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Effects of Holden Mine on the Water, Sediments and Benthic Invertebrates of Railroad Creek (Lake Chelan)

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Effects of Holden Mine on the Water, Sediments and Benthic Invertebrates of Railroad Creek (Lake Chelan)

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Abstract

Iron, zinc, copper, cadmium, lead, other metals, and cyanide were analyzed in drainage from the abandoned Holden mine, tailings pile leachate, and Railroad Creek water and sediment collected above and below the mine. Creek samples were subjected to toxicity tests with *Ceriodaphnia dubia*, *Hyalella azteca*, and Microtox®. The health of Railroad Creek's benthic invertebrate community was quantitatively assessed.

Chemical results are compared to historical data and analyzed in terms of elevation above background, metal loadings, aquatic life criteria, and findings from the bioassays. Benthic community data are summarized and statistically analyzed using organism density, taxa richness, Ephemoptera-Plecoptera-Trichoptera richness, and metals tolerance indices. The impact of metals on indicator taxa and functional feeding groups identified in the creek and the potential influence of insect drift from upstream areas are discussed.

Results show the Holden site is having a devastating effect on the water quality and aquatic life of Railroad Creek. A biological integrity target is recommended to help measure the effectiveness of future pollution control efforts on Railroad Creek.

Acknowledgments

Much of the water quality data and all the flow data used in this report were provided by the U.S. Forest Service through the courtesy of Al Murphy and Keith Anderson, Chelan Ranger District. We are especially indebted to Keith for arranging access to the Holden site, transportation, lodging, and for sharing his considerable knowledge of the area. The survey could not have been conducted without his generous assistance.

Sampling was done with the help of Chris Hall and Bob Raforth, Ecology Central Regional Office. We very much appreciate the efforts of Manchester Laboratory staff in analyzing the samples, especially Jim Ross, Randy Knox, and Sally Cull of the metals group, Karin Fedderson for arranging the bioassay contracts, and Pam Covey for sample tracking.

This report benefited from review comments by Will Kendra, Larry Goldstein, Dave Serdar, Dale Norton, and Bob Raforth.

Summary

Background

The abandoned Holden mine is located 12 miles up Lake Chelan's Railroad Creek in Wenatchee National Forest, near the boundary of Glacier Peak Wilderness. Howe Sound Company began mining zinc, copper, silver, and gold in 1938. Gold was processed on site by flotation, with some use of cyanide and arsenic, until the mid-1940s. The mine closed in 1957 due to declining mineral prices. Approximately $65 million of minerals were produced over the mine's 19-year history.

The mining operation left 250 million cubic yards of tailings covering 80 - 90 acres in three piles up to 150 feet high along the banks of Railroad Creek. Drainage from the mine portal flows 1/4 mile around the upstream end of the tailings piles into the creek. The portal drainage has a pH of 5 - 6 and is milky-white in color. A reddish-brown, high iron-content leachate seeps at various points from the base of the tailings piles; the pH is approximately 3. During low flow, active seepage can be observed upwelling along the edge of Railroad Creek. Copper Creek, a major tributary, flows between the piles.

The precipitation of iron hydroxides has caused cementation of the stream bed adjacent to and for several hundred feet below the tailings. Iron staining can be observed for at least an additional five miles downstream of the tailings. No cementation or staining is evident in Copper Creek.

The impacts of Holden mine on Railroad Creek were investigated as early as 1931 when Howe Sound tested the effects of tailings on trout. Studies reporting elevated concentrations of zinc, copper, and iron in Railroad Creek and low numbers of benthic invertebrates and fish below the mine go back to the 1960s. Routine water quality monitoring of the creek was begun by Battelle Pacific Northwest Laboratory in 1991 and continued by the U.S. Forest Service (Forest Service) through 1995. Other recent metals data have been obtained by the U.S. Geological Survey (Geological Survey) and U.S. Bureau of Mines (Bureau of Mines).

The tailings and portal entrance are now under Forest Service jurisdiction. The Holden town site is currently operated by the Lutheran Bible Institute of Seattle as a non-denominational religious retreat, Holden Village. The Forest Service has made numerous attempts at reducing water quality impacts to Railroad Creek, including putting limestone in the portal drainage ditch to raise the pH as well as using rip-rap, matting, gravel, and vegetation to stabilize the tailings piles and reduce surface percolation.

Survey Description

The Department of Ecology (Ecology) conducted two surveys of Railroad Creek during the summer of 1996. Objectives were to obtain accurate measurements of background metal concentrations, determine compliance with criteria for protecting aquatic life, conduct toxicity tests on water and sediment, and assess the health of the benthic invertebrate community.

An initial reconnaissance survey was conducted on June 12 during spring runoff conditions (615 cfs), followed by more extensive field work during low flow (83 cfs) on September 10-11. Water samples were collected at the downstream end of the mine portal discharge (P-5), mouth of Copper Creek (CC-1), and the three Forest Service monitoring stations on Railroad Creek -- near the wilderness boundary (RC-1), below the tailings piles (RC-2), and at the creek mouth on Lake Chelan (RC-3). A fourth Railroad Creek station was added approximately three miles below the mine at Milepost 7 (MP-7). Samples of the leachate and tailings material were taken from piles #2 and #3. Sediment and benthic macroinvertebrate samples were collected at each of the four water sampling sites on Railroad Creek

Samples were analyzed for metals, cyanide, and a range of conventional parameters. Metals analyzed included iron, aluminum, manganese, zinc, copper, iron, lead, cadmium, nickel, arsenic, mercury, silver, and selenium. Water samples were subjected to a seven-day test of survival and reproduction using the water flea *Ceriodaphnia dubia*. Sediment samples were bioassayed with the amphipod *Hyalella azteca* and Microtox®. The *Hyalella* bioassay measures survival after 10 days. Microtox monitors changes in the light output of a luminescent bacteria.

The health of the benthic invertebrate community in Railroad Creek was quantitatively assessed at each of the above four sampling sites. Riffle environments were specifically chosen to control variability to due habitat type. A suite of instream variables that relate to invertebrate habitat requirements were also measured.

Findings

Water

- Only modest impacts were observed on general water quality conditions in Railroad Creek during spring runoff (June). At low flow (September), Railroad Creek downstream of Holden became more turbid (4.2 vs. 1.6 NTU), had increased total suspended solids (4 vs. <1 mg/L), and was highly colored due to iron hydroxides (34 vs. 7 color units).

- The mine portal drainage and tailings leachage had high concentrations (>1,000 ug/L; parts per billion) of iron, aluminum, manganese, zinc, and copper. Relative to concentrations in Railroad Creek, cadmium, lead, and selenium were also elevated in these discharges. Nickel, arsenic, mercury, and silver were low to non-detectable. Comparable results are reported from limited sampling done by the Forest Service and Geological Survey.

- Downstream of the Holden site, concentrations of iron, aluminum, manganese, zinc, copper, cadmium, and lead in Railroad Creek increased by factors of 3 to >10.

- The water quality of Copper Creek was similar to upper Railroad Creek and showed no impairment from flowing through the tailings piles. Leachate flow paths apparently do not intersect the creek.

- Ecology data are consistent with historical data in showing iron concentrations vary inversely with stream flow, while zinc concentrations tend to be greatest at higher flows. The detection limits for other metals that have been monitored historically, copper and lead, have not been low enough to show trends.

- Metal loads in Railroad Creek downstream of Holden increased by 660 - 1,200 pounds per day for iron, 9 - 70 pounds per day for zinc, 28 pounds per day (June) for copper, and 0.4 pound per day or less for cadmium and lead (total recoverable metals). Loads above the mine were 23 - 87 pounds per day iron, approximately 1 - 5 pounds per day each for zinc and copper, and 0.2 pound per day or less for cadmium and lead.

- Tailings pile leachate was the major source (>99%) of iron to the creek. The mine portal drainage appeared to be the more important source of zinc, copper, cadmium, and lead.

- Concentrations of total recoverable iron and dissolved zinc, copper, and cadmium downstream of Holden exceeded criteria for protection of aquatic life.

- All measurements of downstream iron concentrations exceeded water quality criteria. The higher levels found in September were 3-to-6 times above the Canadian guideline of 300 ug/L (684 - 1,970 ug/L) and up to twice the U.S. Environmental Protection Agency (EPA) 1,000 ug/L criteria (1,970 ug/L).

- Iron also consistently exceeded the maximum contaminant level (MCL) of 300 ug/L for aesthetics set by state drinking water regulations.

- Dissolved zinc, copper, and cadmium concentrations measured in June exceeded EPA water quality criteria. Copper substantially exceeded the acute criterion from the tailings pile to the creek mouth. The acute zinc criterion and chronic cadmium criterion were exceeded below the tailings (RC-2) but not in the samples collected at the creek mouth. Zinc apparently remained at problem levels for an undetermined distance downstream of Holden during June.

- Lower metals concentrations and higher hardness conditions encountered in September during low flow resulted in few violations of criteria for dissolved metals. The zinc concentrations below the tailings piles were marginally above the acute criterion and fell to the criterion level by three miles downstream at MP-7. Copper and cadmium were within criteria at all areas.

- Historical data indicate the creek is probably in continual violation of the Canadian guideline for iron and commonly exceeds EPA's iron criterion in August-September. Exceedances of the EPA water quality criteria for total recoverable zinc also appear to be a common occurrence in Railroad Creek.

- Arsenic concentrations in Railroad Creek (0.32-0.88 ug/L) exceeded EPA human health criteria for fish consumption (0.14 ug/L) but this appears to be a natural condition also encountered in other Lake Chelan tributaries.

- Cyanide was not detectable in the mine portal drainage, tailings leachate, or in Railroad Creek. Other water data on cyanide are limited to 1982-83 when trace amounts were reported in the portal drainage and creek.

- The *Ceriodaphnia* bioassay on Railroad Creek water samples collected during low flow showed an effect on reproduction but not survival. Lowest-observed-effect levels (LOELs) for reproduction were 6.5% (creek water diluted with control water) below the tailings piles and 25% at the creek mouth. The accuracy of these LOELs is uncertain due to an interrupted dose response in the test (i.e., reproduction improved in the middle range of the dilution series).

Sediment

- Relative to upper creek sediments, the tailings are elevated in iron (2-4x), zinc (2x), copper (3-6x), lead (5-10x), and selenium (>10x). The Bureau of Mines reports similar levels of metals in the tailings material and has detected traces of cyanide.

- Sediment samples collected below Holden mine were comprised of from 5 - 14% tailings particles.

- Copper concentrations in the creek sediments below Holden were an order of magnitude above state background levels in freshwater sediments and soil. Zinc, cadmium, and arsenic were also slightly elevated. Similar concentrations are reported by the Bureau of Mines and Geological Survey.

- Iron and copper concentrations approach or exceed levels expected to have a severe adverse effect on sediment-dwelling organisms. Ecology results suggest less of a potential for adverse impacts due to iron than those obtained by the Bureau of Mines. The Bureau of Mines detected traces of cyanide in Railroad Creek sediment samples; all concentrations were below effects levels.

- Results from the *Hyalella* and Microtox bioassays on Railroad Creek sediments suggest that, although some metals are elevated, the concentrations are not toxic. Certain adverse effects could, however, be occurring in the sediments for which these bioassays would not be pertinent tests (e.g., iron precipitates interfering with egg or gill respiration; low interstitial dissolved oxygen due to oxidation of iron).

Benthic Invertebrates

- An extreme drop in the number of benthic invertebrate species and density of organisms was observed below Holden mine, with a slight recovery progressing downstream. The average number of invertebrates/m^2 was 3,130 above the mine, 50 directly below the mine (RC-2), 110 three miles below the mine (MP-7), and 361 at the creek mouth (RC-3).

- Differences between sites in invertebrate density, richness metrics, and community similarity were statistically significant except for richness variables at RC-2 and MP-7, illustrating a lack of recovery for at least three miles below the mine.

- The rich benthic invertebrate community above the mine was reduced to a meager assemblage of metals-tolerant species below the mine. Feeding groups and indicator species sensitive to metals were eliminated while metals tolerant species increased.

- Although drift of insects from upstream areas and tributaries might be expected to ameliorate effects seen in the benthic community, the depression of invertebrate species in Railroad Creek was extreme from the tailings piles to Lake Chelan (approximately 11 miles).

- To measure the effectiveness of future pollution control efforts on Railroad Creek, a biological integrity target of 80% of upstream benthic invertebrate community metrics (e.g., species richness) is proposed for invertebrate communities downstream of Holden mine.

Recommendations

1. Do more thorough water quality monitoring for zinc, copper, cadmium, and lead using sampling and analytical methods capable of measuring background concentrations in Railroad Creek. The analyses should include dissolved metals and hardness for comparison to state standards and EPA criteria. Station RC-2 should be sampled at the same location as in Ecology's 1996 surveys, rather than its historical location near tailings pile #3.

2. Develop a biological monitoring program to identify stream biota changes due to management and clean-up projects. This report recommends a biological integrity target to help measure the effectiveness of future pollution control efforts on Railroad Creek.

3. Obtain more data to resolve the question of whether cyanide is a significant water quality concern for Railroad Creek.

4. Investigate the impact of the Holden site on the wet land/beaver pond on Railroad Creek below Seven Mile Creek.

5. Identify flow pathways for tailings piles leachate into Railroad Creek.

6. Evaluate the presence of tailings particles in Railroad Creek during rain events and assess the amount and frequency of tailings transport incidents by examining cores from the beaver pond area and/or Lake Chelan.

7. Ecology's Water Quality Program should consider the following as additional reasons for listing Railroad Creek as water quality limited (303d): zinc exceeded numeric state surface water quality criteria on two or more sampling dates; toxicity shown in *Ceriodaphnia* bioassay of water samples; and impairment of characteristic uses and aesthetic values.

8. Railroad Creek should be de-listed for arsenic because water column concentrations are due to natural conditions.

Introduction

The abandoned Holden mine is located on the upper reaches of Lake Chelan's Railroad Creek in Wenatchee National Forest, near the boundary of Glacier Peak Wilderness (Figure 1). Acid drainage from the mine portal, as well as acid leachate and sloughing from massive tailings piles bordering the creek, are long-standing water quality concerns. The U.S. Forest Service (Forest Service) has been working to stabilize the site and mitigate impacts to the creek since the 1960s.

Although Holden mine has been the subject of numerous studies, understanding of its effects on Railroad Creek has been lacking in several areas, including the following:

- Natural background levels of copper, lead, cadmium, and other metals had not been measured with sufficient precision to quantify concentration changes below the mine.
- Compliance with Washington State water quality standards could not be determined because of a lack of data on dissolved metals and hardness.
- No toxicity testing had been done on water or sediment samples.
- The health of the benthic invertebrate community had not been adequately assessed.
- Existing data on metals bioaccumulation were difficult to interpret in terms of risk to aquatic life.

In an attempt to fill these data gaps, the Department of Ecology (Ecology) Environmental Investigations and Laboratory Services Program conducted two surveys of Railroad Creek during the summer of 1996. A companion study also evaluated the presence of tailings particles in the creek and their physical/chemical characteristics, results of which are reported by Huntamer (1997). This work was done at the request of the Ecology Central Regional Office in Yakima.

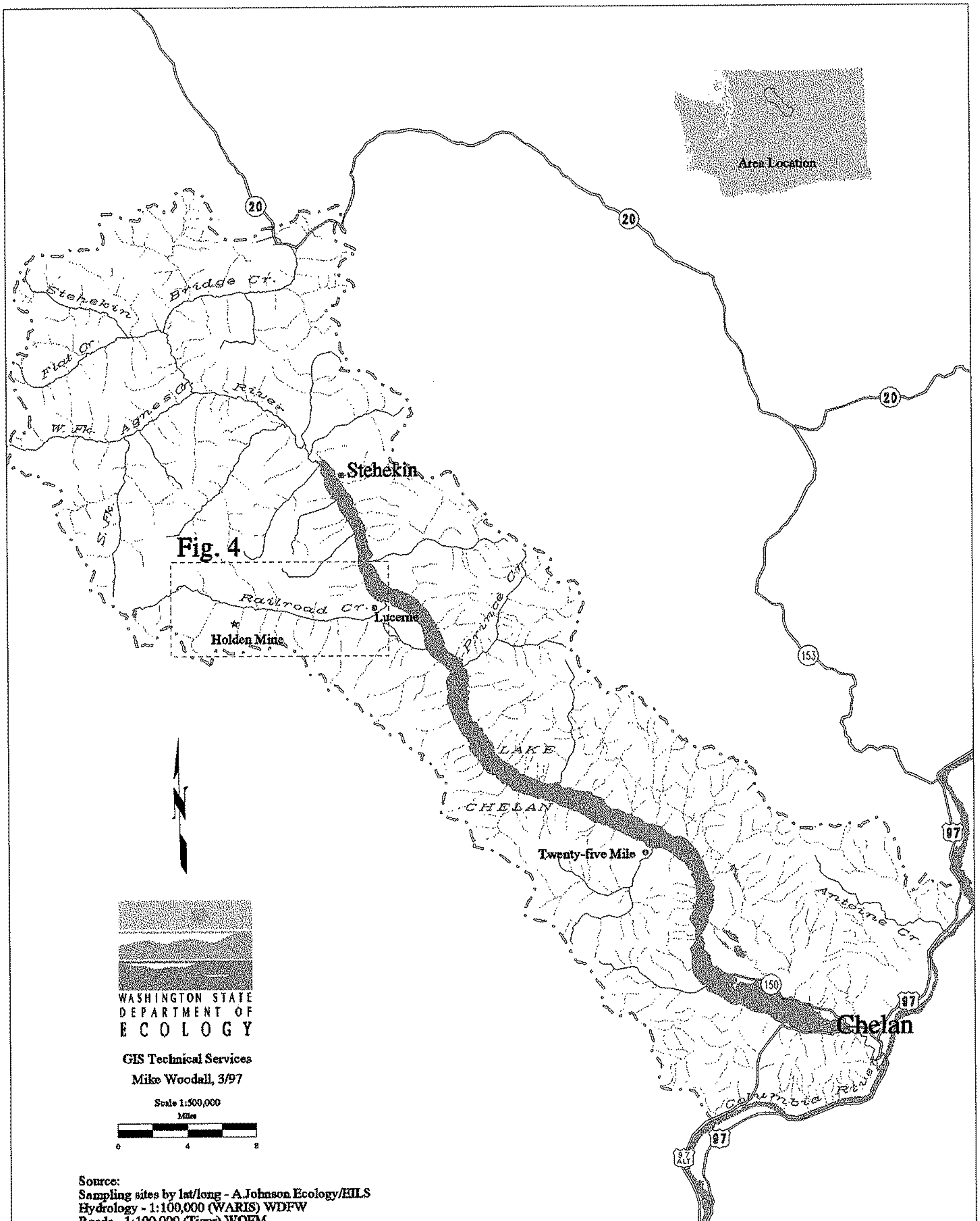


Figure 1. Location of Railroad Creek and Holden Mine

Background

Setting and History

Dames and Moore (1996) recently completed a comprehensive review of data on Holden mine that includes a detailed description of the site and its history (*Existing Data Evaluation & Needs Assessment Report, Holden Mine Site, Chelan County, Washington* prep. for Alumet Inc.). A brief synopsis is provided below.

Railroad Creek originates from Lyman Lake at the base of Lyman Glacier in Washington's north-central Cascades. It flows 18 miles through a steep-sided, glaciated valley to Lake Chelan. Half of the 64 square mile watershed lies within Glacier Peak Wilderness. Holden mine is located 12 miles upstream and 2,100 feet above Lake Chelan. In the vicinity of the mine, the stream gradient is 2-3% but increases to 5-7% the last four miles before entering the lake. The bottom is predominantly cobble and bolder. Several smaller tributaries enter downstream of the mine, the largest of which is Copper Creek.

Watershed geology is dominated by igneous and metamorphic bedrock with valley bottoms overlain with a mixture of unconsolidated glacial, fluvial, and colluvial deposits. Stream flows are maintained by glaciers and ground water. Railroad Creek's discharge peaks in May or June due to snowmelt, with low flow occurring in September. Forest Service stream flow data show extremes of 138 - 1,160 cfs during 1992 - 1995. The creek contributes 12% of the annual inflow to Lake Chelan. Average rainfall is estimated at 35 inches, mostly falling as snow. Average temperatures range from 0° F in January to the 80s in July and August.

Two communities are located in the watershed. The village of Lucerne at the mouth of Railroad Creek can be reached by ferry from 25-Mile Creek (26 miles one-way) or the city of Chelan (45 miles). From Lucerne, a gravel road follows the creek up to the mine. The Holden town site is now operated by the Lutheran Bible Institute of Seattle as a non-denominational religious retreat, Holden Village. Howe Sound Company deeded the mine site and mining claims to the institute in 1960. The tailings and mine portal entrance are under Forest Service jurisdiction. Alumet Inc. is the current principal responsible party.

The ore body, a massive sulfide deposit, was discovered in 1887 by J. R. Holden, a survey engineer for Great Northern Railroad. Howe Sound Company began mining zinc, copper, silver, and gold in 1938. Ore concentrates were barged to Chelan, then trucked to Tacoma for smelting. Gold was initially processed on site by flotation, with some use of cyanide and arsenic, until the mid-1940s when Forest Service restrictions made this unfeasible. The mine closed in 1957 due to declining mineral prices. Approximately $65 million of minerals were produced over the mine's 19-year history.

Figure 2 shows the Holden site. The mining operation left 250 million cubic yards of tailings covering 80-90 acres in three piles up to 150 feet high along the banks of Railroad Creek. The piles have diverted the creek north of its original course. Drainage from the mine portal varies from less than 0.2 to 2 cfs and flows 1/4 mile around the upstream end of the tailings piles into Railroad Creek. Copper Creek emerges between tailings piles #1 and #2. Part of its flow is diverted to generate power for Holden Village.

The portal drainage undergoes little change in quality or quantity between the mine and Railroad Creek (Kilburn et al., 1995; Forest Service, unpublished data). pH is typically in the range of 5 - 6. It has a milky-white color due to "amorphous aluminum and iron hydroxides" (Kilburn et al., 1995). A reddish-brown, high iron-content leachate seeps at various points from the base of the tailings piles. The pH is approximately 3. During low flow, active seepage can be observed upwelling along the edge of Railroad Creek (Figure 3a).

Piezometer readings have shown a direct hydraulic connection between the creek and ground water beneath the tailings piles (PNL, 1991). The contribution of ground water to stream flow in the tailings pile reach has not been measured.

The low pH, and resulting high metal content, of the portal drainage and tailings leachate has been attributed to the oxidation of iron sulfides which causes scavenging of hydroxyl ions in iron hydroxide precipitates (PNL, 1992). The precipitation of iron hydroxides has further caused cementation of the stream bed ("ferricrete") adjacent to and for several hundred feet below the tailings piles. Iron staining can be observed for least an additional five miles downstream of the tailings. No cementation or staining is evident in Copper Creek. Figure 3b illustrates the discoloration of Railroad Creek below tailings pile #3.

The Forest Service has made numerous attempts at reducing water quality impacts to Railroad Creek. Included among these efforts are: 1) placing limestone in the portal drainage ditch to raise the pH and take metals out of solution; 2) installing riprap along the creek bank to reduce erosion of the tailings piles; 3) placing matting to stabilize tailing pile slopes; 4) covering portions of the piles with gravel; and 5) various re-vegetation experiments to reduce surface percolation through the piles (the tailings are not conducive to plant growth without soil amendment). A bulldozer has been used to break up portions of the cemented stream bed.

Previous Surface Water Studies

The impacts of Holden mine on Railroad Creek were investigated as early as 1931 when Howe Sound tested the effects of tailings on trout. More recently, Pine (1967) found low numbers of benthic invertebrates from the tailings piles to within one mile of Lake Chelan. He also observed reddish-brown staining of the creek bed to within three miles of the lake. Krema (1967) noted an absence of fish immediately below the tailings piles. Similar observations of depressed stream fauna and staining have been made by subsequent investigators (e.g., Thorsen, 1970; ORB, 1975; Forest Service, 1977; PNL, 1992).

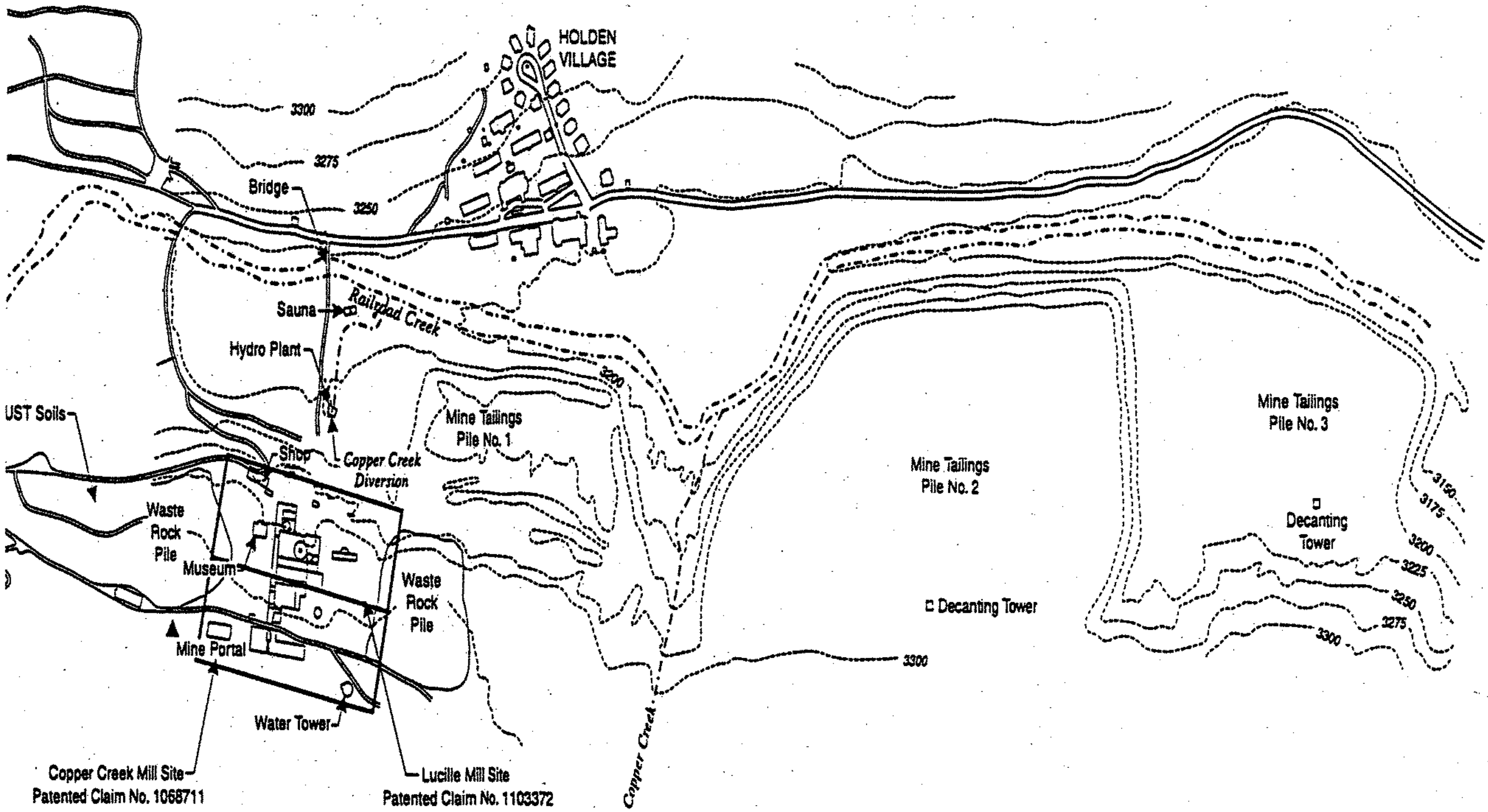


Figure 2. Holden Mine Site and Village. Source: Dames and Moore, 1997.

The following two pages are:

Figure 3a. Leachate at Base of Tailings Pile #1 Next to Railroad Creek (viewed from Pile #2 with Copper Creek in foreground and Holden Village in background, September 1996)

Figure 3b. Railroad Creek Looking Upstream Toward Tailings Pile #3 from Ecology RC-2 Sampling Site (Glacier Peak Wilderness in background, September 1996)

The water quality data available through 1995 are presented in detail in Dames and Moore's review. Reports of elevated concentrations of zinc, copper, and iron in discharges from the Holden site and in Railroad Creek go back to 1966 (Krawcyzk, 1967). Additional historical metals data can be found in Crates (1968), Dean (1970), ORB (1975), and Forest Service (1982, 83). Dames and Moore concluded these sources generally "lacked sufficient test parameters, sampling locations, and sufficient frequency of samples to assess potential impacts from the tailings piles or mine."

Table 1 shows the surface water data that have been obtained since 1983. Selected findings from these studies are discussed later in this report.

As part of a larger study on Lake Chelan, conducted for the Department of Ecology, Patmont et al. (1989) analyzed total recoverable iron, zinc, and arsenic concentrations in water samples from the mouth of Railroad Creek during 1986-87. The same metals were analyzed in Lake Chelan bottom sediments offshore of the creek. Results are also reported on metal concentrations in Lake Chelan fish tissue samples collected within a 2-mile radius of the mouth of Railroad Creek.

Routine water quality monitoring on Railroad Creek was begun by Battelle Pacific Northwest Laboratory (PNL) in 1991 and continued by the Forest Service through 1995. Metals analysis has included total recoverable zinc, lead, copper, and iron. Lack of funding prevented sampling in 1996, but the Forest Service continues to monitor flow. Sampling stations (Figure 4) have consisted of the mine portal; portal discharge at Railroad Creek (P-5); and Railroad Creek above the mine at the wilderness boundary, immediately below tailings pile #3, and at Lucerne (RC-1, -2, and -3, respectively). Only the creek stations have been sampled consistently. Metals data were obtained on Railroad Creek rainbow trout muscle and liver samples in 1991 and 1992 (PNL, 1992; Forest Service, unpublished data).

The U.S. Geological Survey (Geological Survey) analyzed an extensive series of metals and other elements in site discharges, Railroad Creek, and tributaries in August 1994, including tailings, stream sediments, and other solids. The U.S. Bureau of Mines (Bureau of Mines) analyzed a range of metals in tailings and sediment samples collected in March and June 1994; they also analyzed for cyanide.

Because the PNL/Forest Service fish tissue data were not tabulated by Dames and Moore, the results are summarized in Appendix A and briefly discussed here. Concentrations of lead and arsenic, the only two metals analyzed with potential human health significance, were at or below detection limits (1-1.5 mg/Kg) in rainbow trout fillets. None of the metals analyzed were substantially higher in Railroad Creek muscle samples compared to control samples (25-Mile Creek). It should be noted, however, that fish muscle may be a poor indicator for the metals of primary interest at the Holden site, as these are either regulated by fish as essential trace elements -- iron, zinc, and copper -- or have a low potential to accumulate in muscle -- lead and cadmium (Phillips, 1980; Merz, 1981; Ginn and Barrick, 1988).

Table 1. Recent Surface Water Data on Holden Mine, Railroad Creek, and Vicinity

Year	Sample Type	N =	Analysis	Investigator	Reference
1986-1987	creek water sediment (Lk. Chelan) fish muscle & whole (var. spp.; Lk. Chelan)	5 2 7	As,Fe,Zn As,Fe,Zn As,Cd,Cu,Hg,Pb,Se,Zn	Ecology	Patmont et al. (1989)
1991	portal drainage creek water	16 24	Cu,Fe,Pb,Zn, other elements, general water quality	Battelle	PNL (1991)
1991	rainbow trout muscle rainbow trout liver	7 7	Cu,Pb,Zn	Battelle	PNL (1992)
1992-1995	portal drainage creek water	92	Cu,Fe,Pb,Zn, other elements, general water quality, flow	Forest Service	USFS (unpub.)
1992	rainbow trout muscle rainbow trout liver	18 18	As,Al,Cu,Fe,Pb,Ni,Zn	Forest Service	USFS (unpub.)
1994	portal drainage tailings tailings leachate salts & percipitates creek & trib. sediments creek & trib. minerals creek & trib. water	1 1 2 9 14 14 17	Al,As,Cd,Cu,Fe,Pb,Mn, Ni,Se,Ag,Zn, other elements	Geolgical Survey	Kilburn et al. (1994)
1994	tailings creek sediments	7 6	Al,As,Cd,Cu,Fe,Pb,Mn, Hg,Ni,Se,Ag,Zn, other elements,CN	Bureau of Mines	Lambeth (1995)

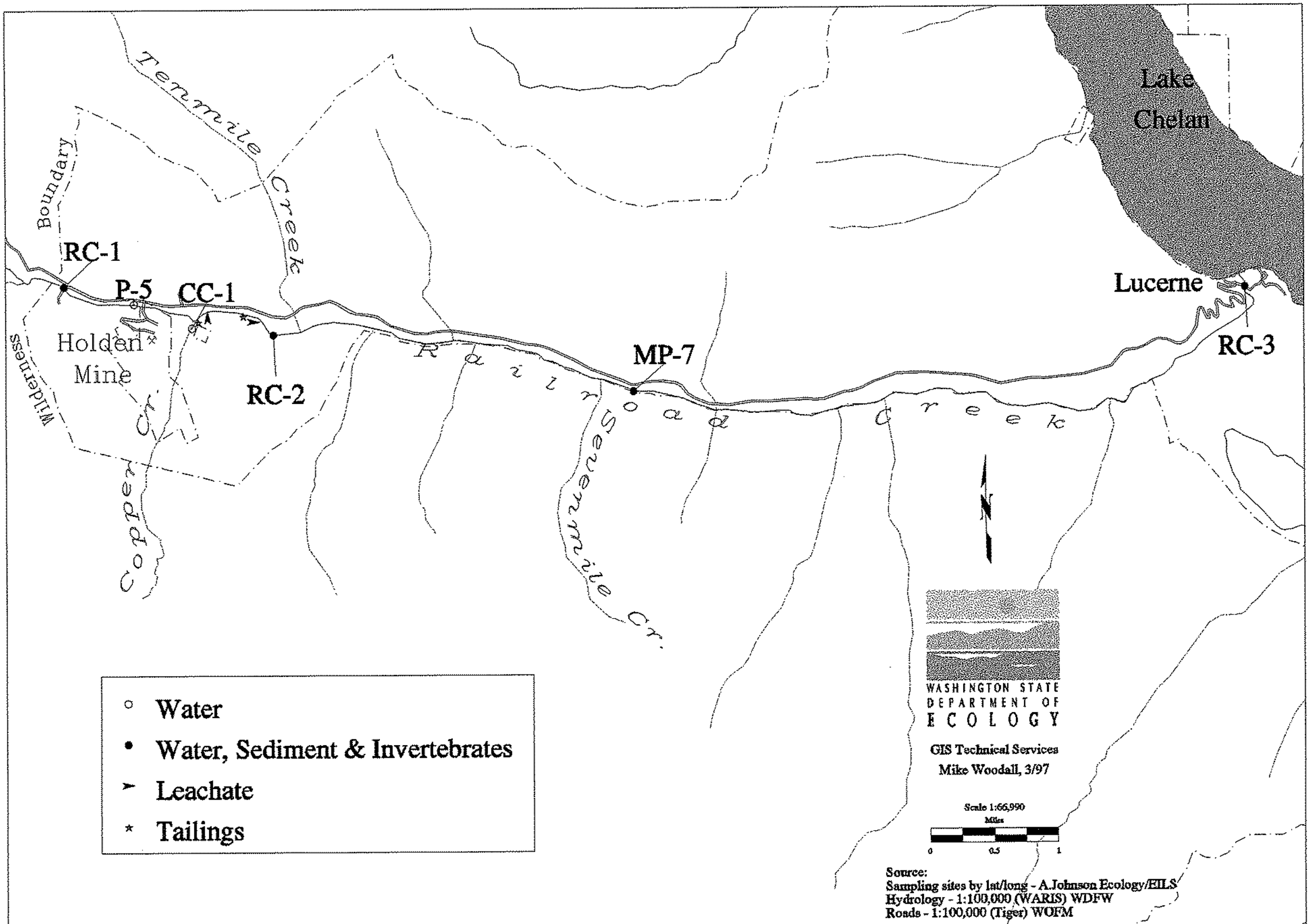


Figure 4. Ecology 1996 Sampling Sites on Railroad Creek

There were some elevations in iron and copper in the Railroad Creek liver samples compared to the control site, but results for both muscle and liver showed order of magnitude differences between 1991 and 1992, raising questions about the representativeness of these data. Patmont et al. (1989) concluded there was a "slight increase" in copper and zinc concentrations in fish collected in Lake Chelan near Railroad Creek, primarily evident in whole fish samples.

Description of Ecology 1996 Surveys

Reconnaissance/High Flow Survey

An initial survey was conducted on June 12 to inspect the site, locate monitoring stations, obtain initial water quality data, and do qualitative sampling of benthic invertebrates. Flow at the mouth of Railroad Creek was 615 cfs, which is typical for June (Figure 5). Water samples were collected at the downstream end of the mine portal discharge (P-5), mouth of Copper Creek (CC-1), and the three Railroad Creek monitoring stations -- RC-1 near the wilderness boundary, RC-2 below the tailings piles, and RC-3 at Lucerne (Figure 4). RC-2 has historically been located on the left bank directly opposite the downstream end of tailings pile #3. To allow more thorough mixing of the leachate, Ecology samples were collected approximately 100 yards further downstream. A sample of the leachate was taken from the east side of tailings pile #3. All water samples were simple grabs, the creek samples coming from center channel.

Samples were analyzed for a range of conventional water quality parameters, cyanide, and metals. To achieve low detection limits, metals samples were collected using ultra-clean techniques and analyzed using low-level methods. Metals analyzed included those in the Forest Service monitoring program (zinc, copper, iron, and lead); other metals shown to be elevated in Geological Survey samples of Holden discharges (iron, aluminum, manganese, cadmium, and nickel); and arsenic, mercury, and silver.

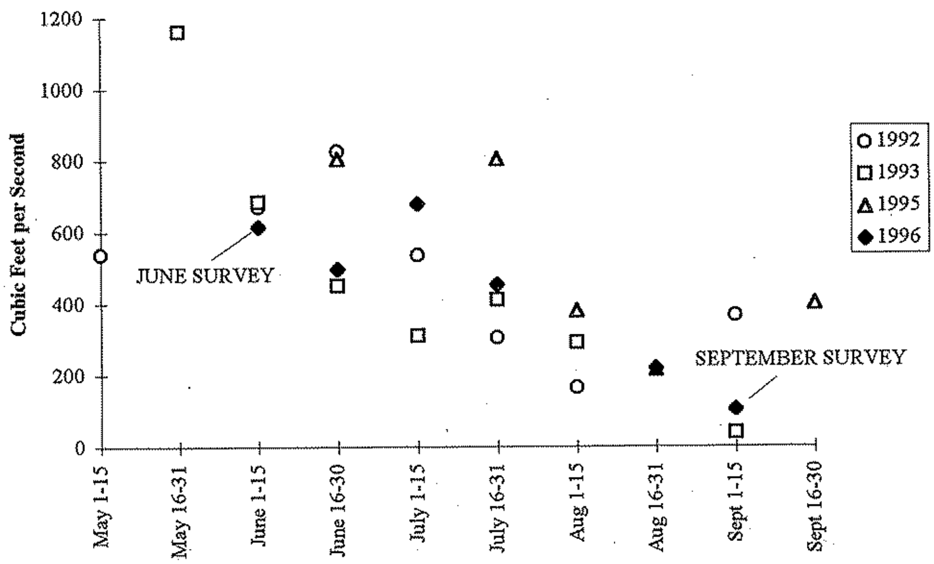
Low Flow Survey

More extensive field work was conducted during low flow on September 10-11, including both water and sediment chemistry, bioassays, quantitative sampling of benthic invertebrates, and the Huntamer (1997) tailing particles study, earlier mentioned. Railroad Creek was flowing at 83 cfs which is at the low end of the range observed during late summer and fall (Figure 5). Plans to analyze metals in several invertebrate species could not be carried out because the benthic community below the mine was too poor to provide adequate sample size.

The same sites were sampled as in the June reconnaissance survey, with the addition of a fourth station on Railroad Creek at Milepost 7 (MP-7), approximately three miles below the mine. A leachate sample was collected at the edge of Railroad Creek adjacent to tailings pile #2. Water quality parameters not found at significant levels in the reconnaissance (e.g., cyanide and mercury) were not analyzed in September. An analysis for selenium was added at the request of the Ecology Central Regional Office.

Sediment samples were collected at each water sampling station on Railroad Creek. These samples were composites of multiple grabs taken from pockets of fines deposited

Figure 5. USFS Flow Data for Railroad Creek @ Mouth (showing flow during Ecology 1996 surveys)



among the cobble and bolder substrate. The composites were analyzed for the same metals as water samples, and for grain size and percent solids. Samples of tailings material were taken from piles #2 and #3.

The toxicity of water samples from RC-1, -2 and -3 was assessed through bioassays with the crustacean *Ceriodaphnia dubia* (water flea). This is a seven-day test of survival and reproduction. Results have shown good correlation with impacts seen in benthic invertebrate and fish communities (Eagleson et al., 1990; Dickson et al., 1992).

Aliquots from each of the Railroad Creek sediment samples were subjected to *Hyalella azteca* (amphipod crustacean) and Microtox® bioassays. The *Hyalella* bioassay measures survival after 10-days exposure to bulk sediment. Microtox is a bacterial test (*Vibrio fischeri*) that monitors changes in light output of the test organism; a water extract of the sediments was used for this analysis.

Sites RC-1, -2, -3 and MP-7 were used to quantitatively assess the health of the benthic invertebrate community. Riffle environments were specifically chosen to control variability due to habitat type. Biological communities integrate the effects of different pollutant stressors and thus provide a holistic measure of their aggregate impact over time (Plafkin et al., 1989). Benthic invertebrates are used as measures of biotic integrity by the Ecology Ambient Monitoring Section (Plotnikoff, 1994). A suite of instream variables that relate to invertebrate habitat requirements was also measured.

Field and Laboratory Methods

Water and Sediment

Water samples for metals were collected in 0.5 liter teflon bottles, pre-cleaned for low-level metals analysis by the Ecology/EPA Manchester Laboratory (Kammin et al., 1995). Samples for determination of dissolved metals were filtered in the field through a 0.45 micron Nalgene filter unit (#450-0045, type S), also pre-cleaned by Manchester. The samples were preserved to pH<2 in the field with sub-boiled 1:1 nitric acid, carried in small teflon vials, one per sample. Sample containers and preservation for conventional water quality variables followed standard Ecology practice (MEL, 1994). Samples for *Ceriodaphnia* bioassay were collected in one-gallon glass jars, with teflon lid liners, cleaned to EPA QA/QC specifications (EPA, 1990). The conventional and bioassay samples were place on ice immediately after collection.

Sediment samples were taken with stainless steel scoops and homogenized in the field in stainless steel beakers. Sampling equipment was cleaned by washing with Liquinox detergent and sequential rinses with tap water, dilute nitric acid, and de-ionized water. The homogenate was split into glass jars, described above, or twist-lock bags for grain size. Sediment samples were placed on ice immediately after being split into containers.

Sample analyses were conducted by Manchester Laboratory except for sediment grain size (Soil Technology Inc.), *Ceriodaphnia* bioassay (Parametrix Inc.), and sediment bioassays (CH2M Hill). Metals analysis of water samples was by inductively coupled plasma/optical emission spectrometry (ICP/OES) for high-level samples and ICP/mass spectrometry for low-level samples (EPA method 200.8). Mercury was analyzed by cold vapor atomic fluorescence (CVAF) (EPA methods 245.7). Analytical methods for cyanide (weak acid dissociable) and conventional water quality determinations are described in MEL (1994). The *Ceriodaphnia* bioassay followed EPA (1991).

Metal concentrations in sediment samples were analyzed by ICP (EPA method 200.7; method 270.2 for selenium) or CVAA for mercury (EPA method 245.5). Grain size distribution was determined using the Puget Sound Estuary Program method. Sediment bioassays followed ASTM method E1383-90 for *Hyalella* and the Microtox Eluate Test Protocol (Microbics Corp.).

Benthic Invertebrates

Sampling

Sampling sites were located in riffle habitats no greater than 15 m in length with water depths less than 3 ft and water velocities between 20 cm/sec and 150 cm/sec (visually estimated because of flow meter malfunction). Sites met the following habitat comparability criteria (Bode, 1995):

- Substrate particle size: mean composition of the substrate should not differ by more than 3 phi units.
- Visual substrate embeddedness: the substrate difference should not exceed 50% unless the percentage is within a value of 20%.
- Canopy cover: the canopy cover should not differ by more than 50% unless the actual values are less than 20%.

A d-frame kick net (500 micron mesh) was used to sample the benthic macroinvertebrate community. Four, $0.1m^2$ samples were randomly placed within each of the four sites. Sampleable area was defined as being within the middle 75% of the riffle's width and middle 90% of its length. The first sample was placed at the downstream edge of the designated sampling site and each additional sample was taken upstream to prevent disturbance. Each sample had an effort of 1-2 minutes kicking upstream of the net to dislodge invertebrates. All hard substrates within the sample area were then removed by hand and scrubbed to remove attached organisms. Samples were preserved in 95% ethanol for laboratory analysis.

Several habitat parameters were estimated at each riffle. Micro-habitat variables measured at each sample location included depth and visual substrate characterization. Percent substrate was classified into seven categories: bedrock, boulder (>256mm), cobble (64-256mm), large gravel (32-64mm), small gravel (16-32mm), coarse sand (2-16mm), and fine sand (<2mm). Organic substrate was categorized as coarse particulate organic matter (>1mm) or fine particulate organic matter (<1mm). General riffle characteristics were estimated at three cross-sectional transects with a surveyors rod and tape including bankfull width, wetted width and five equally spaced depth measurements. Overall riffle estimates were made from EPA Region 10's visual habitat quality assessment procedures (Hayslip, 1993), canopy cover was estimated visually, and water surface gradient was measured to the nearest 1% with a hand-held clinometer.

Once in the laboratory, invertebrates were sorted from benthic debris with a 6x stereo-microscope and placed in 70% ethanol for later identification. Invertebrate identifications followed Plotnikoff and White (1996) with the exception of Chironomidae which were identified to the lowest taxonomic level possible.

Data Analysis

Several techniques were employed to analyze differences between sites for the biological data including direct gradient analysis, sample similarity, ordination, and analysis of variance (ANOVA). Direct gradient analysis uses graphical and tabular data formats to illustrate changes in variables and species across sites. Benthic community data were summarized by metrics and indices (taxa richness, EPT richness, Metals Tolerance Index), species composition data, and trophic status. Taxa richness was defined as the total number of distinct identifiable taxa. Communities stressed from pollution or other perturbations generally decrease in overall taxa richness. EPT richness is defined as the total number of distinct identifiable taxa found in the orders Ephemeroptera, Plecoptera, and Trichoptera, which are considered the "clean water taxa". As with total taxa richness, pollution impacts will decrease this index.

The Metals Tolerance Index (MTI) was derived by McGuire and Ingman (1989) to show the relative number of metal pollution tolerant taxa within the community. This index has a range of 0 to 10 and will tend to increase with increasing levels of metals. It is calculated as follows:

$$MTI = \sum (\%RA_i * t_i)$$

where, $\%RA_i$ = percent relative abundance of each taxon
t_i = metals tolerance value of taxon

t_i values were adopted from research on the Clark Fork River in Montana (McGuire, 1989; Bukantis, 1996; McGuire and Ingman, 1996). Their applicability to Railroad Creek is provisional until further information is gathered on central Washington benthic invertebrates.

Several multivariate techniques were used to describe the benthic invertebrate community including the Bray-Curtis similarity coefficient and non-metric multidimensional scaling. Between sample similarity as defined by Bray-Curtis (1957) measures the contribution of each occurring taxa across all sites. Since highly abundant taxa can mask the effects of rare taxa in multivariate analysis, the data were log transformed to increase the contribution of rare taxa to the analysis (Green, 1979). Low similarity would be expected between samples from impact and control sites. Hierarchical clustering with group average linking was used to show sample groupings from the calculated similarity matrix. Clustering, however, can be misleading in the event of a steady gradation in community structure across sites due to an environmental effect. Therefore an ordination technique, non-metric multidimensional scaling (MDS), was also used as a check of sample relationships shown by the Bray-Curtis similarity matrix (Clarke, 1993).

Several variables are recommended to test site differences including total taxa richness, EPT taxa richness, organism density, MTI, and site similarities (Winner et al., 1980; Clements et al., 1988; Clarke and Warwick, 1994; McGuire and Ingman, 1996). Density was logarithmically transformed as suggested by Green (1979) to alleviate the problem of unequal variances between samples (heteroscedasticity) known to occur with invertebrate data. Systat was used to calculate a one-way ANOVA test for overall site differences for each variable and Tukey's multiple comparison test was used to test for significance between sites (α=0.05). Tukey's is a conservative, *a posteriori* test which controls the experiment-wise error rate for all comparisons (Ott, 1988). A permutation test for differences between average site similarities was calculated with the software program Primer (Plymouth Marine Laboratories, 1995). Primer first tests for overall significance and, if true, performs pair-wise tests between all sites.

Quality of the Data

Metals and Cyanide

No significant problems were encountered in the metals analysis, and the accuracy of the data is good. A series of bottle and filter blanks have been prepared and analyzed using the methods described in this report and show no significant contamination arising from collection, preservation, or handling techniques (Appendix B).

Manchester Laboratory prepared written quality assurance reviews of the metals data (Appendix C). These assess adherence to sample holding times, instrument calibration, results on procedural blanks, spike recoveries, precision data, and laboratory control samples. The following minor problems were identified:

1. One of the two laboratory duplicates for the June dissolved metals samples had low matrix spike recoveries for zinc (69% / 112%) and aluminum (73% / 92%). The lower recoveries are slightly outside acceptance limits of +/-25% set by the EPA Contract Laboratory Program (CLP). Recoveries on a laboratory control sample were 96-97% of the values certified for zinc and aluminum.

2. ICP/MS matrix spike recoveries for zinc in the September total recoverable metals samples for Railroad and Copper creeks were very low (20-27%). Zinc concentrations in these samples were also measured by ICP/OES, a method more appropriate for higher levels of zinc. ICP/OES zinc recoveries were 96-97%.

   The ICP/OES zinc results compare closely to those obtained by ICP/MS (15-17% higher for RC-2, RC-3, and MP-7) but the low concentrations above the mine (RC-1) and in Copper Creek (CC-1) could not be quantified at the ICP/OES detection limit of 4 ug/L. Therefore, the total recoverable zinc data in the present report are by ICP/OES except for RC-1 and CC-1 where the ICP/MS values of 3.0 and 1.1 ug/L, respectively, are used.

3. The concentration of copper (0.14 ug/L) in the ICP/MS procedural blank for September total recoverable metals samples may have contributed significantly to the result for CC-1 (0.23 ug/L).

4. Zinc spike recoveries for the sediment samples were marginally outside CLP limits (71-73%). Laboratory control sample recoveries of zinc were acceptable at 87%.

5. Check standards showed potential selenium interferences in the leachate sample collected from tailings pile #2. The selenium result on this sample may be biased high.

The analytical precision of the metals data on water can be further assessed from results of duplicate (split) analysis on a sample collected at RC-2 below the tailings piles (Table 2). Duplicate measurements agreed within 11% or better except for dissolved aluminum (21%) and dissolved lead (67%). Results on field replicates -- separate samples collected 15-30 minutes apart -- provided later in this report, showed overall variability in the data (analytical + field) was low, including aluminum and lead.

The matrix spike recovery was 94% in the cyanide analysis of water samples. Method blanks and duplicate analysis of a Railroad Creek sample gave the same results -- no cyanide detectable at a detection limit of 10 ug/L.

Table 2. Results of Duplicate Metals Analyses, RC-2, September 10, 1996 (ug/L)

	Analysis #1	Analysis #2	RPD*
Total Recoverable			
Iron	1960	1980	1%
Aluminum	92	100	8%
Manganese	20	20	0
Zinc	26	27	4%
Copper	2.4	2.4	0
Cadmium	0.13	0.12	8%
Lead	<0.10	0.10	≥1%
Selenium	<0.4	<0.4	0
Dissolved			
Aluminum	6.3	7.8	21%
Zinc	30	28	7%
Copper	0.86	0.77	11%
Cadmium	0.13	0.13	0
Lead	0.06	0.03	67%

*RPD = relative percent difference (range of duplicates as percent of mean)

Bioassays

Appendix D contains descriptions of test conditions and acceptability prepared by the laboratories conducting the water and sediment bioassays. Water quality parameters and control responses were within quality assurance guidelines. Results of reference toxicant tests were within expected ranges, showing the organisms were appropriately sensitive.

Benthic Invertebrates

All taxa identified were verified with Ecology's regional invertebrate reference collection. The invertebrate samples from Railroad Creek will be stored at the Ecology headquarters building for six years and made available for validation by interested parties.

Results and Discussion

Water Quality

Spring Runoff

Table 3 shows the general water quality conditions encountered in June. As shown by previous investigations, the mine portal drainage and tailings pile leachate had low pH values and high levels of conductivity and sulfate. The leachate was much more acidic than the mine portal drainage (pH of 3.7 vs. 5.1). Nutrient levels were low in both discharges.

Cyanide was not detectable in the portal drainage, tailings leachate, or in Railroad or Copper creeks. The historical data record in Dames and Moore (1996) shows some

Table 3. General Water Quality Characteristics - - June 12, 1996

	Mine Portal Drainage (P-5)	Tailings Pile #3 Leachate - -	Railroad Creek above Mine (RC-1)	Copper Creek at Mouth (CC-1)	Railroad Creek below Tailings (RC-2)	Railroad Creek at Milepost 7 (MP-7)	Railroad Creek at Mouth (RC-3)
Flow (cfs)*	~1.5	- -	277	~114	391	ns	615
Temperature (C)	10.1	9.5	5.1	4.4	5.4	ns	8.1
Field pH	5.1	3.7	7.4	7.5	7.3	ns	7.1
Conductivity (umho/cm)	498	1080	28	29	34	ns	40
Hardness (mg/L)	191	412	11	12	14	ns	16
Alkalinity (mg/L)	<10	<10	10	<10	<10	ns	13
Sulfate (mg/L)	242	548	2.2	3.0	5.7	ns	5.2
NO2+NO3 (mg/L)	0.03	<0.01	0.09	0.26	0.11	ns	0.09
Total P (mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	ns	<0.01
Turbidity (NTU)	8.5	3.8	1.5	<0.5	1.6	ns	2.1
TSS (mg/L)	13	na	1	1	2	ns	3
Cyanide (mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	ns	<0.01

*flow data provided by USFS
na = not analyzed
ns = not sampled

instances of low levels of cyanide during 1982-83 in the portal drainage ("trace" - 1.2 ug/L) and downstream Railroad Creek ("trace" - 5.6 ug/L). However, "traces" of cyanide are also reported in Railroad Creek above the mine during this same period. Dames and Moore report no further cyanide determinations. The present survey appears to include the first analysis for cyanide in the tailings pile leachate. The state water quality standards for cyanide are 5.5 ug/L (chronic) and 22 ug/L (acute), as weak acid dissociable.

Only modest impacts to Railroad Creek were observed in terms of general water quality parameters (Table 3). The largest increase was seen in sulfate which was at 2.2 mg/L above the mine and 5.7 mg/L downstream of the tailings piles. These sulfate levels are low for natural waters (McKee and Wolfe, 1963; Hem, 1985). There was little or no evidence of an effect on creek pH. Except for a somewhat higher nitrate concentration, water quality in Copper Creek was almost identical to upper Railroad Creek.

Results of metals analysis show a much greater impact on the creek (Table 4). High concentrations of iron, aluminum, manganese, zinc, and copper were evident in the portal drainage and tailings leachate. The leachate was substantially higher in iron (39,900 ug/L), aluminum (25,700 ug/L), and manganese (2,140 ug/L), while the portal had more zinc (6,840 ug/L) and copper (2,040 ug/L). Relative to concentrations in Railroad Creek, cadmium (5.5 - 35 ug/L) and lead (2.0 - 31 ug/L) were also elevated in these discharges. Arsenic, mercury, and silver were low in all areas.

Forest Service monitoring data for the portal drainage show similar levels of iron, zinc, copper, and lead (see Appendix E). Other metals data on discharges from the Holden site are extremely limited. The Geological Survey (Kilburn et al., 1994) analyzed dissolved metals in one sample each of portal drainage and active leachate (a quiescent pool of leachate was also sampled). Results show most metals are primarily in a dissolved state and confirm the elevated aluminum, manganese, and cadmium and low arsenic and silver seen in the Ecology samples (Appendix E).

Large increases in metal concentrations were observed in Railroad Creek downstream of the tailings piles. There was an order of magnitude increase in total recoverable iron (from 71 to 599 ug/L) and in dissolved zinc (1.3 to 40 ug/L) and copper (0.96 to 10 ug/L). Concentrations of total recoverable aluminum and manganese and dissolved cadmium and lead rose by factors of 3 to 6. Dissolved zinc, copper, cadmium, and lead concentrations were decreased by approximately half at the mouth of Railroad Creek, a reduction in rough proportion to the increase in stream flow (391 to 695 cfs, Table 3). A similar decrease was not seen in total recoverable iron, aluminum, or manganese, suggesting additional downstream inputs, perhaps from entrained sediment particles.

Metal concentrations in Copper Creek were comparable to or slightly lower than upper Railroad Creek, showing no impact from flowing through the tailings piles.

Table 4. Metal Concentrations in Water Samples - - June 12, 1996 (ug/L)

	Mine Portal Drainage (P-5)	Tailings Pile #3 Leachate - -	Railroad Creek above Mine (RC-1)	Copper Creek at Mouth (CC-1)	Railroad Creek below Tailings (RC-2)	Railroad Creek at Milepost 7 (MP-7)	Railroad Creek at Mouth (RC-3)
<u>Total Recoverable</u>							
Iron	591	39900	71	32	599	ns	438
Aluminum	6650	25700	13	3.8	44	ns	37
Manganese	299	2140	1.3	<1.0	8.2	ns	7.9
Zinc	6840	522	3.7	1.1	36	ns	22
Copper	2040	191	1.4	0.24	14	ns	7.9
Cadmium	35	5.5	<0.02	<0.02	0.21	ns	0.13
Lead	31	2.0	0.13	0.04	0.21	ns	0.17
Nickel	4.1	36	0.34	0.30	0.44	ns	0.43
Arsenic	0.23	0.35	0.69	<0.2	0.63	ns	0.42
Mercury	0.002	0.015	<0.001	<0.001	0.001	ns	0.002
Silver	<0.1	<0.1	0.02	<0.01	<0.01	ns	0.03
<u>Dissolved</u>							
Zinc	na	na	1.3	<0.4	40	ns	20
Copper	na	na	0.96	0.10	10	ns	5.2
Cadmium	na	na	0.05	<0.02	0.29	ns	0.16
Lead	na	na	0.02	<0.02	0.07	ns	0.04
Nickel	na	na	0.22	0.22	0.36	ns	0.26
Silver	na	na	<0.01	<0.01	<0.01	ns	<0.01

na = not analyzed
ns = not sampled

Low Flow

Water quality results from the September low flow survey are in Tables 5 (conventional parameters) and 6 (metals). Although the portal drainage appeared more concentrated in terms of conductivity, hardness, sulfate, iron, and manganese, most metal concentrations were lower than in June. This may reflect the influence of higher pH. Metal concentrations in the leachate sample from tailings pile #2 compared closely to earlier results for pile #3. Except for a much higher concentration of iron, metal concentrations in the two leachate samples were within a factor of approximately 2.

Table 5. General Water Quality Characteristics - - September 10-11, 1996

	Mine Portal Drainage (P-5)	Tailings Pile #2 Leachate - -	Railroad Creek above Mine (RC-1)	Copper Creek at Mouth (CC-1)	Railroad Creek below Tailings (RC-2)	Railroad Creek at Milepost 7 (MP-7)	Railroad Creek at Mouth (RC-3)
Flow (cfs)*	~1	- -	55.3	~8	63.8	- -	83.4
Temperature (C)	12.5	na	10.4	8.0	11.1	8.2	11.1
Field pH**	6.0	3.1	6.4	7.4	7.3	7.1	6.3
Lab pH	7.2	2.8	7.3	7.4	6.8	7.0	7.4
Conductivity (umho/cm)	778	2905	32	33	47	56	55
Hardness (mg/L)	350	1060	14	13	18	22	22
Sulfate (mg/L)	394	2250	3.4	4.3	11	13	12
Sulfide (mg/L)	<1	na	<1	<1	<1	<1	<1
Turbidity (NTU)	9.4	na	1.6	1.3	4.2	3.6	2.8
TSS (mg/L)	13	na	<1	<1	4	3	1
Color (units)	30	50	7	5	34	35	25

*flow data provided by USFS
**accuracy of these data uncertain (see text)
na = not analyzed

Downstream of the tailings piles, Railroad Creek became more turbid, had increased total suspended solids, and was highly colored. Huntamer (1997) determined that the color is not due to mine tailings but rather to "flakes of an iron-bearing mineral, possibly goethite (a-FeOH)". These coat the tailings particles and may be dislodged by stream turbulence. Another source is "in situ" formation due to changes in pH as the leachate enters the creek. His examination of "cementation" fragments from the stream bed also showed the presence of flakes with similar characteristics. Scanning electron microscopy with X-ray microanalysis of the "orange coating" on the tailing pile and station RC-2 grains were compared to the orange coating on the cementation fragments. Elements detected in all three samples included iron, oxygen, aluminum, silicon and calcium. The coating on the tailing pile grains and station RC-2 also showed some sodium, potassium and sulfur.

The effect of the Holden site on Railroad Creek pH during the September survey is uncertain. The field meters used in September were extremely slow to equilibrate in the creek water and the results, particularly above the mine, are questionable.

Table 6. Metal Concentrations in Water Samples - - September 10-11, 1996 (ug/L)

	Mine Portal Drainage (P-5)	Tailings Pile #2 Leachate - -	Railroad Creek above Mine (RC-1)	Copper Creek at Mouth (CC-1)	Railroad Creek below Tailings (RC-2)	Railroad Creek at Milepost 7 (MP-7)	Railroad Creek at Mouth (RC-3)
Total Recoverable							
Iron	1370	279000	77	<20	1970+/-10*	1240	684
Aluminum	3970	22600	32	19	96+/-4	110	50
Manganese	358	5030	1.9	<1	20+/-0.1	19	13
Zinc	3300	1150	3.0	1.1	30	28	21
Copper	291	209	3.7	0.23	2.4+/-0	1.8	1.4
Cadmium	7.4	4.0	<0.10	<0.10	0.12+/-0.01	0.12	<0.10
Lead	<20	<20	0.12	<0.10	<0.10	<0.10	<0.10
Arsenic	<0.02	na	0.88	<0.2	0.68	0.51	0.32
Selenium	<40	93	<0.4	<0.4	<0.4	<0.4	<0.4
Dissolved							
Aluminum	na	na	7.4 +/- 0.1	5.7	5.4 +/- 1.0	3.2 +/- 0	6.4 +/- 0.1
Zinc	na	na	0.85 +/- 0.06	1.5	30 +/- 0	25 +/- 0	19 +/- 3
Copper	na	na	0.26 +/- 0.01	1.2	0.93 +/- 0.07	0.39 +/- 0.13	0.40 +/- 0.06
Cadmium	na	na	0.02 +/- 0.01	<0.01	0.13 +/- 0	0.12 +/- 0	0.08 +/- 0.01
Lead	na	na	0.02 +/- 0.01	0.04	0.06 +/- 0	<0.01	0.09 +/- 0.02

*mean +/- range of replicate samples
na = not analyzed

As during high flow, there were large increases in iron, aluminum, manganese, zinc, copper, cadmium, and lead below Holden. Levels of total recoverable iron, aluminum, and manganese were 2-3 times higher at RC-2 than in June, while dissolved metals were generally lower. The order of magnitude decrease seen in copper at this site between June and September (from 10 ug/L to 0.93 ug/L) can be accounted for by the lower concentration measured in the mine drainage (see metal load estimates below).

Copper Creek had somewhat higher concentrations of aluminum, zinc, and copper than during June but metals levels remained low. The Geological Survey has analyzed Copper Creek water samples collected above and below the tailings piles and found no difference in metals concentrations (Kilburn et al., 1994). Leachate flow paths apparently do not intersect the creek.

Except for iron, downstream attenuation in metal concentrations was in general proportion to the increase in flow (63.8 to 83.4 cfs, Table 3). The 65% drop in iron concentrations between RC-2 and RC-3 may reflect precipitation onto the stream bed. An analysis of the filtered samples from RC-2 showed that 68 - 72% of the iron was dissolved; an unusually high concentration of dissolved silicon (2,610 ug/L) was also measured (Jim Ross, Manchester Laboratory, personal communication).

The June and September data on Railroad Creek are consistent in showing that zinc and cadmium occur almost entirely in the dissolved form downstream of the Holden site. Copper and lead, on the other hand, are substantially associated with particulates. Copper, for example, averaged 70% dissolved during June and only 30% dissolved in September (Tables 4 and 6).

Metal Loads

The concentration and flow data obtained in June and September were used to derive estimates of metals loads in Railroad Creek and the mine portal drainage (Table 7). The increased load below the tailings piles ranged from less than 1 pound per day for cadmium and lead, to 660 - 1,200 pounds per day of iron, with the higher loads being measured in June. Aluminum, manganese, zinc, and copper loads were raised by 5 - 76 pounds per day, except for the copper load in September, where no substantive change was detectable.

A comparison with the loads estimated for the portal drainage suggests that tailings pile leachate was responsible for > 99% of the iron getting into the creek at the time these surveys were conducted. The mine portal drainage can account for most (>70%) of the creek's increased aluminum levels, although this conclusion runs counter to the high levels of aluminum in the leachate samples. The portal drainage also appears to be the more important source of zinc, copper, cadmium, and lead. Figure 6 illustrates the iron, aluminum, zinc, and copper loadings.

Aquatic Life Criteria

Table 8 summarizes water quality criteria pertinent to the metals data Ecology obtained on Railroad Creek. EPA defines acute criteria as the highest concentration of a pollutant to which aquatic life can be exposed for a short period of time (1-hour average) without deleterious effects. The chronic criteria are for an extended period of exposure (4 days) without deleterious effects. For criteria that vary with hardness, the values in Table 8 were calculated for 14 and 22 mg/L, the range observed downstream of Holden in June and September. Other hardness data for Railroad Creek are limited to a series of measurements in 1991 showing similar levels of 10 - 24 mg/L (Dames and Moore, 1996).

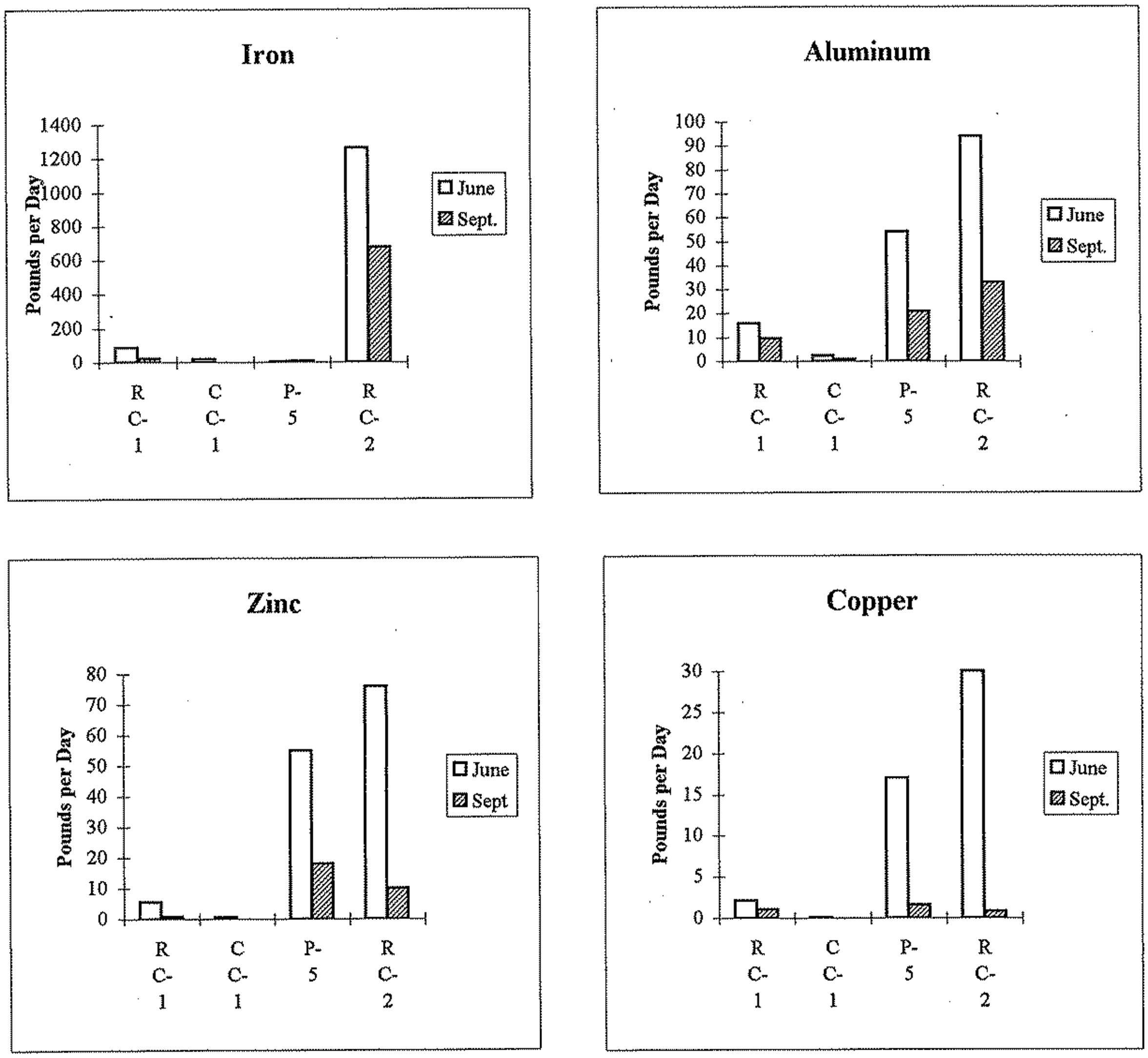
Table 7. Metal Load Estimates (lbs/day; total recoverable metals)

	[a] Railroad Creek above Mine (RC-1)	[b] Copper Creek at Mouth (CC-1)	[c] Railroad Creek below Tailings (RC-2)	[c-a+b] Increased Load in Railroad Creek below Tailings	Mine Portal Drainage (P-5)
			June 12		
Iron	87	19	1265	1159	4.8
Aluminum	16	2.3	94	76	54
Manganese	1.6	<0.6	17	15	2.4
Zinc	5.5	0.7	76	70	55
Copper	2.1	0.1	30	28	17
Cadmium	<0.03	<0.01	0.4	0.4	0.3
Lead	0.2	0.02	0.4	0.2	0.2
			September 10-11		
Iron	23	<0.9	679	656	7.4
Aluminum	9.6	0.8	33	23	21
Manganese	0.6	<0.04	7	5	1.9
Zinc	0.9	0.05	10	9	18
Copper	1.1	0.01	0.8	-0.3	1.6
Cadmium	<0.03	<0.0004	0.04	- -	0.04
Lead	0.04	<0.0004	<0.03	- -	<0.1

The EPA (1986) freshwater aquatic life criterion of 1,000 ug/L shown for iron is probably not sufficiently protective. Canada's recommendation of 300 ug/L takes into account that acute toxicity to aquatic insects can occur down to 320 ug/L and that a criterion of 1,000 ug/L is close to the EC-50 of 1,500 ug/L for hatchability of eggs of some fish species. A limit of 300 ug/L iron has been previously set for the Great Lakes and for Ontario (CCREM, 1987).

EPA has no recent criteria for aluminum. The British Columbia Ministry of Environment considers the Canadian guideline of 5 ug/L total recoverable aluminum overly protective for pH < 6.5 and has developed less restrictive dissolved aluminum criteria to protect Pacific Northwest species (Butcher, 1988a,b). When pH is < 6.5, the values B.C. recommends not to be exceeded vary with pH; the table shows criteria of 47 and 20 ug/L for pH = 6.0. The extensive historical data on Railroad Creek pH show few values below 6.5 (Dames and Moore, 1996).

Figure 6. Load Estimates for Selected Metals (total recoverable)



Manganese is rarely found to be a concern for aquatic life in freshwaters. EPA (1986) reports tolerance values from 1,500 ug/L to over 1,000 mg/L. Neither EPA nor Canada has recommended any aquatic life criteria for manganese.

Water quality criteria for zinc, copper, cadmium, lead, nickel, and silver are for the dissolved fraction and are function of hardness, metals toxicity decreasing with increasing hardness. EPA (1995) recently proposed revisions to the aquatic life criteria for these metals. Ecology intends to adopt the new values in place of current water quality standards (WAC 173-201A) during the triennial review (Mark Hicks, Ecology Water Quality Program, personal communication). The new criteria are, in most cases, slightly less restrictive than current state standards (e.g., @ 14 mg/L hardness, the acute zinc and copper state standards are 20 and 2.4 ug/L vs. 22 and 2.7 ug/L as revised by EPA).

Table 8. Aquatic Life Criteria for Metals (ug/L)

1. TOTAL RECOVERABLE METALS

	Acute	Chronic
Iron[1]	- -	1,000
" [2]	- -	300
Aluminum[2]	100 (@ pH > 6.5)	
"	5 (@ pH ≤ 6.5)	
Manganese[1]	- -	- -
Arsenic[3]	360	190
Mercury[3]	2.4	0.012
Selenium[3]	20	5

2. DISSOLVED METALS

	@ 14 mg/L hardness		@ 22 mg/L hardness	
	Acute	Chronic	Acute	Chronic
Zinc[4]	22	20	32	29
Copper[4]	2.7	2.1	4.1	3.1
Cadmium[4]	0.44	0.24	0.72	0.34
Lead[4]	7.2	0.28	12	0.47
Nickel[4]	268	30	393	44
Silver[4]	0.12	- -	0.26	- -

	@ pH > 6.5		@ pH = 6.0	
	Acute	Chronic	Acute	Chronic
Aluminum[5] (@ pH > 6.5)	100	50	47	20

[1]EPA Gold Book
[2]CCREM
[3]WAC 173 201A
[4]EPA (1995)
[5]Butcher (1988a,b)

Equations for EPA (1995) criteria for dissolved Zn, Cu, Cd, and Pb:

Acute

$Zn=0.978[e^{(0.8473[\ln(hardness)]+0.8604)}]$

$Cu=0.96[e^{(0.9422[\ln(hardness)]-1.464)}]$

$Cd=[1.136672-((\ln(hardness))(.041838))]x\ [e^{(1.128[\ln(hardness)]-3.828)}]$

$Pb=[1.46203-((\ln(hardness))(.145712))]x\ [e^{(1.273[\ln(hardness)]-1.460)}]$

Chronic

$Zn = 0.986[e^{(0.8473[\ln(hardness)]+0.7614)}]$

$Cu=0.96[e^{(0.8545[\ln(hardness)]-1.465)}]$

$Cd=[1.101672-((\ln(hardness))(.041838))]x\ [e^{(0.7852[\ln(hardness)]-3.490)}]$

$Pb=[1.46203-((\ln(hardness))(.145712))]x\ [e^{(1.273[\ln(hardness)]-4.705)}]$

Concentrations of total recoverable iron and dissolved zinc, copper, and cadmium found in Railroad Creek downstream of the Holden site during Ecology's 1996 surveys exceeded criteria for protection of aquatic life. Figures 7 - 9 illustrate the magnitude of the exceedances.

All downstream concentrations of iron exceeded water quality criteria (Figure 7). The higher levels found in September were 3-to-6 times above the Canadian guideline of 300 ug/L (684 - 1,970 ug/L) and up to twice the EPA 1,000 ug/L criterion (1,970 ug/L).

Figure 8 compares the dissolved zinc, copper, and cadmium concentrations measured in June to EPA criteria, based on the hardness values measured at each sampling site. Copper substantially exceeded the acute criterion from the tailings pile to the creek mouth. The acute zinc criterion and chronic cadmium criterion were exceeded below the tailings at RC-2 but not in the samples collected at the mouth. Zinc apparently remained at problem levels for an undetermined distance downstream.

The lower dissolved metals concentrations and higher hardness conditions encountered in September resulted in few violations of criteria (Figure 9). Zinc concentration below the tailings pile was marginally above the acute criterion and met the criterion by MP-7, three miles downstream. Copper and cadmium were within their respective criteria at all areas.

Figure 7. Total Recoverable Iron in Railroad Creek Compared to Water Quality Criteria, Ecology 1996 Samples

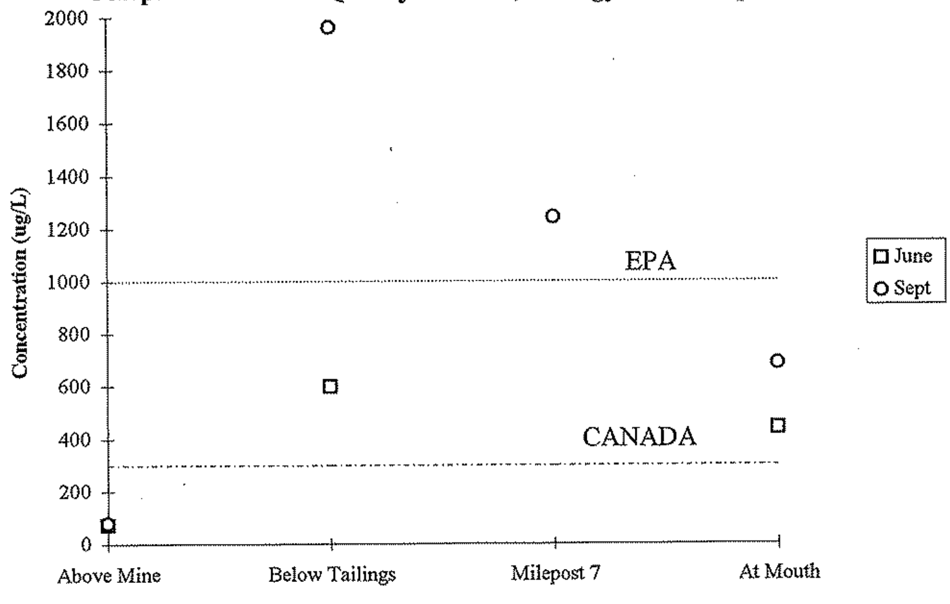


Figure 8. Dissolved Metals in Railroad Creek Compared to EPA Water Quality Criteria, Ecology June 1996 Samples (Zn & Cu vs. acute; Cd vs. chronic)

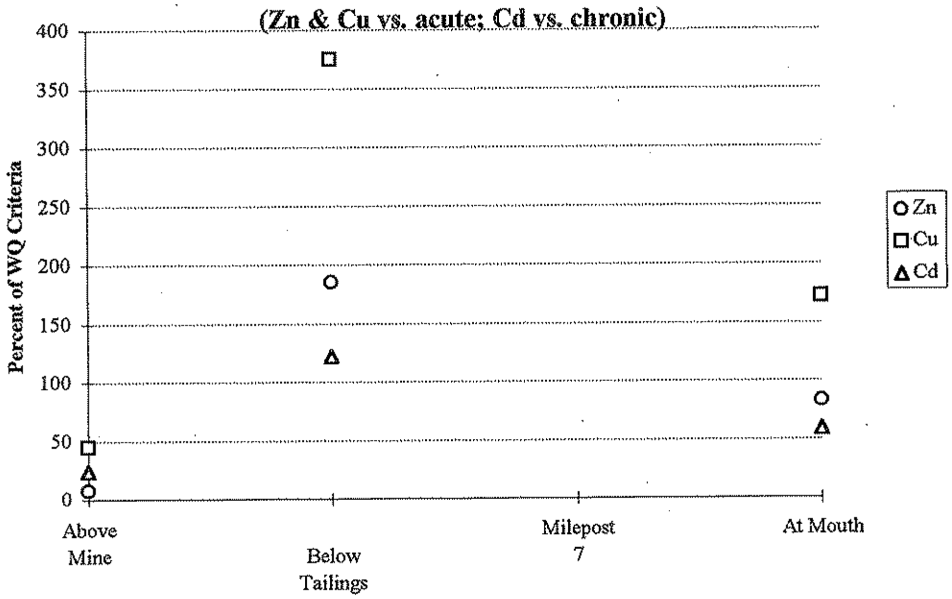
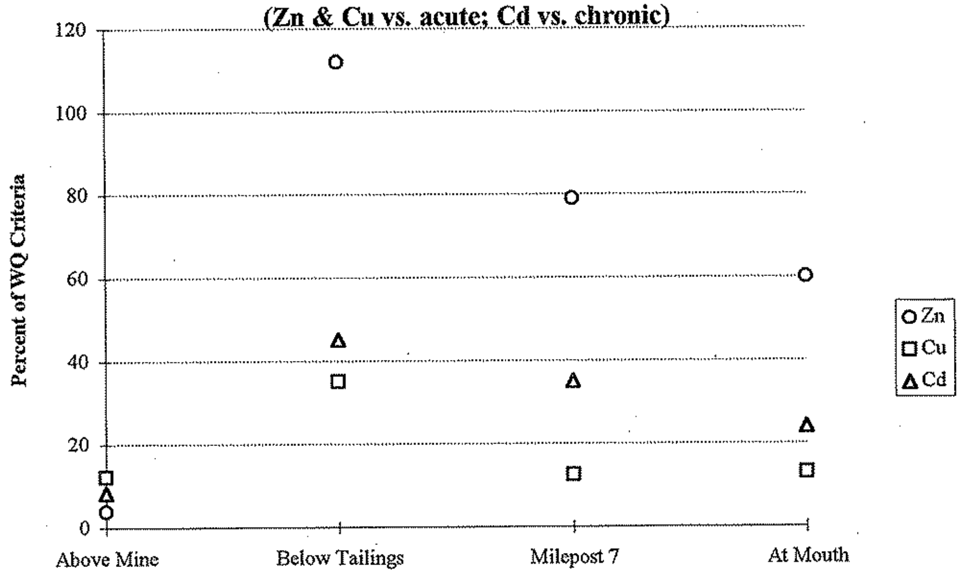


Figure 9. Dissolved Metals in Railroad Creek Compared to EPA Water Quality Criteria, Ecology September 1996 Samples (Zn & Cu vs. acute; Cd vs. chronic)



The Forest Service/PNL 1991-95 routine monitoring data for total recoverable iron and zinc at RC-2 are plotted along with Ecology's recent results in Figures 10 and 11. Due to the higher detection limits used in the 1991-95 monitoring program, the data on the two other metals analyzed, copper and lead, are not useful for showing trends or water quality criteria violations.

The iron plot suggests an inverse relation with stream flow, also noted by Dames and Moore and consistent with results of Ecology surveys. As shown in the figure, the creek at this site has been in continual violation of the Canadian guideline for iron and commonly exceeds EPA criterion in August-September. The low value reported by the Forest Service for September 14, 1994 (<10 ug/L) is likely an error.

An opposite pattern is indicated for zinc, which has generally been found at the highest levels in spring and early summer. Figure 11 shows the older EPA (1986) acute criterion for total recoverable zinc, calculated for the extremes in hardness seen at this site in 1991 and 1996. Like iron, exceedances of the water quality criteria for zinc appear to be a common occurrence in Railroad Creek.

Tetra Tech (1996) has noted the Dames and Moore review does not use appropriate water quality criteria in evaluating existing data on Railroad Creek. Results of Ecology's 1996 survey and the preceding analysis of historical data indicate they seriously understate the extent of water quality problems due to metals: "...introduction of acid drainage has seldom resulted in exceedances of surface water quality criteria in Railroad Creek" (Dames and Moore, 1996).

Toxicity Test

The *Ceriodaphnia* bioassay, conducted on a dilution series of water samples collected in September, confirms Railroad Creek was toxic below the mine. As shown in Table 9, a 6.5% concentration of the water from RC-2 and a 25% concentration from RC-3 were the lowest observed effect levels (LOELs) for reproduction. No-observed-effect levels (NOELs) were <6.5% and 12.5%, respectively. The reproductive LOEL and NOEL above the mine were ≥ 100%. Survival of *Ceriodaphnia* was not affected above or below the mine.

Ceriodaphnia reproduction showed an unusual response to varying dilutions of creek water, detailed in Table 10. Exposure to full-strength water from RC-2 caused low reproduction (mean of 9.3 offspring vs. 21.2 - 23.3 in controls). Dilution with increasing amounts of control water resulted in more offspring (21.7 @ 50% and 20.3 @ 25%) until further dilution again depressed reproduction (8.9 @ 12.5% and 9.6 @ 6.5%). A similar dose response occurred for RC-3 but at higher concentrations.

Figure 10. Total Recoverable Iron in Railroad Creek below Tailings Piles (RC-2) Compared to Water Quality Criteria 1993-96 Data

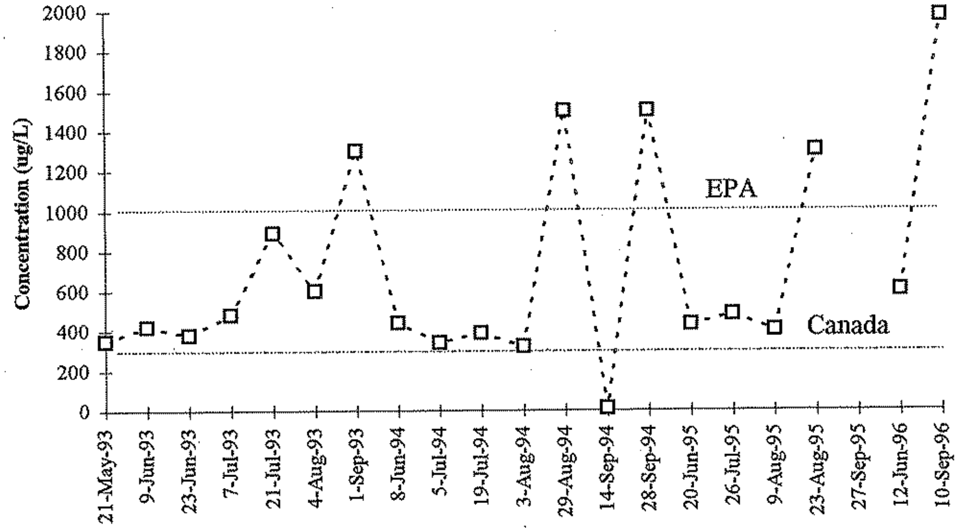


Figure 11. Total Recoverable Zinc in Railroad Creek below Tailings Piles (RC-2) Compared to EPA 1986 Acute WQ Criteria 1991-96 Data

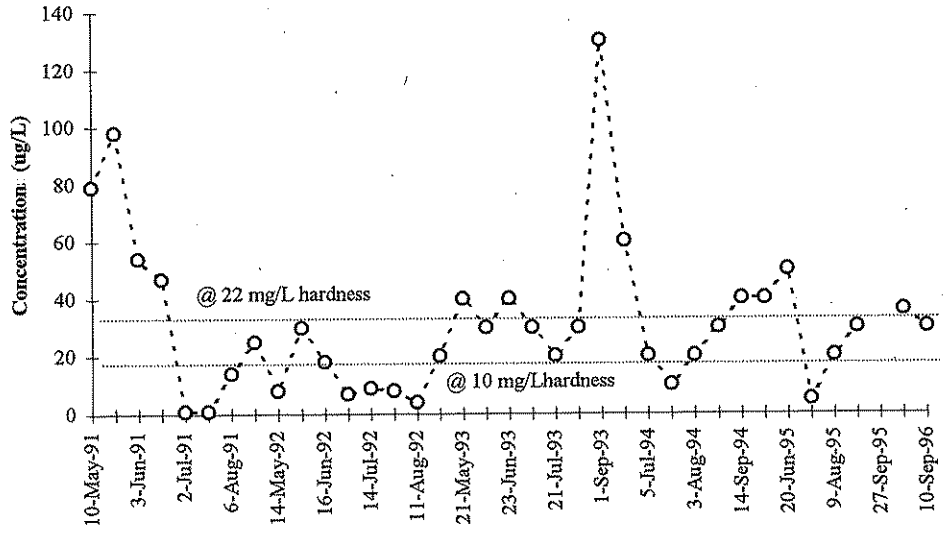


Table 9. Results of *Ceriodaphnia* Bioassays on Water Samples - - September 10,1996

Endpoint	Railroad Creek above Mine (RC-1)	Railroad Creek below Tailings (RC-2)	Railroad Creek at Mouth (RC-3)
Survival			
NOEC*	100 %	100 %	100 %
LOEC**	> 100 %	> 100 %	> 100 %
Reproduction			
NOEC	100 %	< 6.25 %	12 .5 %
LOEC	> 100 %	6.25 %	25 %

*NOEC = no observed effect concentration
**LOEC = lowest observed effect concentration

Table 10. Detailed Results of *Ceriodaphnia* Reproduction
[Average number of offspring produced; 10 replicates each]

Concentration Tested	Railroad Creek above Mine (RC-1)	Railroad Creek below Tailings (RC-2)	Railroad Creek at Mouth (RC-3)
0 %	21.2	23.3	21.3
6.5 %	16.0	9.6	19.9
12.5 %	18.9	8.9	16.5
25 %	19.0	20.3	9.6
50 %	18.1	21.7	13.3
100 %	17.3	9.3	16.0

The phenomenon of an adverse effect being reduced at higher test concentrations, although uncommon, has been observed in *Daphnia magna* bioassays of lead spiked into Spokane River water (Stinson, 1993). Charles Stephan, of the EPA Duluth Laboratory reports a similar response in tests conducted by other investigators on silver's effect to marine organisms. He hypothesized the solubility of the metal in question may be exceeded in mid-range in these tests. That, combined with complexing with other components in the solutions, could produce two or more effects levels (Stinson, 1993). An alternate possibility is the presence of a critical micronutrient that ameliorates a toxic effect at mid-range (Stephan, personal communication).

Regardless of the reason behind the dose response, the absence of a toxic effect in the Railroad Creek sample collected above the mine and in laboratory control/dilution water clearly indicates adverse effects in samples from below the Holden site. There is, however, uncertainty as to the accuracy of the LOEL and NOEL values determined from this test.

Human Health Criteria

Results for metals analyzed in Railroad Creek water samples were compared to state drinking water standards (DOH, 1992) and EPA human health criteria (National Toxics Rule, 40 CFR Part 131). Iron concentrations in Railroad Creek consistently exceeded the drinking water MCL (maximum contaminant level) of 300 ug/L. This standard is set for aesthetic considerations rather than health effects. There were no other instances of drinking water standards being exceeded.

EPA human health criteria are for consumption of water and/or fish tissue, based on bioconcentration factors and water column concentrations. The arsenic concentrations measured in Railroad Creek above and below the mine during June (0.42-0.69 ug/L) and again in September (0.32-0.88 ug/L) exceeded the EPA criteria of 0.14 ug/L for fish consumption and 0.018 ug/L for consumption of both fish and water. These criteria are for a one-in-one-million increased cancer risk. A number of conservative assumptions are incorporated into this risk estimate, including an upper-bound cancer potency, daily consumption rate, and life-time exposure.

Every two years Ecology is required under Section 303(d) of the Clean Water Act to prepare a list containing waterbodies not expected to meet state surface water quality standards after implementing technology-based controls -- commonly referred to as the 303(d) or water quality limited list (Ecology, 1994). Class AA (extraordinary) water use and quality criteria apply to Railroad Creek as it lies within a national forest area and wilderness area and is a tributary to Lake Chelan (WAC 173-201-080). EPA human health values are one of many criteria used to compile the 303(d) listing.

Based on the data in Patmont et al. (1989), Railroad Creek has previously been classed as water quality limited due to arsenic exceeding the EPA human health criteria. The concentrations of 0.46 +/-0.38 ug/L (n=5) measured by Patmont et al. at the mouth of

Railroad Creek compare closely to Ecology results. Because Patmont found similar concentrations (0.41+/-0.18 ug/L) in the Stehekin River at the head of Lake Chelan and because the highest concentrations in Ecology samples were from above Holden mine, it appears this level of arsenic is naturally occurring. Arsenic concentrations in the range of 0.2 - >1 ug/L are commonly found in Washington rivers (Brad Hopkins, Ecology Ambient Monitoring Program, unpublished data).

The EPA fish tissue concentration corresponding to the 0.14 ug/L arsenic criterion is 0.006 mg/Kg. The data available from the Forest Service on arsenic in Railroad Creek fish, previously mentioned (Appendix A), show concentrations at or below a detection limit of 1.5 mg/Kg, too high to allow conclusions about the degree to which the EPA health criteria may be exceeded.

Sediment Quality

Metal Concentrations

Metal concentrations measured in the tailings samples and Railroad Creek sediments are shown in Table 11. Relative to upper creek sediments, the tailings were elevated in iron (2-4x), zinc (2x), copper (3-6x), lead (5-10x), and selenium (>10x). The Bureau of Mines reports similar levels of metals in the tailings material (Lambeth, 1995).

Railroad Creek sediments downstream of the mine had increased concentrations of all the above metals, although only zinc and copper were elevated by more than a factor of 2. The highest concentrations were found in the sediments at MP-7.

During collection of these sediment samples, tailings were not visually evident in the creek. Microscopic examination of the sediments and microchemical tests conducted by Huntamer (1997) indicated tailings particles were present and in greater amounts moving upstream towards the tailings piles. He was also able to detect "a few grains" of tailings in the sediments above the mine and concluded these were probably windborne. However, Bob Raforth, Ecology Central Regional Office, reports there has been past use of tailings for road construction and a ball field above RC-1 (personal communication). Particle counts gave the following estimates for the amount of tailings in the Railroad Creek sediment samples: RC-1, 1/4%; RC-2, 14%; MP-7, 12%; and RC-3, 5%.

Analysis of the filters from the suspended solids and dissolved metals determinations showed very little suspended tailings particles in the creek. The presence of tailings in the creek was not evaluated during the earlier high flow survey.

The Bureau of Mines also analyzed cyanide in each of the tailings piles and detected 0.59 mg/Kg and 0.31 mg/Kg in samples from piles #1 and #2, respectively. Traces of cyanide (0.03 - 0.07 mg/Kg) were detected in other creek sediment and soil samples

Table 11. Metal Concentrations in Tailings and Sediment Samples - - September 11, 1996

	Tailings Pile #2 - -	Tailings Pile #3 - -	Railroad Creek above Mine (RC-1)	Railroad Creek below Tailings (RC-2)	Railroad Creek at Milepost 7 (MP-7)	Railroad Creek at Mouth (RC-3)
Metals (mg/Kg, dry weight)						
Iron	34500	53700	15700	19000	26300	14800
Aluminum	3810	4930	10400	8540	13300	7890
Manganese	87	114	271	217	289	285
Zinc	137	133	62	113	216	144
Copper	80	182	29	101	147	59
Lead	28	54	4.9	5.6	11	2.4
Selenium	4.0	6.3	<0.3	0.5	0.6	<0.30
Cadmium	<0.3	<0.3	<0.3	<0.3	0.9	0.5
Grain Size (%)						
Gravel	0	na	13	5	3	29
Sand	95	na	85	87	85	71
Silt	4	na	1	6	11	0
Clay	0	na	1	1	1	0
Percent Solids	99	na	79	67	63	80

na = not analyzed

analyzed by the Bureau, but it is unclear, as reported, if some of these are detection limits rather than quantified values.

Background Levels and Guidelines

Recent metals and cyanide data collected by the Bureau of Mines, Geological Survey, and Ecology on Railroad Creek sediments downstream of the Holden mine portal drainage are summarized in Table 12. These data are compared to background levels in Washington State and to sediment quality guidelines.

Metal concentrations measured by the Bureau of Mines and Ecology agree closely. Much higher concentrations of iron, aluminum, manganese, chromium, and nickel are seen in Geological Survey data, but this reflects the more rigorous sample digestion (including hydrofluoric acid) used in these analyses (Kilburn et al., 1994). For unknown reasons, there is a substantial discrepancy between the Bureau of Mines and the Geological Survey on silver concentrations in the sediments.

Table 12. Metal Concentrations in Railroad Creek Sediments Downstream of Holden Mine Portal Compared to Background and Sediment Guidelines (mg/Kg, dry; mean (maximum))

	Ecology (present study) (n=3)	Bureau of Mines (1994) (n=5)	USGS (1994) (n=4)	Washington State Background		Sediment Quality Guidelines[3]	
				Freshwater Sediments[1]	Soil[2]	Lowest Effect	Severe Effect
Iron	20030 (26300)	31800 (41300)	63000 (71000)	--	22030	20000	40000
Aluminum	9910 (13300)	10300 (11700)	78000 (83000)	--	21960	--	--
Manganese	264 (289)	263 (357)	1110 (1400)	--	510	460	1100
Zinc	158 (216)	115 (152)	220 (270)	84	51	120	820
Copper	102 (147)	97 (184)	135 (200)	24	17	16	110
Lead	6.3 (11)	5.4 (6.5)	9.5 (11)	41*	7.9	31	250
Cadmium	0.4 (0.9)	1.4 (1.8)	0.6 (0.6)	0.5	0.5	0.6	10
Selenium	0.4 (0.6)	na	na	--	--	--	--
Arsenic	na	8.6 (11)	4.5 (6.6)	3.4	2.9	6	33
Chromium	na	6.8 (13)	80 (93)	58	18	26	110
Mercury	na	0.02 (0.02)	na	--	0.03	0.2	2
Silver	na	1.7 (5.6)	0.1 (0.2)	--	--	0.5	--
Nickel	na	17 (26)	29 (32)	--	16	16	75
Cyanide	na	0.04 (0.06)	na	--	--	0.1	--

na = not analyzed
*reported value suspect
Note: 1/2 detection limit used to calculate means
[1]PTI. 1989 (draft).
[2]San Juan, C. 1994.
[3]Persaud, D. et al. 1993.

Comparison to state background shows iron, zinc, copper, cadmium, and arsenic are elevated in Railroad Creek sediments below the mine. Copper stands out among these as being an order of magnitude above background levels typical of freshwater sediments and terrestrial soil.

No Washington State or federal criteria have been established for metals in freshwater sediments. In lieu of this, Table 12 lists sediment quality guidelines for protection of freshwater benthic invertebrates proposed by Ontario, Canada. The lowest effects levels are tolerated by the majority of invertebrate species. Pronounced disturbances would be expected when metal concentrations are at severe effects levels. Ecology has evaluated these guidelines against sediment chemistry and bioassay data sets on Washington freshwaters and found them to be accurate predictors of toxicity (Jim Cubbage, freshwater sediment criteria development project, personal communication).

Excluding the hydrofluoric-generated Geological Survey data -- which are not appropriate for comparison -- two metals, iron and copper, approach or exceed severe effects levels in the sediments. Ecology results suggest less of a potential for adverse impacts due to iron than results obtained by the Bureau of Mines. Cyanide concentrations reported by the Bureau are below effects levels.

Toxicity Tests

Results from the *Hyalella* and Microtox bioassays tend to support the conclusion that metal concentrations in Railroad Creek sediments are not at toxic levels (Table 13). Amphipod survival in sediment collected below the tailings piles and at MP-7 was not significantly different from survival in laboratory control sediments. No adverse effects were observed in the Microtox tests for any of the sediment sampling sites.

Amphipod survival was reduced somewhat in sediments from above the mine and at the creek mouth, 65% and 63%, respectively. No relation to metal concentrations is apparent. Grain size differences are a possible confounding factor here as both of these samples

Table 13. Results of Bioassays on Sediment Samples - - September 10, 1996

Endpoint	Railroad Creek above Mine (RC-1)	Railroad Creek below Tailings (RC-2)	Railroad Creek at Milepost 7 (MP-7)	Railroad Creek at Mouth (RC-3)
<u>*Hyalella*</u>				
Percent Survival (control survival = 93.3%)	65.0 %	93.3 %	91.7 %	63.3 %
<u>Microtox</u>				
EC50*	> 90 %	> 90 %	> 90 %	> 90 %

*EC50 = effective concentration reducing light output by 50%

were coarse relative to RC-2 and MP-7 sediments (Table 11). *Hyalella,* however, is not generally found to be responsive to grain size (EPA, 1994).

It should be noted that certain adverse effects could be occurring in Railroad Creek sediments for which these bioassays would not be pertinent tests. For example, iron precipitates can interfere with egg or gill respiration (Sykora et al., 1972) and the oxidation of iron can cause low interstitial dissolved oxygen.

Benthic Invertebrates

Habitat Characteristics

Invertebrate communities are effected by both instream habitat characteristics and pollution. Habitat conditions were measured in Railroad Creek to help differentiate their effects on the benthic community from effects due to discharges from the Holden site.

Estimates of habitat parameters at each of the four sampling sites were fairly consistent (Table 14). The progression of stream size from above the mine (RC-1) to the creek's

Table 14. Habitat Variables at Each Biological Monitoring Site.

Variable	Railroad Creek above mine (RC-1)	Railroad Creek below Tailings (RC-2)	Railroad Creek at Milepost 7 (MP-7)	Railroad Creek at mouth (RC-3)
Avg. Wetted Width (m)	15.2	11.7	18.9	23.5
Avg. Bankful Width (m)	28.5	14.7	26.7	28.8
Avg. Depth (m)	0.24	0.25	0.29	0.34
Avg. Sample Depth (m)	0.29	0.24	0.34	0.37
Wetted Width/Depth	95	69	93	90
Gradient (%)	3	3	3	3
Shear Stress (N/m^2)	7054	7348	8523	9980
Substrate at Sample (%)				
Boulder	13	10	28	48
Cobble	67	73	65	52
Coarse Gravel	20	17	7	8
Fine Gravel	0	0	0	2
Sand	0	0	0	0
Avg. Substrate Phi Values	-6.0	-6.1	-6.7	-7.5
Embeddedness (%)	10	15	5	5
Canopy Cover (%)	25	5	15	15
Visual Habitat Score	120	97	112	115

mouth (RC-3) can be seen in the increase in average wetted and bankfull widths and depth measurements; however, average depth did not differ by more than 0.12 m. Average depth at each sample point was also fairly uniform, differing by only 0.08 m. Shear stress at each riffle, an estimate of stream energy, also showed similar results, differing at most by 30% between the site at the mouth and above the mine.

All measurements for substrate, embeddedness, and canopy cover were within Bode's (1995) acceptable range of habitat similarity, as previously described. Substrates were dominated by cobble with embeddedness levels being low. All riffles were measured at 3% gradient. Width/depth ratios can also be used to illustrate habitat comparability; an increase in the ratio suggests a wider/shallower stream, and a decrease suggests a narrower/deeper stream. RC-2, below the mine, was the only site that differed by more than 5% from the other sites, differing by 27%.

Taxa Richness

Seventy-five taxa from 30 families were identified from 16 total samples at the four Railroad Creek sites (Table 15). Extreme variation was observed between sites with an average density of 3,130 invertebrates/m^2 upstream of the mine to 50 invertebrates/m^2 directly below the mine (Figure 12). A slight community recovery was seen midway down the creek at MP-7 and at the creek's mouth, 110 and 361 invertebrates/m^2, respectively. Total taxa richness and EPT richness followed the same trend as density (Figure 13). The average number of total and EPT taxa was greatest above the mine, 37 and 27, respectively, and lowest downstream of the tailings, three and one, respectively.

This extreme drop in taxa and density with a slight recovery progressing downstream is consistent with both observational and experimental studies of other mining impacts (Clements et al., 1988; Clements et al., 1992; Clements, 1994; Hoilland et al., 1994; Leland et al., 1989; Pekarsky and Cook, 1981; Winner et al., 1980). Pine's (1967) qualitative study of Railroad Creek showed similar results with a decrease of nine families from the upstream site to below the mine where only one family was present. The Metals Tolerance Index (MTI) developed for the Clark Fork River shows a definite shift toward more tolerant organisms downstream of the mine (Figure 13). This index probably needs adjustment for central Washington, but does show biologically significant results.

Analysis of variance for density (log-transformed), total taxa, EPT taxa, and the MTI shows significant differences for all variables over the study area. From Tukey's multiple range test, differences between sites were shown to be significant except for sites RC-2 and MP-7 for taxa richness ($p<0.53$) and EPT richness ($p<0.65$). MTI differed only between the site above the mine and immediately below the tailings piles. The lack of statistical significance between RC-2 and MP-7 for the richness variables illustrates the lack of recovery in the benthic community within the three miles between these two sites. Statistical significance for the MTI was not shown between the three sites below the mine, further showing little benthic community recovery. Even with the slight increase in density

Table 15. Taxa List, Metals Tolerance and Mean Number of Organisms Per Sample for Railroad Creek Sites.

Class/Order	Family	Taxa	Metals Tolerance[1]	RC-1	RC-2	MP-7	RC-3
Ephemeroptera							
	Ameletidae	*Ameletus*	1	0	0	0	1
	Baetidae	*Baetis tricaudatus*	5	25	1	1	8
		Diphetor hageni	1	0	0	0	1
	Ephemerellidae	*Attenella margarita*	1	1	0	0	1
		Caudatella		0	0	0	1
		Drunella coloradensis/flavilinea	0	1	0	0	0
		Drunella doddsi	0	18	0	1	2
		Drunella spinifera	0	1	0	0	0
		Ephemerella		2	0	0	0
		Serratella tibialis	1	2	0	0	0
	Heptageniidae	*Cinygmula*	0	5	0	0	0
		Epeorus deceptivus	0	38	0	0	1
		Epeorus grandis	0	17	0	0	2
		Epeorus longimanus	0	2	0	0	0
	Heptageniidae			12	0	0	2
		Rhithrogena	2	45	0	0	0
	Leptophlebiidae	*Paraleptophlebia*	1	13	0	0	0
Plecoptera							
	Capniidae		0	4	0	0	2
	Chloroperlidae			0	0	3	1
		Kathroperla	2	0	0	1	0
		Sweltsa	4	24	1	2	1
	Leuctridae		0	2	0	0	2
		Moselia	0	1	0	0	0
	Nemouridae	*Malenka*	1	1	0	0	0
		Visoka cataractae	0	2	0	0	1
		Zapada cinctipes	4	12	0	0	9
		Zapada columbiana	1	16	0	2	1
	Peltoperlidae	*Yoraperla*	0	1	0	0	0
	Perlidae	*Doroneuria*	2	2	0	0	1
	Perlodidae			0	0	0	2
		Isoperla	3	2	0	0	0
		Megarcys	1	1	0	0	0
		Skwala	3	1	0	0	0
	Pteronarcidae	*Pteronarcys*	2	2	0	0	0
	Taeniopterygidae		1	10	0	0	2
Trichoptera							
	Glossosomatidae	*Anagapetus*	0	1	0	0	0
	Hydropsychidae	*Hydropsyche*	5	7	0	1	0
		Parapsyche almota	1	2	0	1	0
		Parapsyche elsis	1	6	0	0	2
	Lepidostomatidae	*Lepidostoma*	1	1	0	0	0
	Limnephilidae			1	0	1	0
		Onocosmoecus	2	0	0	0	1
	Rhyacophilidae	*Rhyacophila Betteni Grp.*	4	2	0	0	1
		Rhyacophila Brunnea Grp.	4	5	0	0	2
		Rhyacophila Hyalinata Grp.	4	1	0	0	1
		Rhyacophila Sibirica Grp.	4	1	0	0	0
		Rhyacophila Vagrita Grp.	4	0	0	0	1
		Rhyacophila valuma	4	1	0	0	0
		Rhyacophila Vofixa Grp.	4	0	0	0	1
Diptera							
	Ceratopogonidae	Ceratopogoninae	4	1	2	0	1
	Chironomidae						

Table 15. (cont)

	Diamisinae	*Pegastia*	9	1	0	0	0
	Orthocladiinae			0	3	0	1
		Corynoneura	4	1	0	0	0
		Eukiefferiella	9	2	0	1	3
		Brillia	4	8	3	3	3
		Parametriocnemus	4	1	0	0	1
		Paraphaenocladius	4	6	0	6	1
		Rheocricotopus	5	2	0	0	0
		Tvetenia	4	10	1	0	3
	Tanytarsini	*Cladotanytarsus*	3	1	0	0	0
		Micropsectra	1	3	0	0	0
		Stempellinella		6	0	0	0
	Empididae	*Chelifera*	4	6	0	0	0
		Clinocera	4	1	0	0	0
		Oreogeton	7	0	0	1	0
	Pelecorhynchidae	*Glutops*	1	0	0	1	0
	Simuliidae			19	2	2	2
	Tipulidae			1	0	0	0
		Dicranota	2	2	0	1	1
		Hexatoma	2	2	0	0	0
		Rhabdomastix	1	0	0	0	1
Oligochaeta				5	0	0	2
Turbellaria				1	0	1	0
Nematoda			5	2	0	0	0
Acari			5	0	0	0	1

[1]Metals Tolerance: 0=least intolerant, 10=most tolerant

and number of taxa proceeding from the site below the tailings to the creek's mouth, the community remains dominated by metals tolerant species.

Community Similarity

The Bray-Curtis matrix depicts the relative contribution of each taxa in a sample to the overall community analysis. A dendrogram of all sites, based on Bray-Curtis, shows replicates from above the mine being tightly clustered (Figure 14). The four samples from the mouth also cluster as a group but the two intermediate sites below the mine overlap. Average sample similarity for RC-1, RC-2, MP-7 and RC-3 equaled 70%, 32%, 34% and 39%, respectively. Similarity between samples within a site has been shown to decrease because of disturbance induced variation (Clarke and Warwick, 1994). Unimpacted sites have the lowest between sample community variation. A large increase in variation is shown in all sites below the mine tailings.

A non-metric, multidimensional scaling plot of the Bray-Curtis similarity matrix also showed a high degree of similarity between samples from the unimpacted site, RC-1, but increase in variation in samples as well as overlap between the two sites (RC-2 and MP-7).

Pairwise comparisons showed all downstream sites to be significantly different from RC-1. RC-2 and MP-7 were not significantly different which is consistent with the other variables tested (ANOVA).

Figure 12. Density (#/m²) of Invertebrates in Railroad Creek, September 11, 1996 (n=4, error bars are one standard deviation from the mean).

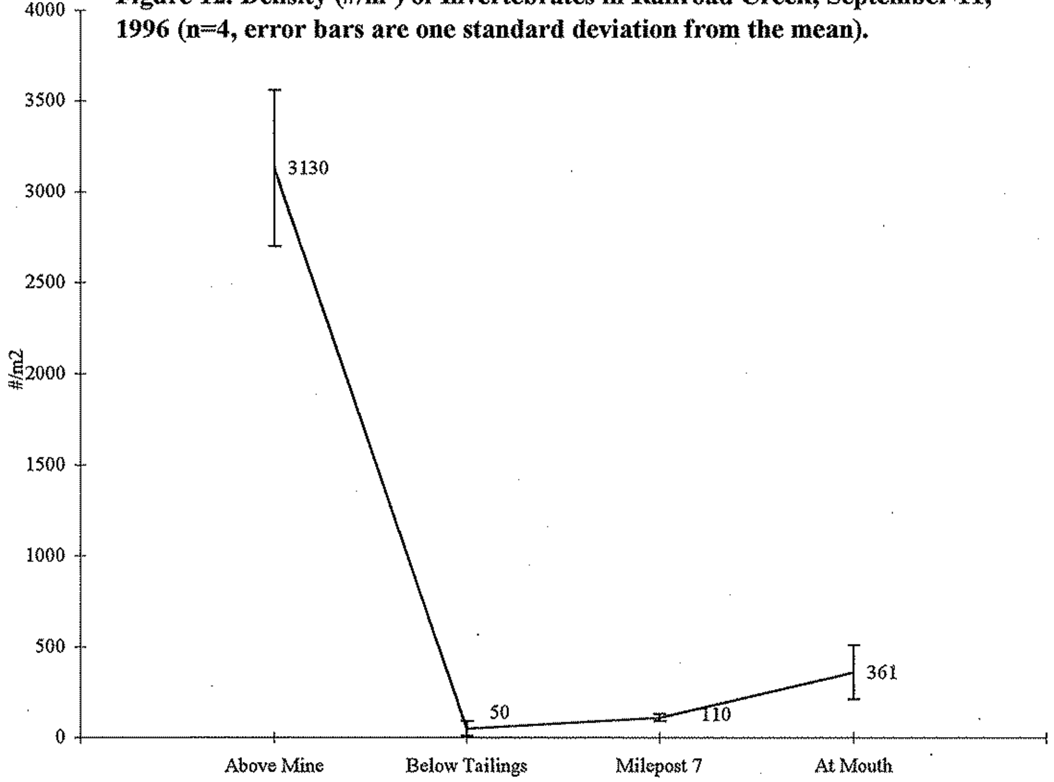


Figure 13. Total Taxa, EPT Taxa and Metals Tolerance Index (MTI) for Railroad Creek, September 11, 1996 (n=4, error bars are one standard deviation from the mean).

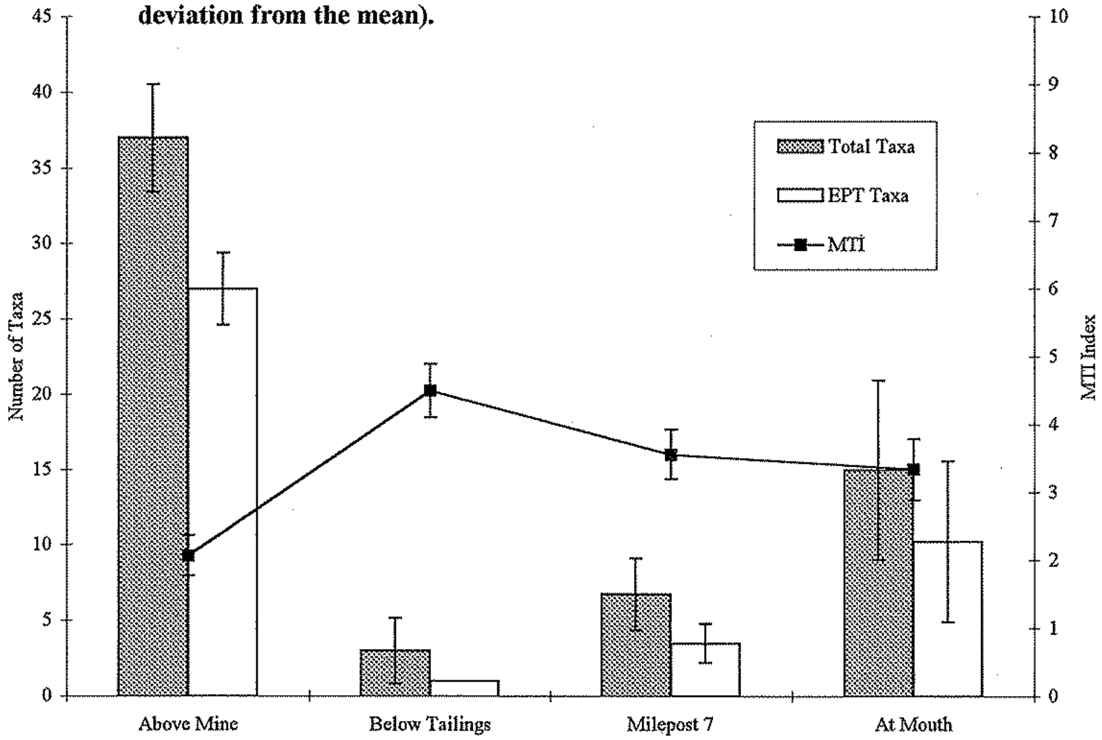
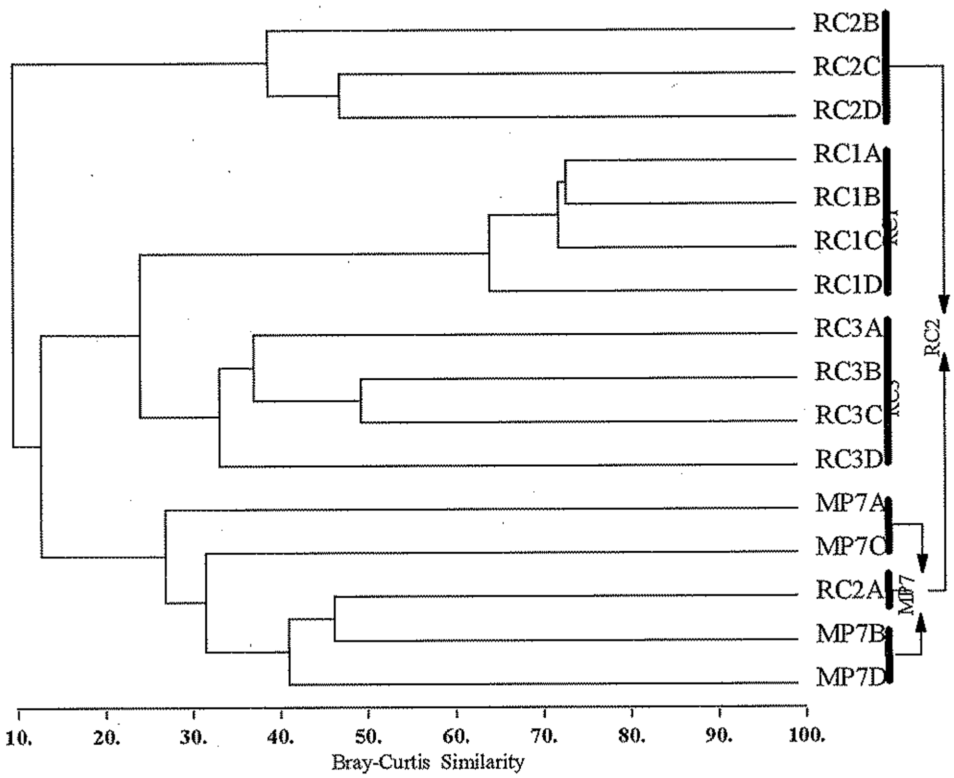


Figure 14. Dendrogram from Hierarchical, Average Linked, Cluster Procedure of Bray-Curtis Similarity Matrix for Railroad Creek --September 11,1996.



Functional Feeding Groups

Invertebrates can be categorized by functional feeding group based on food type. Five categories were used in this analysis: scrapers eat algae; shredders eat large pieces of leaves; collector-gatherers eat large pieces of organic matter; filterers eat fine organic particles; predators eat other invertebrates; and parasites feed on other living invertebrates.

The proportion of invertebrates in each feeding group is shown in Figure 15. Scrapers are the dominant group above the mine, with collector-gatherers and shredders dominating downstream. The elimination of scrapers from sites below the tailings and at MP-7 with some increase in their presence at the mouth is consistent with findings in the literature (Smock, 1983). Scrapers are one of the feeding groups most sensitive to metals. Algae, their food source, are known to bioaccumulate metals (Clements, 1994). Predators increase in proportion three miles below the mine at MP-7, a phenomenon also reported in the literature; as numbers of other taxa decrease, some predator taxa will increase (Leland et al., 1989).

Indicator Species

Total and EPT taxa richness are general indicators of metals impacts. However, community metrics average all species and are less sensitive than analysis of specific taxa. Several taxonomic groups have been shown to be excellent indicators of metals pollution (Table 16). Mayflies, stoneflies, and caddisflies (EPT) have a wide range of tolerance to pollution, with mayflies being the most sensitive of all groups, specifically the family Heptageniidae (Winner et al., 1980; Clements et al., 1988; Nelson and Roine, 1993; Clements, 1994; Kiffney, 1996). The baetid, *Baetis tricuadatus*, is the most insensitive mayfly to metals (Norris et al., 1982). Several taxa of stoneflies and caddisflies, including the families Nemouridae and Rhyacophilidae and the genera *Hydropsyche* and *Doroneuria* are found in areas of moderate pollution or first colonize impacted areas (Winner et al., 1980). Most midges (family Chironomidae) are generally tolerant to pollution and dominate sites where metals impacts are moderate to severe (Armitage, 1980; Chadwick et al., 1986; Clements, 1994; Leland et al., 1989; Hoilland and Rabe, 1992). One chironomid sub-family in particular, Orthocladiinae, is know to be extremely tolerant. However, another group of midges, the Tanytarsini, are very intolerant to metals pollution.

Percent composition of indicator groups in Railroad Creek is illustrated in Figure 16. There was a healthy assemblage of invertebrate species above the mine. The highly intolerant Heptageniidae and Tanytarsini disappeared from the community below the mine, as did all Trichoptera. Only a small proportion of heptageniids recovered at the mouth of Railroad Creek. The most tolerant taxa group, Orthocladiinae, dominated the site below the mine and made up a major proportion of the MP-7 community. Plecoptera and Trichoptera were present in the intermediate site and dominated the community at the mouth.

Indicator groups can be further analyzed by considering taxa which were 1) present only above the mine and those not found above the mine, and 2) either in the top three dominant taxa (density) or present in three or more sites. Twenty-two taxa were found exclusively above the mine (Table 17). Of these, 10 are reported to be highly intolerant to metals. Of the eight taxa found exclusively below the mine, five have moderate-to-high tolerance to pollution.

Four Chironomidae taxa were dominant throughout the creek including *Brillia*, *Eukeifferiella*, *Paraphaenocladius*, and *Tvetnia*. All four of these are highly tolerant Orthocladiinae. Three moderately tolerant dipterans constituted a major proportion of the overall creek community including Simuliidae (*Simulium*), Ceratopogoninae, and *Dicranota*. The most tolerant mayfly, *Baetis tricaudatus*, was the dominant downstream mayfly. *B. tricaudatus* occurred in all sites but at extremely depressed densities in the downstream sites with some population recovery towards the mouth. Three Plecopterans, *Sweltsa*, *Zapada columbiana*, and *Z. cinctipes*, showed population recovery in the downstream sites. These taxa are known to be recolonators after metals impacts or are moderately tolerant of metals. Of all the invertebrates, only the highly tolerant

Figure 15. Percent Composition of Feeding Groups in Railroad Creek, September 1996

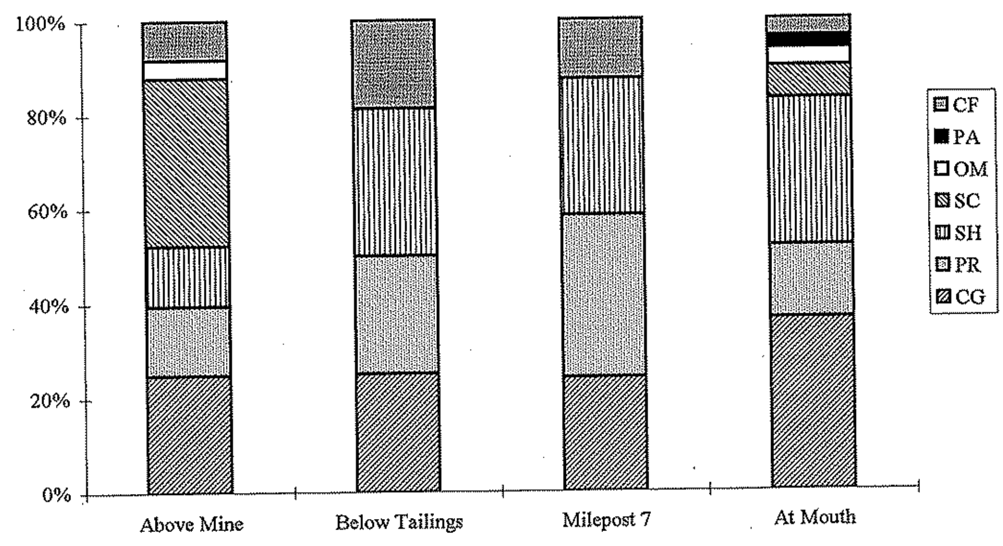


Figure 16. Percent Composition of Indicator Groups for Sites in Railroad Creek -- September 11,1996.

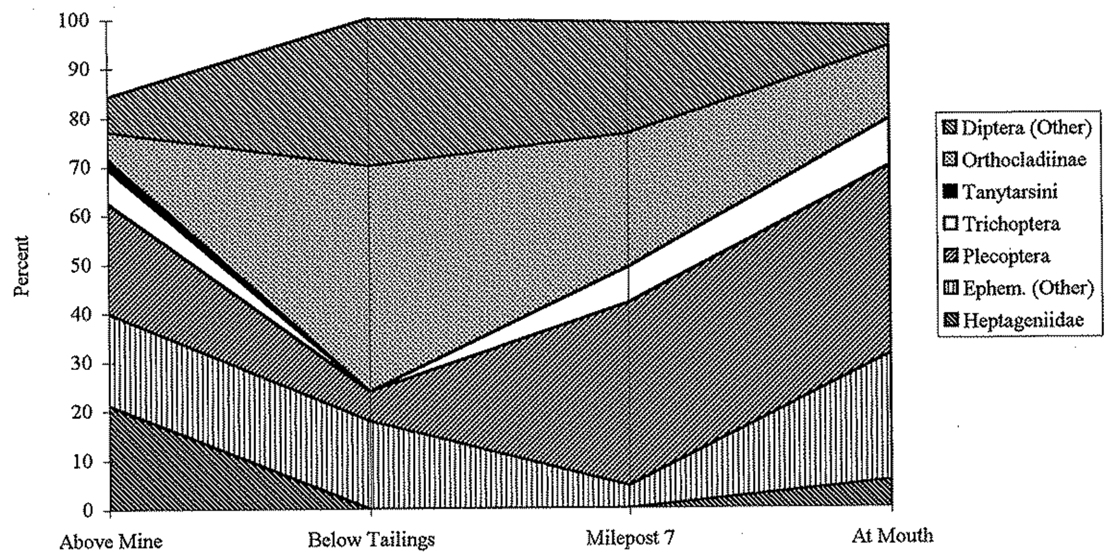


Table 16. Metals Sensitivity of Taxa Found in Railroad Creek (from published literature, see text).

Sensitive	Moderately Sensitive	Not-Sensitive
Heptageniidae	*Baetis tricaudatus*	Orthocladiinae
Epeorus, Rhithrogena, Cinygmula	*Doroneuria*	
Ephemerella	Nemouridae	
Paraleptophlebia	*Hydropsyche*	
Pteronarcys	*Lepidostoma*	
Malenka	*Rhyacophila* Brunnea Grp.	
Tanytarsini	*Rhyacophila* Betteni Grp.	
	Ceratopogoninae	
	Dicranota	
	Empididae	
	Simulium	

Table 17. Taxa Unique to Samples Collected Above or Below Holden Mine.

Taxa only found above mine	Taxa only found below mine
Ephemeroptera	Ephemeroptera
Drunella spinifera, Ephermerella, Serratella tibialis	*Ameletus, Diphetor hageni*
Cinygmula, Epeorus longimanus, Rhithrogena	Plecoptera
Paraleptophlebia	*Kathroperla*
Plecoptera	Trichoptera
Moselia, Malenka, Megarcys, Skwala, Isoperla,	*Rhyacophila Vofixa Grp.*
Yoraperla, Pteronarcys	Diptera
Trichoptera	*Oreogeton, Glutops, Rhabdomastix*
Anagapetus, Lepidostoma, Rhyacophila Sibirica Grp.	Chironomidae
Rhyacophila valuma	Orthocladiinae
Diptera	Acari
Chelifera, Clinocera	
Chironomidae	
Cladotanytarsus,Corynoneura, Micropsectra	
Pegastia, Stempellinella	

Paraphaenocladius and the moderately tolerant Ceratopogoninae had increased densities below the mine. All other taxa, including metals tolerant invertebrates, had extremely reduced densities.

Effects of Drift

At low population levels drift from unimpacted upstream areas and tributaries can alter the local benthic community. Drift of moderately sensitive taxa during times of relatively low metals concentration, as observed to some extent in Railroad Creek during September, can sustain aquatic life in highly polluted environments (Clements, 1994). This phenomenon plays an important role in recolonizing impacted areas (Pekarsky and Cook, 1981; Hoilland and Rabe, 1992). Drift of individuals must be taken into consideration in analyses of benthic invertebrate data to avoid misrepresentation of moderately impacted sites in relation to upstream controls.

Copper Creek, a major unimpacted tributary 1/2 mile upstream of RC-2, probably adds drift of intolerant organisms into Railroad Creek; however, RC-2 had only three organisms per sample collected. Many other tributaries enter the creek before Lake Chelan, yet even with this influx of drifting insects the depression of invertebrates in Railroad Creek was extreme from the tailings piles to Lake Chelan (approximately 11 miles).

Biological Integrity Target

Biological integrity provides a measure of overall stream health, and as such should be monitored to help evaluate the effectiveness of future pollution control efforts on Railroad Creek. Since biological communities can be influenced by near-term climatic and hydrologic events, biometrics from the current investigation should not be used to define a target biological condition. Instead, the attainable level should be defined relative to the upstream biota during any particular sampling period.

Benthic invertebrate monitoring should follow the techniques and site locations outlined in this report. Total taxa richness, Ephemeroptera-Plecoptera-Trichoptera (EPT) richness, and the Metals Tolerance Index (MTI) would serve as appropriate measures of biotic integrity. Each metric should be averaged over all samples for a downstream site and compared to the average of samples from the upstream control. Given the natural variability associated with stream invertebrates, the target would be for metrics at the downstream site to exceed the 80th percentile of metrics at the upstream site.

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Appendices

Appendix A. Summary of Data on Metal Concentrations in Railroad Creek Rainbow Trout

(mean concentrations in mg/Kg, wet weight basis)

Location	Wilderness Boundary		Tailings Piles		Lucerne		25-Mile Cr.(Lk. Chelan)	
Date	1991[1]	1992[2]	1991	1992	1991	1992	1991	1992
N =	7	6	5	3	5	3	7	6
				MUSCLE TISSUE				
Iron	40.6	8.8	30.5	6.1	28.0	7.1	22.6	7.0
Zinc	39.8	9.7	40.7	6.7	49.8	10.2	33.6	7.5
Copper	4.5	0.6	4.0	4.4	4.5	0.5	3.6	0.6
Arsenic	- -	1.5	- -	<1.5	- -	<1.5	- -	<1.5
Aluminum	- -	17.8	- -	1.3	- -	<1	- -	1.1
Lead	- -	<1	- -	<1	- -	<1	- -	<1
Nickel	- -	<0.5	- -	<0.5	- -	0.6	- -	<0.5
				LIVER TISSUE				
Iron	1512	301	1170	145	777	167	334	155
Zinc	132	51.5	135	34.2	186	55.2	118	45.8
Copper	131	11.7	454	87.7	270	21.9	20	26.9
Arsenic	- -	3.3	- -	3.5	- -	9.7	- -	3.4
Aluminum	- -	12.1	- -	7.4	- -	12.6	- -	5.1
Lead	- -	3.0	- -	2.4	- -	6.5	- -	2.3
Nickel	- -	1.4	- -	1.4	- -	3.4	- -	1.2

[1]PNL data as summarized by USFS

[2]USFS unpublished data

Appendix B. Field Blank Results, Ecology Toxics Investigations Section, 1995-96 (ug/L)

1. Bottle Blanks*

Sample No.	95358238	95418106	96178185	96378313
Iron	- -	- -	- -	<20
Aluminum	- -	- -	- -	<15
Manganese	- -	- -	- -	<1
Zinc	<1	<1		1.7
Copper	<0.5	<0.5	- -	0.12
Cadmium	<0.04	<0.04	- -	<0.1
Chromium	<1	<1	<0.4	- -
Lead	<0.03	<0.03	- -	<0.1
Nickel	<1	<1	- -	- -
Arsenic	<1	<1	<0.2	- -
Mercury	<0.001	<0.001	<0.001	- -
Selenium	<1	<1	<0.4	<0.4
Silver	<0.03	<0.03	- -	- -

2. Filter Blanks**

Sample No.	95358239	95398071	96178187	96378314
Aluminum	- -	- -	- -	<0.4
Arsenic	<1	<1	- -	- -
Zinc	<1	<1	0.57	0.56
Copper	<0.05	<0.05	0.08	<0.05
Cadmium	<0.04	<0.04	<0.02	<0.01
Chromium	<1	<1	- -	0.012
Lead	<0.03	<0.03	<0.02	- -
Nickel	<1	<1	0.12	- -
Silver	<0.03	<0.03	<0.01	- -
Selenium	<1	<1	- -	- -

*0.5 L teflon bottles precleaned and filled with blank water by Manchester Laboratory and acidified in the field.

**Teflon bottles cleaned and filled as above, then filtered and acidified in the field

Appendix C.

July 25, 1996

To: Art Johnson

From: Randy Knox, Metals Chemist

Subject: Railroad Creek Project Water

QUALITY ASSURANCE SUMMARY

Data quality for this project is generally good except recovery of aluminum and zinc spikes added to the dissolved spiked sample but not the duplicate spiked sample was low. No other significant quality assurance issues are noted with the data.

Copper, nickel and zinc from sample 96248183 and copper, nickel and zinc from 96248185 are reported by ICP-OES due to high sample levels for 96248185 and high ICPMS internal standards associated with sample 96248183. All aluminum , iron and manganese is reported by ICP-OES.

SAMPLE INFORMATION

The samples from the Railroad Creek Project were received by the Manchester Laboratory on 6/13/96 in good condition.

HOLDING TIMES

All analyses were performed within the USEPA Contract Laboratory Program (CLP) holding times for metals analysis (28 days for mercury, 180 days for all other metals).

INSTRUMENT CALIBRATION

Instrument calibration was performed before each analytical run and checked by initial calibration verification standards and blanks. Continuing calibration standards and blanks were analyzed at a frequency of 10% during the run and again at the end of the analytical run. All initial and continuing calibration verification standards were within the relevant USEPA (CLP) control limits. Mercury initial verification standard was not followed by a blank but later continuing calibration standards showed no evidence of carryover into the blank. Mercury data is not qualified. AA calibration gave a correlation coefficient (r) of 0.995 or greater, also meeting CLP calibration requirements.

PROCEDURAL BLANKS

The procedural blanks associated with these samples show no analytically significant levels of analytes in the procedure blank..

SPIKED SAMPLES ANALYSIS

Spiked and duplicate spiked sample analysis were performed on this data set.. All spike recoveries are within the CLP acceptance limits of +/- 25%.

PRECISION DATA

The results of the spiked and duplicate spiked samples or duplicate samples in the case of hardness data, are used to evaluate precision on this sample set. The relative percent difference (RPD) for all analytes is within the 20% CLP acceptance window for duplicate analysis.

LABORATORY CONTROL SAMPLE (LCS) ANALYSIS

LCS analyses are within the windows established for each parameter.

Please call Bill Kammin at SCAN 360-871-8801 to further discuss this project.

RLK:rlk

October 9, 1996

To: Art Johnson

RJ/C

From: Randy Knox, Metals Chemist

Subject: Railroad Creek Project Water and Sediment

QUALITY ASSURANCE SUMMARY

Data quality for this project is generally good with the noted exceptions as follows: 1. zinc recovery from sediment samples and total recoverable water samples is low, 2. selenium was noted in the interference check standard used for total recoverable, high level ICP samples, and 3. copper and zinc were noted at detectable levels in the total recoverable blank. No other significant quality assurance issues are noted with the data.

SAMPLE INFORMATION

The samples from the Railroad Creek Project were received by the Manchester Laboratory on 09/12/96 in good condition.

HOLDING TIMES

All analyses were performed within the USEPA Contract Laboratory Program (CLP) holding times for metals analysis (28 days for mercury, 180 days for all other metals).

INSTRUMENT CALIBRATION

Instrument calibration was performed before each analytical run and checked by initial calibration verification standards and blanks. Continuing calibration standards and blanks were analyzed at a frequency of 10% during the run and again at the end of the analytical run. All initial and continuing calibration verification standards were within the relevant USEPA (CLP) control limits. Some copper was detected in calibration blanks used with total recoverable ICP data. Sample levels in associated samples were greater than ten times the blank level and were not qualified.

PROCEDURAL BLANKS

The procedural blanks associated with these samples show no analytically significant levels of analytes except copper and zinc in the total recoverable blank determined by ICP-MS. Associated copper and zinc data, at levels less than ten times the blank level, are qualified J, as estimated. Aluminum was also detected in the sediment digestion procedure blank. All sediment aluminum levels are greater than ten times the blank level and data is not qualified.

SPIKED SAMPLES ANALYSIS

Spiked and duplicate spiked sample analysis were performed on this data set. All spike recoveries, except those for zinc from sediments and from total recoverable water samples, are within the CLP acceptance limits of +/- 25%. Sample data for zinc associated with samples with low zinc recovery are qualified J as estimated.

PRECISION DATA

The results of the spiked and duplicate spiked samples -or of duplicate samples for hardness - are used to evaluate precision on this sample set. The relative percent difference (RPD) for all analytes is within the 20% CLP acceptance window for duplicate analysis.

INTERFERENCE CHECK STANDARD

Interference check standards, used with ICP analysis, did not detect significant interference with any element other than selenium. Data for selenium in sample 96378320 is at levels where this interference could be significant and is qualified J as estimated.

LABORATORY CONTROL SAMPLE (LCS) ANALYSIS

LCS analyses are within the windows established for each parameter. Iron recovery from sediment LCS is slightly low but is within manufacturer's advisory range so data is not qualified.

Please call Jim Ross at SCAN 360-871-8808 or Randy Knox at SCAN 360-871-8811 to further discuss this project.

RLK:rlk

Appendix D.

TOXICITY EVALUATION OF EFFLUENT SAMPLES 378283, 378294 AND 378305 USING *Ceriodaphnia dubia*

Prepared for

WASHINGTON DEPARTMENT OF ECOLOGY
Manchester Laboratory
7411 Beach Drive East
Port Orchard, Washington 98366

Prepared by

PARAMETRIX, INC.
5808 Lake Washington Blvd. NE
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SEPTEMBER 1996

EXECUTIVE SUMMARY OF TEST CONDITIONS AND RESULTS

Chronic *Ceriodaphnia dubia* Bioassay

Title:	Toxicity Evaluation Of Effluent Samples 378283, 378294 and 378305 Using *Ceriodaphnia dubia*
	12 -18 September 1996
	arametrix, Inc.; 5808 Lake Washington Boulevard, Kirkland Washington 98033
	Washington State Dept. of Ecology; Manchester Laboratory; 7411 Beach Drive East; Port Orchard, Washington
	Whole effluent collected 11 September 1996
:	*Ceriodaphnia dubia*
	Laboratory stock cultures
f Test:	Chronic definitive
ation:	6 days
est Concentrations:	0, 6.5, 12.5, 25, 50, and 100% effluent

Summary of *C. dubia* Results:

Sample #378283

	C. dubia	
Evaluation	Survival	Reproduction
LC50	>100%	N/A
NOEC	100%	100%
LOEC	>100%	>100%
Reference Toxicant (LC50) =	15.2 ppb Cu	

N/A = Not applicable

Sample #378294

	C. dubia	
Evaluation	Survival	Reproduction
LC50	>100%	N/A
NOEC	100%	<6.25%
LOEC	>100%	6.25%
Reference Toxicant (LC50) =	15.2 ppb Cu	

N/A = Not applicable

Sample #378305

	C. dubia	
Evaluation	Survival	Reproduction
LC50	>100%	N/A
NOEC	100%	12.5%
LOEC	>100%	25%
Reference Toxicant (LC50) =	15.2 ppb Cu	

N/A = Not applicable

1. INTRODUCTION

This report summarizes the procedures and results of biological testing conducted on effluent samples 378283, 378294 and 378305 collected by Washington State Department of Ecology on 11 September 1996. Testing was conducted by Parametrix's Toxicology Laboratory in Kirkland, Washington. Testing consisted of three chronic definitive bioassays with *Ceriodaphnia dubia* as the test species.

2. TEST METHODS AND CONDITIONS

2.1 Sample Handling

Effluent samples were collected on 11 September 1996. The samples were shipped to Parametrix's Toxicology Laboratory and refrigerated at 4°C until used for testing. Subsamples of the effluent were taken upon arrival for analysis of temperature, pH, salinity, dissolved oxygen, conductivity, hardness, alkalinity, total residual chlorine and ammonia.

2.2 Source And Condition Of Organisms

C. dubia were obtained from laboratory stock cultures and were ≤24 hours old at test initiation. A reference toxicant was used to assess the relative health of the test organisms and to ensure that their sensitivity fell within an expected concentration range. Copper, as copper sulfate, was used to assess the relative health of the *C. dubia*.

2.3 Test Methods

The chronic bioassay was conducted according to Short-term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms. EPA/600/4-91/001, July 1994. A summary of test conditions is presented in Table 1.

Table 1. Summary of test conditions for the chronic definitive *Ceriodaphnia dubia* bioassay.

Job Name: Washington State Dept. of Ecology — Job Number: 55-1583-56 (01)

Date: 12-18 September 1996

Test Protocol:	Short-term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms. EPA/600/4-91/001, July 1994.
Test Material:	Whole effluent (composite samples)
Test Organism/Age:	*C. dubia*; ≤24 hrs. old
Source:	In-house cultures
Number/Container:	1
Volume/Container:	15 mL
Test Concentrations:	0, 6.25, 12.5, 25, 50 and 100% effluent
Replicates:	Ten
Reference Toxicant:	Copper, as copper sulfate
Test Duration:	6 days
Control/Dilution Media:	Natural Spring Water collected from Gold Creek Trout Farm, Woodinville, Washington
Test Chambers:	30 mL polypropylene cups
Lighting:	Fluorescent bulbs (50-100 foot candles)
Photoperiod:	16 hours light; 8 hours dark
Aeration:	None
Feeding:	100 µL *Selenastrum* suspension; 100 µl yeast/Cerophyl/trout chow (YCT)
Renewal:	Daily
Temperature:	25 ± 1°C
Chemical Data:	Dissolved oxygen, pH and temperature measured at initiation of test and every 24 hours; specific conductivity measured at initiation and termination; salinity, hardness, alkalinity, residual chlorine and ammonia measured for 100% effluent.
Effect Measured:	Mortality, defined as immobility, and reproduction
Test Acceptability:	Control mortality ≤ 20%; ≥ 60% of control organisms produce three broods, an average total of 15 or more offspring for the first three broods must be produced.

3. RESULTS

Records of biological and chemical data collected during testing, and the statistical analyses used for reporting are included in the appendices of this report.

3.1 Initial Chemical And Physical Determinations

The results of initial chemical and physical determinations made for the 100% effluent samples are summarized in Table 2.

Table 2. Initial chemical and physical determinations.

Parameter Measured	Effluent Collection Dates		
	7/11/96 #378283	7/11/96 #378294	7/11/96 #378305
Temperature (°C)	4	4	4
Salinity (ppt)	0	0	0
Dissolved Oxygen (ppm)	13.2	12.8	13.0
pH	7.1	6.8	7.1
Conductivity (μS)	20	30	40
Total Hardness (ppm as $CaCO_3$)	50	36	24
Total Alkalinity (ppm as $CaCO_3$)	12	10	12
Total Residual Chlorine (ppm)	<0.01	0.028[1]	0.015[2]
Ammonia (ppm)	<1	<1	<1

[1] adjusted to <0.01 with 9.4 μl/l STS
[2] adjusted to <0.01 with 5.0 μl/l STS

3.2 Bioassay Results

Bioassay results are summarized in the Executive Summary and in Table 4. In summary, no significant toxicity was observed for sample 378283 with a NOEC of 100% effluent for survival and reproduction. Sample 378294 showed a NOEC of 100% for survival and a NOEC of <6.25% for reproduction. Sample 378305 showed a NOEC of 100% for survival and a NOEC of 12.5% for reproduction. Results for samples 378294 and 378305 indicated interrupted dose responses for reproduction as seen in the low reproduction observed at 6.25% and 25% effluent, respectively. Control responses were within quality assurance guidelines. Results of the reference toxicant test were within the expected range.

Table 3. Summary of bioassay results for WDOE

Sample #378283

Evaluation	*C. dubia* Survival	*C. dubia* Reproduction
LC50	>100%	N/A
NOEC	100%	100%
LOEC	>100%	>100%
Reference Toxicant (LC50) =	15.2 ppb Cu	

N/A = Not applicable

Sample #378294

Evaluation	*C. dubia* Survival	*C. dubia* Reproduction
LC50	>100%	N/A
NOEC	100%	<6.25%
LOEC	>100%	6.25%
Reference Toxicant (LC50) =	15.2 ppb Cu	

N/A = Not applicable

Sample #378305

Evaluation	*C. dubia* Survival	*C. dubia* Reproduction
LC50	>100%	N/A
NOEC	100%	12.5%
LOEC	>100%	25%
Reference Toxicant (LC50) =	15.2 ppb Cu	

N/A = Not applicable

4. REFERENCES

EcoAnalysis, Inc. 1994. TOXIS Version 2.4. EcoAnalysis, Ojai, California.

U.S. EPA. 1994. Short-term methods for estimating the chronic toxicity of effluents and receiving waters to freshwater organisms. EPA/600/4-91/001, July 1994. U.S. Environmental Protection Agency, Cincinnati, Ohio.

BIOASSAY REPORT
ACUTE BIOASSAYS
Conducted September 17 through 27, 1996

Prepared for

WASHINGTON STATE DEPT. OF ECOLOGY
PORT ORCHARD, WASHINGTON

Prepared by

CH2M HILL
2300 NW Walnut Boulevard
Corvallis, Oregon 97330

September 27, 1996
Lab I.D. No. C01720

INTRODUCTION

CH2M HILL conducted acute bioassays from September 17 through 27, 1996, on samples provided by Washington State Department of Ecology, Port Orchard, Washington. The organisms tested were the amphipod (*Hyalella azteca*) and the bioluminescent bacteria (*Vibrio fischeri*).

METHODS AND MATERIALS

TEST METHODS

The amphipod tests were performed according to: *Standard Guide for Conducting Sediment Toxicity Tests with Freshwater Invertebrates*, ASTM: E1383-90.

The Microtox tests were performed according to: *Microtox M500 Manual, Eluate Test Protocol*, Microbics Corporation Version 3.

TEST ORGANISMS

The amphipods were obtained from Chesapeake Cultures, Nayes, Virginia. The amphipods used were juveniles and were 2 to 3 millimeters in length. The organisms used for the Microtox testing were obtained from Microbics Corporation. All test organisms appeared vigorous and in good condition prior to testing.

DILUTION WATER

The water used for acclimation and dilution water during the static testing for the amphipods was reconstituted moderately hard water with a total hardness of 84 mg/l as $CaCO_3$, alkalinity of 70 mg/l as $CaCO_3$, and pH of 7.5. The dilution water used for the Microtox testing was a 2 percent sodium chloride solution provided by Microbics corporation.

SAMPLE PREPARATION

For the *Hyallela azteca* bioassays, 50 ml of sample was placed in a test chamber, 200 ml of dilution water was then added and allowed to stand overnight. The test solutions were aerated slowly for 30 minutes prior to addition of test organisms.

For the Microtox testing, the sample centrifuged to remove pore water, 7 grams wet weight of sample was combined with 28 ml of dilution water, tumbled for 30 minutes, and allowed to settle overnight. The supernatant was decanted and centrifuged to remove any undissolved particles. The resulting eluate was labeled 100 percent sample.

TEST CONCENTRATIONS

The *Hyalella azteca* bioassay concentration tested was 100 percent sample sediment with reference sediment for the control. The laboratory control was 16 grade washed silica sand. The photoperiod during the test was 16 hours light, 8 hours dark, and the temperature remained at 20±1°C throughout the test.

The dilutions for the Microtox testing were 5.6, 11.3, 22.5, and 45.0 percent eluate with dilution water as control. Due to low observed toxicity in the samples, a second round of testing was performed with dilutions of 27, 36, 45, 54, 63, 72, 81, and 90 percent eluate with dilution water as control.

SAMPLE COLLECTION AND DESCRIPTION

The samples were collected September 12, 1996 and shipped to CH2M HILL's Corvallis laboratory. The samples were stored at 4°C in the dark until test initiation. Chain of custody for sample collection is provided in Appendix C.

MONITORING OF BIOASSAYS

The amphipod tests were monitored at initiation and every 48 hours thereafter for dissolved oxygen and pH. Conductivity was monitored at test initiation and termination. Mortality was determined at test termination. Light intensity output of the bacteria was monitored at test initiation and termination in the Microtox test. Temperature was monitored continuously throughout the testing period.

RESULTS AND DISCUSSION

STATIC BIOASSAYS

The raw data sheets are presented in Appendix A and the results are summarized in the Tables below. Table 1 summarizes the survival data from the *Hyalella azteca* tests:

Table 1
Summary of Results
Hyalella azteca

Sample ID	# alive / # tested (% survival)
Test date 9/17/96	
Lab Control	56 / 60 (93.3%)
378284 RC-1 100%	39 / 60 (65.0%) [a]
378295 RC-2 100%	56 / 60 (93.3%)
378306 RC-3 100%	38 / 60 (63.3%) [a]
378326 RC-4 100%	55 / 60 (91.7%)

[a] Indicates a statistically significant reduction in survival when compared to the Lab Control at p equal to 0.05 using Homoscedastic t-Test.

The *Hyalella azteca* showed a statistically significant reduction in survival when compared to the lab control in the 378284 RC-1 and 378306 RC-3 samples. Sediment control survival was 93.3 percent.

Table 2 summarizes the results of the Microtox testing performed

Table 2
Summary of Results
Microtox Testing

Sample ID	EC50 value First round	EC50 value Second round
378284 RC-1	> 45%	> 90%
378295 RC-2	> 45%	> 90%
378306 RC-3	> 45%	> 90%
378326 RC-4	> 45%	> 90%

The Microtox testing showed no reduction in bacteria luminescence when compared to the control.

REFERENCE TOXICANT TEST

The 48-hour LC_{50} value and 95-percent control chart limits for the reference toxicant test (cadmium for the amphipods and phenol for the bacteria) conducted in September are listed below. The results indicate that the organisms was within their expected sensitivity range.

Table 3
Reference Toxicant Tests

Species	LC_{50}	95% C.I.
Microtox	18.2 mg/l	14.1 to 21.7 mg/l
Hyalella azteca	4.0 µg/l	-0.1 to 22.1 µg/l

Appendix E. Recent USFS[1] and USGS[2] Data on Metals in Holden Mine Portal Drainage and Tailings Pile Leachate (ug/L)

Date	Iron	Aluminum	Manganese	Zinc	Copper	Cadmium	Lead	Nickel	Arsenic	Mercury	Silver
Mine Portal Drainage (P-5)				U.S. Forest Service (total recoverable metal)							
6/20/95	640	na	na	7700	1900	na	30	na	na	na	na
7/26/95	420	na	na	6200	770	na	20	na	na	na	na
8/9/95	1200	na	na	6300	660	na	10	na	na	na	na
8/23/95	850	na	na	5200	410	na	10	na	na	na	na
9/27/95	1800	na	na	3300	350	na	20	na	na	na	na
				U.S. Geological Survey (dissolved metal)							
8/1/94	370	940	350	4900	580	21	22	4	<2	na	<0.1
Leachate, Tailings Pile # 2 (active)											
8/1/94	50000	>6000	1000	3800	53	6.8	2.7	18	<2	na	<0.1
Leachate, Tailings Pile # 3 (quiescent)											
8/1/94	23000	1500	140	130	21	<1	1.4	4	<2	na	<0.1

[1]USFS (unpublished data)

[2]Kilburn et al. (1994) [this report contains data on metals in addition to those listed above]