WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

Screening Level Investigation of Water and Sediment Quality of Creeks in Ten Eastern Washington Mining Districts, with Emphasis on Metals

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Screening Level Investigation of Water and Sediment Quality of Creeks in Ten Eastern Washington Mining Districts, with Emphasis on Metals

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Abstract

There are numerous abandoned metals mines and inactive mining districts in Washington State. Inactive and abandoned mines, waste rock dumps, and tailings can be the source of contaminated water, including acid rock drainage, that has the potential to severely impact nearby streams. Almost no data are available to evaluate the extent of the problem.

The purpose of this screening level study was to investigate streams near selected mining districts for water quality and sediment quality impacts. The project was the first application in Washington mining districts of EPA ultra-clean methods for measuring toxic metals at water quality criteria levels. As the first systematic investigation of mining district impacts on water and sediment quality, the results from this study were intended to identify the significant parameters for future sampling projects. Findings from this study highlighted districts that required follow-up sampling to define the extent of impacts. The study results will also aid watershed planning through identification of water quality impaired streams.

Water and sediment samples were collected in streams draining ten metals mining districts in eastern Washington. Samples were collected upstream and downstream of the districts and analyzed for metals and general chemistry parameters. Discharges from several individual mines and tailings facilities were also sampled. Field work took place in June 1997 for characterization of high-flow conditions, and in October 1997 for low-flow conditions.

Water quality impacts are seasonal in most districts, with maximum degradation commonly occurring during high-flow. Results showed increases in metals concentrations in the streams that drain most districts, in some cases by an order of magnitude or more. Iron, zinc, and lead were most frequently present in elevated concentrations. State water quality standards for zinc, cadmium, and/or copper were exceeded in three streams. Iron problems were pervasive in the study area. None of the mine or tailings water discharges met water quality standards. Impacts were subtle in some districts where a significant distance separated upstream and downstream samples.

Metals concentrations in sediments from four streams substantially exceeded sediment quality guidelines. Zinc, copper, arsenic, cadmium, and silver were common contributors to the exceedences.

Among the general chemistry parameters, sulfate and total dissolved solids appeared to be the most useful indicators of water quality and sediment quality impacts from mining. A ratio of sulfate to total dissolved solids above 20% was found to adequately identify exceedences of water quality and sediment quality standards or guidelines.

Water Body Numbers
WA-38-1070
WA-39-1420
WA-48-1010
WA-49-1021
WA-52-1010
WA-60-1010
WA-61-7300
WA-61-7340
WA-62-1010
WA-CR-1040

Summary

This project was designed to obtain water and sediment quality data on streams draining ten selected metals mining districts in eastern Washington. Water draining from some individual mines and tailings was also sampled. The study was conducted jointly by the Department of Ecology and the Department of Natural Resources to fill a data gap for characterization of discharges from abandoned metals mines, waste rock dumps, or tailings found in inactive mining districts. Potential impacts to water quality and sediment quality from acid rock drainage (ARD), nitrate from blasting, and cyanide were investigated in this study.

The ten mining districts were selected to represent various geologic settings, mining methods, and extent of mining activity. Sampling was conducted in the following areas:

1. Swauk District, Kittitas County – *Williams Creek, Swauk Creek*
2. Northport District, Stevens County – *Deep Creek, Silver Creek*
3. Republic District, Ferry County – *Swamp Creek, Granite Creek, Eureka Creek*
4. Wauconda District, Okanogan County – *Toroda Creek*
5. Myers Creek District, Okanogan County – *Myers Creek*
6. Conconully District, Okanogan County – *Unnamed Stream, Arlington Mine, First Thought Mine*
7. Twisp District, Okanogan County – *Alder Creek, Alder Mine*
8. Bumping Lake District, Yakima County – *Unnamed Copper City Stream, Deep Creek*
9. Metaline District, Pend Oreille County – *Frog Creek, Pend Oreille Mine Tailings*
10. Wenatchee District, Chelan County – *Cannon Mine Tailings*

Sampling was conducted during June 1997 to characterize high-flow conditions and during October 1997 for low-flow conditions. The largest stream in the vicinity of the mining district was typically selected for sampling. Sample sites were established upstream and downstream of the district. In a few districts, mine water or tailings water discharges were sampled.

This study was the first use of the EPA ultra-clean sampling procedure for metals, with analysis by ICP/MS, to achieve previously unattained low detection levels in samples from Washington mining districts. Previous sampling has been unable to achieve detection levels low enough to determine whether state water quality standards were being exceeded for some metals. Field parameters, general water quality parameters, cyanide, and nitrate were also included in the sampling program. These parameters were selected because they are indicators of water quality impacts caused by mining operations. Streamflow was also measured at some sites.

Results were compared (1) between upstream and downstream locations, (2) between high-flow and low-flow conditions, and (3) to the state water quality standards and other guidelines. The distance between sampling sites, which varied from district to district, influenced upstream and downstream comparison. Some samples were separated by as much as seven miles. Intervening inflows were

not accounted for by the limited sampling dedicated to each district. Even with this potential interference, water quality impacts of varying degree were identified in most districts.

Changes between upstream and downstream metals concentrations amounted to an order of magnitude or more in nine of the 13 creeks sampled. Iron, zinc, and lead were most frequently elevated, followed by copper, cadmium, and arsenic. Exceedences of state metals standards for protection of aquatic life were noted in three streams: Alder Creek, an unnamed stream at Arlington Mine, and an unnamed stream at the Copper City Mill site. Metals contributing to the standards violations included zinc, cadmium, and copper. Iron approached or exceeded water quality guidelines in eight of the 13 creeks studied. Samples of mine and tailings water discharges exceeded water quality standards.

Three of 13 creeks exceeded the state turbidity standard and had TSS levels that afford low protection to aquatic communities. Two streams had violations of the state pH standard, Alder Creek and the unnamed Copper City stream. In both cases there was close proximity to mine drainage. Cyanide was not detected in any of the samples. Nitrate, potentially present due to blasting, was mostly found at low concentrations.

Sediment samples were collected during low-flow in eight creeks. Four streams substantially exceeded sediment quality guidelines: Alder Creek, Eureka Creek, Swamp Creek, and the unnamed Copper City stream. Zinc, copper, arsenic, cadmium, antimony, and silver exceeded the guidelines.

Among the general water quality parameters included in the study, increased concentrations of sulfate and total dissolved solids (TDS) are indicators of mining related impacts. A 20% cutoff ratio of sulfate to TDS identified nearly all exceedences of water quality standards or sediment quality guidelines at the sites included in this project.

Results demonstrate the need for similar sampling at other mining districts in eastern and western Washington. Ideally, ground water impacts would also be evaluated, but that undertaking would be beyond the scope of a screening level investigation. Future sampling should include low-level metals analyses and account for seasonal variability of water quality impacts.

Conclusions reached in this report resulted in the following specific recommendations for future screening level sampling projects in mining areas:

- Sample for general chemistry parameters hardness, TDS, TSS, turbidity, and sulfate
- Measure the field parameters temperature, pH, conductivity, and streamflow
- Use the ultra-clean method for metals
- Calibrate and refine the proposed SO_4:TDS ratio for identifying ARD impacts in streams
- Sample during high-flow and low-flow conditions
- Minimize the distance between upstream and downstream samples
- Account for potential alternate pathways for migration of contaminants
- Contribute data in support of a new statewide inventory of abandoned mines

Specific locations recommended for follow-up sampling that were identified as exceeding water quality or sediment quality standards or guidelines, or were otherwise adversely impacted, include:

- Alder Creek, both at the Alder Mine and the Alder Mill, Twisp District
- Unnamed stream at the Copper City Mill, Bumping Lake District
- Unnamed stream near the Arlington Mine, Conconully District
- Eureka Creek, Republic District
- Toroda Creek, Bodie Mill Tailings, Wauconda District
- Deep Creek, Anderson Mill Tailings, Northport District

It is further recommended that expanded sampling be conducted in the Conconully, Republic, and Bumping Lake districts, due to their size and the limited extent of sampling in these districts during this study.

Acknowledgements

We thank the following people for their contributions to this project:

- *Jari Roloff* and *Keith Ikard*, DNR, for preparing the figures and maps in this report.

- *Jim Ross, Randy Knox*, and *Sally Cull* of the metals group, Ecology Manchester Environmental Laboratory, for analyzing samples.

- *Bill Yake,* Ecology, and *Ray Lasmanis*, DNR, for reviewing the report.

- *Joan LeTourneau*, Ecology, for formatting and editing the final report.

Introduction

There are numerous abandoned metals mines and inactive mining districts in Washington State. Former mining districts, consisting of inactive and abandoned mines, waste rock dumps, and tailings can be the source of acid rock drainage (ARD), nitrate from blasting, and cyanide that have the potential to severely impact nearby streams. Almost no data are available to evaluate the extent of the problem. Recognizing this data gap, the Department of Natural Resources (DNR), and the Department of Ecology (Ecology) jointly conducted this study.

The purposes of this study were to (1) gather and present screening level water quality data on selected parameters from streams near some metals mining districts in Washington State and (2) characterize mine water discharges from a few inactive or abandoned mines. The study was not a comprehensive examination of mining districts across the state or exhaustive in scope of potential parameters of concern. Similarly, the study was not intended to evaluate mine water discharges from numerous individual mines within the selected districts, although a few mines were opportunistically sampled to characterize this type of effluent.

All districts included in the study are located in eastern Washington (Figure 1). Ten mining districts were selected to represent a range of geological environments, mining methods, and extent of mining activity. Geologic notes were taken at each sample site and an overview is presented of the geology, mineralogy, and historical mining operations and practices in each district for comparison to the water quality results.

For most mining districts, the general approach was to establish sampling locations in the largest and nearest potentially impacted stream. One sample site was placed upstream of the mining district, with a second sample site in the same stream downstream of the mining district. Water quality samples were initially collected in June 1997, representing high streamflow conditions. Most of the same locations were resampled in October 1997, representing low streamflow conditions. Some sites and parameters were not resampled in October. Mine discharges were not resampled. Sediment samples were obtained at selected sites in October. Fine material was preferentially selected for analysis.

Water samples were collected using the EPA (1995) ultra-clean sampling procedure for metals, with analysis by ICP/MS (inductively coupled plasma/mass spectrometry). These methods achieved previously unattained low detection levels. For certain metals, notably lead, silver, and cadmium, detection limits for methods previously used are higher than the state surface water quality standards (Chapter 173-201A WAC). Data obtained in this study fill a gap caused by lack of previously available information at these low concentrations.

Although the study focused on metals, some general water quality parameters were included. These parameters were selected as general indicators for identifying ARD conditions or to identify other impacts potentially associated with mining operations, such as cyanide or nitrate releases.

Differences observed between upstream and downstream water quality were compared during high-flow and low-flow conditions, and finally to state surface water quality standards

(Chapter 173-201A WAC) or in one case, state ground water quality standards (Chapter 173-200 WAC). For metals, this study reveals that while water quality impacts due to discharges from the mining districts were detectable, most of the receiving waters remained within water quality standards. However, the impacted streams did not meet the antidegradation requirements in the standards. Mines and tailings discharges did not meet state water quality standards. For general water quality parameters, most district level samples showed that water quality standards were not exceeded, but there were differences of varying significance between upstream and downstream water quality.

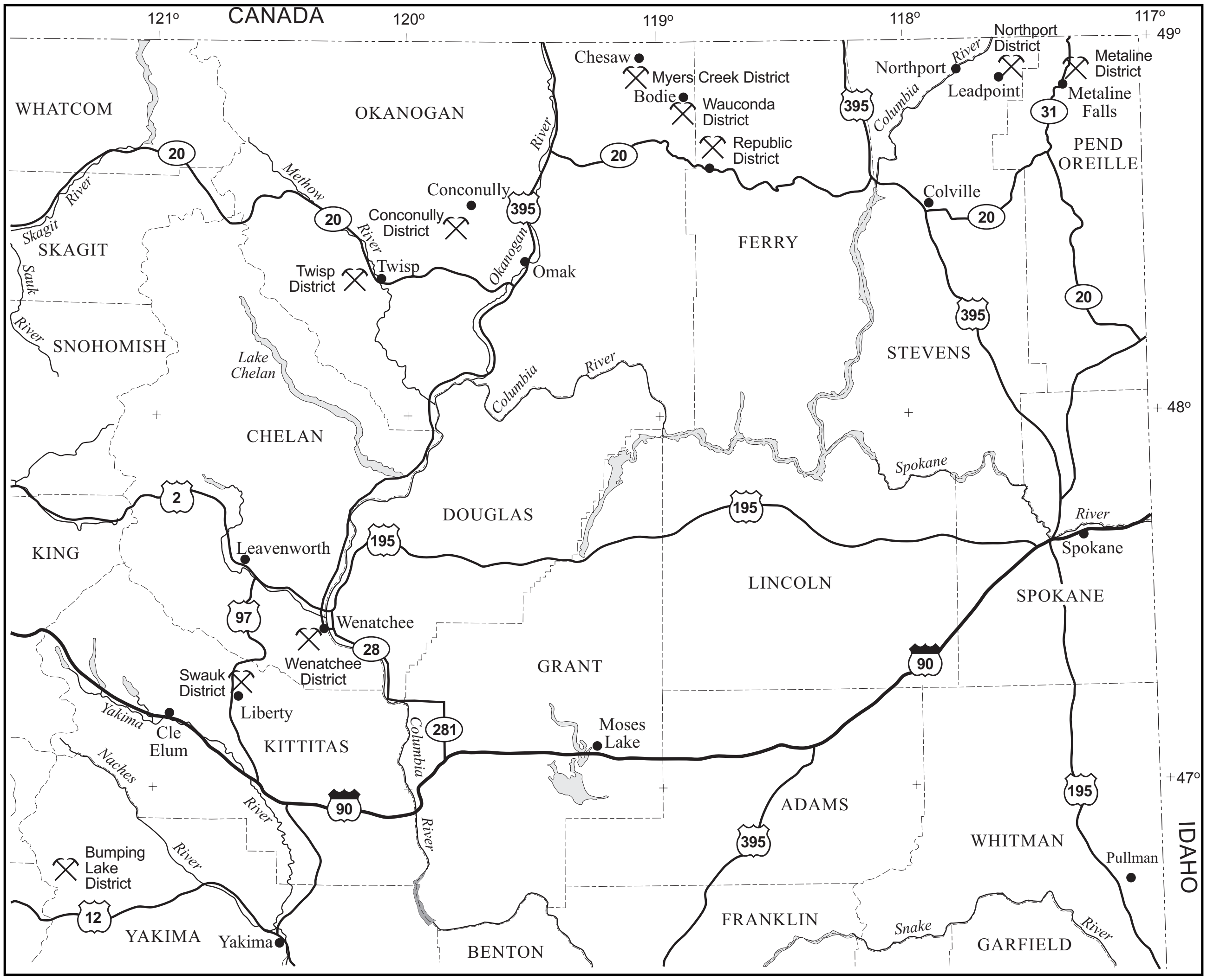

Figure 1. Locations of Mining Districts Included in Ecology/DNR 1997 Screening Study

Water Quality Criteria

State surface water quality standards pertinent to the present study are summarized in Table 1 and include standards for temperature, pH, turbidity, metals, and cyanide. The metals and cyanide standards are for acute (1-hour average not to be exceeded more than once every three years) and chronic (4-day average not to be exceeded more than once every three years) exposure. It should be noted that field work was not conducted during periods when violations of the temperature standard would be likely to occur.

The standards for arsenic, cadmium, copper, lead, silver, and zinc, as well as the acute standard for mercury, are for the dissolved fraction. The dissolved fraction of these metals was analyzed in the present study, except for arsenic and mercury which were analyzed as total recoverable. The EPA total recoverable criteria, 359 and 189 µg/L (parts per billion), on which the state arsenic standards were based are essentially identical to the dissolved arsenic standards (360 and 190 µg/L). The chronic mercury standard (0.012 µg/L) is for total recoverable. The acute standard for dissolved mercury (2.1 µg/L) is rarely exceeded in state surface waters and was not approached in the total recoverable analysis conducted for this study.

The standards for cadmium, copper, lead, silver, and zinc are hardness dependent. Metals toxicity generally decreases with increasing hardness. For example, the cadmium acute and chronic criteria are to 0.30 and 0.19 µg/L at 10 mg/L hardness, but increase to 3.7 and 1.0 µg/L at a hardness of 100 mg/L (parts per million). Equations for calculating hardness-based metals criteria are provided in Appendix A.

There is no state standard for iron. EPA has recommended that total iron concentrations not exceed 1,000 µg/L under conditions of continuous exposure to aquatic communities (EPA, 1986, 1999). Canada has a substantially lower guideline of 300 µg/L total iron, noting that the EPA criterion is too close to levels shown to adversely affect some aquatic species (CCREM, 1986).

Total suspended solids (TSS) also are not addressed in the state standards, except indirectly by way of the turbidity standard. The National Academy of Sciences (1973) considers the level of protection afforded aquatic communities to vary with TSS as follows:

- <25 mg/L - high
- 25 to 80 mg/L - moderate
- 80 to 400 mg/L - low
- >400 mg/L - very low

Table 1. State Surface Water Quality Standards Pertinent to the Present Study
[see WAC 173-201A for complete standards]

Parameter	Class AA (extraordinary)	Class A (excellent)
Temperature	Shall not exceed 16.0°C due to human activities. When natural conditions exceed 18 °C. no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3 °C.	Shall not exceed 18.0°C due to human activities. When natural conditions exceed 18.0 °C no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3 °C.
pH	Shall be within the range of 6.5 - 8.5 with a human caused variation within the above range of less than 0.2 units	Shall be within the range of 6.5 - 8.5 with a human caused variation within the above range of less than 0.5 units
Turbidity	Shall not exceed 5 NTU over background turbidity when the background turbidity is 50 NTU or less, or have more than a 10 percent increase in turbidity when the background turbidity is more than 50 NTU.	Shall not exceed 5 NTU over background turbidity when the background turbidity is 50 NTU or less, or have more than a 10 percent increase in turbidity when the background turbidity is more than 50 NTU.
Metals (µg/L)	Acute Criterion (@ 100 mg/L hardness)	Chronic Criterion (@ 100 mg/L hardness)
Arsenic[a]	360	190
Cadmium[a]	3.7	1.0
Copper[a]	17.0	11.4
Lead[a]	65	2.5
Mercury	2.1[a]	0.012[b]
Silver[a]	3.5	no criterion
Zinc[a]	114	104
Cyanide[c] (µg/L)	22	5.2

[a] dissolved fraction

[b] total recoverable

[c] weak acid dissociable

Sediment Quality Criteria

There are no state standards for metals in freshwater sediments to protect aquatic life. Three sets of sediment guidelines were used to evaluate findings from the present study (Table 2). The province of Ontario (Persaud et al., 1993) and Environment Canada (1994) have determined adverse effects levels from simultaneously collected data on benthic invertebrate communities and metals concentrations in freshwater sediments. In an Ecology study, Cubbage et al. (1997) calculated apparent effects thresholds (AETs) from an analysis of bioassay and metals data in Ecology's FSEDQUAL database on freshwater sediments statewide. These sources have no guidelines for selenium, beryllium, or thallium. The AETs have not been proposed or adopted by Ecology.

Results from these three efforts agree reasonably closely for most metals. Because the level of adverse effects being used as basis for the guidelines varies from "probable" to "severe", values for some metals are widely different, for example zinc, 310-820 mg/Kg, and copper, 110-840 mg/Kg (parts per million).

Table 2. Guidelines on Metals in Freshwater Sediments (mg/Kg, dry)

	Ontario[a]	Canada[b]	Ecology[c]
Metal	Severe Effects Level	Probably Effects Level	Apparent Effects Threshold
Iron	40,000	- -	- -
Manganese	1,100	- -	1800
Zinc	820	310	520
Lead	250	91	260
Copper	110	200	840
Chromium	110	90	280
Nickel	75	36	46
Cadmium	10	3.5	7.6
Arsenic	33	17	40
Silver	- -	- -	4.5
Antimony	- -	- -	3.0
Mercury	2.0	0.49	0.56
Selenium	- -	- -	- -
Beryllium	- -	- -	- -
Thallium	- -	- -	- -

[a] Persaud et al. (1993)

[b] Environment Canada (1994)

[c] Cubbage et al. (1997)

Methods

Sampling and Field Analysis

All water samples were collected as simple grab samples. Water samples for metals analysis were collected directly into pre-cleaned 500 mL Teflon bottles. Samples for dissolved metals were vacuum-filtered in the field through a disposable 0.45 µm cellulose nitrate filter (#450-0045, type S). Non-talc, disposable gloves were worn during the filtering procedure. The filtrate was transferred to a clean Teflon bottle and preserved to pH <2 with 5 mL sub-boiled 1:1 nitric acid, carried in small Teflon vials, one per sample. Unfiltered water samples for total recoverable metals were preserved in the same manner. Sample containers and preservation for general water quality parameters are described in MEL (1994).

The Teflon bottles, acid vials, and filter units were pre-cleaned for low-level metals analysis using procedures described in Kammin et al. (1995). Briefly, the bottles and vials were soaked in 1:1 nitric acid for 72 hours and rinsed with de-ionized (DI) water. The cleaned bottles were filled with DI water and placed in zip-lock bags. The filters were cleaned by allowing 1:1 nitric acid to gravity filter, then vacuum filtering 500 mL of DI water. The unit was taken apart, air-dried, reassembled, filter lids secured with tape, and placed in zip-lock bags.

Field measurements for pH and temperature were obtained with an Orion Model 250A meter; field conductivity was measured with an Orion Model 120 conductivity meter. The pH meter was calibrated daily. Ferrous iron was qualitatively recorded as present or absent by use of a colorimetric 2,2'-dipyridyl solution. Measurements of streamflow were made with a Marsh-McBirney flowmeter and top-setting rod.

Sediment samples were composites of multiple grabs 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 DI water. The homogenate was split into glass jars, with Teflon lid liners, cleaned to EPA QA/QC specifications (EPA, 1990), or put in twist-lock bags for grain size.

All samples were double-bagged in polyethylene and placed on ice for transport to the Ecology Manchester Environmental Laboratory (MEL). Chain-of-custody was maintained.

Laboratory Analysis

Sample analysis was conducted at MEL, except for grain size which was done by Rosa Environmental & Geotechnical Laboratory, Seattle.

Water samples were analyzed for zinc, arsenic, copper, lead, cadmium, and silver by Inductively Coupled Plasma/Mass Spectrometry (ICP/MS) following EPA method 200.8. Mercury was analyzed by EPA method 245.7, Cold Vapor Atomic Absorption (CVAA). Total recoverable samples were digested with nitric acid by EPA method 200.2, modified for ICP/MS. Dissolved samples were not digested. Samples for mercury determination were digested as described in method 245.7, which involves mercury oxidation by bromine. Analysis for general water quality parameters followed routine methods described in MEL (1994). Cyanide was analyzed as weak acid dissociable by EPA method 335.2. Analysis of other general chemistry parameters followed MEL (1994).

Metals analysis of sediment samples was by ICP according to EPA method 200.7 (iron, manganese, zinc, chromium, copper, lead, nickel, cadmium, silver, beryllium, antimony); Graphite Furnace Atomic Absorption (GFAA) according to EPA methods 206.2 (arsenic), 270.2 (selenium), and 279.2 (thallium); and CVAA according to EPA method 245.5 (mercury)

Metals other than mercury were digested with nitric and hydrochloric acids by EPA method 3050. The mercury digestion in method 245.5 employs aqua regia, potassium permanganate, and potassium persulfate. Grain size was determined by sieve and pipette using the Puget Sound Estuary Program method (EPA, 1996).

Data Quality

All analyses were performed within the EPA Contract Laboratory Program (CLP) holding time for the metals of interest (28 days for mercury; 180 days for other metals). 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 run. All initial and continuing calibration verification standards were within relevant CLP control limits. AA calibration gave a correlation coefficient (r) of 0.995 or greater, also meeting CLP calibration requirements.

Matrix spike and matrix spike duplicates were performed with each sample set. Spike recoveries were within the CLP acceptance limits of +/-25%, with the following exceptions:

- Silver matrix spike recoveries for the May-June water samples ranged from 73-77%, marginally outside the CLP limit. These data were qualified as estimates (J flag).
- One of four zinc spikes was high (208%) for the October water samples, due to high native zinc (Alder Creek).
- Antimony and thallium spike recoveries were low for sediment samples, 35-48% and 15-25%, respectively. Results for these metals were qualified as estimates.

Laboratory control samples (LCS) were analyzed with each sample set. Results were within acceptance windows established for each parameter, with the following exceptions:

- Silver recoveries in the LCS were marginally low (74%) for the June water samples.
- Antimony recovery was low (46%) in the LCS analyzed for sediment samples. These data were qualified as noted above.
- Iron recovery was marginally low (73%) in the sediment LCS.

Procedural blanks associated with these samples showed no analytically significant levels of metals. Results from analysis of bottle and filter blanks prepared for this and similar studies showed no evidence of significant contamination arising from sample collection, preservation, or handling (Appendix B).

There were no significant data quality issues for general water quality parameters, cyanide, or nitrate in terms of holding time, instrument calibration, procedural blanks, precision, laboratory control samples, or matrix spikes.

Selected water (Appendix C) and sediment (Appendix D) samples were analyzed in duplicate to evaluate analytical precision. For general chemistry parameters, results agreed within 7% or better. Duplicate analyses of cadmium, copper, and arsenic in water generally agreed within 20%, for mercury within 33%, and for zinc within 40%. Results for lead were variable (8-61%), with the higher values being a function of the low lead concentrations in these samples. Precision of the iron data on high level samples was poor (109-111%) compared to lower level samples (2.5%). The higher of the two results was in agreement with iron concentrations indicated by the analysis for hardness (Ross, 1999). Silver was not detected in any of the water samples analyzed in duplicate.

Results on duplicate sediment samples agreed within 20% for all metals except antimony (48%). Duplicate determinations of percent gravel, sand, silt, and clay were within 4 - 38%.

The results from duplicate analyses were averaged for use in this report.

Results

In this section, study results are presented on a district-by-district basis. In the associated tables, the data are flagged where water and sediment quality standards or guidelines are exceeded. To aid in comparing results between districts, a summary of the complete project data is found in:

- Appendix E - field measurements and general chemistry
- Appendix F - metals in water samples
- Appendix G - grain size and metals in sediment samples
- Appendix H - field measurements for mines and tailings

1. Swauk District, Kittitas County

Geology* and Historical Mining Operations and Practices

The Swauk District production has been, and is currently, mainly from placer gold operations in and along Swauk Creek (Swauk Creek Area) and Williams Creek (Liberty Area). The source of the gold is quartz veins mostly in arkoses of the Eocene Swauk Formation and the Silver Pass Formation. Veins also occur in dikes and stocks of the Teanaway Basalt that intrude the Swauk and Silver Pass Formations (Margolis, 1994).

The hydrothermal system at Liberty affected rock over at least a 20 square mile area. Fluids followed fractures within thinly bedded siltstone and shale above the sandstone, resulting in the formation of upward branching quartz veins containing native gold. Hydrothermally altered Teanaway Basalt locally contains higher amounts of gold, arsenic, and mercury than adjacent altered arkose. (Margolis, 1994)

Evaluation of Water Quality Samples

Water quality samples and field parameters were obtained in upper and lower Williams Creek and in upper and lower Swauk Creek during high-flow and low-flow conditions (Figure 2). Sediment samples were collected at all four sites during the low-flow sampling event. Williams Creek is tributary to Swauk Creek, approximately ¼ mile upstream from the lower Swauk sample location. Samples in Swauk Creek were about seven miles apart. The Williams Creek samples were collected about one mile above and one mile below the town of Liberty. The downstream Swauk Creek sample is about two miles below the downstream Williams Creek sample. No individual mine discharges were sampled within the district.

Williams Creek

A comparison of upstream and downstream general chemistry results for Williams Creek (Table 3) shows little change in temperature or pH and decreases in conductivity, hardness, alkalinity, and TDS going downstream. Turbidity and total suspended solids (TSS) increased downstream during high-flow (June). Flow measurements in June were 0.83 cubic feet per second (cfs) in the upper drainage, and 32 cfs at the downstream sampling site about 1 mile above Williams Creek's confluence with Swauk Creek. Flow was not determined in October. The results for general chemistry comparing high and low-flow show that, while there were increases in all parameters except turbidity and TSS, the concentrations were relatively low. An inverse relationship between dissolved constituents and TSS/turbidity with flow is commonly seen in streams.

Cyanide was not detectable at or below 0.005 mg/L. Nitrate/nitrite was not detectable at or below 0.01 mg/L. These parameters were analyzed during high-flow only.

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*Appendix I shows the composition of minerals referred to in this report.

*Appendix J shows a glossary of geologic terms referred to in this report

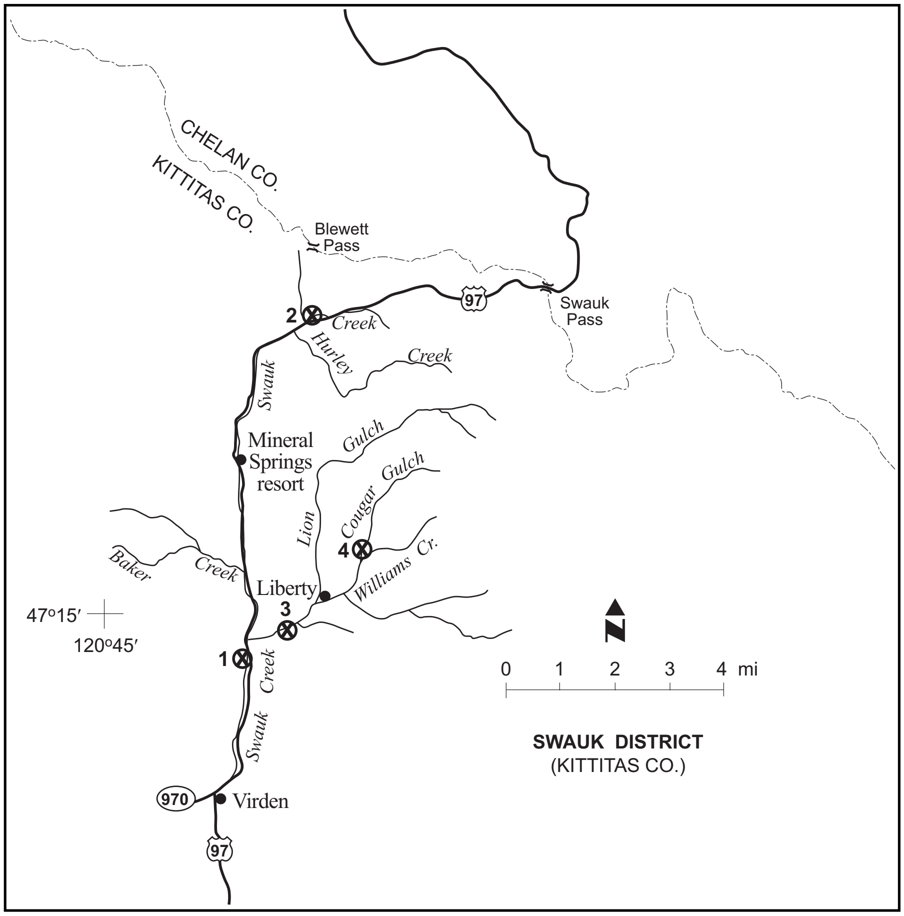

Figure 2. Locations of Water and Sediment Samples Collected in Williams and Swauk Creeks - Swauk District

During low-flow the downstream lead concentration increased by an order of magnitude over the upstream concentration, from <0.02 to 0.32 µg/L, with the zinc concentration increasing by a factor of 3, from 0.36 to 1.0 µg/L (Table 4). The district has not historically been a lead or zinc producer. No downstream changes were seen for zinc or lead during high-flow, at which time lead was not detected (< 0.02 µg/L).

Iron increased in concentration downstream from 120 to 310 µg/L during high-flow. Iron was not analyzed for the low-flow survey. An iron concentration of 310 µg/L is at the Canadian water quality guideline of 300 µg/L (CCREM, 1986). The other metals analyzed either showed no downstream increases (arsenic and copper) or were not detected (cadmium, silver, and mercury). All metals concentrations in Williams Creek were well within state standards for protection of aquatic life. As previously mentioned, there is no state water quality standard for iron.

Replicate water samples were collected in Williams Creek during low-flow to provide estimates of the variability in the metals data for the downstream site. Results (Table 5) showed close agreement between separately collected samples. These data were averaged for use in Table 4.

Table 3. Field Measurements and General Chemistry Results for Swauk District Water Samples Collected June and October, 1997

	Flow (cfs)		Temp. (^{o}C)		pH (units)		Cond. (µmho/cm)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Williams Creek Above	0.83	NM	8.4	3.3	7.45	7.50	210	276
Williams Creek Below	32	NM	9.0	3.3	7.56	7.36	120	178
Swauk Creek Above	14	NM	8.4	4.9	7.43	7.80	112	183
Swauk Creek Below	NM	NM	10.0	7.5	7.38	7.90	131	201

	Hardness (mg/L)		Alkalinity (mg/L)		TDS (mg/L)		TSS (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Williams Creek Above	103	130	109	140	119	166	2	1
Williams Creek Below	58	78	61	88	93	124	9	1
Swauk Creek Above	52	84	57	94	83	123	6	1
Swauk Creek Below	64	91	70	100	97	134	14	1

	Turbidity (NTU)		Sulfate (mg/L)		Cyanide (mg/L)		NO_3+NO_2 (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Williams Creek Above	2.4	0.5UJ	1.4	2.9	0.005U	NA	0.01U	NA
Williams Creek Below	6.8	1.1J	1.2	3.0	0.005U	NA	0.01U	NA
Swauk Creek Above	3.5	0.5UJ	0.5U	2.0	0.005U	NA	0.11	NA
Swauk Creek Below	7.7	0.6J	1.3	3.0	0.005U	NA	0.23	NA

NM = not measured
NA = not analyzed
J = estimated value
U = not detected at or above the reported value
UJ = not detected at or above the reported estimated value

Table 4. Metals Concentrations in Swauk District Water Samples Collected June and October, 1997 (µg/L)

	Iron (total recoverable)		Zinc (dissolved)		Arsenic (total recoverable)		Copper (dissolved)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Williams Creek Above	**120**	NA	**0.68**	**0.36**	1.5U	**0.38**	**0.50**	**0.41**
Williams Creek Below	**310***	NA	**0.50**	**1.0**	1.5U	**0.30**	**0.55**	**0.43**
Swauk CreekAbove	**269**	NA	**0.45**	**0.15**	**1.60**	**0.23**	**0.44**	**0.24**
Swauk Creek Below	**287**	NA	**1.3**	**1.6**	1.5U	**0.25**	**0.46**	**0.36**

	Lead (dissolved)		Cadmium (dissolved)		Silver (dissolved)		Mercury (total recoverable)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Williams Creek Above	0.02U	0.02U	0.02U	0.02U	0.04UJ	0.02U	0.002U	0.002U
Williams Creek Below	0.02U	**0.42**	0.02U	0.02U	0.04UJ	0.02U	0.002U	0.002U
Swauk Creek Above	0.02U	0.02U	0.02U	0.02U	0.04UJ	0.02U	0.002U	0.002U
Swauk Creek Below	0.02U	**0.054**	0.02U	0.02U	0.04UJ	0.02U	0.002U	0.002U

Note: Metals detections highlighted in **BOLD**
*exceeds water quality standard or guideline
NA = not analyzed
U = not detected at or above the reported value
UJ = not detected at or above the reported estimated value

Sediment data are summarized in Table 6. Sediments collected in Williams Creek were primarily gravel and sand. Metals concentrations decreased following the order iron > manganese > zinc > chromium/nickel/copper > arsenic > beryllium > mercury. Lead, silver, cadmium, selenium, antimony, and thallium were below detection limits. The same general pattern of relative abundance was seen in nearby Swauk Creek. This pattern was common to sediments from most of the other mining districts.

Metals concentrations in downstream sediments were comparable to or slightly lower than upstream. Samples from both areas of Williams Creek were within guidelines for protection of aquatic life (Table 2).

Table 5. Metals Concentrations in Replicate Water Samples Collected in Williams Creek, October 1997 (µg/L)

Sample Number:	438254	438276	RPD
Iron (total recoverable)	NA	NA	- -
Zinc (dissolved)	1.2	0.90	30%
Arsenic (total recoverable)	0.29	0.31	7%
Copper (dissolved)	0.44	0.42	5%
Lead (dissolved)	0.32	0.53	50%
Cadmium (dissolved)	0.02U	0.02U	0%
Silver (dissolved)	0.02U	0.02U	0%
Mercury (total recoverable)	0.002U	0.002U	0%

RPD = relative percent difference (range as percent of duplicate mean)
NA = not analyzed
U = not detected at or above reported value

Swauk Creek

General chemistry and seasonal patterns in Swauk Creek were generally similar to findings for Williams Creek, except for higher concentrations of nitrate/nitrite (Table 3). The only flow measurement obtained in Swauk Creek was 14 cfs at the upstream site during high-flow.

For the most part, metals concentrations in Swauk Creek showed little change between upstream and downstream (Table 4). Similar to Williams Creek, lead and zinc increased in a downstream direction during low-flow, although in the case of lead to a much lesser degree. As in Williams Creek, cadmium, silver, and mercury were not detected. Except for the higher lead in Williams Creek, metals concentrations were similar in the two streams.

Iron concentrations in upper and lower Swauk Creek were 269 - 287 µg/L, approaching the 300 µg/L Canadian water quality guideline. The concentrations of all other metals were within state standards. The fact that upper Swauk Creek contains a relatively high iron concentration suggests that the lower creek may carry a very large iron load during higher flow conditions.

Metals concentrations in Swauk Creek sediments showed an increase in the downstream sample, except for chromium and mercury (Table 6). The increase seen in the lower creek does not appear to be due to a grain size effect, as the percentage of fine material (3.0%) was lower than in the upstream sample (5.7%). Downstream metals levels in Swauk Creek were slightly but consistently higher than in downstream Williams Creek. No sediment quality guidelines were exceeded.

Table 6. Grain Size and Metals Concentrations in Swauk District Sediment Samples Collected October 1997 (mg/Kg, dry)

Sample Location	% Gravel	% Sand	% Silt	% Clay	Fe	Mn	Zn
Williams Creek Above	60.2	38.4	0.8	0.7	**24500**	**448**	**54**
Williams Creek Below	59.6	38.4	1.6	0.4	**19200**	**325**	**38**
Swauk Creek Above	40.2	54.0	5.2	0.5	**14500**	**255**	**31**
Swauk Creek Below	60.2	36.8	2.1	0.9	**23700**	**398**	**48**

Sample Location	Cr	Ni	Cu	As	Pb	Hg	Ag
Williams Creek Above	**26**	**28**	**19**	**4.3**	3U	**0.03**	0.3 U
Williams Creek Below	**18**	**15**	**11**	**3.0**	3U	**0.02**	0.3 U
Swauk Creek Above	**25**	**15**	**8.8**	**1.8**	3U	**0.05**	0.3 U
Swauk Creek Below	**25**	**19**	**15**	**3.3**	3U	**0.03**	0.3 U

Sample Location	Cd	Se	Be	Sb	Tl
Williams Creek Above	0.5 U	0.3 U	**0.47**	3 UJ	0.3 UJ
Williams Creek Below	0.5 U	0.3 U	**0.41**	3 UJ	0.3 UJ
Swauk Creek Above	0.5 U	0.3 U	**0.35**	3 UJ	0.3 UJ
Swauk Creek Below	0.5 U	0.3 U	**0.50**	3 UJ	0.3 UJ

Note: Metals detections highlighted in **BOLD**
U = Not detected at or above the reported value
UJ = not detected at or above the reported estimated value

2. Northport District, Stevens County

Geology and Historical Mining Operations and Practices

The Northport District was composed mainly of lead-zinc mines. Among the most significant of the formerly productive mines were the Gladstone and the Keystone in the Silver Creek drainage.

All the mines in the Northport District are Mississippi Valley type lead-zinc deposits occurring in Cambrian-Ordovician Metaline Formation. These carbonate rocks are enriched in lead and zinc, with the ore minerals consisting mainly of sphalerite and galena. Cerussite and anglesite are also present. Non-ore minerals consist of pyrite, silicified dolomitic limestone, quartz, and fluorite. Besides zinc and lead, minor silver was also produced from some mines. Copper is present at some locations.

The Anderson (Calhoun) Mine/Mill operated until 1968. The ore averaged less than 4% lead and zinc combined. The last production from the Gladstone Mine was 1955, and the last production from the Keystone was in 1940 (Derkey et al., 1990). The Keystone also shipped iron ore occurring as hematite and limonite during 1936-1940 (Derkey et al., 1990).

Evaluation of Water Quality Samples

Water quality samples and field measurements were obtained from Deep Creek (Anderson Mine/Mill Area near Leadpoint) and in upper and lower Silver Creek (Gladstone Mountain Area) during high-flow and low-flow (Figure 3). The Anderson Mine/Mill Area samples were located about ¼ mile apart and were intended to bracket the millsite and tailings deposited along the east bank of Deep Creek. The mine and mill are located on the west bank. Silver Creek flows along the north side of Gladstone Mountain and is tributary to Deep Creek downstream from the lower Deep Creek sample site. The Silver Creek samples were separated by approximately two miles. The topographic map for the area indicates that numerous mines are located on the upper flanks of Gladstone Mountain, ½ mile or more from Silver Creek. No individual mines were investigated in the district and no mine, mill, or tailings discharges were sampled. No sediment samples were obtained in the Northport District.

Anderson Mine/Mill Area

Table 7 shows the Anderson Mine/Mill Area had little effect on general water quality parameters in Deep Creek, at the sample locations selected. An exception was sulfate, which increased substantially downstream during both high-flow, from 12 to 19 mg/L, and low-flow, from 22 to 30 mg/L. Estimates of streamflow during high-flow appear to indicate that there was a large increase in discharge between upstream and downstream sites, from 100 to 180 cfs. These results are questionable, as there are no tributaries entering Deep Creek between the two locations. No discharge measurements were made at low-flow. Sulfate concentrations were relatively high in Deep Creek compared to other stream samples collected during this study. Cyanide was not detected and nitrate/nitrate was low.

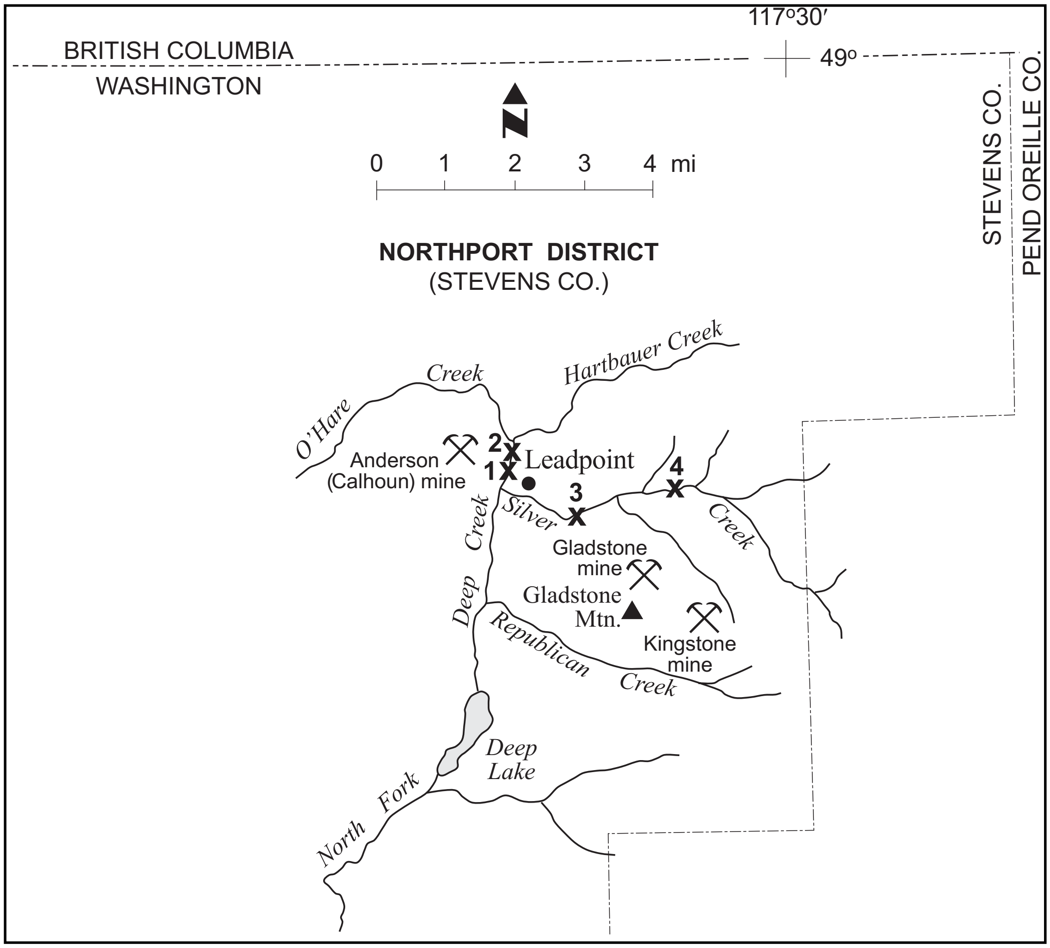

Figure 3. Locations of Water Samples Collected in Deep and Silver Creeks - Northport District

The pH readings obtained during June were anomalously high and the data were therefore rejected. During low-flow, pH measurements were near neutral.

Substantial increases are noted in the concentrations of zinc and lead between upstream and downstream samples in Deep Creek (Table 8). This result corresponds to the mineralogy of the ore deposits in the district. The most pronounced increases occurred during high-flow, at which time cadmium and mercury also became detectable downstream at 0.046 and 0.0025 µg/L, respectively. The large increase in zinc concentration during high-flow, from 1.3 to 44 µg/L, is noteworthy. Except for lead, metals concentrations were higher under high-flow conditions. Although Anderson Mine/Mill was clearly a source of metals contamination to Deep Creek, no state standards were exceeded. With the large flow volume in Deep Creek, this site may be considered an illustration of the role dilution plays in modifying impacts of mines adjacent to major streams.

Table 7. Field Measurements and General Chemistry Results for Northport District Water Samples Collected June and October, 1997

	Flow (cfs)		Temp. (°C)		pH (units)		Cond. (µmho/cm)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Deep Creek Above	100	NM	12.5	6.4	REJ	7.67	322	511
Deep Creek Below	180	NM	15.3	7.1	REJ	7.36	340	547
Silver Creek Above	NM	NM	6.3	5.1	REJ	7.96	136	239
Silver Creek Below	NM	NM	6.8	5.5	REJ	7.94	162	309

	Hardness (mg/L)		Alkalinity (mg/L)		TDS (mg/L)		TSS (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Deep Creek Above	186	287	165	256	207J	303	5J	1
Deep Creek Below	186	298	169	267	204J	337	2J	1
Silver Creek Above	82	127	69	120	88J	142	288J*	1
Silver Creek Below	117	170	86	158	96J	173	307J*	1

	Turbidity (NTU)		Sulfate (mg/L)		Cyanide (mg/L)		NO_3+NO_2 (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Deep Creek Above	5.2J	1.3J	12	22	0.005U	NA	0.012	NA
Deep Creek Below	3.4J	1.0J	19	30	0.005U	NA	0.020	NA
Silver Creek Above	100J	0.5UJ	3	6	0.005U	NA	0.024	NA
Silver Creek Below	130J*	0.5UJ	4	8	0.005U	NA	0.022	NA

*exceeds water quality standard or guideline
NM = not measured
NA = not analyzed
J = estimated value
U = not detected at or above the reported value
UJ = not detected at or above the reported estimated value
REJ = data rejected

Gladstone Mountain Area

No flow measurements were taken in Silver Creek. Elevated levels of TSS, 288 mg/L, and turbidity, 100 NTU, were recorded at the upstream site during high-flow, increasing to 307 mg/L and 130 NTU downstream (Table 7). The turbidity increase exceeds the 10% allowed in the state standards. TSS concentrations of 288 - 307 mg/L afford a low level of protection to aquatic communities (NAS, 1974). Other general chemistry parameters showed consistent but modest increases between upstream and downstream. No cyanide was detected and nitrate/nitrite was low.

A comparison of high- and low-flow conditions shows the typical pattern of increased dissolved parameters, and decreased turbidity and TSS at lower stream flow, as seen in Deep Creek and elsewhere. However, the concentrations for all parameters except turbidity and TSS are lower by nearly half in Silver Creek compared to Deep Creek.

No useable pH data were obtained for Silver Creek during high-flow. At low-flow, pH measurements were near neutral, but still higher than in Deep Creek.

Lead (low-flow) and mercury (high-flow) in Silver Creek increased by an order of magnitude between upstream and downstream sites (Table 8). The increase in lead concentration corresponds to the mineralogy of the mines and the mineralization of the Gladstone Mountain Area. Zinc was also produced but is not reflected in the water quality results. Since mercury is not typically associated with lead-zinc ore deposits, the source is uncertain. Water quality standards, however, were not exceeded. Although iron concentrations decreased between upstream and downstream sites, from 409 to 261 µg/L, the levels are high, approaching or exceeding the 300 µg/L Canadian guideline.

Table 8. Metals Concentrations in Northport District Water Samples Collected June and October, 1997 (µg/L)

Sample Location	Iron (total recoverable) High Flow	Iron (total recoverable) Low Flow	Zinc (dissolved) High Flow	Zinc (dissolved) Low Flow	Arsenic (total recoverable) High Flow	Arsenic (total recoverable) Low Flow	Copper (dissolved) High Flow	Copper (dissolved) Low Flow
Deep Creek Above	**144**	NA	**1.3**	**1.4**	1.5U	**0.67**	**0.44**	**0.33**
Deep Creek Below	**140**	NA	**44**	**7.3**	1.5U	**0.58**	**0.60**	**0.39**
Silver Creek Above	**409J***	NA	**0.79**	**0.40**	1.5U	**0.15**	**0.18**	**0.10**
Silver Creek Below	**261J**	NA	**0.53**	**0.24**	1.5U	**0.22**	**0.20**	**0.13**

Sample Location	Lead (dissolved) High Flow	Lead (dissolved) Low Flow	Cadmium (dissolved) High Flow	Cadmium (dissolved) Low Flow	Silver (dissolved) High Flow	Silver (dissolved) Low Flow	Mercury (total recoverable) High Flow	Mercury (total recoverable) Low Flow
Deep Creek Above	0.04U	**0.15**	0.04U	0.02U	0.08UJ	0.02U	0.002U	0.002U
Deep Creek Below	**0.13**	**0.19**	**0.046**	0.02U	0.08UJ	0.02U	**0.0025**	0.002U
Silver Creek Above	**0.035**	**0.074**	0.02U	0.02U	0.04UJ	0.02U	0.002U	0.002U
Silver Creek Below	**0.028**	**0.40**	0.02U	0.02U	0.04UJ	0.02U	**0.0079**	0.002U

Note: Metals detections highlighted in **BOLD**
*exceeds water quality standard or guideline
NA = not analyzed
J = estimated value
U = not detected at or above the reported value
UJ = not detected at or above the reported estimated value

3. Republic District, Ferry County

Geology and Historical Mining Operations and Practices

The Republic District, which has been producing gold and silver since 1896 (Lasmanis, 1996), is located in the Republic Graben, a north trending, fault bounded structural low. The Okanogan dome is to the west and the Kettle dome is east of the district. The dominant rocks in the Republic Area are greenschist facies rocks, clastic and volcaniclastic and volcanics, amphibolite facies metamorphic rocks, and granitic plutons of the Okanogan and Kettle metamorphic core complexes (Cheney and Rasmussen, 1996). There is no current mining activity in the vicinity of the project sample sites.

Gold and silver is the principal mineralization in the district which occurs in Eocene epithermal veins (Lasmanis, 1996). Epithermal vein deposits (metal-bearing hot springs) have been the mainstay of production from the district. The Knob Hill Mine, which was the longest producing mine in the western part of the district, was in production from 1910 until 1995. A cyanide mill was added to the operation in 1937 (Lasmanis, 1996). Flotation cells were added in 1940. The principal ore minerals are gold, electrum, tellurides, chalcopyrite, stibnite, realgar, tetrahedrite, polybasite, pyargyrite, argentite, umangite, and naumannite. Host rocks for the deposits are dacite and andesite flows, breccias, tuffs, and tuff breccias of the Eocene Sanpoil Formation (Derkey et al., 1990).

Replacement/exhalative deposits also occur in the eastern part of the Republic District (Derkey, 1994). These deposits occur at the contact between carbonate and clastic sedimentary rocks. Gold is sporadically distributed in massive iron oxide-sulfide zones in carbonate rocks, and in stockworks of pyrrhotite and quartz-sulfide veinlets (mostly pyrite) in clastic sedimentary rock (Derkey, 1994). Deposits of this type have been mined at the Overlook, Lamefoot, and Key Mines. These deposits are enriched in gold, silver, copper, and iron. Ore minerals consist of pyrite, pyrrhotite, magnetite, and chalcopyrite. Host rock for the deposits are unnamed Permian-Triassic graywacke, argillite, cherts, and limestone.

Evaluation of Water Quality Samples

Water quality samples and field parameters were obtained near Republic (Figure 4) in streams that drain the western part of the district. One set of samples was collected in Swamp Creek about 2 ½ miles above its confluence with Granite Creek. A second set of samples was located in Granite Creek, about 1 mile below the confluence with Swamp Creek. A third sample site was established on Eureka Creek approximately at the point where it enters the north city limit for Republic. Eureka Creek drains one of the main mining areas in the western part of the district and is tributary to Granite Creek about ¾ mile downstream of the Granite Creek sample location. Sediment samples were collected at all three sites. No individual mines were investigated in the district and no mine, mill, or tailings discharges were sampled. No water or sediment samples were obtained from streams in the eastern part of the district.

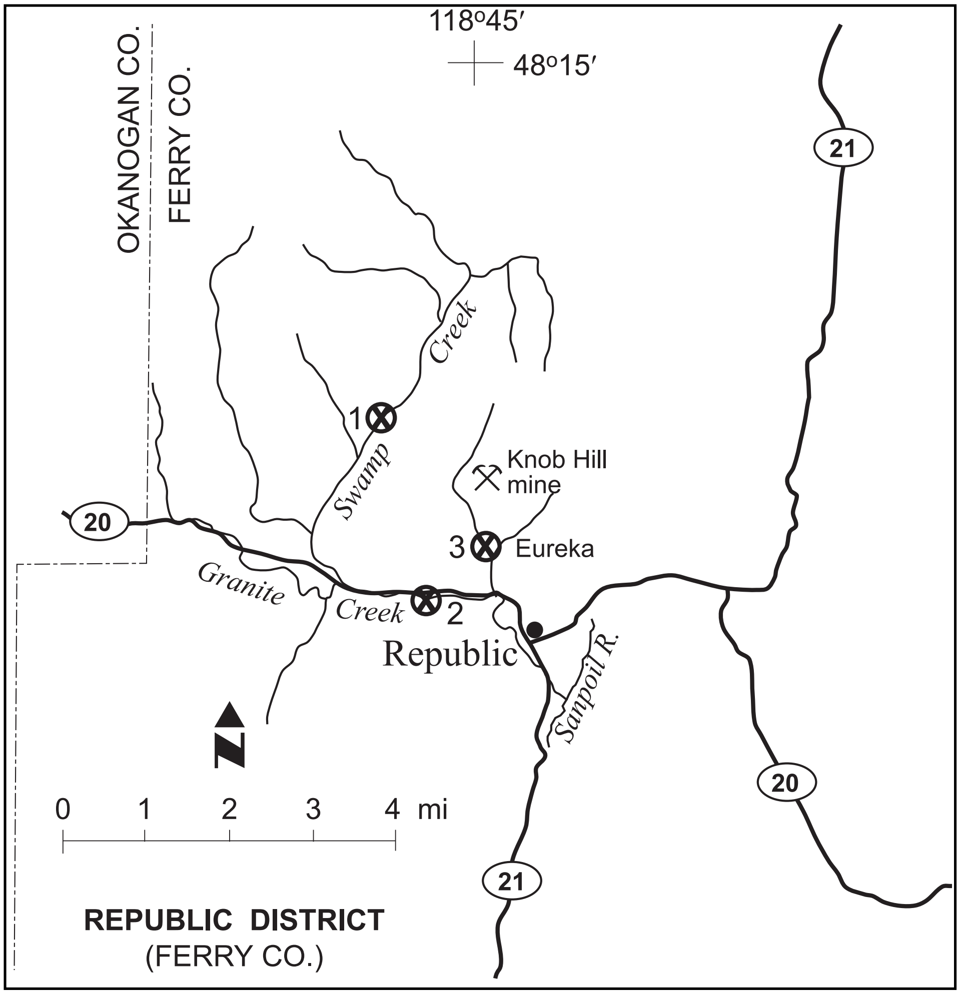

Figure 4. Locations of Water and Sediment Samples Collected in Swamp, Granite, and Eureka Creeks - Republic District

If the Swamp Creek station is considered a representative site for background or upstream water quality, the concentrations of most general chemistry parameters decrease downstream to the sample site on Granite Creek (Table 9). By contrast, in comparison to either Swamp Creek or Granite Creek, substantially higher levels of most constituents occur in Eureka Creek. For example, sulfate concentrations at 310-472 mg/L were one-to-two orders of magnitude higher in Eureka Creek than Swamp or Granite Creek, 6.9-56 mg/L. These are the highest sulfate concentrations measured in stream samples for this study. In Swamp Creek, the nearly order of magnitude increase in sulfate concentration from high-flow to low-flow is unusual among the stream samples in this project. At low-flow, seeps were observed discharging into Swamp Creek from an iron-stained outcrop of bedrock adjacent to the sample site. The pH of the seepage was measured at 5.96, with a conductivity of 990 µmhos/cm. The large increase in sulfate concentrations at low-flow is likely the result of less dilution of this local source.

Table 9. Field Measurements and General Chemistry Results for Republic District Water Samples Collected June and October, 1997

	Flow (cfs)		Temp. (^{o}C)		pH (units)		Cond. (µmho/cm)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Swamp Creek Above	7.2	0.26	11.0	8.7	6.93	7.40	149	388
Granite Creek Below	51	6.3	9.5	5.9	7.48	7.93	162	263
Eureka Creek	1.2	0.17	10.2	8.2	7.25	7.77	908	1208

	Hardness (mg/L)		Alkalinity (mg/L)		TDS (mg/L)		TSS (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Swamp Creek Above	64	178	66	139	147J	275	2J	5
Granite Creek Below	67	115	72	120	144J	186	8J	1
Eureka Creek	390	568	121	135	647J	921	23J	4

	Turbidity (NTU)		Sulfate (mg/L)		Cyanide (mg/L)		NO_3+NO_2 (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Swamp Creek Above	13J	5.4J	7.7	56	0.005U	NA	0.28	NA
Granite Creek Below	9.3J	1.1J	6.9	11	0.005U	NA	0.034	NA
Eureka Creek	11J	2.4J	310	472	0.005U	NA	1.6	NA

NA = not analyzed
J = estimated value
U = not detected at or above the reported value

The nitrate/nitrite result for Eureka Creek during high-flow, 1.6 mg/L, was also the highest detected in any stream during the project. There is no obvious source for this high value. Cyanide was not detected in any samples.

The conductivity in Eureka Creek reflects the effect of high TDS and sulfate concentrations. However, pH was still neutral, and higher than Swamp Creek.

Zinc, arsenic, copper, and mercury were substantially higher in Eureka Creek (Table 10). Except for arsenic, the higher concentrations of these metals were observed during high-flow. The arsenic values of 14-15 µg/L were the highest encountered in streams sampled for this study.

Mercury remained at detectable levels of 0.0020 - 0.0091 µg/L during both high and low-flow in each of the three creeks, whereas mercury was generally only detected during high-flow in other study areas. No water quality standards were exceeded for these metals, although the high mercury concentration in Swamp Creek approached the 0.012 µg/L chronic criterion.

Table 10. Metals Concentrations in Republic District Water Samples Collected June and October, 1997 (µg/L)

	Iron (total recoverable)		Zinc (dissolved)		Arsenic (total recoverable)		Copper (dissolved)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Swamp Creek Above	**894J***	NA	**2.8**	**4.9**	1.5U	**3.5**	**1.7**	**1.1**
Granite Creek Below	**520***	NA	**3.3**	**1.6**	**2.4**	**2.0**	**1.9**	**0.82**
Eureka Creek	**242J**	NA	**18J**	**7.8**	**14**	**15**	**4.6J**	**2.6**

	Lead (dissolved)		Cadmium (dissolved)		Silver (dissolved)		Mercury (total recoverable)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Swamp Creek Above	**0.11**	**0.023**	**0.11**	0.02U	0.04UJ	0.02U	**0.0053**	**0.0028**
Granite Creek Below	**0.12**	**0.32**	**0.095**	0.02U	0.04UJ	0.02U	**0.0054**	**0.0020**
Eureka Creek	**0.14J**	0.02U	0.1U	0.02U	0.2UJ	0.02U	**0.0091**	**0.0033**

Note: Metals detections highlighted in **BOLD**
*exceeds water quality standard or guideline
NA = not analyzed
J = estimated value.
U = not detected at or above the reported value
UJ = not detected at or above the reported estimated value

Iron concentrations were high in Swamp and Granite creeks at 894 and 520 µg/L, respectively, vs. 242 µg/L in Eureka Creek. These concentrations far exceed the 300 µg/L Canadian guideline, and in Swamp Creek approach EPA's 1,000 µg/L aquatic life criterion. The Swamp Creek metals results may be influenced by two factors (1) the presence of a wetland area immediately upstream of the sample site, and (2) the observation during low-flow of water seeping into Swamp Creek from iron-stained bedrock adjacent to the sample site.

Replicate water samples were collected in Granite Creek during low-flow to provide estimates of the variability in the metals data for this site (Table 11). Except for zinc and lead, there was good agreement between the separately collected samples. Results for zinc and lead differed by about factors of 2-to-3. These data were averaged for use in Table 10.

Table 11. Metals Concentrations in Replicate Water Samples Collected in Granite Creek, October 1997 (µg/L)

Sample Number:	438251	438255	RPD
Iron (total recoverable)	NA	NA	- -
Zinc (dissolved)	0.97	2.3	81%
Arsenic (total recoverable)	2.0	1.9	7%
Copper (dissolved)	0.73	0.90	22%
Lead (dissolved)	0.16	0.48	100%
Cadmium (dissolved)	0.02U	0.02U	0%
Silver (dissolved)	0.02U	0.02U	0%
Mercury (total recoverable)	0.002U	0.003	>50%

RPD = relative percent difference (range as percent of duplicate mean)
NA = not analyzed
U = not detected at or above reported value

Grain size of the sediment samples was similar for Swamp and Eureka creeks at 7-15% fines (Table 12). Substantially coarser material with only 0.3% fines was obtained in Granite Creek. All metals were at higher concentrations in Swamp Creek and Eureka Creek sediments than in Granite Creek sediments. In particular, the Swamp Creek site approached the 40,000 mg/Kg sediment guideline for iron, while both Swamp and Eureka creeks exceed the guidelines for arsenic and for silver, 17-40 mg/Kg and 4.5 mg/Kg, respectively (Table 2). Other metals that were relatively high in Eureka and/or Swamp Creek sediments included zinc, lead, mercury, selenium, beryllium, and antimony. The sediment results generally parallel the water results.

Replicate sediment samples collected in Eureka Creek showed similar results for all metals analyzed except antimony (Table 13). These data were averaged for use in Table 12.

Table 12. Grain Size and Metals Concentrations in Republic District Sediment Samples Collected October 1997 (mg/Kg, dry)

Sample Location	% Gravel	% Sand	% Silt	% Clay	Fe	Mn	Zn
Swamp Creek	43.0	41.7	12.4	3.0	**35100**	**364**	**91**
Granite Creek	39.5	60.2	0.2	0.1	**6550**	**152**	**15**
Eureka Creek	37.0	56.0	5.9	1.1	**16100**	**545**	**191**

Sample Location	Cr	Ni	Cu	As	Pb	Hg	Ag
Swamp Creek	**26**	**43**	**33**	**116***	**3.1**	**0.55**	**14***
Granite Creek	**8.8**	**4.7**	**2.9**	**2.3**	3U	0.005 U	0.3 U
Eureka Creek	**26**	**24**	**37**	**130***	**18**	**0.16**	**6.4***

Sample Location	Cd	Se	Be	Sb	Tl
Swamp Creek	0.5 U	**3.1**	**3.6**	**3.3***	0.3 UJ
Granite Creek	0.5 U	0.3 U	**0.10**	3 UJ	0.3 UJ
Eureka Creek	0.5 U	**4.7**	**0.68**	**6.0***	0.3 UJ

Note: Metals detections highlighted in **BOLD**
*exceeds sediment quality guideline
U = not detected at or above the reported value
UJ = not detected at or above the reported estimated value

Table 13. Metals Concentrations in Replicate Sediment Samples Collected in Eureka Creek, October 1997 (mg/Kg. dry)

Sample Number:	438256	438279	RPD
Iron	15800	16400	3.7%
Manganese	529	561	5.9%
Zinc	187	196	4.4%
Chromium	25	28	9.5%
Nickel	23	24	4.3%
Copper	34	40	16%
Arsenic	119	140	16%
Lead	15	20	29%
Mercury	0.16	0.17	3.1%
Silver	5.4	7.4	31%
Cadmium	0.5U	0.5U	ND
Selenium	4.5	4.9	7.5%
Beryllium	0.65	0.71	8.1%
Antimony	3.9J	8.0	68%
Thallium	0.3U	0.3U	ND

RPD = relative percent difference (range as percent of duplicate mean)
J = estimated value
U = not detected at or above reported value

4. Wauconda District - Bodie Area, Okanogan County

Geology and Historical Mining Operations and Practices

Mining began in the Bodie District in 1902. Several dumps from adits on the hillside can still be seen at elevations ranging from 2,750 to 3,250 feet. A 10-stamp amalgamation-cyanide mill was built to recover the gold, and from 1902 to 1916 around 15,000 tons of gold ore were milled. Because of poor gold recovery, as well as mining and management problems, operations ceased in 1916. In 1930 the mine was reactivated. The company constructed a 70-ton mill using amalgamation plates and shaker tables to recover free gold and gold-bearing sulfides from low-grade ore. In 1938, the capacity of the mill was increased to 125 tons per day, and cyanidation and flotation circuits were added. Mining and milling operations were carried out until 1944. Tailings were trammed to the mill and then deposited along Toroda Creek. Estimates of the volume of the tailings range from 40,000 to 70,000 tons (Moen, 1980). Currently nothing remains of the Bodie Mill, and several adits are inaccessible because of caved portals and drifts.

The geology of the mines consists of Eocene lava flows and pyroclastic breccias. Gold and silver mineralization at the Bodie is confined mainly to a quartz fissure vein, as well as to a breccia that parallels the vein. The Bodie vein is 2-to-22 feet wide, and for the most part consists of many closely spaced parallel quartz veins. Silicified, propylitzed, and pyritized andesite and dacite, as well as some gouge, occur between individual veins and wall rock. Calcite is present in the quartz vein, but only in minor amounts. Much of the vein quartz resembles the gold-bearing vein quartz of the Republic District.

Ore minerals in the Bodie vein consist of gold, chalcopyrite, pyrite, pyrrhotite, and magnetite. Gold is seldom visible even under high magnification; the sulfides and magnetite are fine grained and disseminated in the quartz. Commodities were gold, silver, and iron (Derkey et al., 1990). Almost all wall rock adjacent to the vein contains minor disseminated pyrite and pyrrhotite and is hydrothermally altered.

Evaluation of Water Quality Samples

Water quality samples and field parameters were obtained in Toroda Creek near the Bodie Mine and Mill (Figure 5). The Bodie Area samples are about ¼ mile apart and were intended to bracket tailings from the Bodie Mill that were deposited along the east bank of Toroda Creek. None of the individual mines was investigated in the district and no mine, mill, or tailings discharges were sampled. Sediment samples were collected at both sample locations in the district.

Flow measurements in Toroda Creek above and below the Bodie Mine gave similar results for high-flow, 44 and 41 cfs, and low-flow, 5.5 and 6.2 cfs. Table 14 shows that most general chemistry parameters decreased slightly in concentration downstream under both flow regimes. A comparison of high-flow and low-flow general chemistry parameters shows there were slight increases in dissolved constituents during low-flow, with lowered turbidity and TSS. No cyanide was detectable and nitrate/nitrite concentrations were relatively low at 0.13 - 0.14 mg/L.

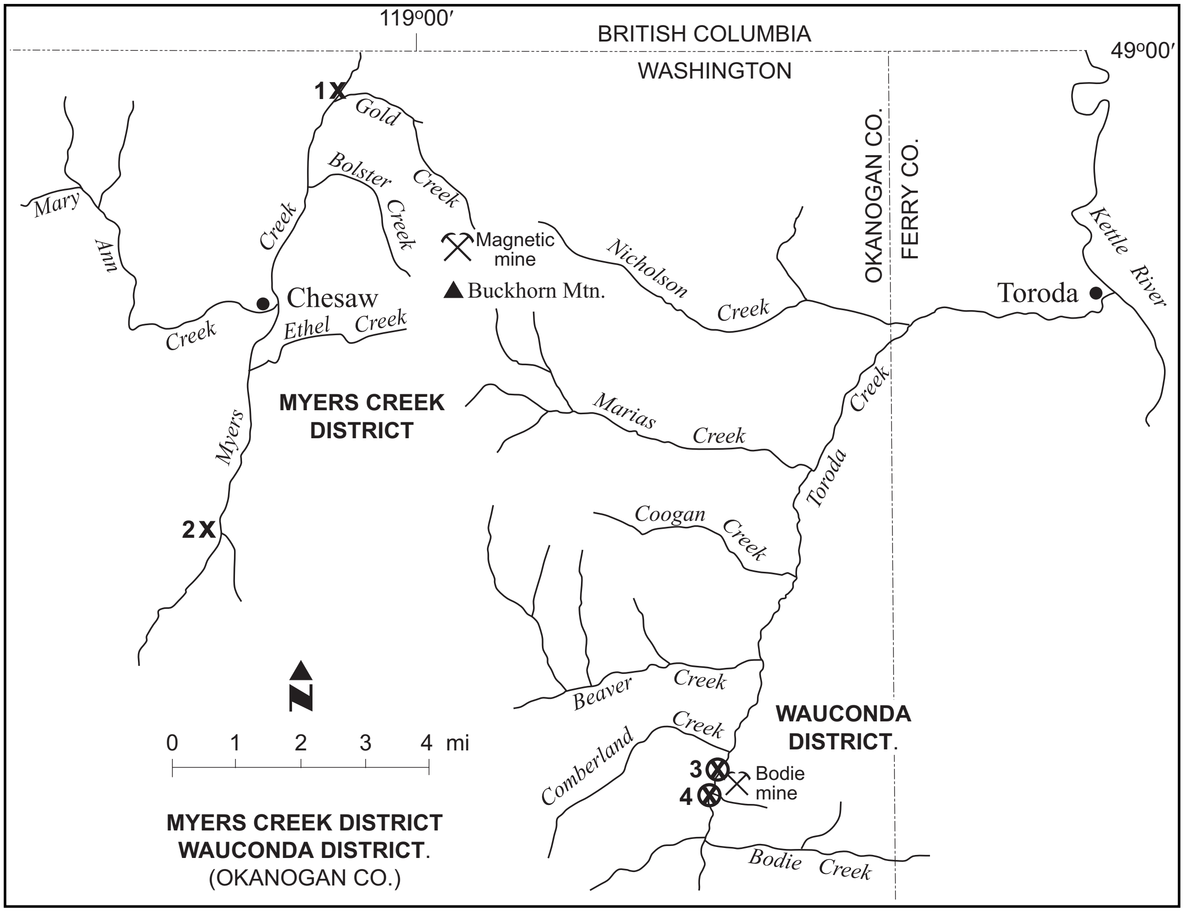

Figure 5. Locations of:
Water and Sediment Samples Collected in Toroda Creek - Wauconda District
Water Samples Collected in Myers Creek - Myers Creek District
(x = water samples, ⊗ = water and sediment samples)

Except for zinc and lead, the Bodie Mine site did not appear to be having a significant effect on metals concentrations in Toroda Creek (Table 15). Zinc concentrations increased by about a factor of 5 during both high and low-flow. Lead concentrations increased by about a factor of 3 during high-flow only. Neither zinc nor lead was among the economic metals recovered from mines in the district. Paralleling the general chemistry results, all other metals decreased in concentration in a downstream direction. At these concentrations, all metals meet state water quality standards. Because the tailings are deposited on a terrace in the Toroda Creek floodplain, and the close spacing of the sample sites, it is possible that alternate pathways allow discharge of contaminants below the downstream sample site.

No appreciable differences were observed in the grain size or metals concentrations of the sediments above and below Bodie Mine (Table 16). Metals concentrations do not exceed any of the sediment quality guidelines.

Table 14. Field Measurements and General Chemistry Results for Wauconda District Water Samples Collected June and October, 1997

	Flow (cfs)		Temp. (^{o}C)		pH (units)		Cond. (µmho/cm)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Toroda Creek Above	44	5.5	10.3	5.9	7.84	7.88	313	393
Toroda Creek Below	41	6.2	10.3	6.7	7.95	8.00	318	392

	Hardness (mg/L)		Alkalinity (mg/L)		TDS (mg/L)		TSS (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Toroda Creek Above	142	184	146	183	211J	252	14J	1
Toroda Creek Below	138	182	145	182	218J	248	10J	2

	Turbidity (NTU)		Sulfate (mg/L)		Cyanide (mg/L)		NO_3+NO_2 (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Toroda Creek Above	9.4J	0.6J	16	22	0.005U	NA	0.13	NA
Toroda Creek Below	5.2J	0.5J	17	22	0.005U	NA	0.14	NA

NA = not analyzed
J = estimated value
U = not detected at or above the reported value

Table 15. Metals Concentrations in Wauconda District Water Samples Collected June and October, 1997 (µg/L)

	Iron (total recoverable)		Zinc (dissolved)		Arsenic (total recoverable)		Copper (dissolved)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Toroda Creek Above	**181J**	NA	**0.97**	**0.59**	1.5U	**1.2**	**1.2**	**0.79**
Toroda Creek Below	**71**	NA	**5.7**	**3.2**	**2.0**	**1.2**	**1.1**	**0.82**

	Lead (dissolved)		Cadmium (dissolved)		Silver (dissolved)		Mercury (total recoverable)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Toroda Creek Above	**0.029**	**0.14**	**0.026**	0.02U	0.04UJ	0.02U	**0.0026**	**0.0027**
Toroda Creek Below	**0.077**	0.02U	**0.022**	0.02U	0.04UJ	0.02U	0.002U	0.002U

Note: Metals detections highlighted in **BOLD**
NA = not analyzed
J = estimated value
U = not detected at or above the reported value
UJ = not detected at or above the reported estimated value

Table 16. Grain Size and Metals Concentrations in Wauconda District Sediment Samples Collected October, 1997 (mg/Kg, dry)

Sample Location	% Gravel	% Sand	% Silt	% Clay	Fe	Mn	Zn
Toroda CreekAbove	49.9	48.0	2.0	0.2	**11200**	**151**	**37**
Toroda Creek Below	40.4	54.4	4.1	1.1	**11300**	**147**	**32**

Sample Location	Cr	Ni	Cu	As	Pb	Hg	Ag
Toroda CreekAbove	**13**	**5.9**	**9.1**	**3.4**	**3.5**	0.005U	0.3 U
Toroda Creek Below	**14**	**6.4**	**11**	**5.1**	3U	**0.03**	**0.35**

Sample Location	Cd	Se	Be	Sb	Tl
Toroda CreekAbove	0.5 U	0.3 U	**0.25**	3 UJ	0.3 UJ
Toroda Creek Below	0.5 U	0.3 U	**0.33**	3 UJ	0.3 UJ

Note: Metals detections highlighted in **BOLD**
U = not detected at or above the reported value
UJ = not detected at or above the reported estimated value

5. Myers Creek District, Okanogan County

Geology and Historical Mining Operations and Practices

Geology of the Myers Creek District consists of a wide variety of igneous, sedimentary, and metamorphic rocks. Ages range from Permian through upper Eocene. The oldest rocks are found in the western part of the district and consist of Permian or Triassic meta-sedimentary and meta-igneous rocks. East of these rocks are thick sequences of Eocene volcanic rocks and associated tuffaceous sedimentary rocks. The granitic rocks of the district appear to be chiefly of Mesozoic age and trend northeast through the center of the district. In the southwestern part of the district, granitic and eugeosynclinal rocks are flanked by plutons of granodiorite quartz monzonite of the Okanogan gneiss dome (late Mesozoic) (Moen, 1980).

The most important occurrences of mineralization of the Myers Creek District are in the Chesaw and Buckhorn Mountain Area in the northeast part of the district. In the Chesaw Area quartz fissure veins predominate. Most veins are only sparsely mineralized with gold, silver, copper, lead, and zinc. Ore minerals are usually accompanied by pyrite and arsenopyrite (Moen, 1980). Deposits may also contain iron, tungsten, molybdenum, and fluorite.

In the Chesaw Area, the Cretaceous diorite to granodiorite rocks intrude Permian or Triassic metasedimentary rocks and provide contact metamorphic mineral deposits. In the Buckhorn Mountain Area, three miles northeast of Chesaw, contact metamorphic deposits predominate. The largest mineral deposit found in the district is at the proposed Crown Jewel Mine on Buckhorn Mountain. The Crown Jewel is a gold skarn type deposit found in folded and faulted volcanics, clastic sediments, and carbonates on the western margin of the Eocene Toroda Creek Graben. Northeast trending, southeast dipping sinuous shear zones, and brittle faults cut all rock types. Faulting is thought to be related to the development of the Toroda Creek Graben (TerraMatrix, 1997).

Evaluation of Water Quality Samples

Water quality samples and field parameters were obtained from two locations about seven miles apart on Myers Creek (see Figure 5 in previous section). The upstream sample site is about four miles above Chesaw while the downstream site is below the confluence of Myers Creek with Gold Creek, about three miles north of Chesaw. No individual mines were investigated in the district and no mine, mill, or tailings discharges were sampled. No sediment samples were collected in this district.

Flows between the two sampling sites on Myers Creek increased from 48 to 90 cfs during high-flow and 7.4 to 13 cfs during low-flow. Comparison of upstream and downstream general chemistry results shows that substantial increases occur downstream for all parameters except cyanide and nitrate/nitrite (Table 17). The increase in sulfate concentration during both high and low-flow stands out among the general chemistry parameters. General chemistry parameters show a typical relationship with flow. No cyanide was detected and nitrate/nitrite was low.

During high-flow, TSS increased from 21 mg/L, which is highly protective of aquatic communities, to 131 mg/L, which affords a low level of protection. The increase in turbidity during high-flow, from 7.9 to 45 NTU, exceeds the 5 NTU state standard.

Except for iron, large downstream increases in metals concentrations were not seen (Table 18). The iron concentration in downstream Myers Creek at 480 µg/L exceeds the 300 µg/L guideline. All other metals meet state water quality standards. Lead showed an anomalously large increase in the upstream low-flow sample.

Table 17. Field Measurements and General Chemistry Results for Myers Creek District Water Samples Collected June and October, 1997

	Flow (cfs)		Temp. (°C)		pH (units)		Cond. (µmho/cm)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Myers Creek Above	48	7.4	6.4	3.6	7.38	7.83	102	283
Myers Ceek Below	90	13	9.1	5.1	7.75	7.91	289	501

	Hardness (mg/L)		Alkalinity (mg/L)		TDS (mg/L)		TSS (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Myers Creek Above	45	140	46	133	82	179	21	6
Myers Ceek Below	148	256	119	217	188	328	131*	14

	Turbidity (NTU)		Sulfate (mg/L)		Cyanide (mg/L)		NO_3+NO_2 (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Myers Creek Above	7.9J	1.5J	3.8	11	0.005U	NA	0.037	NA
Myers Ceek Below	45J*	6.1J	29	50	0.005U	NA	0.054	NA

*exceeds water quality standard or guideline
NA = not analyzed
J = estimated value
U = not detected at or above the reported value

Table 18. Metals Concentrations in Myers Creek District Water Samples Collected June and October, 1997 (µg/L)

Sample Location	Iron (total recoverable) High Flow	Iron (total recoverable) Low Flow	Zinc (dissolved) High Flow	Zinc (dissolved) Low Flow	Arsenic (total recoverable) High Flow	Arsenic (total recoverable) Low Flow	Copper (dissolved) High Flow	Copper (dissolved) Low Flow
Myers Creek Above	**104J**	NA	**1.1**	**0.55**	**1.8**	**2.5**	**0.44**	**0.26**
Myers Ceek Below	**480J***	NA	**0.48**	**0.60**	**3.4**	**3.5**	**0.55**	**0.51**

Sample Location	Lead (dissolved) High Flow	Lead (dissolved) Low Flow	Cadmium (dissolved) High Flow	Cadmium (dissolved) Low Flow	Silver (dissolved) High Flow	Silver (dissolved) Low Flow	Mercury (total recoverable) High Flow	Mercury (total recoverable) Low Flow
Myers Creek Above	**0.034**	**0.53**	0.02U	0.02U	0.04UJ	0.02U	**0.0031**	0.002U
Myers Ceek Below	**0.038**	0.02U	0.02U	0.02U	0.04UJ	0.02U	0.002U	0.002U

Note: Metals detections highlighted in **BOLD**
*exceeds water quality standard or guideline
NA = not analyzed
J = estimated value
U = not detected at or above the reported value
UJ = not detected at or above the reported estimated value

6. Conconully District, Okanogan County

Geology and Historical Mining Operations and Practices

The Conconully Mining District is located in central Okanogan County. Mines investigated in this district were the Arlington, Hough's, First Thought, and Last Chance. Mineralization in this district is generally associated with intrusion of the Cretaceous Conconully granodiorite pluton into older gneiss and schist.

The Arlington, which ceased operation in 1940, was one of the principal mines of the district. It is located on Ruby Hill in the NE 1/4SE1/4 sect. 6 T.34N., R.25E at an elevation of 4,080 feet. The main adit is caved at its portal. The Arlington Mine is located on a 1-to-6 foot thick quartz fissure vein that occurs near the contact of the Conconully granodiorite pluton and gneiss. Faulting has offset the vein as much as 10 feet (Moen, 1973). Underground workings have a total length of 4,500 feet and include shafts, drifts, and crosscuts.

The primary minerals include galena, tetrahedrite, pyrargyrite, chalcopyrite, and sphalerite. Commodities produced were silver, copper, lead, gold, and zinc. One thousand tons of silver ore, which had a net value of $25,000, were mined by the summer of 1893 and concentrated at a mill in Ruby City. Between 1914 and 1921, several thousand tons of ore which contained 66.6 oz/ton silver were mined at a net profit of $31,000. A 50-ton-per-day flotation mill was established in 1937 and was located approximately 100 feet below the upper adit. Between 1938 and 1939, 5,780 tons of ore that had a net value of $71,683 were concentrated in the mill (Moen, 1973; Derkey et al., 1990).

The First Thought and Last Chance mines are located in sec. 31 T.35 N., R.25E. at an approximate elevation of 3,000 feet. Mineralization at the First Thought Mine occurs in discontinuous lenticular lenses of quartz that are as much as 90 feet thick and as much as 700 feet in length. The lenticular lenses of quartz occur in highly foliated feldspathic quartzite and micaceous gneiss. The strike of the lense is parallel to the foliation of the gneiss. Ore minerals are concentrated in ore shoots along the walls of the lenses. Underground mine workings at the First Thought Mine are in excess of 4,000 feet and are on three levels that have a vertical extent of 350 feet. Adit No. 1 is the main adit of the mine. Ore minerals are galena, tetrahedrite, chalcopyrite, chalcocite, sphalerite, and stephanite. Pyrite is a common constituent (Moen, 1973; Derkey et al., 1990). Commodities were silver, lead, copper, and zinc.

The Last Chance Mine is a quartz fissure vein that averages 12 feet in thickness and occurs in granodiorite and hornblende-mica schist. The mine workings are 0.2 mile south of the First Thought Mine Adit No. 1, and about one mile north of the Arlington Mine. The mine consists of a shaft sunk to a depth of 300 feet. At the bottom of the shaft, a crosscut was driven 800 feet eastward to intersect the adjoining First Thought Mine. Ore minerals consist of tetrahedrite, galena, chalcopyrite, and sphalerite. Pyrite is common. Water fills the shaft nearly to its collar, and the adit is caved near its portal.

Evaluation of Water Quality Samples

Water quality samples and field parameters were obtained from two locations on an unnamed stream that drains to the north from Ruby Hill (Figure 6). The upstream sample site is less than ¼ mile above the Arlington Mine while the downstream site is about ¾ mile downstream below Hough's Mine. Mine drainage discharges were sampled for characterization at the Arlington Mine and at the First Thought Mine. Field parameters were also obtained at the Hough's Mine and the Last Chance Mine. From cursory inspection, it did not appear that any of the mines discharged directly to surface water. No sediment samples were collected in this district.

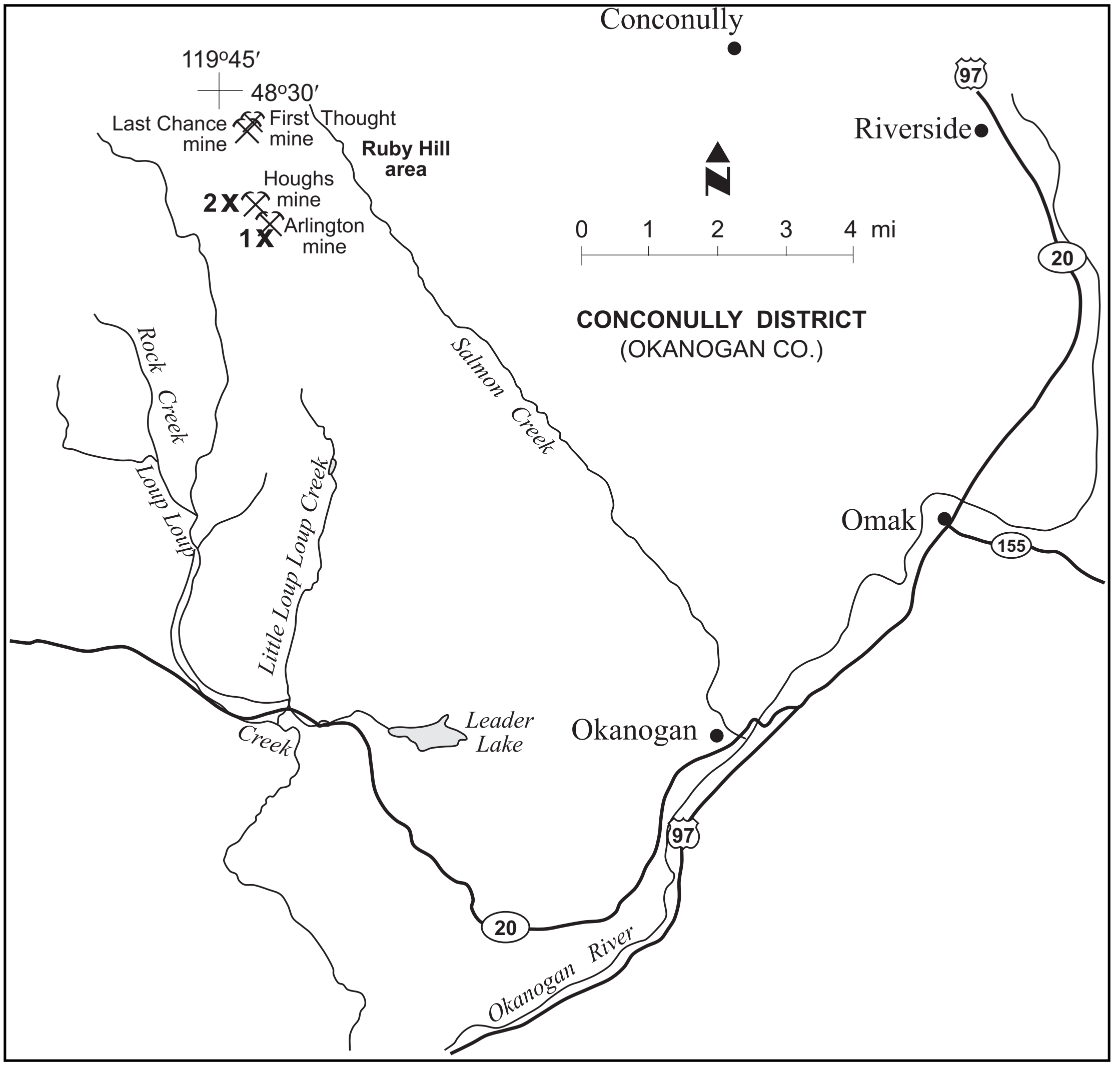

Figure 6. Locations of Water Samples Collected at Arlington Mine - Conconully District

Flows in the unnamed stream near the Arlington Mine were 0.15 cfs or less. General water quality parameters increased in concentration substantially from upstream to downstream (Table 19). Sulfate stands out, with an increase from 5.3 mg/L upstream to 118 mg/L downstream during low-flow. Most parameters showed increases of nearly 50% or more under the low-flow condition. Cyanide was not detected and nitrate/nitrite concentrations were low.

Table 19. Field Measurements and General Chemistry Results for Conconully District Water Samples Collected June and October, 1997

	Flow (cfs)		Temp. (°C)		pH (units)		Cond. (µmho/cm)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Arlington Above	0.10	0.001	4.9	5.3	6.64	7.90	82	123
Arlington Mine	0.15	0.09	6.0	7.4	6.98	7.15	725	630
Arlington Below	NM	NM	7.8	8.5	7.87	8.50	359	543
First Thought Mine	NM	NM	5.9	NA	6.64	NA	1950	NA

	Hardness (mg/L)		Alkalinity (mg/L)		TDS (mg/L)		TSS (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Arlington Above	34	58	37	60	72	103	48	2
Arlington Mine	355	NA	165	NA	474J	NA	10J	NA
Arlington Below	175	283	97	161	246	364	173*	19
First Thought Mine	1120	NA	44	NA	1630J	NA	40J	NA

	Turbidity (NTU)		Sulfate (mg/L)		Cyanide (mg/L)		NO_3+NO_2 (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Arlington Above	22J	1.5J	3.0	5.3	0.005U	NA	0.010U	NA
Arlington Mine	45J	NA	205	NA	0.005U	NA	0.064	NA
Arlington Below	180J*	21J*	14	118	0.005U	NA	0.018	NA
First Thought Mine	270J	NA	1110	NA	0.005U	NA	0.045	NA

*exceeds water quality standard or guideline

NM = not measured

NA = not analyzed

J = estimated value

U = not detected at or above the reported value

Potential water quality problems are indicated downstream for TSS, which was 173 mg/L at high-flow, and turbidity, which was 180 NTU at high-flow and 21 NTU at low-flow. The TSS concentration affords a low level of protection for aquatic communities. The turbidity increases exceed state standards.

General chemistry results from sampling at the Arlington Mine and the First Thought Mine illustrate the differences among mines within a mining district (Table 19). Although both mines were sampled at their portals, the concentrations of most general chemistry parameters are substantially lower in the discharge from the Arlington Mine than in the discharge from the First Thought Mine. At both mines, all parameters are dramatically elevated above the background concentrations measured in the unnamed stream.

Comparison of upstream and downstream samples shows increased concentrations for most metals (Table 20). Arsenic, copper, and zinc showed the greatest changes. These results reflect the mineralogy of the ores found in the district. A very large increase in iron concentrations was observed, from an already elevated upstream value of 249 µg/L to 5,640 µg/L downstream, far in excess of the EPA water quality criterion of 1,000 µg/L.

Metals exhibited variable changes in concentrations from high-flow to low-flow, with most decreasing during low-flow conditions. The main exceptions were lead, which increased in both the upstream and downstream sample during low-flow, and zinc, which increased in the upstream sample only. None of the metals concentrations exceeded state water quality standards.

Discharges from the Arlington Mine and the First Thought Mine did not meet water quality standards for zinc or cadmium, or guidelines for iron (Table 20). Most metals concentrations were much higher in the First Thought discharge. The First Thought Mine had the highest arsenic concentration measured during this project, 69 µg/L. Both mines exceeded background water quality as measured at the upper stream site, although the First Thought was located in a different subdrainage.

Field parameters were measured at four mines in the district during high-flow (Table 21). The Arlington Mine, which is located nearest the stream, had field parameters that were closest to the stream values. Field parameters among the four mines differed substantially, but all had depressed pH and elevated conductivities compared to the instream values, suggesting some level of ARD generation within the mines and discharge of TDS, likely containing high concentrations of sulfate, from the mine portals.

Table 20. Metals Concentrations in Conconully District Water Samples Collected June and October, 1997 (µg/L)

	Iron (total recoverable)		Zinc (dissolved)		Arsenic (total recoverable)		Copper (dissolved)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Arlington Above	**249J**	NA	**0.56**	**3.5**	1.5U	**0.48**	**0.59**	**0.56**
Arlington Mine	**331J***	NA	**371***	NA	**1.6**	NA	**0.79**	NA
Arlington Below	**5640**	NA	**2.6**	**2.0**	**6.5**	**2.5**	**1.3**	**1.2**
First Thought Mine	**48300J***	NA	**8230***	NA	**69**	NA	**2.9**	NA

	Lead (dissolved)		Cadmium (dissolved)		Silver (dissolved)		Mercury (total recoverable)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Arlington Above	**0.037**	**0.093**	0.02U	0.02U	0.04UJ	0.02U	0.002U	0.002U
Arlington Mine	**1.4**	NA	**4.0***	NA	0.2UJ	NA	0.002U	NA
Arlington Below	0.04U	**0.097**	**0.040**	**0.021**	0.08UJ	0.02U	**0.0023**	0.002U
First Thought Mine	0.2U	NA	**33***	NA	0.4UJ	NA	0.002U	NA

Note: Metals detections highlighted in **BOLD**
*exceeds water quality standard or guideline
NA = not analyzed
J = estimated value
U = not detected at or above the reported value
UJ = not detected at or above the reported estimated value

Table 21. Field Measurements for Selected Mines in Conconully District, June and October, 1997

	Temp. (°C)		pH (units)		Cond. (µmho/cm)		Ferrous Iron	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Arlington Mine	6.0	7.4	6.98	7.15	725	630	Present	NA
First Thought Mine	5.9	NA	6.64	NA	1950	NA	Present	NA
Last Chance Mine	12.3	NA	6.85	NA	1007	NA	NA	NA
Hough's Mine	5.2	NA	6.66	NA	435	NA	Absent	NA

NA = not analyzed

7. Twisp District, Okanogan County

Geology and Historical Mining Operations and Practices

The general geology of the mineralized area in the Twisp District includes Jurassic-Cretaceous Newby Group dacite breccias that are host to volcanogenic massive sulfide mineralization at the Alder Mine. The Newby Group was intruded by the Alder Creek Stock.

The Alder Mine, which was the main mine of the district, was developed by three adits that total several hundred feet and an open pit mine. A 300 ton-per-day flotation mill was built at an off-site location near Twisp. Production mainly consisted of gold and copper, with silver and zinc also present. The ore minerals of the deposit are chalcopyrite, gold, copper, sphalerite, chalcocite, galena, malachite, and azurite (Derkey et al., 1990).

Evaluation of Water Quality Samples

Water quality samples and field measurements were obtained from upstream and downstream locations on Alder Creek during high-flow, and field parameters only were measured at a third site about midway down the creek. During low-flow, water quality samples and field parameters were obtained at all three locations (Figure 7). The upstream sample site is near the head of Alder Creek, while the downstream site is about two miles away. The middle sample site is about ½ mile below the upstream sample and appears to be situated directly below the discharge from one of the adits at the Alder Mine. From cursory inspection, it did not appear that the adits discharged directly to Alder Creek. Field parameters were measured at two mine adits, and the North Adit was sampled for characterization. Field parameters were also measured at a tailings impoundment located near Twisp. Sediment samples were analyzed from the three locations in Alder Creek.

The flow in Alder Creek increased substantially between upstream and downstream, from 0.10 to 1.8 cfs during high-flow and from 0.01 to 0.22 cfs during low-flow. Most general water quality parameters decreased modestly from upstream to downstream (Table 22). A comparison between the upstream and middle Alder Creek sites reveals the impact of the Alder Mine adit. At this site all general chemistry parameters, except total alkalinity and hardness, show increases. The pH measured in middle Alder Creek is lower than found upstream or downstream. The high-flow pH measurement of 4.91 does not meet the state water quality standard (6.5).

For metals, comparison of upstream, middle, and downstream sample results are only available for low-flow (Table 23). Zinc, copper, lead, and cadmium concentrations are substantially elevated in the downstream sample, but even more so at the middle location. Thus, there is an increase from the upstream location to the middle location, but lower concentrations in the downstream sample. These changes are consistent with the general chemistry results. The middle sample is located directly downhill from the Alder Mine North Adit and the water quality results correspond to the mineralogy of the ore produced from the mine. Dilution would account for the decreased concentrations between the middle sample and furthest downstream sample. Nearly all metals concentrations are uniformly lower during low-flow conditions, illustrating seasonality in water quality in this district. Zinc, copper, and cadmium, three of the metals with the highest concentration during high-flow, show the greatest decrease during low-flow conditions.

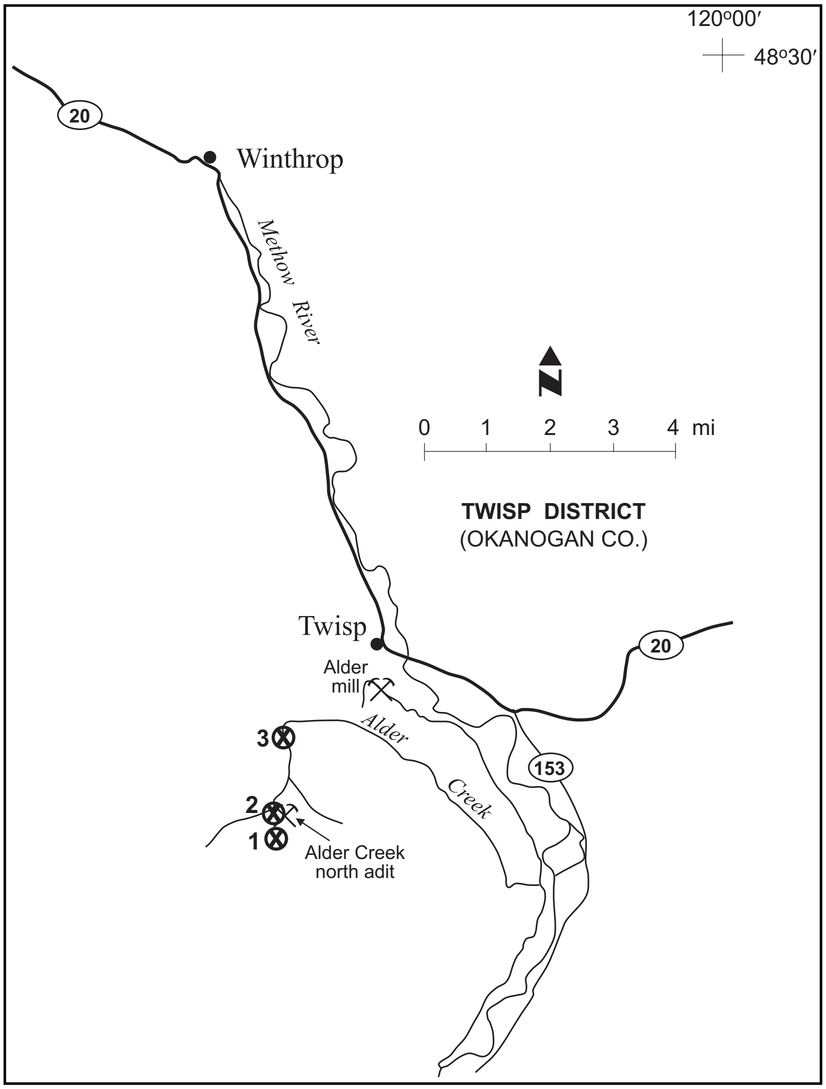

Figure 7. Locations of Water and Sediment Samples Collected in Alder Creek at Alder Mine - Twisp District

At the downstream Alder Creek location during high-flow, state water quality standards are exceeded for zinc and cadmium. For a hardness level of 298 mg/L, the zinc concentration of 484 µg/L exceeded the acute criterion of 289 µg/L and the cadmium concentration of 9.5 mg/L exceeded the chronic criterion of 2.3 µg/L. During low-flow, cadmium levels were at or slightly below the chronic standard in both middle and downstream Alder Creek.

Only the North Adit was sampled for general chemistry and metals. The results indicate that water quality standards are exceeded for zinc, copper, lead, and cadmium. Iron also exceeds guidelines. The discharge from this adit consisted of the rusty yellow-orange indicator of low pH ARD.

Table 22. Field Measurements and General Chemistry Results for Twisp District Water Samples Collected June and October, 1997

	Flow (cfs)		Temp. (°C)		pH (units)		Cond. (µmho/cm)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Alder Creek Above	0.10	0.01	8.2	4.4	8.00	8.30	673	739
Alder Creek Middle	NM	0.10	4.8	5.2	4.91*	6.90	2650	782
Alder Creek Below	1.8	0.22	7.4	7.2	8.09	8.40	578	642
Alder Mine North Adit	NM	NM	6.0	NA	3.51*	NA	3060	NA

	Hardness (mg/L)		Alkalinity (mg/L)		TDS (mg/L)		TSS (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Alder Creek Above	365	424	311	346	406	459	11	12
Alder Creek Middle	NA	387	NA	272	NA	474	NA	37
Alder Creek Below	298	354	225	256	354	422	1	1
Alder Mine North Adit	1430	NA	10U	NA	3220	NA	13	NA

	Turbidity (NTU)		Sulfate (mg/L)		Cyanide (mg/L)		NO_3+NO_2 (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Alder Creek Above	5.2J	5.1J	59	70	0.005U	NA	0.035	NA
Alder Creek Middle	NA	4.8J	NA	123	NA	NA	NA	NA
Alder Creek Below	0.8J	2.3J	80	103	0.005U	NA	0.019	NA
Alder Mine North Adit	38J	NA	2230	NA	0.005U	NA	0.020	NA

*exceeds water quality standard or guideline
NM = not measured
NA = not analyzed
J = estimated value
U = not detected at or above the reported value

Table 23. Metals Concentrations in Twisp District Water Samples Collected June and October, 1997 (µg/L)

	Iron (total recoverable)		Zinc (dissolved)		Arsenic (total recoverable)		Copper (dissolved)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Alder Creek Above	**62**	NA	**1.9**	**0.93**	1.5U	**1.3**	**0.78**	**0.87**
Alder Creek Middle	NA	NA	NA	**289**	NA	**0.88**	NA	**3.9**
Alder Creek Below	**40**	NA	**484***	**116**	1.5U	**1.0**	**3.0**	**1.0**
Alder Mine North Adit	**18500J***	NA	**321000***	NA	**3.5***	NA	**20800***	NA

	Lead (dissolved)		Cadmium (dissolved)		Silver (dissolved)		Mercury (total recoverable)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Alder Creek Above	**0.076**	**0.022**	0.04U	0.02U	0.08UJ	0.02U	0.002U	**0.0023**
Alder Creek Middle	NA	**0.17**	NA	**2.2**	NA	0.02U	NA	0.002U
Alder Creek Below	**0.074**	**0.058**	**9.5***	**2.6**	0.08UJ	0.02U	0.002U	0.002U
Alder Mine North Adit	**414***	NA	**3980***	NA	5UJ	NA	0.002U	NA

Note: Metals detections highlighted in **BOLD**
*exceeds water quality standard or guideline
NA = not analyzed
J = estimated value
U = not detected at or above the reported value
UJ = not detected at or above the reported estimated value

Field parameters were measured at several locations in the Alder Creek Area (Table 24). Discharges from two adits at the Alder Mine were tested, although only the North Adit discharge was sampled for laboratory analyses. The North Adit measurements are similar to the measurements at the middle Alder Creek site, located immediately downstream. Discharge from the South Adit was characterized by a brilliant blue-green coloration as it flowed across two waste rock dumps. The color differences suggest a difference in mineralogy between the two adits but most likely reflect observed pH differences in the discharges).

Table 24. Field Measurements for Selected Mines and Tailings in Twisp District, June 1997

	Temp. (^{o}C)		pH (units)		Cond. (µmho/cm)		Ferrous Iron	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Alder Mine North Adit	6.0	NA	3.51	NA	3060	NA	Absent	NA
Alder Mine South Adit	5.0	NA	6.98	NA	784	NA	Absent	NA
Alder Tailings Pond	24.0	NA	7.94	NA	715	NA	NA	NA
Alder Tailings Seepage	13.2	NA	3.44	NA	5480	NA	NA	NA

NA = not analyzed

At the Alder Mill tailings disposal facility, field parameters were measured in tailings seepage and ponded water on the tailings. The low pH and high conductivity measurements in the tailings seepage are similar to those in the North Adit.

Grain size was variable in the sediment samples from Alder Creek, ranging from approximately 12% fines upstream, to 42% fines at the mid-stream site, and 1% fines downstream (Table 25). Sediment quality guidelines are far exceeded in the middle and downstream samples for zinc and cadmium. The middle Alder Creek sample is also much above sediment guidelines for copper. The same metals are substantially elevated in the water quality samples. Upstream sediments did not exceed sediment quality guidelines.

Table 25. Grain Size and Metals Concentrations in Twisp District Sediment Samples Collected October 1997 (mg/Kg, dry)

Sample Location	% Gravel	% Sand	% Silt	% Clay	Fe	Mn	Zn
Alder Creek Above	57.3	30.3	10.8	1.5	**21400**	**671**	**50**
Alder Creek Middle	15.5	41.9	37.4	5.3	**16300**	**359**	**5460***
Alder Creek Below	61.5	37.1	1.2	0.2	**15600**	**313**	**2240***

Sample Location	Cr	Ni	Cu	As	Pb	Hg	Ag
Alder Creek Above	**11**	**6.1**	**30**	**9.8**	3U	**0.07**	0.3 U
Alder Creek Middle	**8.8**	**9.0**	**1450***	**7.0**	**16**	**0.04**	0.3 U
Alder Creek Below	**11**	**6.6**	**36**	**5.7**	3U	0.005 U	0.3 U

Sample Location	Cd	Se	Be	Sb	Tl
Alder Creek Above	0.5 U	0.3 U	**0.21**	3 UJ	0.3 UJ
Alder Creek Middle	**128***	**1.8**	**0.46**	3 UJ	0.3 UJ
Alder Creek Below	**46***	0.3 U	**0.18**	3 UJ	0.3 UJ

Note: Metals detections highlighted in **BOLD**
*exceeds sediment quality guideline
U = not detected at or above the reported value
UJ = not detected at or above the reported estimated value

8. Bumping Lake District - Copper City Area, Yakima County

Geology and Historical Mining Operations and Practices

Most, if not all, of the mineralization of the Bumping Lake District is associated with emplacement of a granitic batholith and the intrusion of stocks, dikes, and sills of rhyodacite porphyry (Simmons et al., 1983). The Bumping Lake District was organized in 1913. The core of the district is on Miners Ridge above Copper City where copper-tungsten mines were located. Northwest trending shear zones as much as 16 feet thick contain narrow veins of chalcopyrite, arsenopyrite, pyrite, scheelite, and molybdenite. The last recorded production was in 1942. Two of the significant mines of this district are the New Find and Red Bird. There are numerous undocumented mines in the district (Jenkins, 1999). Copper, gold, silver, and tungsten ores were produced from these mines (Derkey et al., 1990).

Evaluation of Water Quality Samples

Water quality samples and field parameters were obtained from two locations on an unnamed stream that is tributary to Deep Creek near the abandoned mining camp of Copper City, and one sample was taken in Deep Creek near its point of discharge into Bumping Lake (Figure 8). The upstream sample site is about 5 ½ miles from the downstream site. The upstream site is located above the remnants of a small abandoned mill which collapsed into the stream. The stream was also sampled at its point of reemergence from the mill debris. None of the individual mines in the district were investigated and no mine or tailings discharges were sampled. Sediment samples were collected from all three sites in this district.

General chemistry and metals samples were collected only during high-flow. General chemistry at upstream and downstream sites is similar (Table 26). pH values for the upstream site, 6.16, and where the stream emerged from the abandoned mill, 6.00, were below the 6.5 state standard. No cyanide was detected and nitrate/nitrite was low.

For metals (Table 27), there were consistent and substantial increases in iron, zinc, arsenic, copper, and lead below the collapsed mill. The copper concentration below the mill at 14 µg/L exceeds the acute standard of 2.7 µg/L for 14 mg/L hardness. Metals concentrations further downstream in Deep Creek were similar to those above the mill. Cadmium, silver, and mercury were not detected in any water samples.

The grain size distribution of the three Copper City sediment samples was similar. Fines content varied from 0.7 - 3.0% (Table 28). The sediments show a metals impact from the mill. Copper, arsenic, and silver concentrations at the mill site are much higher than sediment quality guidelines, and most other metals are substantially elevated as well.

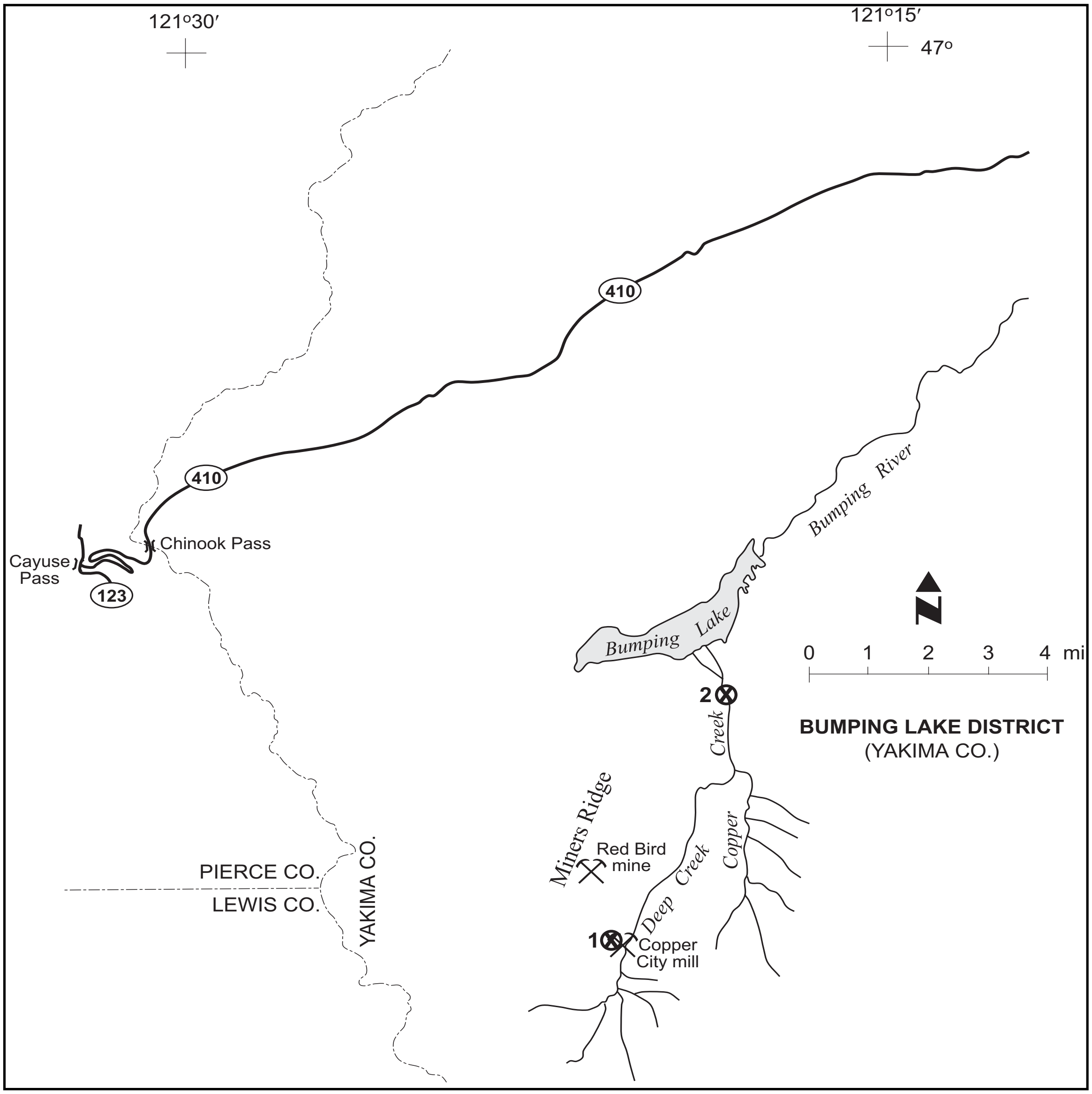

Figure 8. Locations of Water and Sediment Samples Collected in the Copper City Area - Bumping Lake District

Table 26. Field Measurements and General Chemistry Results for Bumping Lake District Water Samples Collected June and October, 1997

	Flow (cfs)		Temp. (°C)		pH (units)		Cond. (µmho/cm)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Copper City Above	0.25	NM	1.5	3.3	6.16*	7.43	29	77
Copper City Below Mill	0.25	NM	2.2	3.7	6.00*	7.42	37	77
Copper City Below	NM	NM	2.1	4.7	6.82	6.54	35	53

	Hardness (mg/L)		Alkalinity (mg/L)		TDS (mg/L)		TSS (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Copper City Above	12	NA	13	NA	20	NA	1U	NA
Copper City Below Mill	14	NA	15	NA	22	NA	2	NA
Copper City Below	13	NA	13	NA	19	NA	2	NA

	Turbidity (NTU)		Sulfate (mg/L)		Cyanide (mg/L)		NO_3+NO_2 (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Copper City Above	0.8J	NA	1.4	NA	0.005U	NA	0.010U	NA
Copper City Below Mill	0.6J	NA	1.7	NA	0.005U	NA	0.010	NA
Copper City Below	0.9J	NA	2.8	NA	0.005U	NA	0.014	NA

*exceeds water quality standard or guideline
NM = not measured
NA = not analyzed
J = estimated value
U = not detected at or above the reported value

Table 27. Metals Concentrations in Bumping Lake District Water Samples Collected June 1997 (µg/L)

	Iron (total recoverable)		Zinc (dissolved)		Arsenic (total recoverable)		Copper (dissolved)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Copper City Above	10U	NA	**0.96**	NA	**1.6**	NA	**0.26**	NA
Copper City Below Mill	**26**	NA	**3.1**	NA	**9.6**	NA	**14***	NA
Copper City Below	**18**	NA	**1.1**	NA	**1.6**	NA	**0.29**	NA

	Lead (dissolved)		Cadmium (dissolved)		Silver (dissolved)		Mercury (total recoverable)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Copper City Above	0.02U	NA	0.02U	NA	0.04UJ	NA	0.002U	NA
Copper City Below Mill	**0.036**	NA	0.02U	NA	0.04UJ	NA	0.002U	NA
Copper City Below	0.02U	NA	0.02U	NA	0.04UJ	NA	0.002U	NA

Note: Metals detections highlighted in **BOLD**
*exceeds water quality standard or guideline
NA = not analyzed
U = not detected at or above the reported value
UJ = not detected at or above the reported estimated value

Table 28. Grain Size and Metals Concentrations in Bumping Lake District Sediment Samples Collected October 1997 (mg/Kg, dry)

Sample Location	% Gravel	% Sand	% Silt	% Clay	Fe	Mn	Zn
Copper City Above	58.4	38.6	2.7	0.3	**13600**	**319**	**90**
Copper City Below Mill	61.6	35.4	2.7	0.3	**27800**	**510**	**224**
Copper City Below	47.2	52.0	0.7	0.0	**15400**	**288**	**65**

Sample Location	Cr	Ni	Cu	As	Pb	Hg	Ag
Copper City Above	**10**	**6.4**	**11**	**34**	**5.0**	**0.02**	0.3 U
Copper City Below Mill	**7.9**	**4.5**	**4640***	**2630***	**58**	**0.04**	**12***
Copper City Below	**4.7**	**4.9**	**32**	**16**	**6.6**	**0.01**	0.3 U

Sample Location	Cd	Se	Be	Sb	Tl
Copper City Above	0.5 U	0.3 U	**0.24**	3 UJ	0.3 UJ
Copper City Below Mill	0.5 U	**0.88**	**0.42**	3 UJ	0.3 UJ
Copper City Below	0.5 U	0.3 U	**0.23**	3 UJ	0.3 UJ

Note: Metals detections highlighted in **BOLD**
*exceeds sediment quality guideline
U = not detected at or above the reported value
UJ = not detected at or above the reported estimated value

9. Metaline District - Pend Oreille Mine, Pend Oreille County
10. Wenatchee District - Cannon Mine, Chelan County

These two large underground metals mining operations ceased production in recent years. At the Pend Oreille Mine, lead and zinc ore was mined, milled, and the tailings were placed in three piles on a hillside near the mill. The Cannon Mine was a gold producer that used flotation to recover the gold values. Tailings were deposited in an earthen-lined valley bottom tailings facility. Water samples were obtained at each site during the high-flow sampling period, with emphasis on sampling water discharged from each mine's tailings.

At the Pend Oreille Mine (Figure 9), in addition to the tailings seepage sample, samples were collected in Frog Creek, which is a small stream tributary to the Pend Oreille River, and in a spring. Due to the layout of mine facilities relative to the sample sites, all sample results may be influenced by tailings seepage or other mine/mill discharges to some extent. General chemistry concentrations are consistently lower downstream (Table 29). General chemistry concentrations in tailings seepage water are elevated compared to both the upstream and downstream samples. In particular, sulfate in the tailings seepage, 907 mg/L, is substantially higher than either the upstream, 290 mg/L, or downstream, 175 mg/L, samples.

Metals results follow a similar pattern as the general chemistry (Table 30). Most downstream concentrations are lower or about the same as upstream. Tailings seepage is high in metals, with zinc, at 11,600 µg/L, not meeting water quality standards, and cadmium, at 2.6 µg/L, being elevated an order of magnitude or more above the upstream sample, <0.1 µg/L. Also in the tailings seepage, iron, copper, and lead showed increases of about 2-to-3 times above the upstream sample. Metals results reflect the mineralogy of the ore deposits found in the district.

The Cannon Mine (Figure 10) samples were collected in the discharge from a french drain at the toe of the recently reclaimed tailings impoundment. The tailings facility is located in a canyon that does not contain a perennial stream below the tailings impoundment. As a result, no upstream or downstream samples were collected at this site for comparison to the tailings water discharge.

The purpose of collecting a sample from the french drain was to characterize the discharge from a relatively modern tailings impoundment. The sources of water discharged from the french drain are bedrock springs beneath the tailings embankment and pore water expelled from the tailings. These commingled sources are collected in the french drain and then discharged to a series of constructed wetlands. Any overflow from the last wetland subsequently infiltrates to ground water.

Since this facility discharges to ground water under a State Waste Discharge Permit issued by Ecology, it is appropriate to compare the sample results to the ground water quality standards (Chapter 173-200 WAC). Among general chemistry parameters, the value for sulfate exceeds the regulatory criteria of 250 mg/L and the TDS value exceeds the criterion of 500 mg/L (Table 31). These concentrations are similar to values documented in nearby ground water monitoring wells and reflects a contribution from springs beneath the tailings impoundment. pH is slightly below the ground water criterion of 6.5, and is lower than historic values previously obtained. Nitrate/nitrite, at 2.1 mg/L, is the highest measured in any sample analyzed during this project. It may be the residue from blasting during underground mining operations. With the exception of arsenic, all metals are below regulatory criteria (Table 32). Arsenic has an extremely low criterion in ground water of 0.05 µg/L that is frequently exceeded under natural conditions.

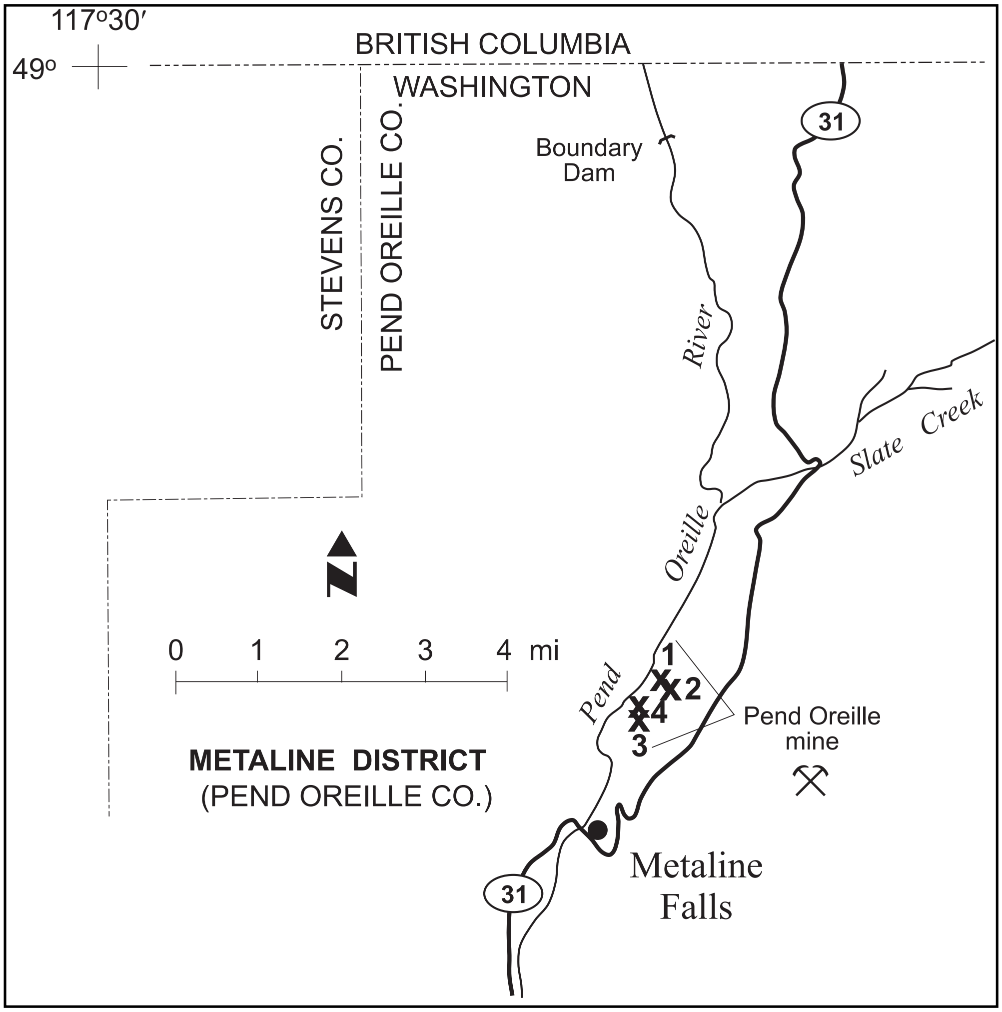

Figure 9. Locations of Water Samples Collected at Pend Oreille Mine - Metaline District

Table 29. Field Measurements and General Chemistry Results for Pend Oreille Mine Water Samples Collected June 1997

	Flow (cfs)		Temp. (^oC)		pH (units)		Cond. (µmho/cm)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Frog Creek Above	0.10	NM	8.9	NA	7.55	NA	868	NA
Spring Above Tailings	0.001	NM	7.2	NA	8.82	NA	741	NA
Tailings Seepage	0.004	NM	15.4	NA	7.45	NA	1888	NA
Frog Creek Below	0.20	NM	7.4	NA	8.30	NA	780	NA

	Hardness (mg/L)		Alkalinity (mg/L)		TDS (mg/L)		TSS (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Frog Creek Above	526	NA	266	NA	635J	NA	3J	NA
Spring Above Tailings	407	NA	260	NA	492J	NA	3J	NA
Tailings Seepage	1240	NA	260	NA	1700J	NA	1UJ	NA
Frog Creek Below	405	NA	238	NA	518J	NA	1UJ	NA

	Turbidity (NTU)		Sulfate (mg/L)		Cyanide (mg/L)		NO_3+NO_2 (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Frog Creek Above	1.2J	NA	290	NA	0.005U	NA	0.20	NA
Spring Above Tailings	1.1J	NA	140	NA	0.005U	NA	0.31	NA
Tailings Seepage	0.5UJ	NA	907	NA	0.005U	NA	0.010U	NA
Frog Creek Below	0.5UJ	NA	175	NA	0.005U	NA	0.025	NA

NM = not measured
NA = not analyzed
J = estimated value
U = not detected at or above the reported value

Table 30. Metals Concentrations in Pend Oreille Mine Water Samples Collected June 1997 (µg/L)

	Iron (total recoverable)		Zinc (dissolved)		Arsenic (total recoverable)		Copper (dissolved)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Frog Creek Above	**56**	NA	**6.1**	NA	1.5U	NA	**0.41**	NA
Spring Above Tailings	**49**	NA	**48**	NA	1.5U	NA	**1.0**	NA
Tailings Seepage	**113**	NA	**11600***	NA	1.5U	NA	**0.98**	NA
Frog Creek Below	**54.00**	NA	**13**	NA	1.5U	NA	**0.44**	NA

	Lead (dissolved)		Cadmium (dissolved)		Silver (dissolved)		Mercury (total recoverable)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Frog Creek Above	0.1U	NA	0.1U	NA	0.2UJ	NA	0.002U	NA
Spring Above Tailings	**0.42**	NA	0.1U	NA	0.2UJ	NA	0.002U	NA
Tailings Seepage	**0.36**	NA	**2.6**	NA	0.4UJ	NA	0.002U	NA
Frog Creek Below	0.1U	NA	0.1U	NA	0.2UJ	NA	0.002U	NA

Note: Metals detections highlighted in **BOLD**
*exceeds water quality standard or guideline
NA = not analyzed
U = not detected at or above the reported value
UJ = not detected at or above the reported estimated value

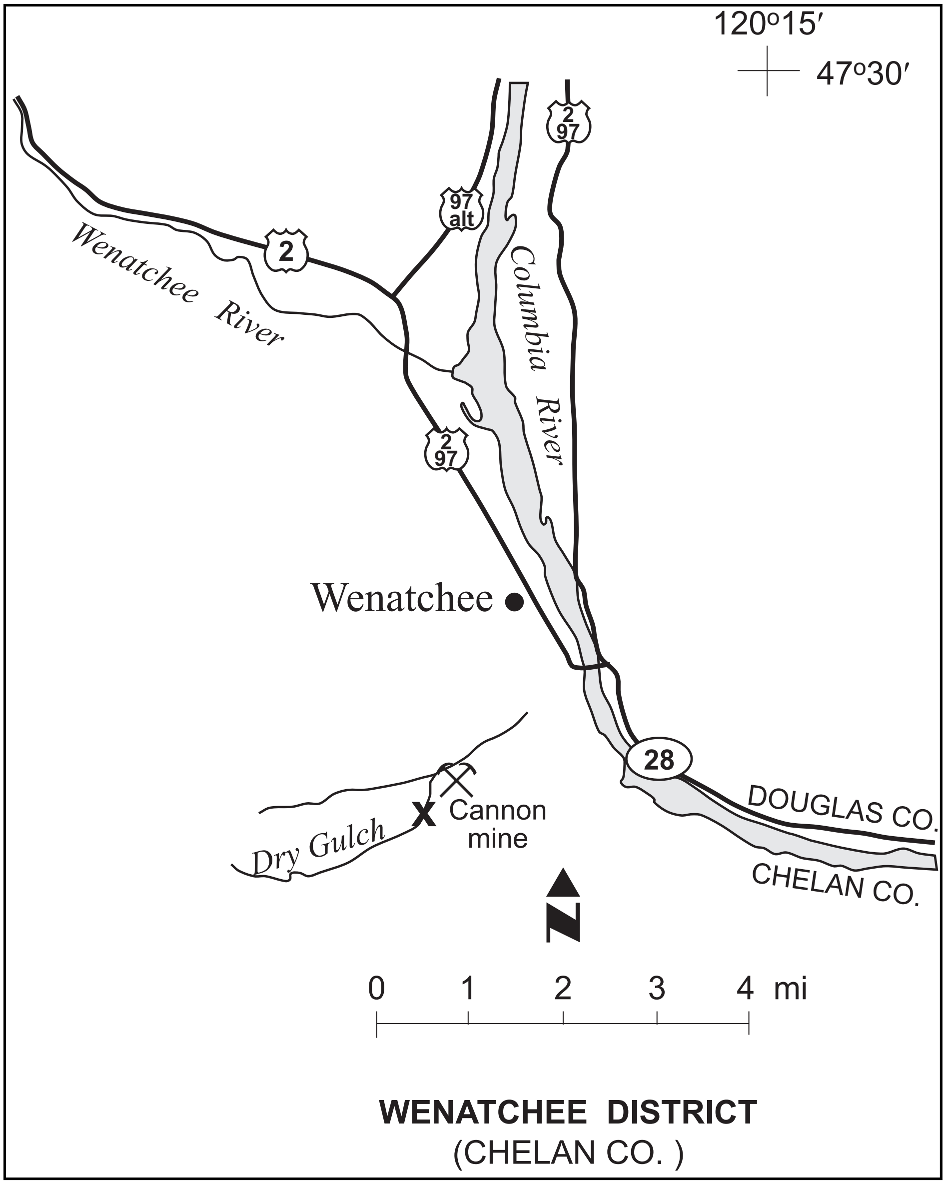

Figure 10. Locations of Water Samples Collected at Cannon Mine - Wenatchee District

Table 31. Field Measurements and General Chemistry Results for Cannon Mine Water Samples Collected June 1997

	Flow (cfs)		Temp. (^{o}C)		pH (units)		Cond. (µmho/cm)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Tailings Underdrain	0.11	NM	13.8	NA	6.44	NA	1990	NA

	Hardness (mg/L)		Alkalinity (mg/L)		TDS (mg/L)		TSS (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Tailings Underdrain	895	NA	346J	NA	1560J	NA	1UJ	NA

	Turbidity (NTU)		Sulfate (mg/L)		Cyanide (mg/L)		NO_3+NO_2 (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Tailings Underdrain	0.5UJ	NA	633	NA	0.005UJ	NA	2.1	NA

NM not measured
NA = not analyzed
J = estimated value
U = not detected at or above the reported value

Table 32. Metals Concentrations in Cannon Mine Water Samples Collected June 1997 (µg/L)

	Iron (total recoverable)		Zinc (dissolved)		Arsenic (total recoverable)		Copper (dissolved)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Tailings Underdrain	**77**	NA	**29**	NA	**1.7**	NA	**3.9**	NA

	Lead (dissolved)		Cadmium (dissolved)		Silver (dissolved)		Mercury (total recoverable)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Tailings Underdrain	**0.26**	NA	0.2U	NA	0.4UJ	NA	**0.0021**	NA

Note: Metals detections highlighted in **BOLD**
NA = not analyzed
U = not detected at or above the reported value
UJ = not detected at or above the reported estimated value

Discussion

Value of Low-Level Methods

The usefulness of low-level methods for collection and analysis of metals in receiving waters, as opposed to previous methods with increased potential for sample contamination and higher detection levels, is well illustrated by this study. The accuracy and precision of the data were good, requiring little qualification. The percentage of non-detects for all metals except arsenic and silver is low. As a result, metals concentrations were measured in streams where previously no data were available. An improvement in instrument detection limits for arsenic, from 1.5 to 0.2 µg/L, took place midway through this project, permitting quantification of arsenic in all the low-flow water samples.

Importance of Seasonal Sampling

One aspect of the study was to investigate whether a significant difference in water quality existed between high-flow and low-flow conditions. Water quality seasonality could have an important effect on sampling results in a semi-arid climate such as eastern Washington. For example, efflorescent salts from the oxidation of pyrite can develop during the low precipitation season of late summer and fall. Percolating water from snowmelt and spring precipitation then flushes these highly soluble salts into the receiving water from waste rock piles, tailings, fractures, or mine workings where they were precipitated. If this transport mechanism is operating in a district, higher concentrations and probably higher metals loadings should occur during a spring sampling event than during a fall sampling.

The data from this study demonstrate seasonal variations in most districts. pH values tend to be lower and TSS higher during high-flow, acting to increase the concentrations of dissolved and particulate metals. Zinc, copper, cadmium, and mercury concentrations were routinely higher during high-flow conditions. Although the higher concentrations of lead tended to occur during low-flow, results were variable. The detection limits for arsenic in the high-flow samples masked any seasonal differences that may have occurred. Future screening level sampling projects should investigate seasonality by collecting samples during both high- and low-flow conditions. Likewise, any interpretation of data obtained from previous sampling projects should include the consideration of whether seasonality was adequately addressed through comparison of high-flow and low-flow data.

Fingerprinting Acid Rock Drainage

Acid rock drainage (ARD), sometimes referred to as acid mine drainage, is defined as:

Drainage with a pH of less than 4.5 from sulfur-bearing rock materials. Acid rock drainage is predominantly present when these rocks have been exposed to air and water through natural (i.e., landslide) or man-induced (i.e., mining) processes. The reaction with air and water over time can produce sulfuric acid and sulfate salts. Sulfuric acid can also dissolve metals, if present in the rock, and release the metals into the environment. (American Geologic Institute, 1987).

One purpose of this study was to identify a fingerprinting method to screen for ARD impacts on receiving waters. This approach would use a geochemical profile, or fingerprint, that signals the presence of ARD. An advantage of fingerprinting would be lowered cost of data collection by focussing on those parameters that make up the fingerprint. A fingerprint could also be used to interpret data from other studies that were not directed toward ARD detection. Most of the mining districts sampled occur in a carbonate geologic environment so that low pH values were not commonly measured. Instead, this study concluded that the concentration of sulfate, which is generated by the oxidation of pyrite, was more useful than pH for fingerprinting ARD.

Parameters selected in advance of this study were those believed to be the most likely to detect ARD and other potential impacts associated with mining or milling operations. Little or no geochemical data were available on the districts and mines included in this study. After the first round of sampling in June, a number of parameters were dropped from the resampling scheduled for October.

Cyanide was dropped from the second sampling program because it was never detected at sites where cyanide was known to have been used in processing ore. Studies demonstrate that cyanide is destroyed under the oxidizing and near neutral pH conditions that exist in the streams sampled in this investigation (Norman and Raforth, 1995).

Another parameter dropped from the second round of sampling was nitrate, a byproduct of the blasting operations at mines. The initial round of sampling, including sampling of discharges from mine adits, did not show substantial water quality impacts from this source.

Iron was also dropped from the October sampling, primarily because the June data indicated that most water quality impacts from iron stemmed directly from adit discharges, which were not resampled in October. Adit discharges were not resampled because one round of characterization was deemed adequate at the screening level of this investigation. However, a round of samples from the adits and receiving waters during low-flow would have been helpful to address seasonality effects, particularly at the three sites that exceeded water quality standards during high-flow. Future sampling programs should include iron.

As illustrated at the Alder Mine, pH is not necessarily the primary manifestation for ARD. Most mine drainage and streams draining the investigated mining districts tested at nearly neutral pH. However, some metals included in this study – zinc and cadmium, for example – once released by ARD can remain mobile under nearly neutral pH conditions and have an adverse impact on receiving water. This is demonstrated at the Alder Mine. Tables 22 and 23 show that mine drainage from the North Adit contains high concentrations of metals at a low pH value typical of what is considered as classic ARD conditions. Most of these metals are present at elevated levels in the middle and downstream Alder Creek samples, although the pH is nearly neutral. As a result, in the mining districts sampled in this study, collection of pH data alone would not diagnose ARD impacts on the receiving water.

A potential method of fingerprinting suggested by evaluating the data in this study is the ratio of sulfate to TDS. Sulfate is generated by the ARD process and would comprise a major portion of

TDS where ARD is present. A recent study of lakes that have formed in open pit mines supports this approach (Eary, 1999). Sulfate is likely to be conservative under the oxidizing conditions of this sampling study and other studies of this type. To further investigate this relationship, the SO_4:TDS ratios (expressed as a percentage) in Table 33 were calculated with the objective of exploring whether sulfate was present at a disproportionately high percentage of TDS in receiving waters that are impacted by ARD.

Overall, high levels of TDS are also associated with ARD (Appendix E and as implied by the high conductivity measurements in Appendix H). An advantage of creating ratios is that dilution introduced by water sources unaffected by ARD would be accounted for. However, the more distant the sampling from the ARD source, the higher the probability that a high TDS source with low sulfate will interfere with this approach. Also, potentially confounding this method is that the source of ARD in a receiving water can be mineralized rock in a mining district rather than discharges from mines in the district. This is not necessarily negative as the objective is to identify impacts at a screening level. Districts that contribute ARD to receiving water will likely contain individual mines that are ARD sources as well.

The analyses of the mine adit drainage samples from the Arlington Mine, the First Thought Mine, and the Alder Mine-North Adit were used to establish a baseline for comparison. The discharges from these adits contain high concentrations of metals and are considered generally indicative of ARD chemistry. It was assumed that the SO_4:TDS ratio would be a maximum at those locations. At these three adits, the SO_4:TDS ratio ranges from 43% to 69%, and this range is the upper bound for ARD identified by this study.

To estimate a threshold for identifying ARD in receiving water, the data from this study were augmented with ratios calculated from TDS and sulfate data recently obtained in the vicinity of the proposed Crown Jewel Mine at Buckhorn Mountain (Figure 5). The calculated ratios result from several years (1992-1996) of monthly baseline water quality monitoring in three small streams in the Myers Creek watershed. The Crown Jewel data were organized into two categories for comparison with the data collected as part of this project. High-flow data were obtained by averaging each year's data collected during June. Similarly, low-flow data represent the average of all data collected during October. These averages were based on from three to six data points each.

The set of data labeled Gold Creek Area is from a series of stations located in the Gold Creek drainage. The Magnetic Mine is in the upper part of the Gold Creek watershed, but does not have a surface discharge directly into Gold Creek (Figure 5). The Gold Creek Spring sample location is approximately at the headwaters of Gold Creek and about 1,000 feet downhill from the mine. The lower Gold Creek sample site is about ¾ miles downstream from Gold Creek Spring. Gold Creek is tributary to Myers Creek, just above the Myers Creek downstream sample site for the present study. There are no tributaries to Gold Creek between the sample sites.

The Magnetic Mine contains water that is high in sulfate but at neutral pH, high alkalinity, and with low metals concentrations (TerraMatrix, 1997). These results indicate that the ARD process is actively liberating sulfate in the mine. The SO_4:TDS ratio for June of 50% is in the same range as associated with the other mine discharges sampled in this project that are considered to be generating ARD. Seasonality of the ratio is also demonstrated in the difference between high-flow and low-flow. Water quality results from Gold Creek Spring reflect a ratio similar to that found at

Table 33. SO$_4$:TDS Ratios

Sample Location	High-flow	Low-flow
Swauk District		
Liberty Area		
Williams Creek Above	1%	2%
Williams Creek Below	1%	2%
Swauk Creek Area		
Swauk Creek Above	1%	2%
Swauk Creek Below	1%	2%
Northport District		
Anderson Mine Area		
Deep Creek Above	6%	7%
Deep Creek Below	9%	9%
Gladstone Mtn Area		
Silver Creek Above	3%	4%
Silver Creek Below	4%	5%
Republic District		
Swamp Creek Above	5%	20%
Granite Creek Below	5%	6%
Eureka Creek	48%	51%
Wauconda District-Bodie Area		
Toroda Creek Above	8%	9%
Toroda Creek Below	8%	9%
Myers Creek District		
Myers Creek Above	5%	6%
Myers Creek Below	16%	15%
Conconully District-Ruby Hill Area		
Arlington Above	4%	5%
Arlington Mine	43%	NA
Arlington Below	6%	32%
First Thought Mine	68%	NA
Twisp District-Alder Area		
Alder Creek Above	15%	15%
Alder Creek Middle	NA	26%
Alder Creek Below	23%	24%
Alder Mine North Adit	69%	NA
Bumping Lake District - Copper City Area		
Copper City Above	7%	NA
Copper City Mill	8%	NA
Copper City Below	15%	NA
Pend Oreille Mine		
Frog Creek Above	46%	NA
Spring Above Tailings	28%	NA
Tailings Seepage	53%	NA
Frog Creek Below	34%	NA
Cannon Mine		
Tailings Underdrain	41%	NA
Crown Jewel		
Gold Creek		
Magnetic Mine	50%	32%
Gold Creek Spring	42%	40%
Lower Gold Creek	29%	25%
Myers Creek District		
Lower Bolster Creek	12%	12%
Lower Ethel Creek	18%	12%

NA = not analyzed

the Magnetic Mine, although seasonality is much less apparent. Seasonal effects at Gold Creek Spring may be mitigated by perennially high ground water conditions that minimize oxygen flux through ARD-prone bedrock. Finally, the lower Gold Creek sample illustrates the decline with distance in the ratio, but the ratio is still relatively high when compared to downstream samples collected in the current project. The relationship of decreasing ratio downstream over a relatively short distance also illustrates that sample spacing is an important consideration in design of a screening sampling program. The sequence of samples at the Crown Jewel supports the proposed upper bound for determining ARD as estimated from the data from the mines in this project. The results from the Crown Jewel also illustrate the change in the ratio downstream, although the relatively high SO_4:TDS ratio is preserved in this small stream.

Also of interest from the Crown Jewel baseline data are ratios calculated from samples obtained in lower Bolster Creek and lower Ethel Creek (Figure 5). These streams, along with Gold Creek, drain the east side of the Myers Creek District. All three streams enter Myers Creek above the Myers Creek downstream sampling site. As a result, ratios obtained at these sites, based on several years of sampling, can be compared to the results at the Myers Creek downstream site. The SO_4:TDS ratios obtained in lower Bolster Creek and lower Ethel Creek are close to the ratio at the Myers Creek downstream site in this study and support the sample results there. There are no known mines in Ethel Creek drainage. There is one mine at the head of Bolster Creek that does not discharge ARD (TerraMatrix, 1997). The low ratios imply that ARD is not generated in either Bolster Creek or Ethel Creek, although mineralized rock is present in the headwaters of both drainages (TerraMatrix, 1997). The results from these two streams illustrate the fact that not every mine or mining district will generate ARD.

The SO_4:TDS ratios for the mining districts in Table 33 were compared to the results from metals and sediment sampling to estimate a threshold for detecting ARD. Inspection of Table 33 shows that ratios calculated from mines are not necessarily reflected in nearby receiving waters, as illustrated by the Arlington Mine in the Conconully District. This apparent disconnection could be caused by lack of direct discharge of mine drainage into the receiving water, distance between samples, or dilution of small volumes of mine drainage by large flow volume in the receiving water. Selection of a SO_4:TDS ratio of 20% would identify all exceedences of water quality standards or sediment quality guidelines in all districts except the sample at the Copper City Mill in the Bumping Lake District. At the Pend Oreille Mine, applying this threshold would correctly identify the water quality standards exceedence from the tailings discharge, but apparently would misidentify the other sample sites where metals exceedences were not detected. Sediments were not sampled at the mine for comparison to the ratio. However, as previously pointed out, water quality at all four sample sites at the mine were probably impacted by tailings drainage. The other potential misidentification occurred at the Cannon Mine. There, the ratio was influenced by commingling of high sulfate ground water with seepage from the tailings.

Water Quality Impacts in Mining Districts

The question of the extent to which the selected mining districts were adversely impacting the receiving water was not completely answered by the results of this study. At the screening level of this investigation, the dilution factor introduced by the distance between stream samples was one contributor to the uncertainty. The possibility that there were other intervening sources of contamination unrelated to mining should also be recognized. Finally, because sample size was small, the results may not be representative of conditions at some sites, especially during high-flow.

In the Bumping Lake District-Copper City Area, the small stream passing through the collapsed mill did not meet the water quality standard for copper. The downstream sample was located several miles away, and did not reflect the mill's impact on local water quality due to dilution afforded by the distance between sample locations and the greatly increased flow in the creek.

A different illustration of dilution likely occurred at the Northport District-Anderson Mine Area. At this site, tailings were placed along the bank of Deep Creek. Samples bracketing this site were closely spaced but, due to the large volume of flow in Deep Creek, dilution may obscure any impacts in the stream. Further, since the tailings were deposited on the Deep Creek floodplain, substantial impacts to water quality may occur downstream of the selected sample site by way of an alternate pathway. Elevated concentrations of sulfate and zinc did occur in the downstream sample, demonstrating that the tailings are affecting Deep Creek water quality. Under this circumstance, clear demonstration of the level of water quality impacts by tailings would require a detailed study that might include ground water characterization.

In districts where individual mine adit discharges exceed water quality standards, documenting a direct connection to surface water was not part of the investigation. Even at the Alder Mine, where the clearest evidence for ARD impacts on a stream can be inferred, it was not determined whether either of the adits discharge through overland flow directly to the creek. In the Conconully District, where several mines discharge ARD, lack of major streams draining the district hampers the evaluation of the relationship between adit discharges and water quality in the nearby streams. For the purposes of this study, water quality results were only compared to the state surface water quality standards (except for Cannon Mine); the ground water quality standards are equally applicable. Future investigations should account for the ground water pathway to surface water and consider these regulatory criteria.

Keeping these shortcomings in mind, water quality impacts identified by this study can be summarized as shown in Table 34.

Violations of the state pH standard were encountered in two of the 13 creeks sampled in the study, Alder in the Twisp District and the unnamed Copper City stream. In both of these cases there was close proximity to mine and mill drainage.

Three of 13 creeks had violations of the state turbidity standard and TSS levels that afforded low protection to aquatic communities. These were: Silver Creek in the Northport District, Myers Creek in the Myers Creek District, and the unnamed stream in the Conconully District near the Arlington Mine. Whether these violations were caused by mining activities, other land use, or are naturally occurring could not be determined.

Exceedences of the state metals standards were found in three streams. Zinc exceeded standards in the unnamed Arlington stream. Zinc and cadmium exceeded standards in Alder Creek. Copper exceeded standards below the Copper City Mill.

Table 34. Summary of Water and Sediment Quality Impacts Identified in Mining Districts During Present Study [x indicates exceedance; (x) indicates potential to exceed]

Location	State pH standard not met	State turbidity std. not met	TSS levels not protective	>2-fold metals increase	>10-fold metals increase	State metals standards exceeded	Iron guideline exceeded	Sediment guidelines exceeded
Swauk District								
Liberty Area								
Williams Creek Above								
Williams Creek Below				Fe, Zn, Pb	Pb		x	
Swauk Creek Area								
Swauk CreekAbove							(x)	
Swauk Creek Below				Zn, Pb	Zn(Pb)		(x)	
Northport District								
Anderson Mine Area								
Deep Creek Above								no samples
Deep Creek Below				Zn, Pb	Zn			no samples
Gladstone Mtn Area								
Silver Creek Above		(x)	x				x	no samples
Silver Creek Below		x	x	Pb, Hg	Pb, Hg		(x)	no samples
Republic District								
Swamp Creek Above							x	As,Ag,Sb(Fe)
Granite Creek Below				Pb	Pb		x	
Eureka Creek				Zn, As, Cu, Hg	As		(x)	As,Ag,Sb
Wauconda District-Bodie Area								
Toroda Creek Above								
Toroda Creek Below				Zn, Pb				
Myers Creek District								
Myers Creek Above								no samples
Myers Ceek Below		x	x	Fe			x	no samples
Conconully District-Ruby Hill Area								
Arlington Above							(x)	no samples
Arlington Mine				Zn, Pb, Cd, Ag		Zn	x	no samples
Arlington Below		x	x	Fe,Zn,As,Cu, Cd,Ag	Fe (As)		x	no samples
First Thought Mine						Zn	x	no samples
Twisp District-Alder Area								
Alder Creek Above	x							
Alder Creek Middle	x			Zn, Cu, Pb, Cd	Zn,Cd	(Cd)		Zn,Cu,Cd
Alder Creek Below				Zn, Cu, Pb, Cd	Zn,Cd	Zn,Cd		Zn,Cd
Alder Mine North Adit						Zn,Cu,Cd,Pb	x	
Bumping Lake District-Copper City Area								
Copper City Above								
Copper City Below Mill	x			Fe, Zn, As, Cu	Cu	Cu		Cu,As,Ag
Copper City Below								
Metaline District-Pend Oreille Mine								
Frog Creek Above				no background sample for comparison				no samples
Spring Above Tailings								no samples
Tailings Seepage						Zn		no samples
Frog Creek Below								no samples
Wenatchee District-Cannon Mine								
Tailings Underdrain				no background				no samples

Order of magnitude increases in concentrations of at least one metal downstream of mining activity were documented for most of the creeks (nine of 13). Water quality problems due to iron were pervasive in the study area, occurring in eight of 13 creeks. The only downstream sites not showing a large metals impact was in Myers Creek. Zinc and lead were the most frequently elevated metals, in addition to iron. In a few instances substantial increases in arsenic, copper, and mercury were documented.

Although some increases in metals concentrations are to be expected moving from upstream to downstream in a drainage, the higher concentrations measured in the present study are not routinely encountered in state surface waters. For example, the high zinc concentrations at downstream sites on Deep, Eureka, and Toroda creeks were 44, 18, and 5.7 µg/L, respectively, while typical (median) values are 1 - 3 µg/L (Ecology Ambient Monitoring database). In Williams, Deep, Silver, and Alder creeks the range of elevated downstream lead concentrations was 0.13 - 0.42 µg/L, whereas concentrations less than 0.10 µg/L are normally seen.

Sediment samples were only collected in eight creeks. Four of these, Swamp, Eureka, Alder, and Copper City, exceeded guidelines for several metals each, including zinc, copper, arsenic, cadmium, silver, and antimony. In most instances the level of contamination was many times above guidelines and would be expected to have a severe adverse effect on the benthic community. Swamp Creek sediments also approached the severe effects level for iron.

Recommendations

This study focused on ten metals mining districts in eastern Washington. Many more districts are documented in eastern and western Washington (Derkey, 1990). Water quality information is available for very few of these. Results from this study demonstrate the need for sampling in other districts, to assess water quality impacts to receiving waters in the vicinity of these potential metals loading sources. Analysis of the results from this study can be used to direct future screening level investigations.

For initial screening purposes, future projects should include the general chemistry parameters hardness, TDS, TSS, turbidity, and sulfate at a minimum. Field parameters of temperature, pH, conductivity, and stream flow should be measured. Alkalinity is useful for indicating buffering of the receiving water, but this information may have limited value in a screening level investigation. Sampling for cyanide in streams is probably unwarranted for screening purposes, but could be considered in discharges from mills or tailings where cyanide was used for metals recovery. Nitrate could be considered in a follow up sampling program at mines, waste rock piles, or tailings, but appears to have limited value for screening streams.

Sample sites should be carefully scouted in advance of field work to optimize sample locations. The distance between upstream and downstream samples should be minimized. Potential alternate migration pathways for contaminants should be recognized and accounted for in the selection of sample sites.

For metals, we recommend that the SO_4:TDS ratio be considered as a basic tool to interpret results from preliminary screening of mining districts. From this study, it appears that a 20% ratio adequately describes water quality or sediment quality exceedences of standards or guidelines. This study is somewhat limited in scope, and in other geological, hydrological, and geochemical conditions the 20% threshold arrived at in this report may prove unreliable. Backtesting, using existing water quality data obtained from other mines or mining districts, would help to verify the utility of the proposed threshold value.

This study demonstrated the value of the ultra-clean sampling method for metals. This method is considered most useful for screening level investigations or the early stages of focussed studies. For example, if the SO_4:TDS ratio is relied on for identifying ARD, follow up sampling for metals should use the ultra-clean method. Subsequent metals sampling may not require ultra-clean sampling if low detection limits are not an issue. The suite of metals that was included in this study should be carried forward for screening level studies. Data on a broad suite of metals can be informative for detecting impacts to receiving water as this study has demonstrated. Metals data should be used to calibrate or refine the SO_4:TDS ratio method. The procedure of sampling general chemistry and metals in discharges from individual mines in each district should be continued. Sampling of more individual mines in each district would be desirable, because mine discharge water quality can vary within a district. Water quality data obtained from mines should be compared to receiving water quality.

This study also demonstrated that seasonal variations must be considered in any water quality monitoring program assessing the effects of ARD. Future studies should account for seasonality by conducting both high-flow and low-flow sampling. Seasonal stream flow measurements should accompany water quality sampling. In the event that only one round of samples can be obtained, sampling during high-flow conditions is recommended and should include replicates to assess variability.

Sediment sampling during low-flow conditions appears to have value and should be part of future sampling projects. Sediment data also yield information that relates to subtle long-term impacts to fish habitat and benthic macroinvertebrates that may not be apparent from reviewing water quality data alone. Results from future studies should be compared to benthic macroinvertebrate studies, if any are available in the vicinity, or could be used to identify candidate sites for such studies.

This is the first study in Washington to use sampling and analytical methods that are capable of measuring very low concentrations of metals in waters in mining districts, which in turn allowed us to compare results to current water quality standards. One purpose of comparing to standards is to supplement the ongoing documentation of state water quality conducted by Ecology. Through studies such as this, the state identifies water bodies that do not meet water quality standards for protection of aquatic life and lists these water bodies in a report to EPA, known as the 303(d) list. The state is responsible for improving water quality of impaired water bodies through clean up actions, permitting, best management practices, and implementation of total maximum daily load allocations among dischargers.

This study also focused narrowly on impacts to surface water as the receiving water. In eastern Washington in particular, it is likely that many mine discharges do not reach surface water directly by overland flow. In such cases, there may be ground water impacts which must be accounted for. The Ground Water Quality Standards (Chapter 173-200 WAC) protect present and future beneficial uses of ground water. Assessment of these impacts, however, will be difficult and beyond the scope of any initial study such as this project.

Based on the findings from this study, additional sampling is appropriate for streams that do not meet water quality standards or sediment quality guidelines. Those streams are: Eureka Creek and Swamp Creek; the unnamed stream near the Arlington Mine; Alder Creek, both at the Alder Mine and at the Alder Mill; and the unnamed stream at the Copper City Mill. Due to their size and the limited extent of this study, the Republic District, Conconully District, and Bumping Lake District should be investigated with additional water quality and sediment quality sampling.

The Bodie Mine and the Anderson Mine deposited tailings on a nearby streambank. For that reason, detailed water quality and sediment quality sampling is recommended because of the high risk associated with the location of the tailings. A complete investigation at those two sites would also include ground water quality.

In Washington State, no state agency maintains a comprehensive, centralized database of water quality or sediment quality information that could be used to identify or prioritize impacts from abandoned metals mines on a statewide basis. An effort to address this issue is in the early stages of development. Lead by DNR, with contributions from Ecology, EPA, BLM, and the U.S. Forest Service, a statewide database of information on abandoned mines is being developed. State and federal agencies have each conducted some level of basic investigation of abandoned mines in their jurisdiction for inventory purposes. However, it is apparent that among these agencies, there is no systematic approach for obtaining water quality or sediment quality data comparable to this study.

Data from the present study will be entered into the new DNR database. Additional data from future screening level sampling conducted according to the recommendations in this report should be entered as a contribution toward identifying and prioritizing the water quality and sediment quality impacts of mines or mining districts.

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Appendices

Appendix A. Metals Criteria Formulas

Washington State surface water quality standards for cadmium, lead, silver, and zinc are hardness dependent and can be calculated by the following formulas (WAC 173-201A):

Cadmium - acute = $(1.136672-[(\ln \text{hardness})(0.041838)])(e^{(1.128[\ln(\text{hardness})]-3.828)})$

Cadmium - chronic = $(1.101672-[(\ln \text{hardness})(0.041838)])(e^{(0.7852[\ln(\text{hardness})]-3.490)})$

Copper - acute = $(0.960)(e^{(0.9422[\ln(\text{hardness})]-1.464)})$

Copper - chronic = $(0.960)(e^{(0.8545[\ln(\text{hardness})]-1.465)})$

Lead - acute = $(1.46203-[(\ln \text{hardness})(0.145712)])(e^{(1.273[\ln(\text{hardness})]-1.460)})$

Lead - chronic = $(1.46203-[(\ln \text{hardness})(0.145712)])(e^{(1.273[\ln(\text{hardness})]-4.705)})$

Silver - acute = $(0.85)(e^{(1.72[\ln(\text{hardness})]-6.52)})$

Zinc - acute = $(0.978)(e^{(0.8473[\ln(\text{hardness})]+0.8604)})$

Zinc - chronic = $(0.986)(e^{(0.8473[\ln(\text{hardness})]+0.7614)})$

Appendix B. Field Blank Results, Ecology Environmental Assessment Program (ug/L)

Bottle Blanks[a]

Sample No.	95358238	95418106	96178185	96378313	97208091	97438278[b]
Iron	- -	- -	- -	<20	- -	- -
Aluminum	- -	- -	- -	<15	- -	- -
Arsenic	- -	- -	- -	- -	- -	<0.1
Manganese	- -	- -	- -	<1	- -	- -
Zinc	<1	<1		1.7	<0.2	- -
Copper	<0.5	<0.5	- -	0.12	0.37	- -
Cadmium	<0.04	<0.04	- -	<0.1	<0.02	- -
Chromium	<1	<1	<0.4	- -	- -	- -
Lead	<0.03	<0.03	- -	<0.1	0.021	- -
Nickel	<1	<1	- -	- -	- -	- -
Arsenic	<1	<1	<0.2	- -	- -	- -
Mercury	<0.001	<0.001	<0.001	- -	- -	<0.002
Selenium	<1	<1	<0.4	<0.4	- -	- -
Silver	<0.03	<0.03	- -	- -	- -	- -

Filter Blanks[c]

Sample No.	95358239	95398071	96178187	96378314	97208092	97438277[b]
Aluminum	- -	- -	- -	<0.4	- -	- -
Arsenic	<1	<1	- -	- -	- -	- -
Zinc	<1	<1	0.57	0.56	0.78	1.46
Copper	<0.05	<0.05	0.08	<0.05	<0.05	<0.05
Cadmium	<0.04	<0.04	<0.02	<0.01	<0.02	<0.02
Chromium	<1	<1	- -	0.012	- -	- -
Lead	<0.03	<0.03	<0.02	- -	<0.02	<0.02
Nickel	<1	<1	0.12	- -	- -	- -
Silver	<0.03	<0.03	<0.01	- -	- -	- -
Selenium	<1	<1	- -	- -	- -	<0.02

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

[b] 10-Mines Study

[c] Teflon bottles cleaned and filled as above, then filtered and acidified in the field

Appendix C. Results from Duplicate Analyses on Water Samples (Laboratory Splits)

Location	Williams Creek			Copper City			Swauk Creek		
Date	Jun-97			Jun-97			Jun-97		
Sample No.	28130	28130	RPD*	248230	48230	RPD	228136	28136	RPD
General Water Quality									
Hardness (mg/L)	56.9	58.1	2.1	11.3	11.7	3.5	na	na	- -
Cyanide (mg/L)	nd	nd	- -	na	na	- -	na	na	- -
Sulfate (mg/L)	1.41	1.51	6.8	na	na	- -	na	na	- -
NO2-NO3 (mg/L)	na	na	- -	na	na	- -	na	na	- -
Total Alkalinity (mg/	109	109	0.0	na	na	- -	na	na	- -
TDS (mg/L)	119	120	0.8	na	na	- -	na	na	- -
TSS (mg/L)	na	na	- -	na	na	- -	na	na	- -
Turbidity (NTU)	na	na	- -	na	na	- -	7.4	7.7	4.0
Conductivity (umho/	na	na	- -	na	na	- -	122	122	0.0

Location	Toroda Creek			Alder Creek			Williams Creek		
Date	Jun-97			Oct-97			Oct-97		
Sample No.	28302	28302	RPD	47823	47823	RPD	438272	43827	RPD
General Water Quality									
Hardness (mg/L)	137	139	1.4	na	na	- -	na	na	- -
Cyanide (mg/L)	na	na	- -	na	na	- -	na	na	- -
Sulfate (mg/L)	na	na	- -	70.4	70.4	0.0	na	na	- -
NO2-NO3 (mg/L)	na	na	- -	na	na	- -	na	na	- -
Total Alkalinity (mg/	na	na	- -	na	na	- -	139	140	0.7
TDS (mg/L)	na	na	- -	459	462	0.7	123	124	0.8
TSS (mg/L)	na	na	- -	12	12	0.0	na	na	- -
Turbidity (NTU)	na	na	- -	5.1	5.3	3.8	1.1	1.1	0.0
Conductivity (umho/	na	na	- -	na	na	- -	na	na	- -

Location	Above Arlington			Toroda Creek			Deep Creek		
Date	Oct-97			Oct-97			Oct-97		
Sample No.	43823	43823	RPD	43824	43824	RPD	438262	43826	RPD
General Water Quality									
Hardness (mg/L)	na	na	- -	na	na	- -	na	na	- -
Cyanide (mg/L)	na	na	- -	na	na	- -	na	na	- -
Sulfate (mg/L)	5.31	5.54	4.2	21.6	21.6	0.0	29.9	30.1	0.7
NO2-NO3 (mg/L)	na	na	- -	na	na	- -	na	na	- -
Total Alkalinity (mg/	na	na	- -	182	182	0.0	na	na	- -
TDS (mg/L)	na	na	- -	na	na	- -	na	na	- -
TSS (mg/L)	2	2	0.0	na	na	- -	na	na	- -
Turbidity (NTU)	na	na	- -	na	na	- -	na	na	- -
Conductivity (umho/	na	na	- -	na	na	- -	na	na	- -

*relative percent difference (range as percent of duplicate mean)
nd = not detected
na = not analyzed

Appendix C (continued).

Location	Swauk Creek			Swamp Creek		
Date	Oct-97			Oct-97		
Sample No.	43827	43827	RPD*	438248	438248	RPD
General Water Quality						
Hardness (mg/L)	88.8	93	4.6	178	179	0.6
Cyanide (mg/L)	na	na	- -	na	na	- -
Sulfate (mg/L)	na	na	- -	na	na	- -
NO2-NO3 (mg/L)	na	na	- -	na	na	- -
Total Alkalinity (mg/	na	na	- -	na	na	- -
TDS (mg/L)	na	na	- -	na	na	- -
TSS (mg/L)	na	na	- -	na	na	- -
Turbidity (NTU)	na	na	- -	na	na	- -
Conductivity (umho/	na	na	- -	na	na	- -

Location	Eureka Creek			Myers Creek			Alder Creek		
Date	Jun-97			Jun-97			Jun-97		
Sample No.	28300	28300	RPD	228308	28308	RPD	228322	28322	RPD
Metals (ug/L)									
Tot. Rec. Iron	108	375	111	218	741	109	40	41	2.5
Diss. Copper	4.34	4.88	12	0.531	0.565	0.6	2.76	3.02	9.0
Diss. Cadmium	nd	nd	- -	nd	nd	- -	9.41	9.61	2.1
Diss. Lead	0.10	0.17	52	0.038	0.041	7.6	0.051	0.096	61
Diss. Silver	nd	nd	- -	nd	nd	- -	nd	nd	- -
Diss. Zinc	14.5	20.5	34	0.38	0.57	40	484	491	1.4
Tot. Rec. Arsenic	13	14	7.4	3.1	3.7	18	nd	nd	- -
Tot. Rec. Mercury	0.008	0.011	33	nd	nd	- -	nd	nd	- -

Location	Granite Creek			Williams Creek		
Date	Oct-97			Oct-97		
Sample No.	38254	38254	RPD	438276	38276	RPD
Metals (ug/L)						
Tot. Rec. Iron	na	na	- -	na	na	- -
Diss. Copper	na	na	- -	na	na	- -
Diss. Cadmium	na	na	- -	na	na	- -
Diss. Lead	na	na	- -	na	na	- -
Diss. Silver	na	na	- -	na	na	- -
Diss. Zinc	na	na	- -	na	na	- -
Tot. Rec. Arsenic	1.9	1.9	0	0.30	0.32	6.5
Tot. Rec. Mercury	0.002U	0.005	>90	.002U	na	- -

*relative percent difference (range as percent of duplicate mean)

nd = not detected

na = not analyzed

U = not detected at or above reported value

Appendix D. Results from Duplicate Analyses on Sediment Samples (Laboratory Splits)

Location	Alder Creek			Eureka Creek		
Date	Oct-97			Oct-97		
Sample No.	448232	448232	RPD*	448279	448279	RPD
Grain Size (%)						
Gravel	16.1	14.9	7.7	38.3	35.6	7.3
Sand	43.1	40.6	6.0	54.0	57.9	7.0
Silt	35.6	39.1	9.8	6.6	5.2	24
Clay	5.2	5.4	3.8	1.0	1.2	18
Metals (mg/Kg, dry)						
Iron	na	na	- -	16400	16400	0.0
Manganese	na	na	- -	590	532	10
Zinc	na	na	- -	203	188	7.7
Copper	na	na	- -	43	37	16
Chromium	na	na	- -	26	29	12
Nickel	na	na	- -	24	24	0.0
Arsenic	na	na	- -	143	137	4.3
Lead	na	na	- -	18	22	20
Cadmium	na	na	- -	0.5U	0.53	>5.8
Silver	na	na	- -	7.6	7.1	6.8
Mercury	na	na	- -	0.16	0.17	6.0
Selenium	na	na	- -	5.0	4.7	5.8
Beryllium	na	na	- -	0.71	0.70	1.4
Antimony	na	na	- -	6.1	9.9	48
Thallium	na	na	- -	0.3U	0.3U	nd

*relative percent difference (range as percent of duplicate mean)
na = not analyzed
U = not detected at or above reported value

Appendix E. Field Measurements and General Chemistry Results on Water Samples

Sample Location	Flow (cfs)		Temp. (^{o}C)		pH (units)		Cond. (umho/cn		Hardness (mg/L		lkalinity (mg/L	
	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Swauk District												
Liberty Area												
Williams Creek Above	0.83	NM	8.4	3.3	7.45	7.50	210	276	103	130	109	140
Williams Creek Below	32	NM	9.0	3.3	7.56	7.36	120	178	58	78	61	88
Swauk Creek Area												
Swauk CreekAbove	14	NM	8.4	4.9	7.43	7.80	112	183	52	84	57	94
Swauk Creek Below	NM	NM	10.0	7.5	7.38	7.90	131	201	64	91	70	100
Northport District												
Anderson Mine Area												
Deep Creek Above	100	NM	12.5	6.4	REJ	7.67	322	511	186	287	165	256
Deep Creek Below	180	NM	15.3	7.1	REJ	7.36	340	547	186	298	169	267
Gladstone Mtn Area												
Silver Creek Above	NM	NM	6.3	5.1	REJ	7.96	136	239	82	127	69	120
Silver Creek Below	NM	NM	6.8	5.5	REJ	7.94	162	309	117	170	86	158
Republic District												
Swamp Creek Above	7.2	0.26	11.0	8.7	6.93	7.40	149	388	64	178	66	139
Granite Creek Below	51	6.3	9.5	5.9	7.48	7.93	162	263	67	115	72	120
Eureka Creek	1.2	0.17	10.2	8.2	7.25	7.77	908	1208	390	568	121	135
Wauconda District-Bodie Area												
Toroda Creek Above	44	5.5	10.3	5.9	7.84	7.88	313	393	142	184	146	183
Toroda Creek Below	41	6.2	10.3	6.7	7.95	8.00	318	392	138	182	145	182
Myers Creek District												
Myers Creek Above	48	7.4	6.4	3.6	7.38	7.83	102	283	45	140	46	133
Myers Ceek Below	90	13	9.1	5.1	7.75	7.91	289	501	148	256	119	217
Conconully District-Ruby Hill Area												
Arlington Above	0.10	0.001	4.9	5.3	6.64	7.90	82	123	34	58	37	60
Arlington Mine	0.15	0.09	6.0	7.4	6.98	7.15	725	630	355	NA	165	NA
Arlington Below	NM	NM	7.8	8.5	7.87	8.50	359	543	175	283	97	161
First Thought Mine	NM	NM	5.9	NA	6.64	NA	1950	NA	1120	NA	44	NA
Twisp District-Alder Area												
Alder Creek Above	0.10	0.01	8.2	4.4	8.00	8.30	673	739	365	424	311	346
Alder Creek Middle	NM	0.10	4.8	5.2	4.91*	6.90	2650	782	NA	387	NA	272
Alder Creek Below	1.8	0.22	7.4	7.2	8.09	8.40	578	642	298	354	225	256
Alder Mine North Adit	NM	NM	6.0	NA	3.51*	NA	3060	NA	1430	NA	10U	NA
Bumping Lake District -Copper City Area												
Copper City Above	0.25	NM	1.5	3.3	6.16*	7.43	29	77	12	NA	13	NA
Copper City Below Mill	0.25	NM	2.2	3.7	6.00*	7.42	37	77	14	NA	15	NA
Copper City Below	NM	NM	2.1	4.7	6.82	6.54	35	53	13	NA	13	NA
Metaline District-Pend Oreille Mine												
Frog Creek Above	0.10	NM	8.9	NA	7.55	NA	868	NA	526	NA	266	NA
Spring Above Tailings	0.001	NM	7.2	NA	8.82	NA	741	NA	407	NA	260	NA
Tailings Seepage	0.004	NM	15.4	NA	7.45	NA	1888	NA	1240	NA	260	NA
Frog Creek Below	0.20	NM	7.4	NA	8.30	NA	780	NA	405	NA	238	NA
Wenatchee District-Cannon Mine												
Tailings Underdrain	0.11	NM	13.8	NA	6.44	NA	1990	NA	895	NA	346J	NA

*exceeds water quality standard or guideline

NM = not measured

NA = not analyzed

J = estimated value

U = not detected at or above reported value

Appendix E (continued).

Sample Location	TDS (mg/L)		TSS (mg/L)		Turbidity (NTU		Sulfate (mg/L)		Cyanide (mg/L		NO_3+NO_2 (mg/L	
	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Swauk District												
Liberty Area												
Williams Creek Above	119	166	2	1	2.4	0.5UJ	1.4	2.9	0.005U	NA	0.01U	NA
Williams Creek Below	93	124	9	1	6.8	1.1J	1.2	3.0	0.005U	NA	0.01U	NA
Swauk Creek Area												
Swauk CreekAbove	83	123	6	1	3.5	0.5UJ	0.5U	2.0	0.005U	NA	0.11	NA
Swauk Creek Below	97	134	14	1	7.7	0.6J	1.3	3.0	0.005U	NA	0.23	NA
Northport District												
Anderson Mine Area												
Deep Creek Above	207J	303	5J	1	5.2J	1.3J	12	22	0.005U	NA	0.012	NA
Deep Creek Below	204J	337	2J	1	3.4J	1.0J	19	30	0.005U	NA	0.020	NA
Gladstone Mtn Area												
Silver Creek Above	88J	142	288J*	1	100J	0.5UJ	2.8	5.8	0.005U	NA	0.024	NA
Silver Creek Below	96J	173	307J*	1	130J*	0.5UJ	3.5	8.0	0.005U	NA	0.022	NA
Republic District												
Swamp Creek Above	147J	275	2J	5	13J	5.4J	7.7	56	0.005U	NA	0.28	NA
Granite Creek Below	144J	186	8J	1	9.3J	1.1J	6.9	11	0.005U	NA	0.034	NA
Eureka Creek	647J	921	23J	4	11J	2.4J	310	472	0.005U	NA	1.6	NA
Wauconda District-Bodie Area												
Toroda Creek Above	211J	252	14J	1	9.4J	0.6J	16	22	0.005U	NA	0.13	NA
Toroda Creek Below	218J	248	10J	2	5.2J	0.5J	17	22	0.005U	NA	0.14	NA
Myers Creek District												
Myers Creek Above	82	179	21	6	7.9J	1.5J	3.8	11	0.005U	NA	0.037	NA
Myers Ceek Below	188	328	131*	14	45J*	6.1J	29	50	0.005U	NA	0.054	NA
Conconully District-Ruby Hill Area												
Arlington Above	72	103	48	2	22J	1.5J	3.0	5.3	0.005U	NA	0.010U	NA
Arlington Mine	474J	NA	10J	NA	45J	NA	205	NA	0.005U	NA	0.064	NA
Arlington Below	246	364	173*	19	180J*	21J*	14	118	0.005U	NA	0.018	NA
First Thought Mine	1630J	NA	40J	NA	270J	NA	1110	NA	0.005U	NA	0.045	NA
Twisp District-Alder Area												
Alder Creek Above	406	459	11	12	5.2J	5.1J	59	70	0.005U	NA	0.035	NA
Alder Creek Middle	NA	474	NA	37	NA	4.8J	NA	123	NA	NA	NA	NA
Alder Creek Below	354	422	1	1	0.8J	2.3J	80	103	0.005U	NA	0.019	NA
Alder Mine North Adit	3220	NA	13	NA	38J	NA	2230	NA	0.005U	NA	0.020	NA
Bumping Lake District -Copper City Area												
Copper City Above	20	NA	1U	NA	0.8J	NA	1.4	NA	0.005U	NA	0.010U	NA
Copper CityBelow Mill	22	NA	2	NA	0.6J	NA	1.7	NA	0.005U	NA	0.010	NA
Copper City Below	19	NA	2	NA	0.9J	NA	2.8	NA	0.005U	NA	0.014	NA
Metaline District-Pend Oreille Mine												
Frog Creek Above	635J	NA	3J	NA	1.2J	NA	290	NA	0.005U	NA	0.20	NA
Spring Above Tailings	492J	NA	3J	NA	1.1J	NA	140	NA	0.005U	NA	0.31	NA
Tailings Seepage	1700J	NA	1UJ	NA	0.5UJ	NA	907	NA	0.005U	NA	0.010U	NA
Frog Creek Below	518J	NA	1UJ	NA	0.5UJ	NA	175	NA	0.005U	NA	0.025	NA
Wenatchee District-Cannon Mine												
Tailings Underdrain	1560J	NA	1UJ	NA	0.5UJ	NA	633	NA	0.005UJ	NA	2.1	NA

*exceeds water quality standard or guideline

NA = not analyzed

J = estimated value

U = not detected at or above reported value

UJ = not detected at or above reported estimated value

Appendix F. Metals Concentrations in Water Samples (ug/L)

	Iron (total recoverable)		Zinc (dissolved)		Arsenic (dissolved)		Copper (dissolved)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Swauk District								
Liberty Area								
Williams Creek Above	**120**	NA	**0.68**	**0.36**	1.5U	**0.38**	**0.50**	**0.41**
Williams Creek Below	**310***	NA	**0.50**	**1.0**	1.5U	**0.30**	**0.55**	**0.43**
Swauk Creek Area								
Swauk CreekAbove	**269**	NA	**0.45**	**0.15**	**1.6**	**0.23**	**0.44**	**0.24**
Swauk Creek Below	**287**	NA	**1.3**	**1.6**	1.5U	**0.25**	**0.46**	**0.36**
Northport District								
Anderson Mine Area								
Deep Creek Above	**144**	NA	**1.3**	**1.4**	1.5U	**0.67**	**0.44**	**0.33**
Deep Creek Below	**140**	NA	**44**	**7.3**	1.5U	**0.58**	**0.60**	**0.39**
Gladstone Mtn Area								
Silver Creek Above	**409J***	NA	**0.79**	**0.40**	1.5U	**0.15**	**0.18**	**0.10**
Silver Creek Below	**261J**	NA	**0.53**	**0.24**	1.5U	**0.22**	**0.20**	**0.13**
Republic District								
Swamp Creek Above	**894J***	NA	**2.8**	**4.9**	1.5U	**3.5**	**1.7**	**1.1**
Granite Creek Below	**520***	NA	**3.3**	**1.6**	**2.4**	**2.0**	**1.9**	**0.82**
Eureka Creek	**242J**	NA	**18J**	**7.8**	**14**	**15**	**4.6J**	**2.6**
Wauconda District-Bodie Area								
Toroda Creek Above	**181J**	NA	**0.97**	**0.59**	1.5U	**1.2**	**1.2**	**0.79**
Toroda Creek Below	**71**	NA	**5.7**	**3.2**	**2.0**	**1.2**	**1.1**	**0.82**
Myers Creek District								
Myers Creek Above	**104J**	NA	**1.1**	**0.55**	**1.8**	**2.5**	**0.44**	**0.26**
Myers Ceek Below	**480J***	NA	**0.48**	**0.60**	**3.4**	**3.5**	**0.55**	**0.51**
Conconully District-Ruby Hill								
Arlington Above	**249J**	NA	**0.56**	**3.5**	1.5U	**0.48**	**0.59**	**0.56**
Arlington Mine	**331J***	NA	**371***	NA	**1.6**	NA	**0.79**	NA
Arlington Below	**5640**	NA	**2.6**	**2.0**	**6.5**	**2.5**	**1.3**	**1.2**
First Thought Mine	**48300J***	NA	**8230***	NA	**69**	NA	**2.9**	NA
Twisp District-Alder Area								
Alder Creek Above	**62**	NA	**1.9**	**0.93**	1.5U	**1.3**	**0.78**	**0.87**
Alder Creek Middle	NA	NA	**NA**	**289**	NA	**0.88**	NA	**3.9**
Alder Creek Below	**40**	NA	**484***	**116**	1.5U	**1.0**	**3.0**	**1.0**
Alder Mine North Adit	**18500J***	NA	**321000***	NA	**3.5***	NA	**20800***	NA
Bumping Lake District-Copper City Area								
Copper City Above	10U	NA	**0.96**	NA	**1.6**	NA	**0.26**	NA
Copper City Below Mil	**26**	NA	**3.1**	NA	**9.6**	NA	**14***	NA
Copper City Below	**18**	NA	**1.1**	NA	**1.6**	NA	**0.29**	NA
Metaline District-Pend Oreil								
Frog Creek Above	**56**	NA	**6.1**	NA	1.5U	NA	**0.41**	NA
Spring Above Tailings	**49**	NA	**48**	NA	1.5U	NA	**1.0**	NA
Tailings Seepage	**113**	NA	**11600***	NA	1.5U	NA	**0.98**	NA
Frog Creek Below	**54.00**	NA	**13**	NA	1.5U	NA	**0.44**	NA
Wenatchee District-Cannon								
Tailings Underdrain	**77**	NA	**29**	NA	**1.7**	NA	**3.9**	NA

Note: Detections highlighted in **BOLD**

*exceeds water quality standard or guideline

NA = not analyzed

J = estimated value

U = not detected at or above the reported value

Appendix F (continued).

	Lead (dissolved)		Cadmium (dissolved)		Silver (dissolved)		Mercury (total recoverable)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Swauk District								
Liberty Area								
Williams Creek Above	0.02U	0.02U	0.02U	0.02U	0.04UJ	0.02U	0.002U	0.002U
Williams Creek Below	0.02U	**0.42**	0.02U	0.02U	0.04UJ	0.02U	0.002U	0.002U
Swauk Creek Area								
Swauk CreekAbove	0.02U	0.02U	0.02U	0.02U	0.04UJ	0.02U	0.002U	0.002U
Swauk Creek Below	0.02U	**0.054**	0.02U	0.02U	0.04UJ	0.02U	0.002U	0.002U
Northport District								
Anderson Mine Area								
Deep Creek Above	0.04U	**0.15**	0.04U	0.02U	0.08UJ	0.02U	0.002U	0.002U
Deep Creek Below	**0.13**	**0.19**	**0.046**	0.02U	0.08UJ	0.02U	**0.0025**	0.002U
Gladstone Mtn Area								
Silver Creek Above	**0.035**	**0.074**	0.02U	0.02U	0.04UJ	0.02U	0.002U	0.002U
Silver Creek Below	**0.028**	**0.40**	0.02U	0.02U	0.04UJ	0.02U	**0.0079**	0.002U
Republic District								
Swamp Creek Above	**0.11**	**0.023**	**0.11**	0.02U	0.04UJ	0.02U	**0.0053**	**0.0028**
Granite Creek Below	**0.12**	**0.32**	**0.095**	0.02U	0.04UJ	0.02U	**0.0054**	**0.0020**
Eureka Creek	**0.14J**	0.02U	0.1U	0.02U	0.2UJ	0.02U	**0.0091**	**0.0033**
Wauconda District-Bodie Area								
Toroda Creek Above	**0.029**	**0.14**	**0.026**	0.02U	0.04UJ	0.02U	**0.0026**	**0.0027**
Toroda Creek Below	**0.077**	0.02U	**0.022**	0.02U	0.04UJ	0.02U	0.002U	0.002U
Myers Creek District								
Myers Creek Above	**0.034**	**0.53**	0.02U	0.02U	0.04UJ	0.02U	**0.0031**	0.002U
Myers Ceek Below	**0.038**	0.02U	0.02U	0.02U	0.04UJ	0.02U	0.002U	0.002U
Conconully District-Ruby Hill Area								
Arlington Above	**0.037**	**0.093**	0.02U	0.02U	0.04UJ	0.02U	0.002U	0.002U
Arlington Mine	**1.4**	NA	**4.0***	NA	0.2UJ	NA	0.002U	NA
Arlington Below	0.04U	**0.097**	**0.040**	**0.021**	0.08UJ	0.02U	**0.0023**	0.002U
First Thought Mine	0.2U	NA	**33***	NA	0.4UJ	NA	0.002U	NA
Twisp District-Alder Area								
Alder Creek Above	**0.076**	**0.022**	0.04U	0.02U	0.08UJ	0.02U	0.002U	**0.0023**
Alder Creek Middle	NA	**0.17**	NA	**2.2**	NA	0.02U	NA	0.002U
Alder Creek Below	**0.074**	**0.058**	**9.5***	**2.6**	0.08UJ	0.02U	0.002U	0.002U
Alder Mine North Adit	**414***	NA	**3980***	NA	5UJ	NA	0.002U	NA
Bumping Lake District-Copper City Area								
Copper City Above	0.02U	NA	0.02U	NA	0.04UJ	NA	0.002U	NA
Copper City Below Mil	**0.036**	NA	0.02U	NA	0.04UJ	NA	0.002U	NA
Copper City Below	0.02U	NA	0.02U	NA	0.04UJ	NA	0.002U	NA
Metaline District-Pend Oreille Mine								
Frog Creek Above	0.1U	NA	0.1U	NA	0.2UJ	NA	0.002U	NA
Sping Above Tailings	**0.42**	NA	0.1U	NA	0.2UJ	NA	0.002U	NA
Tailings Seepage	**0.36**	NA	**2.6**	NA	0.4UJ	NA	0.002U	NA
Frog Creek Below	0.1U	NA	0.1U	NA	0.2UJ	NA	0.002U	NA
Wenatchee District-Cannon		NA						
Tailings Underdrain	**0.26**	NA	0.2U	NA	0.4UJ	NA	**0.0021**	NA

Note: Detections highlighted in **BOLD**

*exceeds water quality standard or guideline

NA = not analyzed

J = estimated value.

U = not detected at or above the reported value

UJ = not detected at or above the reported estimated value

Appendix G. Metals Concentrations in Sediment Samples (mg/Kg, dry)

Location	Fe	Mn	Zn	Cr	Ni	Cu	As	Pb
Swauk District								
Liberty Area								
Williams Creek Above	**24500**	**448**	**54**	**26**	**28**	**19**	**4.3**	3U
Williams CreekBelow	**19200**	**325**	**38**	**18**	**15**	**11**	**3.0**	3U
Swauk Creek Area								
Swauk Creek Above	**14500**	**255**	**31**	**25**	**15**	**8.8**	**1.8**	3U
Swauk Creek Below	**23700**	**398**	**48**	**25**	**19**	**15**	**3.3**	3U
Republic District								
Swamp Creek	**35100**	**364**	**91**	**26**	**43**	**33**	**116***	**3.1**
Granite Creek	**6550**	**152**	**15**	**8.8**	**4.7**	**2.9**	**2.3**	3U
Eureka Creek	**16100**	**545**	**191**	**26**	**24**	**37**	**130***	**18**
Wauconda District-Bodie Area								
Toroda Creek Above	**11200**	**151**	**37**	**13**	**5.9**	**9.1**	**3.4**	**3.5**
Toroda Creek Below	**11300**	**147**	**32**	**14**	**6.4**	**11**	**5.1**	3U
Twisp District-Alder Area								
Alder Creek Above	**21400**	**671**	**50**	**11**	**6.1**	**30**	**9.8**	3U
Alder Creek Middle	**16300**	**359**	**5460***	**8.8**	**9.0**	**1450***	**7.0**	**16**
Alder Creek Below	**15600**	**313**	**2240***	**11**	**6.6**	**36**	**5.7**	3U
Bumping Lake District-Copper City Area								
Copper City Above	**13600**	**319**	**90**	**10**	**6.4**	**11**	**34**	**5.0**
Copper City Below Mill	**27800**	**510**	**224**	**7.9**	**4.5**	**4640***	**2630***	**58**
Copper City Below	**15400**	**288**	**65**	**4.7**	**4.9**	**32**	**16**	**6.6**

Location	Hg	Ag	Cd	Se	Be	Sb	Tl
Swauk District							
Liberty Area							
Williams Creek Above	**0.03**	0.3 U	0.5 U	0.3 U	**0.47**	3 UJ	0.3 UJ
Williams Creek Below	**0.02**	0.3 U	0.5 U	0.3 U	**0.41**	3 UJ	0.3 UJ
Swauk Creek Area							
Swauk Creek Above	**0.05**	0.3 U	0.5 U	0.3 U	**0.35**	3 UJ	0.3 UJ
Swauk Creek Below	**0.03**	0.3 U	0.5 U	0.3 U	**0.50**	3 UJ	0.3 UJ
Republic District							
Swamp Creek	**0.55**	**14***	0.5 U	**3.1**	**3.6**	**3.3***	0.3 UJ
Granite Creek	0.005 U	0.3 U	0.5 U	0.3 U	**0.10**	3 UJ	0.3 UJ
Eureka Creek	**0.16**	**6.4***	0.5 U	**4.7**	**0.68**	**6.0***	0.3 UJ
Wauconda District-Bodie Area							
Toroda Creek Above	0.005U	0.3 U	0.5 U	0.3 U	**0.25**	3 UJ	0.3 UJ
Toroda Creek Below	**0.03**	**0.35**	0.5 U	0.3 U	**0.33**	3 UJ	0.3 UJ
Twisp District-Alder Area							
Alder Creek Above	**0.07**	0.3 U	0.5 U	0.3 U	**0.21**	3 UJ	0.3 UJ
Alder Creek Middle	**0.04**	0.3 U	**128***	**1.8**	**0.46**	3 UJ	0.3 UJ
Alder Creek Below	0.005 U	0.3 U	**46***	0.3 U	**0.18**	3 UJ	0.3 UJ

Appendix G (continued).

Location	Hg	Ag	Cd	Se	Be	Sb	Tl
Bumping Lake District-Copper City Area							
Copper City Above	**0.02**	0.3 U	0.5 U	0.3 U	**0.24**	3 UJ	0.3 UJ
Copper City Below Mill	**0.04**	**12***	0.5 U	**0.88**	**0.42**	3 UJ	0.3 UJ
Copper City Below	**0.01**	0.3 U	0.5 U	0.3 U	**0.23**	3 UJ	0.3 UJ

Note: Detections highlighted in **BOLD**
*exceeds sediment quality guidelines
U = not detected at or above the reported value
UJ =not detected at or above the reported estimated value

Appendix H. Field Measurements for Mines and Tailings

Sample Location	Temp. (°C)		pH (units)		Cond. (umho/cm)		Ferrous Iron	
	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Conconully District-Ruby Hill Area								
Arlington Mine	6.0	7.4	6.98	7.15	725	630	Present	NA
First Thought Mine	5.9	NA	6.64	NA	1950	NA	Present	NA
Last Chance Mine	12.3	NA	6.85	NA	1007	NA	NA	NA
Hough's Mine	5.2	NA	6.66	NA	435	NA	Absent	NA
Twisp District-Alder Area								
Alder Mine North Adit	6.0	NA	3.51	NA	3060	NA	Absent	NA
Alder Mine South Adit	5.0	NA	6.98	NA	784	NA	Absent	NA
Alder Tailings Pond	24.0	NA	7.94	NA	715	NA	NA	NA
Alder Tailings Seepage	13.2	NA	3.44	NA	5480	NA	NA	NA
Bumping Lake District - Copper City Area								
Copper City Mill	2.2	3.7	6.00	7.42	37	77	Present	NA
Metaline District-Pend Oreille Mine								
Frog Creek Up	8.9	NA	7.55	NA	868	NA	Absent	NA
Spring Above Tailings	7.2	NA	8.82	NA	741	NA	Absent	NA
Tailings Seepage	15.4	NA	7.45	NA	1888	NA	Present	NA
Frog Creek Down	7.4	NA	8.30	NA	780	NA	Absent	NA
Wenatchee District-Cannon Mine								
Tailings Underdrain	13.8	NA	6.44	NA	1990	NA	Absent	NA

NA = not analyzed

Appendix I. List of Minerals Referred to in this Report

Anglesite PbSO4 ---- 68.32% Pb (MW = 303.26 gm)
Argentite Ag2S ---- 87.06% Ag (MW = 247.80 gm)
Arsenopyrite FeAsS ---- 46.01% As (MW = 162.83 gm)
Azurite Cu3(CO3)2(OH)2 ---- 55.31% Cu (MW = 344.67 gm)
Biotite K(Mg,Fe++)3(Al,Fe+++)Si3O10(OH,F)2
Calcite CaCO3 ---- 40.04% Ca (MW = 100.09 gm)
Cerussite PbCO3 ---- 77.54% Pb (MW = 267.21 gm)
Chalcocite Cu2S ---- 79.85% Cu (MW = 159.16 gm)
Chalcopyrite CuFeS2 ---- 34.63% Cu (MW = 183.53 gm)
Dolomite CaMg(CO3)2 ---- 21.73% Ca (MW = 184.40 gm)
Epidote Ca2(Fe+++,Al)3(SiO4)3(OH)=Ca2(Fe,Al)Al2(SiO4)(Si2O7)O(OH)
Electrum ---- an alloy of gold with silver
Fluorite CaF2 ---- 48.67% F (MW = 78.07 gm)
Galena PbS ---- 86.60% Pb (MW = 239.27 gm)
Hematite Fe2O3 ---- 69.94% Fe (MW = 159.69 gm)
Limonite Fe+++O(OH)
Magnetite Fe++Fe+++2O4 ---- 72.36% Fe (MW = 231.54 gm)
Malachite Cu2(CO3)(OH)2 ---- 57.48% Cu (MW = 221.12 gm)
Molybdenite MoS2 ---- 59.94% Mo (MW = 160.07 gm)
Naumannite Ag2Se ---- 26.79% Se (MW = 294.70 gm)
Polybasite (Ag,Cu)16Sb2S11
Pyrargyrite Ag3SbS3 ---- 22.48% Sb (MW = 541.55 gm)
Pyrite FeS2 ---- 46.55% Fe (MW = 119.98 gm)
Pyrrhotite Fe(1-x)S(x=0-0.17) ---- 62.33% Fe (MW = 85.12 gm)
Quartz SiO2 ---- 46.74% Si (MW = 60.08 gm)
Realgar AsS ---- 70.03% As (MW = 106.99 gm)
Scheelite CaWO4 ---- 63.85% W (MW = 287.93 gm)
Sericite (Muscovite) KAl2(Si3Al)O10(OH,F)2 ---- 9.82% K (MW = 398.31 gm)
Sphalerite (Zn,Fe)S ---- 67.10% Zn (MW = 97.46 gm)
Stephanite Ag5SbS4 ---- 68.33% Ag (MW = 789.36 gm)
Stibnite Sb2S3 ---- 71.68% Sb (MW = 339.70 gm)
Tellurides are a combination of a metal and tellurium (such as Hessite, Telluric Silver) Ag2Te
Tetrahedrite (Cu,Fe)12Sb4S13
Umangite Cu3Se2 ---- 54.69% Cu (MW = 348.56 gm)

Appendix J. Glossary of Geologic Terms

adit - A horizontal passage from the surface into a mine. A tunnel.

amalgamation - The process by which mercury is alloyed with some other metal to produce an amalgam.

amphibolite facies - An assemblage of minerals formed during regional metamorphism at moderate to high-pressures between 450 and 700º C. Amphibolite is a faintly foliated metamorphic rock developed during regional metamorphism. Composed mainly of hornblende and plagioclase feldspars.

argillite - A compact rock, derived from mudstone (claystone or siltstone, or shale, that has undergone a somewhat higher degree of induration (rendered hard).

arkose - A detrital sedimentary rock formed by cementation of individual grains of sand size and predominantly composed of quartz and feldspar. Derived from disintegration of granite.

breccia - Clastic rock made up of angular fragments of such size that an appreciable percentage of rock volume consists of particles of granule size or larger.

carbonate - A mineral formed by combination of complex ion $(CO_3)^{2-}$ with a positive ion. Common example: calcite, $CaCO_3$.

chert - Granular cryptocrystalline silica, similar to flint but usually light in color. Occurs as compact massive rock or as nodules.

clastic - Being or pertaining to a sedimentary rock composed primarily from fragments of preexisting rocks or fossils.

crosscut - A small passageway that may be driven at an angle to the main entry of a mine to connect it with a parallel entry or an air course.

dike - A discordant pluton that is substantially wider than it is thick. Dikes are often steeply inclined or nearly vertical. See also *sill.*

diorite - Coarse-grained igneous rock with composition of andesite (no quartz or orthoclase), composed of 75 percent plagioclase feldspars and balance ferromagnesian silicates.

drift - A horizontal passage underground.

dumps - A place where the ore taken from a mine is tipped. Also a spoil heap at the surface of a mine.

epithermal - Said of a hydrothermal mineral deposit formed within about 1 kilometer of the Earth's surface and in the temperature range of 50-200^{o} C.

fault - Surface of rock rupture along which has been differential movement.

flotation - The method of mineral separation in which a froth created in water by a variety of reagents floats some finely crushed minerals, whereas other minerals sink.

graben - Elongated, trench-like, structural form bounded by parallel normal faults created when block that forms trench floor moves downward relative to blocks that form sides.

granodiorite - Coarse-grained igneous rock intermediate in composition between granite and diorite.

graywacke - A variety of sandstone generally characterized by hardness, dark color, and angular grains of quartz, feldspar, and small rock fragments set in matrix of clay-sized particles. Also called lithic sandstone.

greenschist facies - Assemblage of minerals formed between 150 and 250º C during regional metamorphism. Greenschist - Schist characterized by green color. Product of regional metamorphism. (Green color is imparted by mineral chlorite.)

hydrothermal alteration - The chemical metamorphism of preexisting rocks that is caused by the action of hot water.

igneous rock - Aggregate of interlocking silicate minerals formed by cooling and solidification of magma.

limestone - Sedimentary rock composed largely of mineral calcite, $CaCO_3$, formed by either organic or inorganic processes. Most limestones have clastic texture, but nonclastic, particularly crystalline, textures are common. Carbonate rocks, limestone, and dolomite constitute an estimated 12 to 22 percent of sedimentary rocks exposed above sea level.

massive sulfide - Any mass of unusually abundant metallic sulfide minerals.

metamorphic rock - "Changed-form rock." Any rock changed in texture or composition by heat, pressure, or chemically active fluids after original formation.

mill - Generally the crushing, grinding, and processing of ore to extract the mineral or metal of interest.

mine - An excavation for the purpose of extracting minerals.

mining district - A section of country usually designated by name, having described or understood boundaries within which mineral is found and which is worked under rules and regulations prescribed by the miners therein.

Mississippi Valley type zinc-lead deposit - A stratabound deposit of lead and/or zinc minerals in carbonate rocks. These deposit characteristically have relative simple mineralogy, occur as veins and replacement bodies, are at moderate to shallow depths, show little post-ore deformation, are marginal to sedimentary basins, and are without an obvious source of the mineralization.

open pit - Surficial mining, in which the valuable rock is exposed by removal of overburden.

ore - The naturally occurring material from which a mineral or minerals or metal of economic value can be extracted at a reasonable profit.

placer - A concentration of relatively heavy and resistant minerals in stream or beach deposits; two examples are some deposits of gold and of diamonds.

pluton - A body of igneous rock formed beneath earth surface by consolidation from magma. Sometimes extended to include bodies formed beneath surface by metasomatic replacement of older rock.

portal - A mouth of an adit or tunnel.

propylitic alteration - A hydrothermal alteration or process involving the formation of an altered andesite resembling a greenstone and containing calcite, chlorite, epidote, serpentine, quartz, pyrite, and iron oxides (a propylite).

sedimentary rock - Rock formed from accumulations of sediment, which may consist of rock fragments of various sizes, remains or products of animals or plants, products of chemical action or of evaporation, or mixtures of these. Stratification is the single most characteristic feature of sedimentary rocks, which cover about 75 percent of land area.

sericitic alteration - A type of hydrothermal alteration involving the alteration to or placement by sericite muscovite.

shaft - A vertical or inclined excavation through which a mine is worked.

sill - A concordant pluton that is substantially wider than it is thick. Sills form within a few kilometers of the Earth's surface. See also *dike.*

stamp mill - An apparatus in which rock is crushed by descending pestles (stamps).

stocks - Discordant pluton that increases in size downward, has no determinable floor, and shows area of surface exposure less than 100 km^2.

stockwork - A mineral deposit consisting of a three-dimensional network of planar to irregular veinlets closely spaced so that a whole mass can be mined.

tailings - The portions of washed or milled ore that are regarded as too poor to be treated further, as distinguished from the concentrates or material of value.

tuff - Rock consolidated from volcanic ash.

volcaniclastic - Pertaining to a clastic rock containing volcanic material in whatever proportion and without regard to its origin or environment.

volcanics - Pertaining to the activities, structures, or rock types of a volcano.