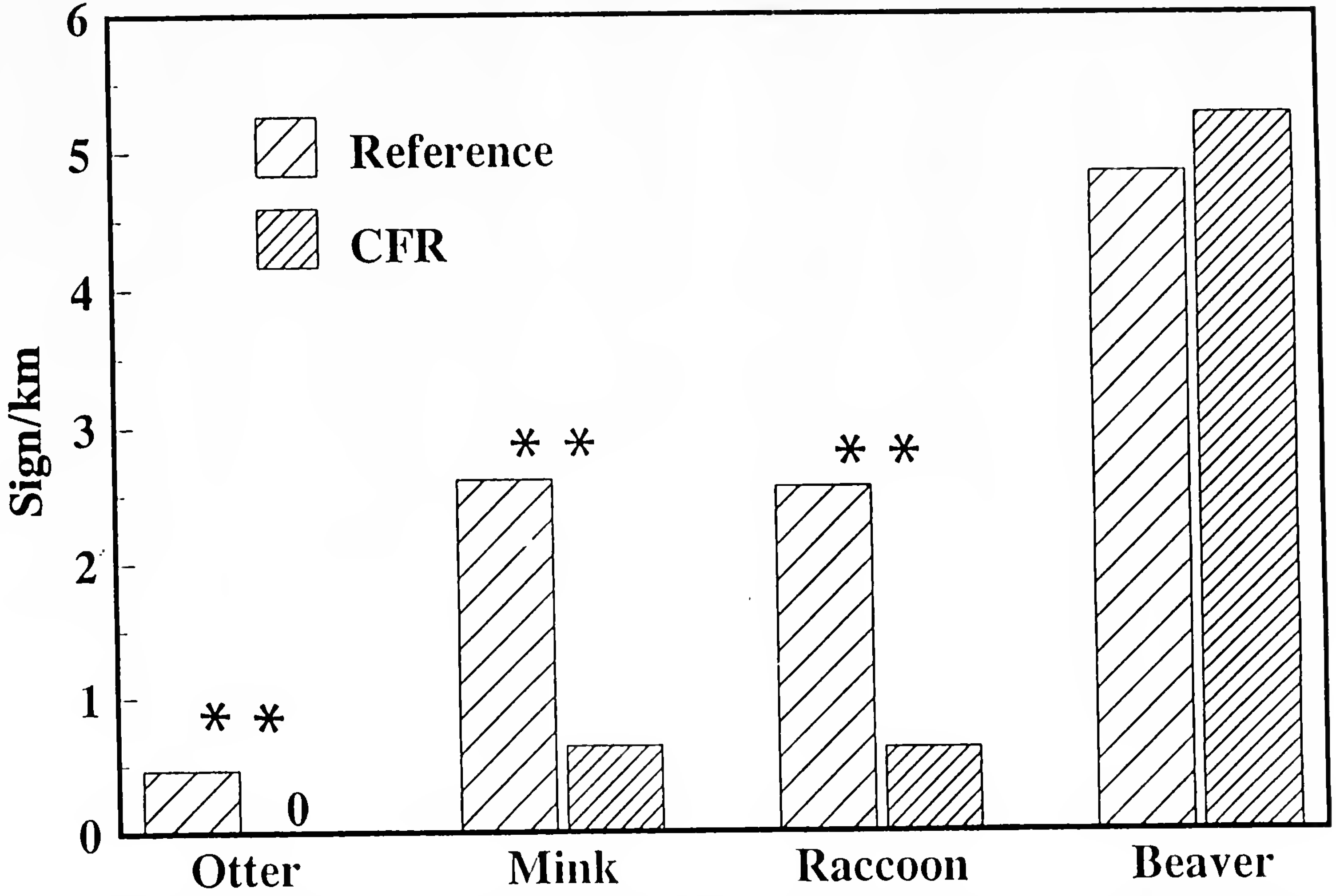

Figure 8-2. **Abundance of Otter, Mink, Raccoon, and Beaver Sign on Six Paired Clark Fork River (CFR) and Reference Sites During the Fall of 1992.** ** indicates significantly different for $p < 0.05$. Source: Appendix E.

- Dietary exposure concentrations of Pb to otter consuming fish from the upper Clark Fork River exceed the safe Pb tissue residue criterion, based on an estimate of probable exposure from consumption of 50% suckers and 50% trout downstream from Warm Springs Ponds.
- Dietary exposure concentrations of Cd to mink and otter, though below the respective safe tissue residue criteria for Cd, may contribute to metal toxicity in mink and otter through synergistic interactions with Pb.
- Otter, mink, and raccoon population abundance on the upper Clark Fork River is lower than on paired reference sites on the Big Hole River.
- Otter are absent from the upper Clark Fork River, based on complete absence of sign information from MDFWP and Bureau of Land Management personnel as well as from fur trappers in the area and historical trapping records for otter, whereas they are present on all comparable rivers in western Montana.
- Habitat structural features that are important for otter and other piscivorous mammals in the riparian zone along the upper Clark Fork River are similar to the habitat structural features on paired reference sites on the Big Hole River, where otter, mink, and raccoons are more abundant.
- The levels of human disturbance to otter and other piscivorous mammals caused by trapping, grazing, irrigation demands, and proximity to highways and human populations appear to be similar or less severe in the upper Clark Fork valley as compared to similar river valleys in western Montana.

All of the above findings from this study and related studies, taken together in a weight-of-evidence approach, indicate that the observed absence of otter on the upper Clark Fork River is caused by metal contamination (particularly lead, with possible contributions from cadmium and other metals) in fish and other aquatic organisms. Furthermore, the findings from this study also support a conclusion that significantly reduced populations of mink and raccoon on the upper Clark Fork River are also caused by metal contamination in the diet.

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