WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

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

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

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Waterbody Numbers: see page viii

Publication No. 02-03-024

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Table of Contents

List of Appendices

List of Figures

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List of Tables

List of Waterbody Numbers

1. St Helens District
   WA-26-1072
   Green River

2. Mazama District
   WA-48-1050
   Methow River

3. Slate Creek District
   WA-04-9180
   Ross Lake

4. Monte Cristo District
   WA-04-1080
   Sauk River

5. Royal Reward Mine Area
   WA-09-1030
   Green River

6. Deer Trail District
   WA-CR-1060
   Franklin D. Roosevelt Lake

7. Big Chief Mine Area
   WA-59-2010
   Clugston Creek

8. Morton Cinnabar District
   WA-26-1095
   Tilton River

9. Mineral Creek Area
   WA-11-1030
   Nisqually River

10. Gold Creek Area
    WA-48-1010
    Methow River

Abstract

This study was designed to characterize water and sediment quality in streams that drain ten metals mining districts in Washington State. The districts were selected based on a preference for sites at high elevation, located in western Washington, or that had arsenic or mercury as primary or secondary minerals. The water quality emphasis for the study was the EPA ultra-clean sampling and low-level analysis methods for metals. General chemistry and field parameters were obtained concurrently with the metals and sediment samples. This study was similar in design to a study conducted by the same authors in 1997.

Water samples were collected upstream and downstream of each district during late summer and fall 2000 for low-flow conditions, and during spring 2001 for high-flow conditions. Sediment samples were collected during low flow. Results were compared upstream to downstream, seasonally, and to state surface water quality standards and sediment quality guidelines.

The expected seasonal contrast between low-flow and high-flow water quality was not strongly evident in the results. Similarly, the ratio of sulfate to total dissolved solids that was intended to be used as a fingerprinting mechanism for Acid Rock Drainage did not perform as expected. One explanation is that record low snowpack and precipitation limited recharge through the mine workings, tailings, and waste rock that are the sources for metals and oxidation products. According to the model developed in the previous study, spring recharge is considered the flushing mechanism that resolubilizes efflorescent minerals and discharges to adjacent streams.

Two districts exceeded water quality standards for metals: copper in the St Helens District and zinc in the Big Chief Mine Area. Sediment quality guidelines were exceeded with much greater frequency than water quality standards. Guidelines for copper and arsenic were most frequently exceeded. Sediment quality was assumed to be unaffected by the low runoff conditions.

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Summary

During this study, water and sediment were sampled from streams in ten metals mining districts in Washington State. The mining districts were selected by emphasizing sites at high elevation, sites in western Washington, or sites that reported arsenic or mercury as major constituents of the ore. The study was a cooperative effort by staff from the Washington State Department of Ecology (Ecology) and the Washington State Department of Natural Resources (DNR). This study was similar in design to a study on another group of ten metals mining districts that was conducted in 1997 by the same staff and published in January 2000 (Raforth et al.).

The following mining districts were included in this study:

1. St Helens District, Skamania County
2. Mazama District, Okanogan County
3. Slate Creek District, Whatcom County
4. Monte Cristo District, Snohomish County
5. Royal Reward Mine Area, King County
6. Deer Trail District, Stevens County
7. Big Chief Mine Area, Stevens County
8. Morton Cinnabar District, Lewis County
9. Mineral Creek Area, Lewis County
10. Gold Creek Area, Okanogan County

Samples were collected at locations intended to characterize upstream and downstream water quality and sediment quality in each mining district. Ecology and DNR sampled for water quality during both low-streamflow and high-streamflow conditions, while sediment samples were collected only during low flow. No mine discharges were sampled during this study. Water samples were analyzed for general chemistry parameters: total dissolved solids, sulfate, hardness, total suspended solids, and turbidity. Iron, aluminum, arsenic, and mercury were analyzed as total recoverable metals; cadmium, copper, lead, and zinc were analyzed as dissolved. EPA ultra clean sampling procedures were followed with analysis by ICP-MS and CVAA (mercury). Results from these analyses were compared between upstream and downstream sites, seasonally between high-flow and low-flow conditions, to state surface water quality standards, and to sediment quality guidelines. State ground water quality standards and human health criteria were not considered in the analysis of these data.

Streams in two districts failed to meet water quality standards for protection of aquatic life. In the St Helens District, both the upstream and downstream sample concentrations exceeded the acute and chronic water quality standard for copper. The downstream concentration was about seven times the upstream concentration during both high-flow and low-flow conditions. In the Big Chief Mine Area, zinc exceeded the acute and chronic water quality standard during low-flow conditions in the North Fork of Clugston Creek. The change in zinc concentration from upstream to downstream was nearly 3 orders of magnitude during both high flow and low flow.

Because the sampling effort in this study tended to be somewhat distant from the potential sources, and thus subject to dilution, the authors also considered water quality impacts to exist where there was at least a 2-fold increase in metals concentration downstream compared to the upstream sample. Zinc, copper, and arsenic had the most frequent increases in downstream concentration. By this analysis, only the Slate Creek District and the Royal Reward Mine Area did not show any water quality impacts. In four districts, the downstream concentration of some metals exceeded the upstream concentration by more than 10-fold. In the Monte Cristo District, arsenic, zinc, and copper had more than 10-fold increases; in the Deer Trail District, iron and lead increased more than 10-fold; in the Big Chief Mine Area, lead and zinc increased more than 10-fold; and in the Mineral Creek Area, arsenic and iron had more than 10-fold downstream concentration increases. The study found that the water quality guideline for iron was exceeded in the Deer Trail District and in the Mineral Creek Area.

In this present study, the expected seasonality in the data was mostly absent. The reason for this is suggested to relate to the record drought that occurred during the winter of 2000-2001. As a result, there was limited recharge of mine workings, tailings, and waste rock by melting snow and spring precipitation that would dissolve efflorescent minerals that form during the dry season. This in turn decreased the discharges from these sites into the adjacent streams where the limited discharge was readily diluted.

This scenario is also suggested to account for the poor correlation between this study and the previous study for using the ratio of sulfate to total dissolved solids (TDS) as an Acid Rock Drainage indicator. The previous study suggested that a 0.20 ratio could be used as a fingerprinting method. The present study did not clearly support that ratio. Instead, the concentrations of sulfate and TDS were so low that ratios were not useful at most sites. For example, sulfate concentrations did not exceed 5 mg/L in nine of the 20 downstream samples, and only two samples exceeded 25 mg/L. By contrast, the previous study results included six downstream samples that did not exceed a sulfate concentration of 5 mg/L but ten samples that exceeded 25 mg/L.

Under these conditions, sediment quality was a better indicator of the impacts on the receiving waters than the water quality parameters. One or more exceedences of the sediment quality guidelines occurred in all districts except the Gold Creek Area. Sediment quality tracked the mineralogy of the ore deposits mined in the districts. In the Morton Cinnabar District where mercury was mined, the downstream sample had the highest mercury concentration found during this study. The highest concentrations of arsenic in sediments were found at the three districts where arsenic was well documented as a major constituent of the ore. The highest arsenic concentration, 543 mg/Kg, was found at the Monte Cristo District where arsenic was present in the ore. At the Royal Reward Mine Area, where arsenic was the primary material mined, the upstream sample concentration was 5 mg/Kg while the downstream sample concentration was 166 mg/Kg.

Recommendations from this study were mostly extensions of those from the previous study. Seasonality should continue to guide any sampling programs so that samples are collected during both high-flow and low-flow conditions. The ratio of sulfate to TDS should be investigated further. Sediment quality should also continue to be included in future studies.

At least two of the mining districts should be investigated further based on the water quality data from this study. The North Fork of Clugston Creek, adjacent to the Big Chief Mine, had the highest concentration of zinc during both low flow and high flow. The mine was not sampled in this study. The unnamed stream in the St Helens District exceeded the water quality standard for copper. Additional samples should be collected from that stream as well as from other streams and mines that were not sampled in this study.

Some districts substantially exceeded one sediment quality guideline, and other districts exceeded several guidelines. Additional sediment sampling should be conducted in other streams that drain those districts to determine the extent of sediment quality impacts. Districts where additional sampling should occur are: St Helens (copper, arsenic, and mercury), Slate Creek (arsenic), Monte Cristo (arsenic), Deer Trail (cadmium, copper, silver, zinc, and lead), Big Chief Mine Area (cadmium, zinc, and lead), Morton Cinnabar District (zinc, lead, and mercury), and the Mineral Creek Area (arsenic).

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Introduction

According to the Washington State Department of Natural Resources (DNR), there are over 3,800 inactive and abandoned metals mines in Washington State (Wolff et al., 2001). Discharges of water and sediment contaminated with metals from some mine adits, waste rock, and tailings piles have adversely impacted streams and rivers that drain metals mining districts. Formation of Acid Rock Drainage (ARD) by water leaching through mineralized rocks in metals mining districts is a source of metals contamination in nearby streams and rivers.

The purpose of this study was to do screening level sampling of water and sediments in streams in the vicinity of selected metals mining districts that include inactive or abandoned mines. The primary emphasis for this study was use of the EPA ultra-clean (1995) sampling procedure and low-level analysis methods for metals. This project was conducted as an extension of a similar sampling effort conducted by the same authors in 1997 (Raforth et al., 2000).

Ten mining districts were selected for study through a literature and file search of information available from DNR, as shown in Figure 1 and tabulated below:

	Mining District	County	Waterbody Sampled
1.	St Helens	Skamania	Unnamed stream/Upper Green River
2.	Mazama	Okanogan	Goat Creek
3.	Slate Creek	Whatcom	Bonita Creek
4.	Monte Cristo	Snohomish	Glacier Creek
5.	Royal Reward Mine Area	King	Green River
6.	Deer Trail	Stevens	Alder Creek
7.	Big Chief Mine Area	Stevens	North Fork Clugston Creek
8.	Morton Cinnabar	Lewis	Chapman Creek/Barnum-McDonnell Mine?
9.	Mineral Creek	Lewis	Mineral Creek
10.	Gold Creek	Okanogan	Foggy Dew Creek/Gold Creek

First priority was given to mining districts in the Cascade Mountains and western Washington, since the previous study had concentrated on low-elevation eastern Washington districts. The size of the mines in a district and the dominant metal mined in a district played a major role in the selection process, with priority given to the larger historical mining operations districts or those produced mercury or arsenic. Finally, the authors used topographic maps to identify streams that were likely to be impacted by any mine drainage.

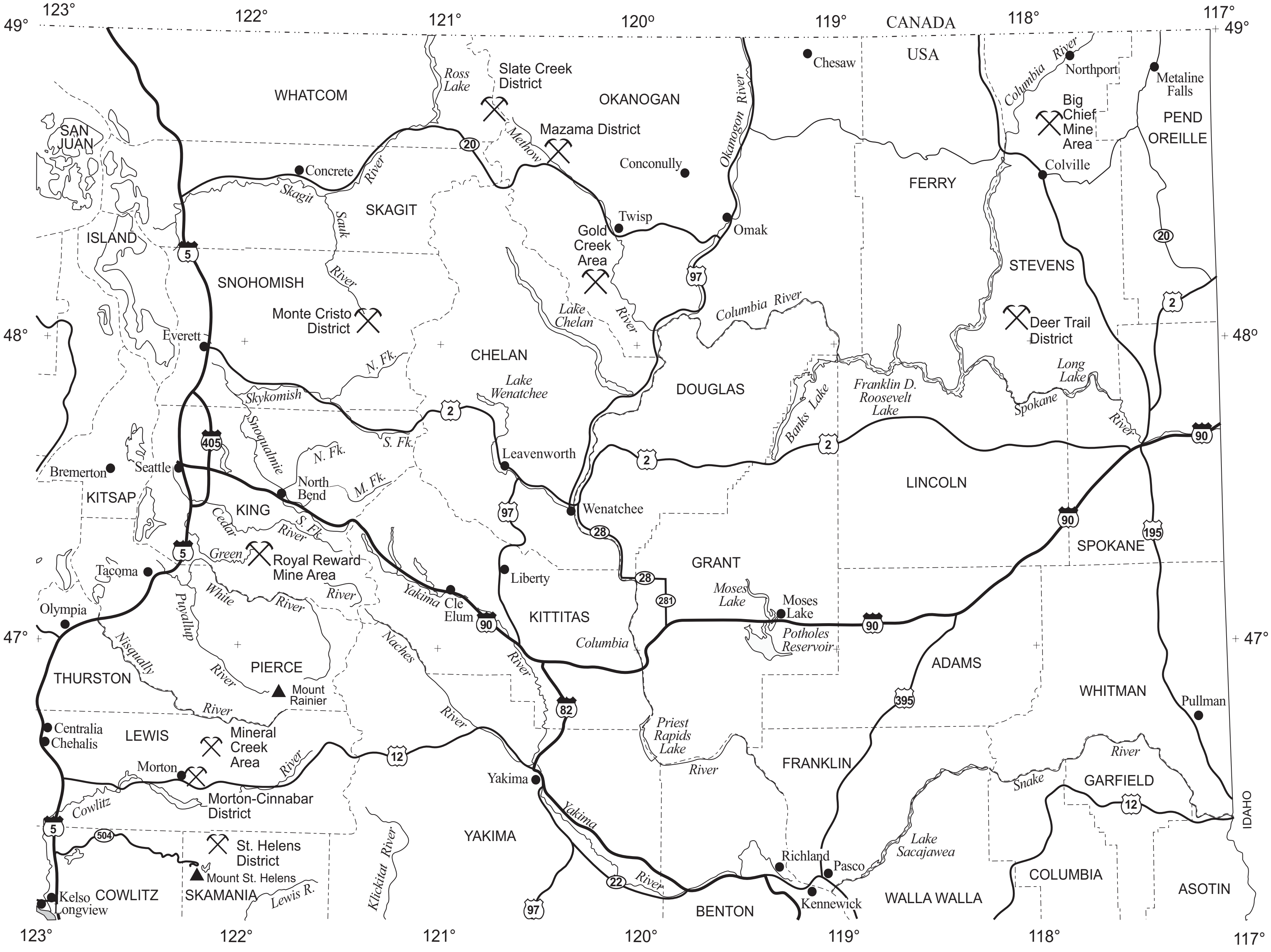

Figure 1. Location of Mining Districts Included in Ecology/DNR Study

Results and recommendations from the earlier study guided the approach used in the present effort. The previous study had recommended that, at a screening level of investigation, certain metals and general chemistry parameters could be omitted and that selected indicator parameters should be used. The list of parameters for the present study included:

Parameter	Units	Medium
Aluminum, Arsenic, Iron, Mercury	ug/L	Water[a]
Cadmium, Copper, Lead, Zinc	ug/L	Water[b]
Hardness, Total Suspended Solids, Total Dissolved Solids, Sulfate	mg/L	Water
Turbidity	NTU	Water
Flow	CFS	Water
Temperature (field measurement)	^{o}C	Water
pH (field measurement)	SU	Water
Conductivity (field measurement)	umho/cm	Water
Aluminum, Antimony, Beryllium, Cadmium, Chromium, Copper, Iron, Manganese, Nickel, Silver, Zinc, Arsenic, Lead, Mercury, Selenium, Thallium	mg/Kg	Sediment

[a] Measured as total recoverable metals

[b] Measured as dissolved metals

This study also continued to investigate potential seasonal water quality changes in mining districts by sampling during high-flow and low-flow conditions. Finally, the authors looked again at the sulfate to total dissolved solids (TDS) ratio as an indicator of ARD.

One sampling site was located upstream and one sampling site was located downstream of each mining district. Water samples were collected as simple grabs during high-flow and low-flow conditions. Mercury was analyzed by CVAA (cold vapor atomic absorption). Other metals samples were analyzed using ICP/MS (inductively coupled plasma/mass spectrophotometry) to achieve low detection levels necessary to compare to state water quality standards (Ch 173-201A WAC), particularly for lead and cadmium. Composite sediment samples were collected during low flow at each upstream and downstream sample location and were analyzed for priority pollutant metals. Suspended sediment and some general chemistry water quality data were also obtained at the metals sample sites.

With one exception, samples of mine drainage from individual mines were not included in this study, unlike the previous study. Instead, water and sediment samples were collected in streams and rivers which were most likely to receive mine discharges in the selected mining districts. Substantial dilution occurs as a result of this approach since most mine discharges are small compared to the streams that drain the mining districts. As a result, cumulative impacts are being measured rather than impacts from individual mines. In some districts, field parameters of pH, temperature, and conductivity were measured at many more locations than where water samples were collected, to document in more detail water quality impacts reflected by those parameters.

State and federal environmental and land management agencies are collecting information about these mines and contributing that information to a centralized database. Each agency has conducted some level of investigation of mined sites that could impact lands that they manage. For the most part, agency investigations have focused on physical hazards created by mine abandonment. Geochemical characterization and quantitative measurements of water quality impacts due to discharges from these mines have not been documented to the same extent.

In the state of Washington, DNR and the Department of Ecology (Ecology) are the agencies responsible for permitting metals mining operations. DNR also has lead responsibility for creating and maintaining the federal and state interagency metals mining database. Ecology has the delegated responsibility from the U.S. Environmental Protection Agency (EPA) for identifying and cleaning up waterbodies that do not meet state water quality standards. The data from this study add geochemical data to the DNR database and is a first step in the federally mandated 303(d) process of listing water-quality-impaired waterbodies. DNR and Ecology jointly conducted this study.

Water Quality Criteria

Washington State surface water quality standards pertinent to the present study are summarized in Table 1 and include standards for temperature, pH, turbidity, and metals. The metals standards are for acute (one-hour average not to be exceeded more than once every three years) and chronic (four-day average not to be exceeded more than once every three years) exposure. 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, 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 ug/L (parts per billion), on which the state arsenic standards were based are essentially identical to the dissolved arsenic standards (360 and 190 ug/L). The chronic mercury standard (0.012 ug/L) is for total recoverable. The acute standard for dissolved mercury (2.1 ug/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, and zinc are hardness dependent. Metals toxicity generally decreases with increasing hardness. For example, the cadmium acute and chronic criteria are 0.30 and 0.19 ug/L at 10 mg/L hardness, but increase to 3.7 and 1.0 ug/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 or aluminum. EPA has recommended that total iron and aluminum concentrations not exceed 1,000 ug/L and 87 ug/L under conditions of continuous exposure to aquatic communities (EPA, 1986, 1999). Canada has a substantially lower guideline of 300 ug/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 condition 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 (ug/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]
Zinc[a]	114	104

[a] dissolved fraction

[b] total recoverable

Sediment Quality Criteria

There are no Washington State standards or EPA national criteria for chemical contaminants in freshwater sediments. Two sets of sediment quality guidelines (Table 2) were used to assess the potential metals toxicity of sediments collected in streams below mining districts: the lowest apparent effect thresholds of Cubbage et al. (1997) and the consensus-based effect concentrations of MacDonald et al. (2000).

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

	Values Based on Wash. St. Data[a]	National Consensus-Based Values[b]	
Metal	Lowest Apparent Effects Threshold	Threshold Effect Concentrations	Probable Effect Concentrations
Iron[c]	- -	- -	- -
Aluminum[d]	- -	- -	- -
Manganese	1800	- -	
Zinc	520	121	459
Lead	260	36	128
Copper	840	32	149
Chromium	280	43	111
Nickel	46	23	49
Cadmium	7.6	0.99	5.0
Arsenic	40	9.8	33
Silver	4.5	- -	- -
Antimony	3	- -	- -
Mercury	0.56	0.18	1.1
Selenium	- -	- -	- -
Beryllium	- -	- -	- -
Thallium	- -	- -	- -

[a] Cubbage et al. (1997)

[b] MacDonald et al. (2000)

[c] Persaud et al. (1993) proposed a severe effect level of 40,000 mg/Kg for iron

[d] Ingersoll et al. (1996) proposed an effects range medium of 58,000 mg/Kg for aluminum

The lowest apparent effects thresholds were developed from bioassays on Washington State freshwater sediments (Microtox® and *Hyalella* tests). The consensus-based effect concentrations integrate work done by a number of investigators, including Cubbage et al., in various U.S. freshwaters. Effects considered include both toxicity in laboratory bioassays and alteration of the benthic invertebrate community. Threshold effect concentrations are those below which harmful effects are unlikely to be observed. Probable effect concentrations are those above which harmful effects are likely to be observed. Because neither of these sources had guidelines for iron or aluminum, the values proposed by Persaud et al. (1993) and Ingersoll et al. (1996) were used for the present assessment. No sediment quality guidelines could be located for selenium, beryllium, or thallium.

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 um 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.

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).

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.

During the fall 2000 sampling program, 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. During spring 2001 sample collection, pH, temperature, and conductivity were measured with a YSI Model 63 meter. The pH meter was calibrated daily. Measurements of streamflow were made with a Marsh-McBirney flowmeter and top-setting rod in Goat Creek in the Mazama District and estimated elsewhere. If the stream configuration permitted, the methodology employed a stick or other floating object timed along a defined length of stream. For small streams, a visual estimate or extrapolation of the time required to fill a one liter sample bottle was used for flow. Since the focus of this study was on higher elevation mining districts, most of the streams were small, high gradient, and choked with cobbles and boulders. As a result, the flow measurements with the Marsh-McBirney flowmeter were viewed as no better than estimates using the visual methods, and subsequent streamflow measurements did not employ the flowmeter.

A Garmin III Plus GPS Unit was used to determine latitude and longitude as well as elevations for the sampling stations. This information is found in Appendix J. Elevations and locations were verified in the field using USGS 7 ½ minute quadrangle maps. Elevations were also checked using a Thommen altimeter.

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 dissolved zinc, arsenic, copper, lead, and cadmium by Inductively Coupled Plasma/Mass Spectrometry (ICP/MS) following EPA method 200.8. Total mercury was analyzed by EPA method 245.7, Cold Vapor Atomic Absorption (CVAA). Total recoverable iron and aluminum samples were digested with nitric acid by EPA method 200.7, 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).

Metals analysis of sediment samples was by ICP according to EPA method SW6010 (iron, aluminum, manganese, zinc, chromium, copper, nickel, cadmium, silver, beryllium, antimony); Graphite Furnace Atomic Absorption (GFAA) according to EPA method SW7060 (arsenic), SW7421 (lead), SW7740 (selenium), and SW7841 (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 0.99 or greater, also meeting CLP calibration requirements.

Matrix spike and matrix spike duplicates were performed with each sample set analyzed for metals. Spike recoveries were within the CLP acceptance limits of +/-25% for recovery and +/- 20% for precision, except as follows:

- Antimony recoveries were low (43-46%) and thallium precision was poor in the August 2000 sediment samples. These data were qualified as estimates (J flag).
- Arsenic and antimony spike recoveries were low for the October 2000 sediment samples (12-15% and 28-29%, respectively). Results for these metals were qualified as estimates.

Laboratory control samples for metals were analyzed with each set of water and sediment samples. Results were within acceptance windows established for each parameter. A standard reference material was analyzed with each set of water samples (SLRS-4: River Water Reference Material for Trace Metals, National Research Council Canada). Results agreed closely with certified values, except for zinc in the August 2000 sample set. The zinc data reported for these water samples may be biased high.

Procedural blanks associated with the water and sediment samples showed no analytically significant levels of metals. Results from analysis of bottle and filter blanks prepared in the field during water sampling in October 2000 and May 2001 showed no evidence of significant metals contamination arising from sample collection, preservation, or handling (Appendix B).

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

Selected water samples were analyzed in duplicate to evaluate analytical precision. For general chemistry parameters (Appendix D) and most metals analyses (Appendix E), results agreed within 20% or better. Poor precision was evident in one instance each for iron (52%), cadmium (73%), and mercury (>67%). The results from duplicate analyses were averaged for use in this report.

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Results

1. St Helens District, Skamania County

Geology[1] and Historical Mining Operations and Practices

As early as 1892, mining claims were staked for copper, gold, and silver in the St Helens District. The area has many adits and small dumps. By 1910 thousands of prospect pits had been dug and over 11,000 feet of underground workings had been driven (Moen, 1977). The largest deposit is the Margaret copper porphyry, which has 577 million tons of proven and probable reserves grading 0.36% copper, 0.1% molybdenum, 0.007 ounces/ton gold, and 0.046 ounces/ton silver (Taylor, 1980). Total metal production for both the St Helens and Washougal (40 miles south) districts from 1903 through 1974 amounted to only $26,538 according to U.S. Bureau of Mines. The Polar Star Mine had the most significant production but was not commercial. Sufficient ore was shipped from the Polar Star to recover 0.9 tonne of copper promotional ingot (Lasmanis, 1995).

Rocks of the St Helens District consist mainly of thick sequences of Tertiary andesite flows, volcaniclasitcs, and intrusive granodiorite (Phillips, 1987). However, the 1980 eruption dominates the landscape and has blanketed the area with pyroclastics. The intrusive rocks are dominantly early Miocene (Evarts et al., 1987). The 1980 eruption of Mount St Helens obliterated the workings in the Spirit Lake area. The workings in the Ryan Lake area to the north of Mount St Helens were not destroyed by the eruption. However, most of the adit portals have collapsed and are difficult to locate.

Pyrite is the most common sulfide and is associated with the volcanic and plutonic rocks, whereas the ore minerals chalcopyrite, sphalerite, galena, pyrrhotite, arsenopyrite, and gold are associated only with the intrusive rocks. Hydrothermal alteration of most veins is intense outward from the veins and consists of silicic, quartz sericitic, argillic, and propylitic alteration. The surface parts of most veins, as well as the adjoining wall rocks of adits, exhibit reddish-brown coloration as a result of the oxidation of pyrite and chalcopyrite (Moen, 1977).

Evaluation of Water Samples[2]

Two water quality samples were collected from an unnamed stream that is tributary to the Green River near its headwaters. The sample sites were just outside the boundary of the Mount St Helens Volcanic Monument in the vicinity of the Margaret copper deposit described above (Figure 2). An upstream sample site was located near the top of a mountain ridge above all known mine workings and was intended to represent background water quality. However,

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[1] Appendix K shows the composition of minerals referred to in this report.
Appendix L shows a glossary of geologic terms referred to in this report.

[2] Complete field, general chemistry, and metals data for water are in Appendices F, G, and H.

the results from the upstream sample suggest that either the entire mountain ridge is mineralized, or the sample should have been collected higher on the ridge. The downstream sample was obtained below all known mine workings along this particular stream. The two sample sites were less than one half mile apart. General chemistry, field parameters, and metals samples were obtained during August 2000, representing low-flow conditions, and during June 2001, representing high-flow conditions. Some pH and conductivity measurements were obtained at various mines in the area and in the Green River.

Among the field parameters (Table 3), pH was noted to drop by about one unit between the upstream and downstream sites during low flow. At high flow, pH was about the same between the two sites. The concentrations of the general chemistry parameters, hardness, TDS, and sulfate all increased more than 2-fold during low flow between the upstream and the downstream sites (Table 3). These parameters also increased during high flow, but somewhat less than 2-fold. Sulfate concentrations in the downstream samples during both high-flow and low-flow conditions were among the highest measured in any district during the project.

Several adits driven near creek level that were discharging mine drainage to the creek were investigated with pH and conductivity measurements (Table 4, adits #1 and #2). Adit #1 did not appear to be adversely impacting water quality as represented by those field measurements. Discharge from adit #2 was near neutral pH, but with about a 3-fold increase in conductivity over the adjacent stream. The Polar Star Mine, a nearby mine not located in the sampled drainage, was also investigated with pH and conductivity measurements. The discharge from this mine had obvious ARD characteristics as reflected by the low pH and high conductivity measurements and presence of yellow-orange iron flocculant in the mine drainage. The pH measurement of 4.29 units was the lowest measured during this study, and the conductivity measurement of 1283 umho/cm was the highest measured during this study. These values were similar to ARD-impacted mine drainage measurements made in the previous study. Some additional pH and conductivity measurements were made in the Green River as an assessment of general background conditions (Table 4).

Among the metals analyzed (Table 5), copper was found to exceed the state water quality acute standard of 2.2 ug/L (low flow) and 2.6 ug/L (high flow) in both the upstream and downstream samples, suggesting that the upstream sample was located within the mineralized zone of the mining district. The downstream sample exceeded the upstream sample by more than 6-fold for both high-flow and low-flow conditions. These results were the highest found during this study. Aluminum showed a greater than 3-fold increase downstream during both low-flow and high-flow conditions. Cadmium and zinc were detected, but did not increase significantly downstream or between the high-flow and low-flow condition, although the downstream concentrations were the second highest in this study. Mercury increased during high flow by more than 2-fold over the low-flow concentration. Interestingly, this district and the Morton Cinnabar District were the only sites where arsenic was not detected during either high-flow or low-flow conditions.

Evaluation of Sediment Samples[3]

Copper was present in the upstream and downstream sediment samples at concentrations that exceeded the National Consensus-Based guidelines (Table 2). The upstream sample concentration was 251 mg/Kg while the probable effect guideline was 149 mg/Kg. The concentration of copper in the downstream sample was 844 mg/Kg, the highest reported in this study, and exceeded the guideline by more than 5-fold. Arsenic (downstream only) was present at a concentration of 28 mg/Kg which also exceeded the Consensus-Based threshold effect guideline of 9.8 mg/Kg. As noted above, arsenic was not detected in any of the water samples, but the copper results were consistent between sediment and the water column and reflect the mineralogy of the mining district.

Mercury increased by more than 20-fold in the downstream sample to 0.3 mg/Kg where it exceeded the Consensus-Based threshold effect guideline of 0.18 mg/Kg. The mercury concentration was the second highest found in this study. Manganese, lead, and selenium increased by more than 2-fold downstream. The sediment and water quality exceedences lead to the conclusion that the upstream sample location was still inside the mineralized area of the district, or that additional, undocumented mine workings further upstream were impacting water and sediment quality.

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[3] Complete metals and ancillary data for sediment are in Appendix I.

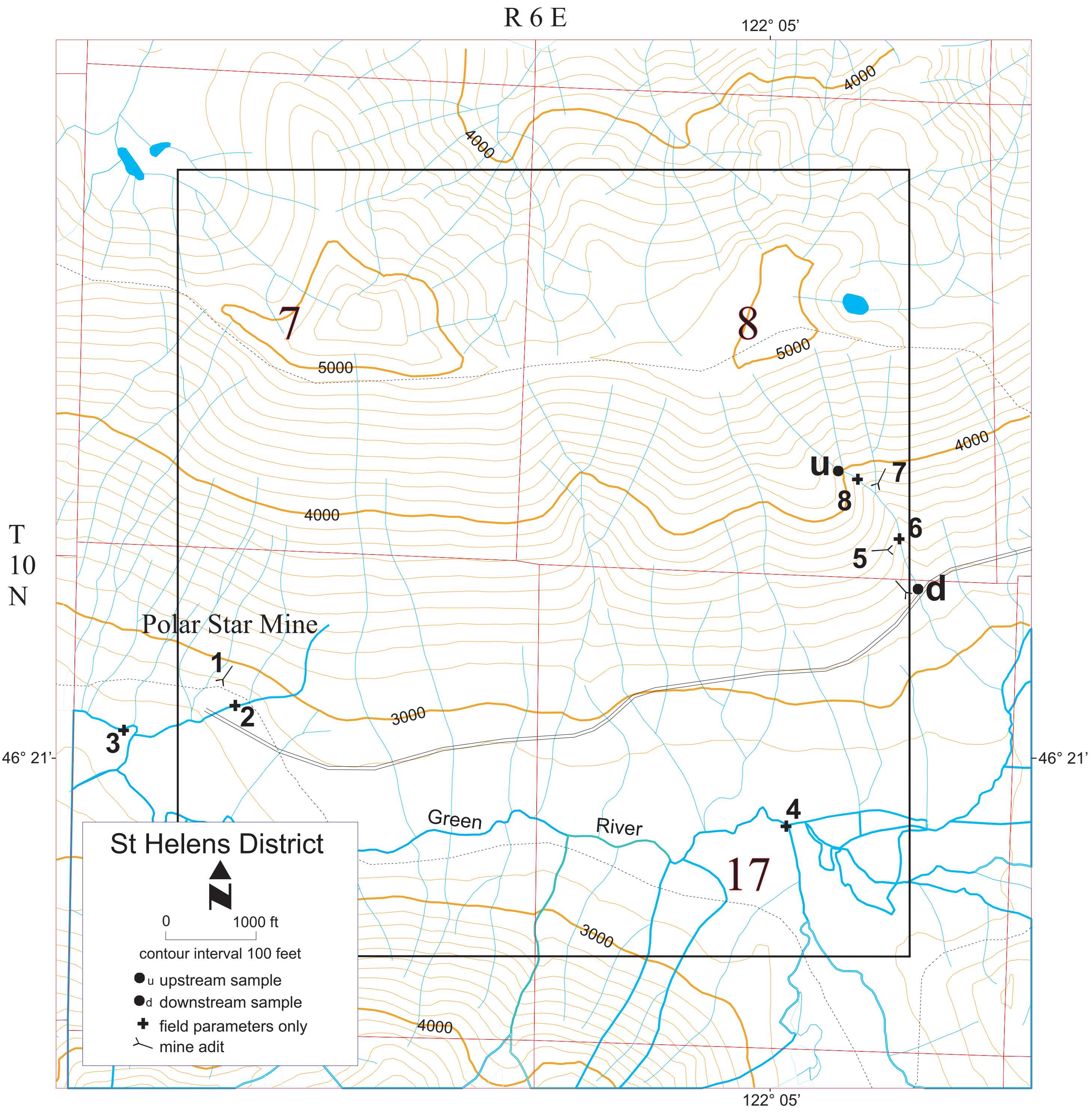

Figure 2. Location of Water and Sediment Samples Collected in Upper Green River, St Helens District

Table 3. Field Measurements and General Chemistry Results for St Helens District Water Samples Collected August 2000 and June 2001

	Flow (cfs)		Temp. (^oC)		pH (units)		Cond. (umho/cm)		Hardness (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Upstream sample	0.04J	0.01J	4.3	6.4	7.36	7.70	36	39	13.6	11.6
Downstream sample	0.2J	0.02J	7.3	10.4	7.30	6.85	59	86	21.6	30.7

	TDS (mg/L)		TSS (mg/L)		Turbidity (NTU)		Sulfate (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Upstream sample	30J	34J	1UJ	1 UJ	0.5UJ	0.5UJ	8.33	7.74J
Downstream sample	48J	73J	1UJ	1 UJ	0.5UJ	0.5UJ	16.2	25.3J

J = estimated value
UJ = not detected at or above the reported estimated value

Table 4. Miscellaneous Field Measurements in the St Helens District Collected August 2000 and June 2001

		Temp. (^oC)		pH (units)		Cond. (umho/cm)	
Sample Location	Map Key	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Polar Star Mine	1	6.7	12.5	4.52	4.29	1283	488
Stream below Polar Star	2	8.0	9.5	6.67	6.67	40	41
Green River abv bridge	3	10.2	17.8	6.72	6.54	34	51
Green River @ horse camp	4	10.1	15.8	6.50	6.48	36	52
Discharge from collapsed adit #1	5	7.1	9.0	7.68	7.13	56	121
Creek upstream of collapsed adit #1	6	6.8	9.7	7.80	7.20	59	91
Discharge from adit #2	7	5.5	6.8	7.31	7.24	147	142
Creek upstream of adit #2	8	5.5	9.3	7.72	7.30	40	45

Table 5. Metals Concentrations in St Helens District Water Samples Collected August 2000 and June 2001 (ug/L)

	Aluminum (total recoverable)		Iron (total recoverable)		Copper (dissolved)		Zinc (dissolved)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Upstream sample	20U	20U	20UJ	20U	**4.69***	**5.98***	**4.9**	**6.11**
Downstream sample	**84**	**74**	**21J**	20U	**38.0***	**38.1***	**4.6**	**7.07**

	Arsenic (total recoverable)		Cadmium (dissolved)		Lead (dissolved)		Mercury (total recoverable)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Upstream sample	0.2U	0.2UJ	**0.043**	**0.039**	**0.033**	0.02U	**0.0044**	.002U
Downstream sample	0.2U	0.2UJ	**0.042**	**0.071**	.02U	0.02U	**0.0053**	.002U

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

Table 6. Grain Size and Metals Concentrations in St Helens District Sediment Samples Collected August 2000 (mg/Kg, dry)

Sample Location	% Gravel	% Sand	% Silt	% Clay	Al	Sb	Be
Upstream sample	61.7	37.2	0.9	0.1	**3570**	5UJ	0.2U
Downstream sample	56.6	41.3	2.0	0.1	**6400**	5UJ	0.2U

Sample Location	Cd	Cr	Cu	Fe	Mn	Ni	Ag
Upstream sample	0.5U	**5.9**	**251***	**10400**	**119**	**5.5**	1U
Downstream sample	0.5U	**5.9**	**844***	**19800**	**306**	**7.5**	1U

Sample Location	Zn	As	Pb	Hg	Se	Tl
Upstream sample	**33.2**	**2.20**	**2.28**	**0.013**	**0.30**	0.3UJ
Downstream sample	**35.0**	**28.1***	**5.95**	**0.298***	**0.78**	0.3UJ

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

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2. Mazama District, Okanogan County

Geology and Historical Mining Operations and Practices

The Mazama District is a quartz diorite hosted porphyry copper system deposit. Copper mineralization is associated with the later intrusive phases in the 88 million year old Cretaceous Fawn Peak intrusive complex. Disseminated chalcopyrite, molybdenite, and pyrite occur in stockwork veinlets. Exploration since 1963 has defined a resource of 149 million short tons grading 0.36 percent copper and 0.01 percent molybdenum (Jones et al., 1995; Lasmanis, 1995). Quartz veins surrounding the deposit were prospected for gold at the turn of the century (Lasmanis, 1995). The Fawn Peak stock is an elongate, northwest trending intrusion along the northeast side of the Methow River Valley. The porphyritic rocks occur along the border of the stock. The stock intrudes the Winthrop Sandstone and Midnight Peak Formation (Stoffel and McGroder, 1990; Barksdale, 1975)

Significant mines of the area were the Mazama, Montana, and American Flag, all associated with the intrusive rocks (Derkey et al., 1990). The Montana produced an unknown amount in 1915, there were no production records for the Mazama Mine, and the American Flag produced a few hundred tons before 1910 and had a small of production in 1940 (Huntting, 1956).

Ore minerals are chalcopyrite and gold. Significant non-ore sulfide minerals are pyrite, arsenopyrite, and pyrrhotite (Derkey et al., 1990).

Evaluation of Water Samples

Two water quality samples were obtained from Goat Creek, a major tributary to the upper Methow River (Figure 3). The upstream sample was intended to represent background water quality conditions above the Mazama Mining District. The downstream sample was located below all known mining activity in the district, about six miles below the upstream sample. General chemistry, field parameters, and metals samples were obtained during August 2000, representing low-flow conditions, and during May 2001, representing high-flow conditions.

For the field measurements and general chemistry parameters (Table 7), pH was noted to decrease by more than 0.5 unit to 6.92 units downstream during low flow in Goat Creek. At high flow, the pH was over one unit higher and did not exhibit a significant change between upstream and downstream sites. TDS increased concentration by more than 50% downstream as compared to upstream during low flow, while during high flow TDS concentration decreased by 60% downstream. Sulfate concentration showed a nearly 4-fold increase downstream during low flow, but only a slight decrease during high flow. All sulfate concentrations are very low.

Several mines were investigated in side drainages between the two water quality sampling sites using pH and conductivity measurements, but none of the mines appeared to be affecting the streams as reflected in those field parameters (Table 8). Field parameters in the stream in the Montana Mine drainage were measured at a point over one mile downstream of the mine and above the confluence with Goat Creek. An anomalous conductivity reading was observed in this stream along with a neutral pH reading, suggesting water quality impacts somewhere upstream. Water samples were not taken in the stream.

The concentration of most metals in the water samples were but above the detection limit low (Table 9). During low-flow conditions, aluminum, copper, and zinc were detected. During high-flow conditions, aluminum, iron, copper, arsenic, and mercury were detected. None of the metals concentrations exceeded state surface water quality standards. The concentration of copper increased more than 2-fold downstream during low flow and decreased during high flow. Arsenic concentration increased by about 50% downstream during high flow, but was not detected during low flow.

Evaluation of Sediment Samples

Except for chromium, copper, and nickel, most metals decreased concentration between the upstream and downstream samples (Table 10). The copper concentration of 33 mg/Kg was at the Consensus-Based effects threshold of 32 mg/Kg. Interestingly, the arsenic concentration of 17.5 mg/Kg slightly exceeded the Consensus-Based effects threshold of 9.8 mg/Kg at the upstream site but not the downstream site, as the concentration decreased downstream by nearly half. Chromium and nickel did not increase downstream by more than twice the background concentration in the upstream sample.

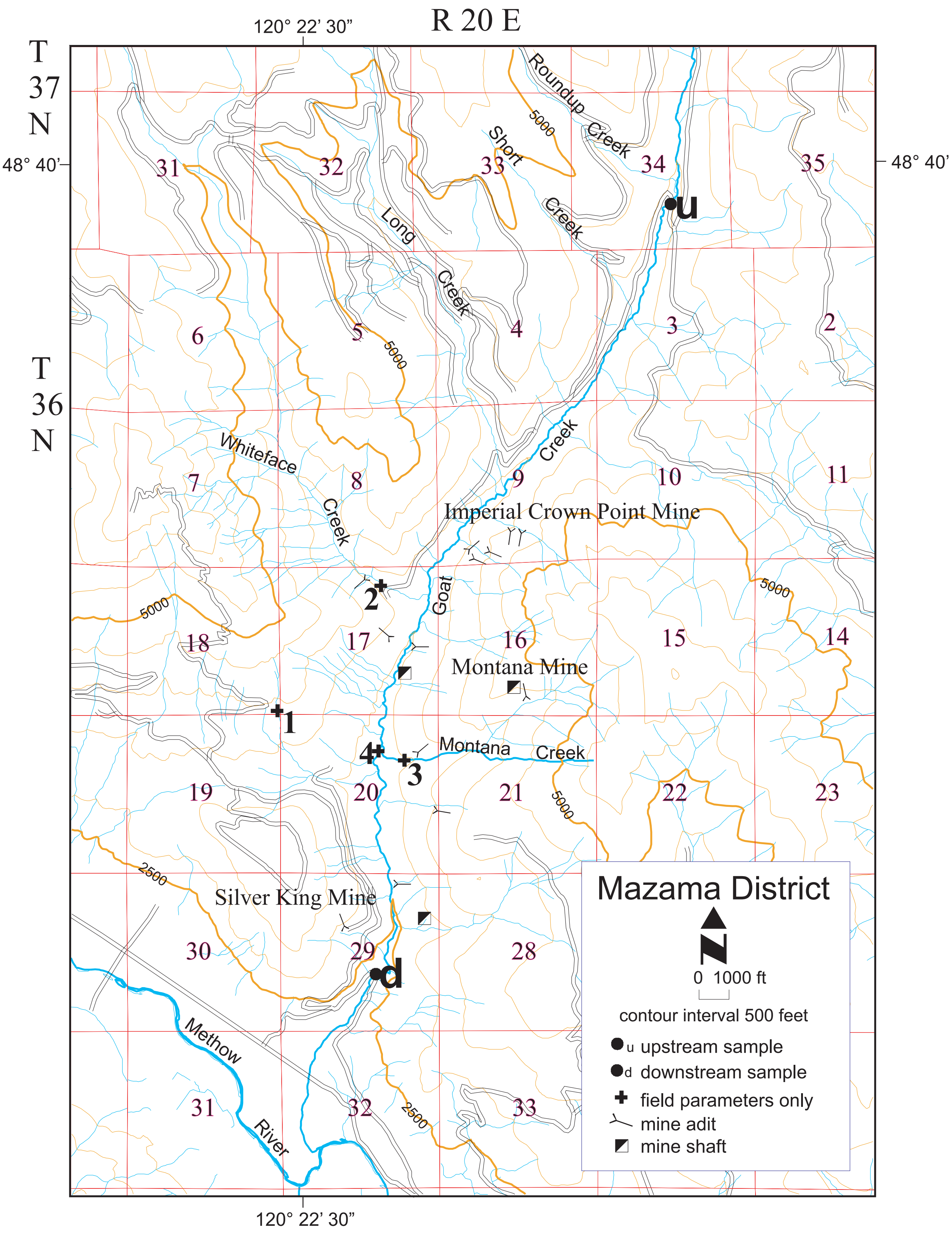

Figure 3. Location of Water and Sediment Samples Collected in Goat Creek, Mazama District

Table 7. Field Measurements and General Chemistry Results for Mazama District Water Samples Collected August 2000 and May 2001

Sample Location	Flow (cfs) High Flow	Flow (cfs) Low Flow	Temp. (^oC) High Flow	Temp. (^oC) Low Flow	pH (units) High Flow	pH (units) Low Flow	Cond. (umho/cm) High Flow	Cond. (umho/cm) Low Flow	Hardness (mg/L) High Flow	Hardness (mg/L) Low Flow
Goat Creek Upstream	10J	5.0J	5.0	12.2	8.03	7.48	85	122	42.5	57.2
Goat Creek Downstream	18J	6.6J	8.1	13.9	8.08	6.92	87	183	44.4	87.5

Sample Location	TDS (mg/L) High Flow	TDS (mg/L) Low Flow	TSS (mg/L) High Flow	TSS (mg/L) Low Flow	Turbidity (NTU) High Flow	Turbidity (NTU) Low Flow	Sulfate (mg/L) High Flow	Sulfate (mg/L) Low Flow
Goat Creek Upstream	255	79J	3J	1 UJ	0.5UJ	0.5UJ	3.29	3.4J
Goat Creek Downstream	86	116J	1J	1 UJ	0.5UJ	0.5UJ	3.03	12.2J

J = estimated value
UJ = not detected at or above the reported estimated value

Table 8. Miscellaneous Field Measurements in the Mazama District Collected August 2000

Sample Location	Map Key	Temp. (^oC) High Flow	Temp. (^oC) Low Flow	pH (units) High Flow	pH (units) Low Flow	Cond. (umho/cm) High Flow	Cond. (umho/cm) Low Flow
Goat Spring	1	NM	16.3	NM	7.24	NM	167
Stream below Chinaman Mine	2	NM	12.3	NM	7.26	NM	136
Montana Crk abv Goat Crk	3	NM	11.6	NM	7.47	NM	303
Goat Crk below Montana Crk	4	NM	14.1	NM	7.90	NM	147

NM = not measured

Table 9. Metals Concentrations in Mazama District Water Samples Collected August 2000 and May 2001 (ug/L)

	Aluminum (total recoverable)		Iron (total recoverable)		Copper (dissolved)		Zinc (dissolved)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Goat Creek Upstream	**77**	**89**	**27**	20U	**0.55**	**0.16**	0.2U	**0.63J**
Goat Creek Downstream	**64**	**130**	**23**	20U	**0.31**	**0.40**	0.2U	**0.43J**

	Arsenic (total recoverable)		Cadmium (dissolved)		Lead (dissolved)		Mercury (total recoverable)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Goat Creek Upstream	**0.62**	0.2UJ	0.02U	0.02U	0.02U	0.02U	**0.0026**	0.002U
Goat Creek Downstream	**0.94**	0.2UJ	0.02U	0.02U	0.02U	0.02U	0.0020U	0.002U

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

Table 10. Grain Size and Metals Concentrations in Mazama District Sediment Samples Collected August 2000 (mg/Kg, dry)

Sample Location	% Gravel	% Sand	% Silt	% Clay	Al	Sb	Be
Goat Creek Upstream	67.4	31.6	0.9	0.1	**12900**	7U	0.2U
Goat Creek Downstream	29.7	69.8	0.4	0.1	**11600**	5UJ	0.2U

Sample Location	Cd	Cr	Cu	Fe	Mn	Ni	Ag
Goat Creek Upstream	0.7U	**16.8**	**20.6**	**25100**	**404**	**9.5**	1U
Goat Creek Downstream	0.5U	**19.5**	**33.3***	**22800**	**350**	**10.9**	1U

Sample Location	Zn	As	Pb	Hg	Se	Tl
Goat Creek Upstream	**53.4**	**17.5***	**5.08**	**0.021**	**0.30**	0.3UJ
Goat Creek Downstream	**43.9**	**9.05**	**4.05**	**0.019**	**0.30**	0.3UJ

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

3. Slate Creek District, Whatcom County

Geology and Historical Mining Operations and Practices

Most of the Slate Creek Mining District is in the eastern part of Whatcom County. The Canadian border is the northern boundary for the district, and the Skagit county line forms the southern boundary. Placer mining began in the 1870s; however, the main rush into the area occurred in 1894, the year following the discovery of the Eureka lode by A. M. Barron. In 1896 a stamp mill was built on the west bank of Bonita Creek. During two years of operation, $120,000 in gold was produced from the "Glory Hole on the Eureka claim" (Moen, 1969).

The major rock unit of the Slate Creek District (in the area of this study's water sampling) is the Harts Pass group (Early Cretaceous); it consists mainly of thick beds of arkosic sandstone, graywacke, slaty argillite, and conglomerate (Stoffel and McGroder, 1990).

Most mineral deposits of the Slate Creek District consist of quartz fissure veins that contain native gold, stephanite, galena, sphalerite, and chalcopyrite. Pyrite, arsenopyrite, and pyrrhotite are the main iron sulfide minerals of the veins. The gold-bearing veins are most numerous in the area drained by Bonita Creek. The fissure veins of the Bonita Creek area occur on faulted crests of major northward and northwestward trending anticlines and near late Cretaceous granodiorite intrusions, presumably the source of the hydrothermal veins (Moen, 1969). At the property of the Western Gold Mining, Inc. on Bonita Creek, gold occurs in an extensive breccia zone. The breccia consists of fragments of slate and argillite that have been cemented by gold-bearing quartz and calcite (Moen, 1969).

Water sampling was conducted in the area of the New Light group of claims which is near the headwaters of Bonita Creek. Claims of the New Light group were among the first to be located in the Slate Creek District and are part of the original Eureka group of claims. Total production for the New Light Mine was $1,250,000, primarily in the early 1900s (Derkey et al., 1990).

Evaluation of Water Samples

Water quality samples and field parameters were obtained from two locations in Bonita Creek (Figure 4). The upstream sample was collected near the headwaters of the stream below a glacial cirque at an elevation of 6300 feet MSL. The downstream sample was taken below the New Light mill, associated with the largest mine in the district at an altitude of 5340 feet. The two samples were about ¾ mile apart. Water quality and sediment samples were collected in August 2000 during low flow. High-flow water samples were taken in June 2001.

General chemistry and field parameters at upstream and downstream sites were similar (Table 11). TDS and sulfate concentrations were low. At the downstream site, low-flow pH of 5.95 units was essentially at the water quality standard of 6 units, while the upstream value was within the standard. Both the upstream and downstream sites showed near neutral pH values during the high-flow sampling.

Several mines and one large dump were discharging water at the time of the field investigations. Field parameters were measured at these sites to assess potential water quality impacts as reflected in those parameters (Table 12). At low-flow conditions, the pH of the stream that flows past the adit for the Western Gold Mine was similar to the pH in Bonita Creek and approximated the water quality standard. Water in the Western Gold adit was near neutral pH. Seepage from the toe of a dump at the Western Gold mill had neutral pH and low conductivity. No water quality samples were collected at these sites.

Water quality results in Bonita Creek for copper, arsenic, and mercury had decreased concentration downstream (Table 13). During high flow, arsenic increased slightly in concentration compared to the low-flow concentration. Mercury concentration increased more than 2-fold from low-flow to high-flow conditions. Copper and zinc decreased in concentration from low-flow to high-flow conditions.

Evaluation of Sediment Samples

All metals except copper increased concentration downstream in this district. Only copper and arsenic exceeded sediment quality guidelines (Table 14). While copper concentration decreased from upstream to downstream, both samples exceeded the Consensus-Based effects threshold of 32 mg/Kg by nearly 2-fold or more. The arsenic concentration of 70 mg/Kg in the upstream sample and 84 mg/Kg in the downstream sample far exceeded the effects threshold guideline of 9.8 mg/Kg. Mercury increased by more than 7-fold from upstream to downstream. Lead and zinc showed a 4-fold or greater concentration increase from upstream to downstream. Aluminum, iron, and nickel concentrations increased by more than 2-fold from upstream to downstream.

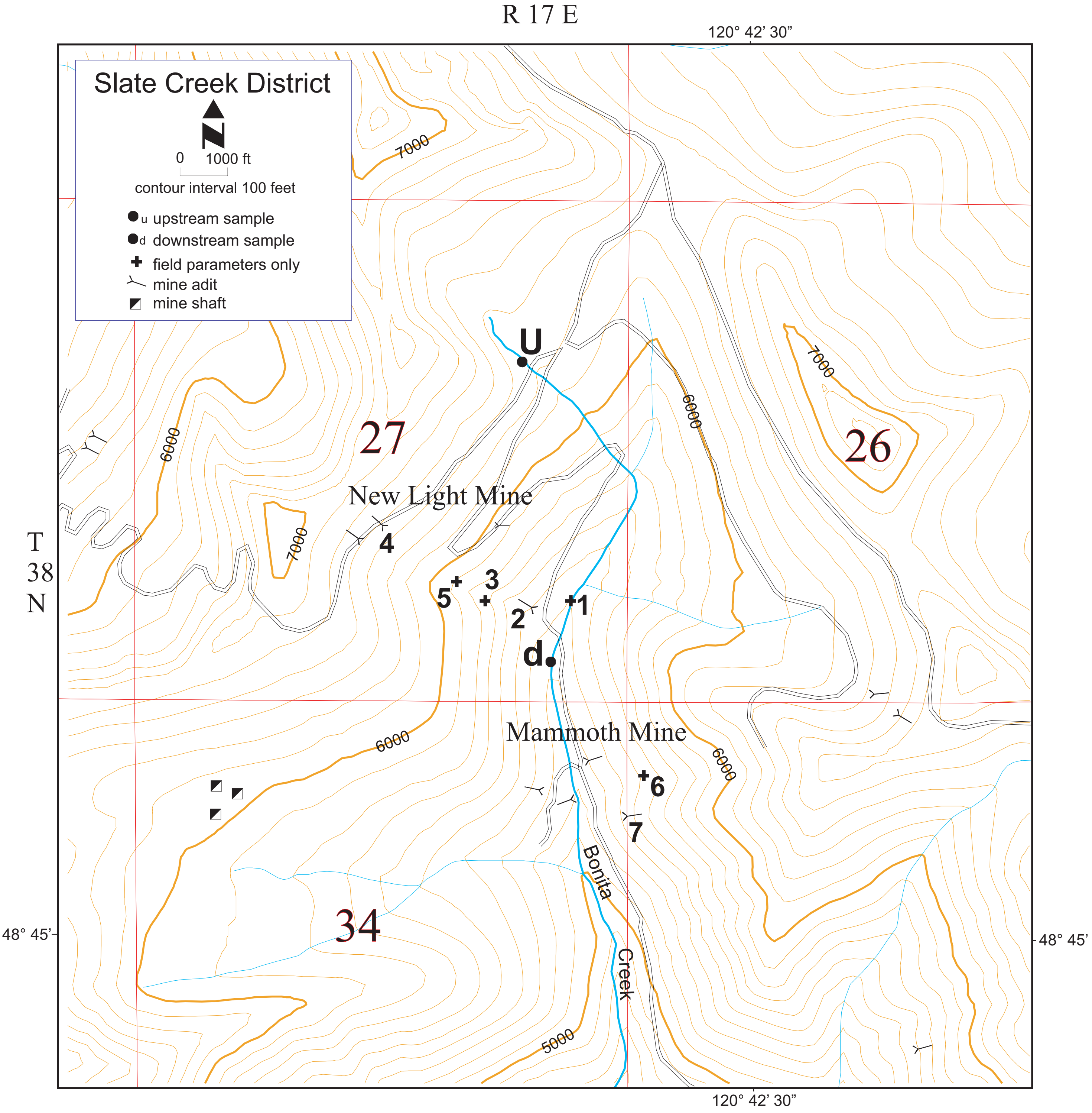

Figure 4. Location of Water and Sediment Samples Collected in Bonita Creek, Slate Creek District

Table 11. Field Measurements and General Chemistry Results for Slate Creek District Water Samples Collected August 2000 and June 2001

Sample Location	Flow (cfs) High Flow	Flow (cfs) Low Flow	Temp. (^{o}C) High Flow	Temp. (^{o}C) Low Flow	pH (units) High Flow	pH (units) Low Flow	Cond. (umho/cm) High Flow	Cond. (umho/cm) Low Flow	Hardness (mg/L) High Flow	Hardness (mg/L) Low Flow
Bonita Creek Upstream	0.5J	0.1J	6.7	15.8	7.88	6.81	29	56	15.6	24.4
Bonita Creek Downstream	8.0J	0.7J	8.9	6.8	7.86	5.95*	52	77	24.4	36.0

Sample Location	TDS (mg/L) High Flow	TDS (mg/L) Low Flow	TSS (mg/L) High Flow	TSS (mg/L) Low Flow	Turbidity (NTU) High Flow	Turbidity (NTU) Low Flow	Sulfate (mg/L) High Flow	Sulfate (mg/L) Low Flow
Bonita Creek Upstream	24	42J	1U	1 J	0.5U	0.5UJ	2.69	4.17J
Bonita Creek Downstream	36	53J	1U	3 J	0.5U	0.5UJ	3.61	5.16J

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

Table 12. Miscellaneous Field Measurements in the Slate Creek District Collected August 2000 and June 2001

Sample Location	Map Key	Temp. (^{o}C) High Flow	Temp. (^{o}C) Low Flow	pH (units) High Flow	pH (units) Low Flow	Cond. (umho/cm) High Flow	Cond. (umho/cm) Low Flow
Spring @ toe of Western Gold dump	1	5.8	NM	7.10	NM	38	NM
Western Gold adit drainage	2	6.0	NM	7.56	NM	199	NM
Creek above Western Gold adit	3	9.2	11.8	7.94	5.97	58	91
New Light Mine, upper adit drainage	4	4.3	14.3	7.75	6.45	97	230
New Light Mine, middle adit drainage	5	3.7	NM	7.62	NM	86	NM
Creek above Mammoth Mine	6	9.7	NM	8.02	NM	82	NM
Mammoth Mine seepage	7	5.5	NM	8.16	NM	268	NM

NM = not measured

Table 13. Metals Concentrations in Slate Creek District Water Samples Collected August 2000 and June 2001 (ug/L)

	Aluminum (total recoverable)		Iron (total recoverable)		Copper (dissolved)		Zinc (dissolved)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Bonita Creek Upstream	50U	**46**	**23J**	20U	**0.50**	**0.852**	0.20U	**0.52J**
Bonita Creek Downstream	50U	**69**	20UJ	20U	**0.38**	**0.506**	**0.37**	**0.95J**

	Arsenic (total recoverable)		Cadmium (dissolved)		Lead (dissolved)		Mercury (total recoverable)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Bonita Creek Upstream	**9.29**	**7.15**	0.02U	0.02U	0.02U	0.02U	**0.0061**	0.002U
Bonita Creek Downstream	**7.42**	**6.00**	0.02U	0.02U	0.02U	0.02U	**0.0049**	0.002U

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

Table 14. Grain Size and Metals Concentrations in Slate Creek District Sediment Samples Collected August 2000 (mg/Kg, dry)

Sample Location	% Gravel	% Sand	% Silt	% Clay	Al	Sb	Be
Bonita Creek Upstream	77.4	22.4	0.0	0.1	**7300**	5UJ	0.2U
Bonita Creek Downstream	73.2	26.5	0.2	0.1	**15600**	7UJ	0.2U

Sample Location	Cd	Cr	Cu	Fe	Mn	Ni	Ag
Bonita Creek Upstream	0.5U	**12.7**	**74.5***	**13500**	**195**	**4.3**	1U
Bonita Creek Downstream	0.7U	**25.5**	**59.8***	**31900**	**379**	**15.4**	1U

Sample Location	Zn	As	Pb	Hg	Se	Tl
Bonita Creek Upstream	**27.2**	**70.2***	**3.94**	**0.008**	**0.54**	0.3UJ
Bonita Creek Downstream	**102**	**84.2***	**18.7**	**0.061**	**0.32**	0.3UJ

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

4. Monte Cristo District, Snohomish County

Geology and Historical Mining Operations and Practices

The first claim in the Monte Cristo District was staked in 1889. By 1894 a 300-ton per-day concentrator was constructed, and ore was shipped until 1903. Mining was carried out on a reduced scale until about 1920 when the last major mining attempt shut down (Northwest Underground Explorations, 1997).

The most important deposits in the Monte Cristo Mining District lie along a northeast-trending, northwest-dipping shear zone. Production records for the district are sketchy, but at least 280,000 tons of polymineralic-sulfide ore containing gold, silver, lead, zinc, and copper was produced. The most significant mines were the Mystery, New Discovery, Pride of the Mountains, Pride of the Woods, Golden Cord, Comet, Justice, and Rainy (Church et al., 1983).

The bedrock geology of the Monte Cristo area consists of the Grotto Batholith granodiorite-granite (Miocene to Oligocene) that intruded the Straight Creek fault, Barlow Pass volcanics and interbedded sedimentary rocks (Eocene), and tonalite intrusions (late Miocene) (Tabor et al., 1993). Slightly younger than the Grotto Batholith is the breccia of Kyes Peak. The Kyes Peak unit is locally rich in angular fragments of the older volcanic, metamorphic, and plutonic rocks. The area has numerous normal faults that generally trend north-northwest (Church et al., 1983). Oldest rock in the Monte Cristo District is Cretaceous Darrington Phyllite (Tabor et al., 1993).

Mineral resources occur in northeast trending, sulfide-bearing quartz veins and shear zones associated with the tonalite intrusions. Mineralization may have been controlled by the intersection of the northwest trending Straight Creek fault system with the Glacier Peak structural belt. The structural belt is characterized by an en echelon, northeast trending shear and fracture system (Church et al., 1983).

Ore minerals consist of chalcopyrite, galena, sphalerite, jamesonite, and realgar. Non-ore sulfide minerals of note are arsenopyrite and pyrite (Derkey et al., 1990).

Evaluation of Water Samples

General chemistry and metals samples were collected in Glacier Creek in August 2000, representing low-flow conditions and in June 2001, representing high-flow conditions (Figure 5). Sediment samples were also collected in August 2000. The upstream sample was obtained near the headwaters of Glacier Creek at the point where it spilled from a glacial cirque at an elevation of 4410 feet MSL. The downstream sample was collected below the confluence of Glacier Creek, Seventysix Gulch Creek, and an unnamed north-flowing tributary at the historic mining town of Monte Cristo, now undergoing restoration. Conductivity, pH, and temperature field parameters were measured at the water sample sites and at two mines.

Field measurements and general chemistry parameters (Table 15) showed little change from upstream to downstream during both high-flow and low-flow conditions. Similarly, there was little change from low-flow to high-flow conditions. Even the temperature changed less than

1^{o} C from low flow to high flow. The temperature data taken along with the low concentrations of TDS and hardness speaks to the pristine and glacial source for this stream.

A waste rock dump was placed on the banks of Glacier Creek a short distance below the upstream sample site. Field parameter measurements were made in Glacier Creek downstream of the waste rock (Table 16). Both pH and conductivity measurements were about the same as the upstream sample site. Another set of field measurements was made in a small stream that drains a waste dump above the valley floor. At this site, well above Glacier Creek, pH was near neutral, but conductivity was substantially elevated above the background value. The high conductivity value suggests some mine-related water quality impacts that should be investigated further. No water samples were collected at these sites.

Several metals increased significantly downstream during both high and low flow (Table 17). Iron, zinc, arsenic, and cadmium all showed at least a 2-fold concentration increase downstream at low flow. At high flow, zinc and arsenic both showed greater than a 20-fold increase downstream while copper increased by more than 10-fold. The upstream sample showed a substantial decrease in concentration from low flow to high flow. Mercury showed a 2-fold increase from low-flow to high-flow conditions. All metals however were within state water quality standards.

A replicate water sample for metals was collected at this site (Table 18). The relative percent difference between the replicate sample and the original sample was 13% or less for all metals, except 130% for iron. This suggests that the apparent iron increase from upstream to downstream samples in Table 17 may not be significant.

Evaluation of Sediment Samples

In stream sediments (Table 19), arsenic showed a 2-fold increase downstream. The upstream concentration of 251 mg/Kg and the downstream concentration of 543 mg/Kg were substantially above the Consensus-Based probable effect guideline of 33 mg/Kg, as well as the 40 mg/Kg apparent effects threshold based on Washington State data (Table 2). The downstream arsenic concentration was the highest value observed during this study. The antimony concentration of 6.2 mg/Kg in the upstream sample and 12 mg/Kg in the downstream sample both exceeded the Washington apparent effects threshold of 3 mg/Kg. This was the only district in the study that had detectable antimony concentrations.

Copper was detected in the upstream sample at 33 mg/Kg and at 84.5 mg/Kg in the downstream sample. Both samples exceeded the Consensus-Based probable effect guideline of 32 mg/Kg. Zinc was found in the upstream sample at 172 mg/Kg and in the downstream sample at 190 mg/Kg. These concentrations exceeded the Consensus-Based threshold effect guideline of 121 mg/Kg. Lead concentrations exceeded the Consensus-Based threshold effect guideline in both upstream and downstream samples, with a slight decrease downstream. In the upstream sample, the mercury concentration of 0.25 mg/Kg slightly exceeded the Consensus-Based threshold effect guideline of 0.18 mg/Kg. Other metals either showed slight increases or slight decreases in the downstream sample.

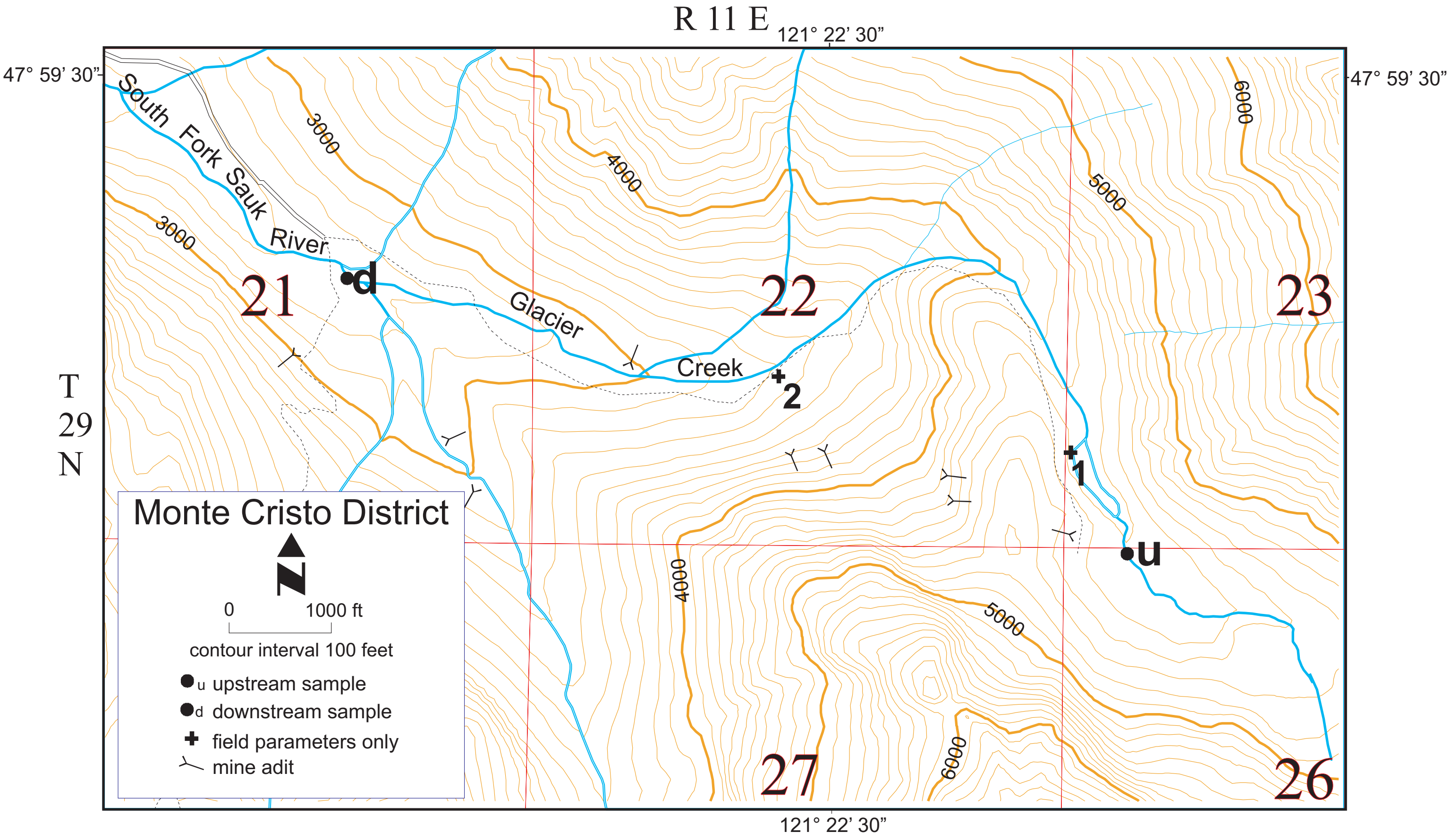

Figure 5. Location of Water and Sediment Samples Collected in Glacier Creek, Monte Cristo District

Table 15. Field Measurements and General Chemistry Results for Monte Cristo District Water Samples Collected August 2000 and June 2001

	Flow (cfs)		Temp. (^oC)		pH (units)		Cond. (umho/cm)		Hardness (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Glacier Creek Upstream	30J	7.5J	2.5	3.4	7.33	6.78	20	18	8.13	6.92
Glacier Creek Downstream	85J	20J	7.0	7.3	7.15	7.02	19	19	7.38	6.80

	TDS (mg/L)		TSS (mg/L)		Turbidity (NTU)		Sulfate (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Glacier Creek Upstream	14	19J	1U	1 UJ	0.5UJ	0.7J	1.44	1.32J
Glacier Creek Downstream	15	21J	1U	1 J	0.5UJ	0.5UJ	2.09	1.72J

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

Table 16. Miscellaneous Field Measurements in the Monte Cristo District Collected August 2000 and June 2001

		Temp. (^oC)		pH (units)		Cond. (umho/cm)	
Sample Location	Map Key	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Glacier Crk below waste rock	1	4.4	3.9	7.80	6.56	18	23
Stream draining waste rock	2	10.4	NM	6.88	NM	111	NM

NM = not measured

Table 17. Metals Concentrations in Monte Cristo District Water Samples Collected August 2000 and June 2001 (ug/L)

	Aluminum (total recoverable)		Iron (total recoverable)		Copper (dissolved)		Zinc (dissolved)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Glacier Creek Upstream	50U	20U	20UJ	20U	0.02U	**0.26**	**0.20**	**1.80J**
Glacier Creek Downstream	50U	20U	20UJ	**95**	**0.31**	**0.27**	**5.04**	**5.75**

	Arsenic (total recoverable)		Cadmium (dissolved)		Lead (dissolved)		Mercury (total recoverable)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Glacier Creek Upstream	**0.28**	**4.52**	0.02U	0.02U	0.02U	**0.03**	**0.0042**	0.002U
Glacier Creek Downstream	**7.37**	**9.24**	**0.04**	**0.04**	**0.02**	0.02U	**0.0058**	0.002U

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

Table 18. Results from Field Replicates on Water Samples in Monte Cristo District Collected August 2000

Location	Glacier Creek - Downstream				
Date	18-Aug-00				
Sample No.	348074		348076		RPD
TSS (mg/L)	na		na		- -
TDS (mg/L)	na		na		- -
Sulfate (mg/L)	na		na		- -
Turbidity (mg/L)	na		na		- -
Iron (ug/L)	20	U	**95**		>130%
Aluminum "	20	U	20	U	0%
Zinc "	**5.6**		**5.6**		0%
Copper "	**0.28**		**0.26**		7%
Arsenic "	**9.2**		**9.3**		1%
Cadmium "	**0.041**		**0.036**		13%
Lead "	0.02	U	0.02	U	0%
Mercury "	0.002	U	0.002	U	0%
Hardness (mg/L)	**6.8**		na		- -

Note: Metals detections highlighted in **BOLD**
na = not analyzed
U = not detected at or above reported value
RPD = relative percent difference (range as percent of duplicate mean)

Table 19. Grain Size and Metals Concentrations in Monte Cristo District Sediment Samples Collected August 2000 (mg/Kg, dry)

Sample Location	% Gravel	% Sand	% Silt	% Clay	Al	Sb	Be
Glacier Creek Upstream	56.4	41.4	1.9	0.2	**10500**	**6.2J***	0.2U
Glacier Creek Downstream	55.0	44.1	0.8	0.1	**12700**	**12.0J***	0.2U

Sample Location	Cd	Cr	Cu	Fe	Mn	Ni	Ag
Glacier Creek Upstream	**0.52**	**17.7**	**33.3***	**25000**	**1190**	**13.4**	1U
Glacier Creek Downstream	0.5U	**21.2**	**84.5***	**29600**	**915**	**12.7**	1U

Sample Location	Zn	As	Pb	Hg	Se	Tl
Glacier Creek Upstream	**172***	**251***	**86.6***	**0.254***	**0.30**	0.3UJ
Glacier Creek Downstream	**190***	**543***	**76.3***	**0.066**	**0.30**	0.3UJ

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

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5. Royal Reward Mine Area, King County

Geology and Historical Mining Operations and Practices

The Royal Reward Mine is located in the Green River Gorge in south King County. Claims were filed for cinnabar deposits in 1872 (Dillhoff and Dillhoff, 1991). The mine produced arsenic and mercury. About 20 flasks of mercury were produced from the Royal Reward (Derkey et al., 1990).

Bedrock in the area of the Royal Reward is Eocene Puget Group consisting predominantly of fluvial and nearshore marine sandstone, siltstone, claystone, and coal. The area is overlain with about 150 feet of Pleistocene glacial drift (Frizzell et al., 1984).

Mineralization occurs along the top of a tightly folded anticline trending N9^{o}W and cut by an east-dipping fault. There are andesite dikes near the mineralization. Ore minerals are cinnabar, orpiment, and realgar. Cinnabar occurs as pods in veins and is also disseminated. Realgar occurs in the calcite-filled veins that cut the sandstone and shale (Livingston, 1971).

Evaluation of Water Samples

Upstream and downstream samples were collected in the Green River about four miles apart (Figure 6). The upstream sample was located above the fish hatchery near the town of Kanaskat. The downstream sample was located about 600 feet downstream of the Royal Reward Mine workings, where visible arsenic mineralization was noted. Arsenic mineralization was also visible in the riverbed trending across to another mine on the south bank. Low-flow samples were collected in October 2000, and high-flow samples were collected in April 2001.

There was little of note in either the field parameters or the general chemistry parameters. The values for pH were observed to be over one unit lower during low flow than during high flow (Table 20).

Most metals changed little from upstream to downstream during both high-flow and low-flow conditions (Table 21), marginally increasing or decreasing from upstream to downstream. Cadmium, lead, and mercury were not detected during either high-flow or low-flow conditions. Metals concentrations decreased by about half from low-flow to high-flow conditions. Iron concentrations at low flow were higher than all but one other district, and the upstream sample concentration of 299 mg/L effectively equaled the Canadian water quality guideline of 300 ug/L (CCREM, 1986). The concentration of iron in the downstream sample was less than half of the upstream value. The high-flow volume in the Green River would effectively dilute and mask any water quality impacts from the small mines observed at this site, despite the presence of visible arsenic mineralization in the river above the downstream sample site.

Evaluation of Sediment Samples

In sediments, the downstream arsenic concentration of 166 mg/Kg was nearly a 5-fold increase over the upstream sample and substantially exceeded the Consensus-Based probable effect guideline of 33 mg/Kg and the Washington State data guideline of 40 mg/Kg (Table 22). The arsenic result confirmed the visual identification of arsenic mineralization in the river adjacent to the Royal Reward Mine. Copper in the downstream sample at 33 mg/Kg was at the Consensus-Based threshold effect value of 32 mg/Kg. Iron concentration of 40,300 mg/Kg in the upstream sample was at the severe effects level of 40,000 mg/Kg proposed by Persaud et al. (1993). The downstream value was slightly below the proposed guideline. Mercury was a co-product of the mine but showed a slight decrease in concentration downstream. Other metals showed either slight increases or slight decreases between the upstream and downstream samples.

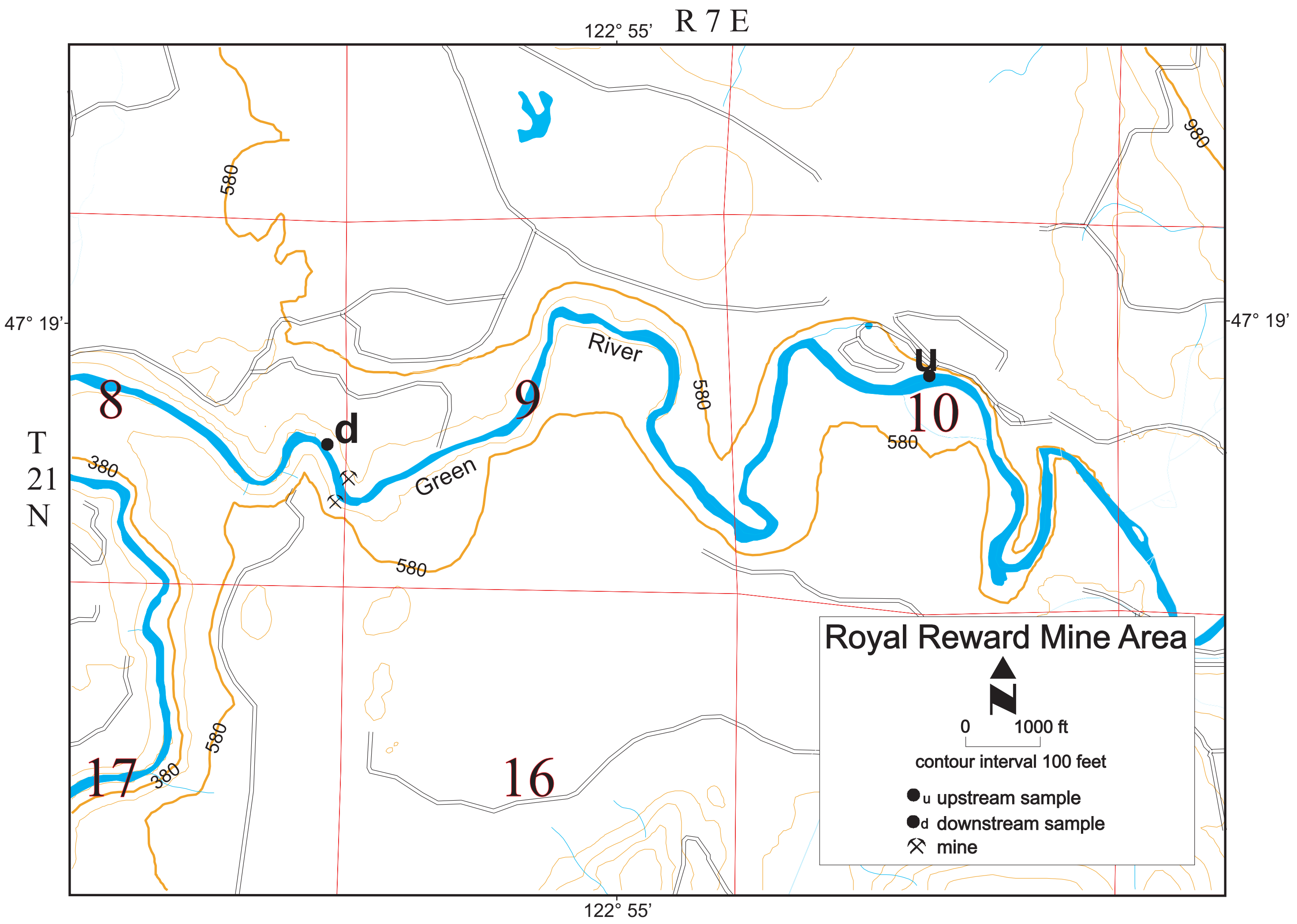

Figure 6. Location of Water and Sediment Samples Collected in Green River, Royal Reward Mine Area

Table 20. Field Measurements and General Chemistry Results for Royal Reward Mine Area Water Samples Collected October 2000 and April 2001

	Flow (cfs)		Temp. (^oC)		pH (units)		Cond. (umho/cm)		Hardness (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Green River Upstream	NM	NM	7.0	13.1	7.90	6.65	39	46	13.6	17.7
Green River Downstream	NM	NM	6.3	12.3	7.82	6.45	40	50	14.3	19.6

	TDS (mg/L)		TSS (mg/L)		Turbidity (NTU)		Sulfate (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Green River Upstream	36	110	2	8J	1.2	4.4J	1.37	1.96
Green River Downstream	38	53	2	3J	1.2	2.1J	1.48	2.16

J = estimated value
NM = not measured

Table 21. Metals Concentrations in Royal Reward Mine Area Water Samples Collected October 2000 and April 2001 (ug/L)

	Aluminum (total recoverable)		Iron (total recoverable)		Copper (dissolved)		Zinc (dissolved)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Green River Upstream	**122**	**318**	**75**	**299**	**0.18**	**0.33**	**0.22**	0.40U
Green River Downstream	**109**	**130**	**85**	**140**	**0.17**	**0.31**	0.2U	**0.61**

	Arsenic (total recoverable)		Cadmium (dissolved)		Lead (dissolved)		Mercury (total recoverable)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Green River Upstream	**0.37**	**0.77**	0.02U	0.02U	0.02U	0.02U	0.002U	0.002U
Green River Downstream	**0.44**	**0.66**	0.02U	0.02U	0.02U	0.02U	0.002U	0.002U

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

Table 22. Grain Size and Metals Concentrations in Royal Reward Mine Area Sediment Samples Collected October 2000 (mg/Kg, dry)

Sample Location	% Gravel	% Sand	% Silt	% Clay	Al	Sb	Be
Green River Upstream	0.6	90.8	7.3	1.3	**28000**	5UJ	1.5U
Green River Downstream	67.5	32.2	0.1	0.2	**21500**	5UJ	1.0U

Sample Location	Cd	Cr	Cu	Fe	Mn	Ni	Ag
Green River Upstream	5.0U	**19.2**	**25.8**	**40300***	**769**	**11.0**	**1.6**
Green River Downstream	2.5U	**15.7**	**32.9***	**39800**	**864**	**14.9**	**1.2**

Sample Location	Zn	As	Pb	Hg	Se	Tl
Green River Upstream	**77.2**	**5.43**	**5.26**	**0.056**	0.40U	0.3U
Green River Downstream	**62.9**	**166***	**4.21**	**0.042**	**0.47**	0.3U

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

6. Deer Trail District, Stevens County

Geology and Historical Mining Operations and Practices

The original discovery of the Deer Trail District was in 1894, and it operated until about 1910. Some mining occurred during the 1920s to about 1947 and more than 3 million dollars in metals were removed. Little work occurred until 1980 when Madre Mining Limited mined almost 2 million dollars worth of zinc, lead, and silver from the Deer Trail Mine (Fluet et al., 1987). The mine closed in 1984 because of low silver prices. Production consisted of gold, silver, lead, zinc, and copper from a network of hydrothermal quartz veins. Moen (1976) reported that there were least 11 adits containing over 4,000 feet of workings in the Deer Trail Mine. This was prior to the major expansion from 1980-1984.

The host rocks of the Deer Trail Mine are PreCambrian Belt Supergroup metasediments belonging to the Deer Trail Group. These metasediments lie to the east of the southern tip of the Kootenay Arc (Fluet et al., 1987). The metasediments in the immediate vicinity of the Deer Trail Mine are the Edna Dolomite, the Togo Formation consisting of undivided metasediments (argillite, phyllite, quartzite, and dolomite), and the Togo Formation quartzite (Joseph, 1990). The Edna Dolomite has been locally metamorphosed by a Cretaceous granodiorite intrusive (Joseph, 1990).

There are at least two major zinc-lead-silver veins in the Deer Trail Mine area where most of the mining has occurred. The Madre vein has a strike length of 700 meters and width averaging 0.7 meter. The Elephant vein has a length of 500 meters and averaged 0.3 meter in width. A third vein, called the Sister Vein, was discovered in the latest stage of exploration. This vein appears to have the same orientation as the Madre vein but the extent is unknown (Fluet et al., 1987). Ore minerals consisted of cerargyrite, native silver, argentite, galena, pyargyrite, sphalerite, cerrussite, tetrahedrite, and pyrite (Moen, 1976).

Evaluation of Water Samples

Two water quality samples and a sediment sample were collected above and below the Deer Trail Mine and Mill Tailings impoundment located in the Cedar Canyon area on upper Alder Creek (Figure 7). The upstream site was in a small tributary to Alder Creek above the mill tailings pond. The downstream sample was taken below the tailings impoundment in the main stream channel below a point where water spills over a beaver dam that impounds water on the surface of the tailings. The two sample sites are about ¼ mile apart. Low-flow water samples and a sediment sample were collected in October 2000. High-flow water samples were obtained in May 2001. A few other mines in the vicinity were investigated using pH and conductivity measurements.

For field parameters (Table 23), pH showed little change from upstream to downstream or from high-flow to low-flow conditions. Conductivity increased from upstream to downstream, with a more than 3-fold increase during high flow. Conductivity decreased from low flow to high flow but showed a greater contrast between the upstream and downstream values during high flow.

During low flow, a second downstream pH and conductivity reading was made in a side channel that has bank seepage as its source and is parallel to the sampled channel. The side channel contained a heavy charge of yellow-orange ferric hydroxide which was associated with seepage from the streambank. The main channel contained less ferric hydroxide. The pH reading of 7.5 units in the side channel was lower than the main channel reading of 8 units and the upstream reading of 8.2 units. The conductivity reading was substantially increased, from 383 umho/cm in the main channel and 224 umho/cm in the upstream sample, to 510 umho/cm in the side channel. The side channel may represent baseflow from water seeping in part through the tailings and is less diluted by the overland flow noted across the top of the tailings that subsequently reports to the main stream channel. The side channel was not sampled for general chemistry, metals, or sediments during low flow, and had coalesced into the main channel during high flow.

Sulfate showed a more than 5-fold concentration increase from upstream to downstream during both high flow and low flow (Table 23) and was the second highest concentration found in this study. There was little change from high-flow to low-flow conditions. TDS increased in concentration by nearly 2-fold downstream during high flow, and by about 50% during low flow. The concentration of TDS decreased from low flow to high flow. The decrease in TDS cannot be accounted for by the change in sulfate concentration. Hardness decreased in the same direction and in about the same amount as TDS, suggesting that TDS and hardness are strongly related at this site through chemical parameters that were not measured individually by this study.

Field parameters were also collected at numerous sites in the Deer Trail District (Table 24), including adit drainage from several mines, water flowing from a cased drill hole, and in the freshwater pond formed on the surface of the Deer Trail mill tailings. All pH values indicated nearly neutral to alkaline water quality. Temperature, pH, and conductivity readings in the water flowing from the drill hole during low flow were nearly the same as readings from the Deer Trail Mine adit. The drill hole was not accessible during high flow due to snow cover. Conductivity measurements were elevated, suggesting some water quality impacts from these facilities.

The concentration of iron increased from upstream to downstream by over 15-fold during low flow. The low-flow concentration of 775 ug/L exceeded the Canadian water quality guideline of 300 ug/L (Table 25), and was the highest concentration found during this study. During high flow, the concentration increased more than 3-fold downstream but did not exceed the guideline. Lead concentration increased by more than 10-fold downstream during both high-flow and low-flow conditions but did not exceed the water quality standard. All metals except aluminum and cadmium increased concentration downstream during both high-flow and low-flow conditions, typically by about 2-fold or more. Most metals, except copper and arsenic, had lower concentrations during high flow than during low flow.

Evaluation of Sediment Samples

Sediment concentrations for copper, manganese, silver, zinc, arsenic, and lead exceeded the sediment quality guidelines in the downstream sample (Table 26). The increase in concentration downstream for copper, manganese, silver, arsenic, and lead was from 5-fold to over 60-fold compared to the upstream site. The concentrations of manganese, silver, and lead were the highest recorded among the districts in this study. The concentrations of cadmium, copper, and zinc were the second highest found in this study.

Copper concentration increased from 6.9 mg/Kg in the upstream sample to 111 mg/Kg in the downstream sample, which was above the Consensus-Based threshold effect value of 32 mg/Kg. Zinc concentration also increased dramatically, from 41 mg/Kg to 452 mg/Kg downstream, exceeding the Consensus-Based threshold of 121 mg/Kg. Lead was another metal with a substantial increase in concentration downstream. In the upstream sample, lead concentration was 7 mg/Kg; the downstream concentration was 447 mg/Kg, well above the Consensus-Based threshold of 36 mg/Kg and the Washington State data apparent effects threshold of 260 mg/Kg. The Deer Trail District was the only district that exceeded the Washington State-based guideline for silver of 4.5 mg/Kg, increasing from less than 0.5 mg/Kg upstream to 11 mg/Kg downstream. Concentrations of cadmium, aluminum, chromium, iron, nickel, and mercury also increased by more than 2-fold in the downstream sample.

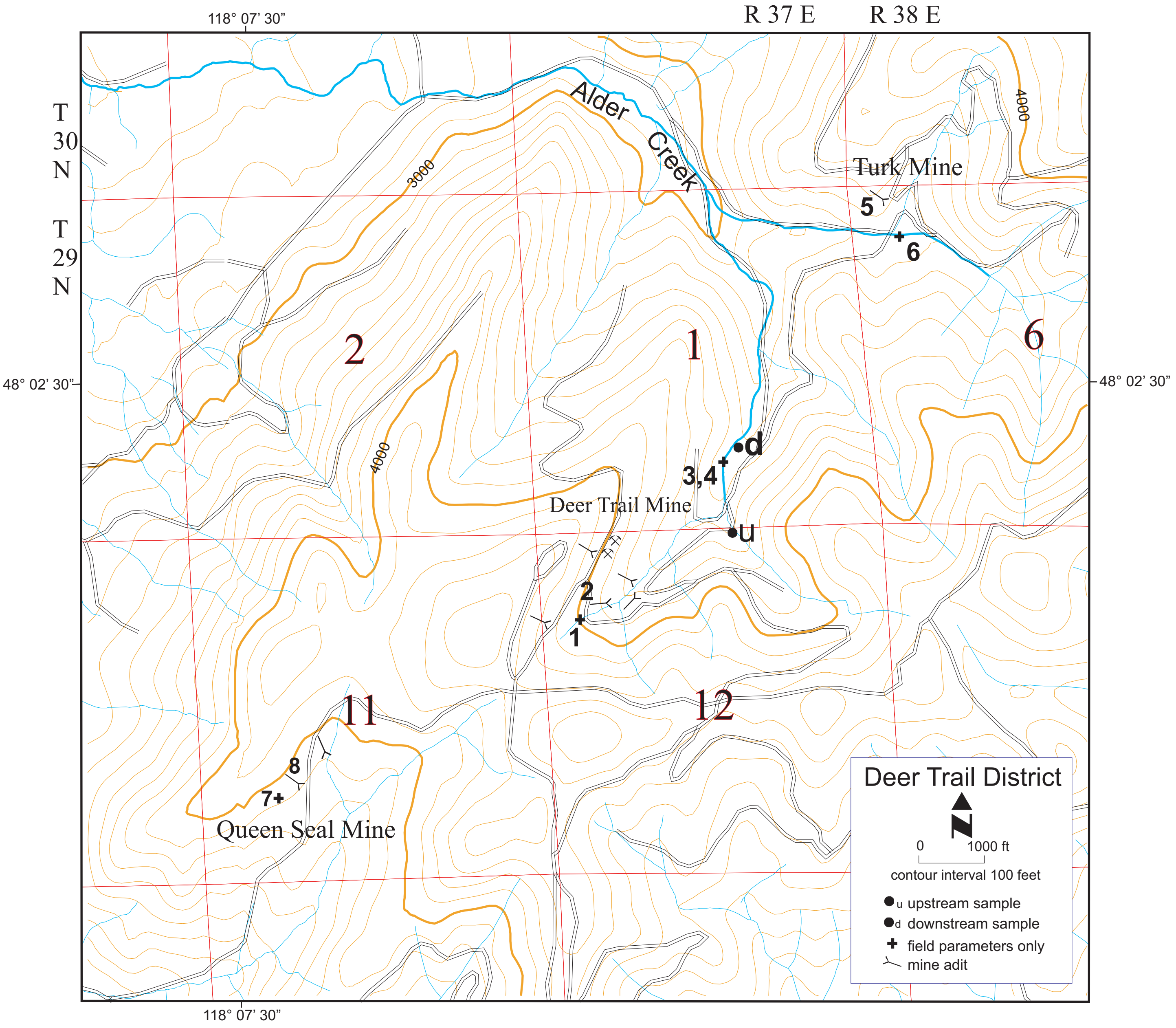

Figure 7. Location of Water and Sediment Samples Collected in Alder Creek, Deer Trail District

Table 23. Field Measurements and General Chemistry Results for Deer Trail District Water Samples Collected October 2000 and May 2001

Sample Location	Flow (cfs) High Flow	Flow (cfs) Low Flow	Temp. (^{o}C) High Flow	Temp. (^{o}C) Low Flow	pH (units) High Flow	pH (units) Low Flow	Cond. (umho/cm) High Flow	Cond. (umho/cm) Low Flow	Hardness (mg/L) High Flow	Hardness (mg/L) Low Flow
Alder Creek Upstream	0.05J	0.05J	4.9	5.2	8.20	8.17	80	224	70.7	124
Alder Creek Downstream	0.3J	0.2J	10.9	6.7	8.52	8.03	288	383	150	196

Sample Location	TDS (mg/L) High Flow	TDS (mg/L) Low Flow	TSS (mg/L) High Flow	TSS (mg/L) Low Flow	Turbidity (NTU) High Flow	Turbidity (NTU) Low Flow	Sulfate (mg/L) High Flow	Sulfate (mg/L) Low Flow
Alder Creek Upstream	108	174	40	2J	1.3J	1.0J	3.88	3.35
Alder Creek Downstream	202	254	19	12J	3.3J	5.2J	23.9	24.8

J = estimated value

Table 24. Miscellaneous Field Measurements in the Deer Trail District Collected October 2000 and May 2001

Sample Location	Map Key	Temp. (^{o}C) High Flow	Temp. (^{o}C) Low Flow	pH (units) High Flow	pH (units) Low Flow	Cond. (umho/cm) High Flow	Cond. (umho/cm) Low Flow
Flowing drill hole casing	1	NM	6.8	NM	7.77	NM	342
Deer Trail Mine adit	2	5.1	6.4	7.73	7.65	111	355
Deer Trail tailings pond	3	13.5	NM	8.28	NM	288	NM
Deer Trail tailings pond inlet	4	7.8	NM	8.34	NM	172	NM
Turk Mine seepage	5	7.2	NM	7.79	NM	118	NM
Stream below Turk Mine	6	4.0	NM	8.09	NM	175	NM
Queen Seal mill drainage	7	NM	7.2	NM	7.55	NM	607
Queen Seal adit drainage	8	NM	8.3	NM	7.43	NM	672

NM = not measured

Table 25. Metals Concentrations in Deer Trail District Water Samples Collected October 2000 and May 2001 (ug/L)

	Aluminum (total recoverable)		Iron (total recoverable)		Copper (dissolved)		Zinc (dissolved)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Alder Creek Upstream	**140J**	**77**	**64**	**42**	**0.20**	**0.16**	0.20U	0.40U
Alder Creek Downstream	**163J**	**70**	**218**	**775***	**0.60**	**0.39**	**0.53**	**0.93**

	Arsenic (total recoverable)		Cadmium (dissolved)		Lead (dissolved)		Mercury (total recoverable)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Alder Creek Upstream	**0.74**	**0.98**	0.02U	0.02U	0.02U	0.02U	0.002U	0.002U
Alder Creek Downstream	**1.67**	**1.60**	0.02U	0.02U	**0.19**	**0.22**	**0.0024**	**0.0023**

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

Table 26. Grain Size and Metals Concentrations in Deer Trail District Sediment Samples Collected October 2000 (mg/Kg, dry)

Sample Location	% Gravel	% Sand	% Silt	% Clay	Al	Sb	Be
Alder Creek Upstream	40.6	55.6	3.5	0.3	**12500**	5UJ	1U
Alder Creek Downstream	58.2	28.6	9.9	3.3	**18000**	5UJ	1U

Sample Location	Cd	Cr	Cu	Fe	Mn	Ni	Ag
Alder Creek Upstream	0.5U	**7.2**	**7.2**	**16800**	**399**	**3.2**	1.0U
Alder Creek Downstream	**2.9***	**18.2**	**111***	**31900**	**3980***	**12.7**	**10.9***

Sample Location	Zn	As	Pb	Hg	Se	Tl
Alder Creek Upstream	**41.2**	**3.63**	**6.9**	0.004U	**0.55**	**0.41**
Alder Creek Downstream	**452***	**21***	**447***	**0.021**	**0.48**	0.3U

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

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7. Big Chief Mine Area, Stevens County

Geology and Historical Mining Operations and Practices

The Big Chief Mine Area deposits are lead–zinc deposits hosted in carbonate rocks. The most extensive underground workings are those of the Big Chief Mine main adits on the north slope of Comstock Mountain in SW ¼ of sec 14; the portals are at elevations of 3,020 and 3,450 feet. The upper adit has about 1,300 feet of workings. The lower adit is reported to have a total length of 2,370 feet (Mills, 1977).

The Big Chief Mine lies within the Kootenay arc, a structural belt containing multi-deformed Proterozoic and Paleozoic shallow water marine sedimentary rocks (Watkinson and Ellis, 1987). Ore deposits may have formed during Kootenay arc development or during emplacement of Jurassic-Cretaceous granitic batholiths (Rhodes and Hyndman, 1988). The Big Chief Mine is in the middle dolomite unit of the Metaline Formation in the Yellowhead horizon (Derkey et al., 1990).

Ore minerals occur as nodules and stringers along zones in fractured and brecciated dolomite and limestone. Also present are three quartz veins carrying ore mineral (Hunting, 1956). Brecciation of the host carbonate is probably solution collapse related (Mississippi Valley-type mineralization) and is not a result of faulting (Mills, 1977). Ore minerals consist of galena, sphalerite, and cerussite.

Evaluation of Water Samples

Water quality and sediment samples were collected in the North Fork of Clugston Creek above and below the confluence with mine drainage from the Big Chief Mine adit (Figure 8). The two sample sites are about ¾ mile apart. Low-flow water quality and sediment samples were obtained in October 2000, and high-flow water samples were obtained in May 2001. The Big Chief Mine adit drainage was tested for pH and conductivity only. The mine discharge does not exhibit characteristics of acid rock drainage in either visual appearance or as measured by field parameters. Several other mines in an adjacent drainage, the South Fork of Clugston Creek, were also investigated only with pH and conductivity measurements.

For field parameters (Table 27), pH showed little change from upstream to downstream during high flow and low flow, although a slight increase was noted from low flow to high flow. Conductivity showed a slight increase downstream during low flow. An increase in sulfate concentration occurred downstream during both low-flow and high-flow conditions (Table 27). During low flow, sulfate increased more than 2-fold downstream, while during high flow the increase downstream was about 50%. At the downstream site, sulfate concentration was lower during high flow than during low flow. Hardness was also highest in the downstream sample during low flow and was the second highest concentration reported during this study.

Field parameters were measured in adit drainage from the Big Chief Mine and in the vicinity of the Chloride Queen Mine in the adjacent stream drainage (Table 28). Big Chief Mine adit drainage pH was about one unit lower than measured in the North Fork of Clugston Creek. The conductivity in the adit drainage was somewhat elevated above the measurements in North Fork Clugston Creek. At the Chloride Queen Mine, in the South Clugston Creek drainage, drainage from waste rock near the mine had high conductivity during low flow and a pH similar to the Big Chief Mine drainage. During high flow, conductivity decreased and pH increased. Measurements in the South Fork of Clugston Creek upstream and downstream of the Chloride Queen also indicated lower pH and increased conductivity during low flow compared to high flow.

Among metals, the zinc concentration increased from the upstream value of 0.5 ug/L to 335 ug/L during low flow, which exceeded the state chronic standard of 237 ug/L (Table 29). This was the highest zinc concentration found during this study. At high flow, the upstream concentration was less than 0.2 ug/L, while the downstream concentration of 177 ug/L nearly exceeded the hardness corrected criterion of 208 ug/L. The cadmium concentration of 0.14 ug/L was the second highest in the study, but was well below the hardness corrected water quality standard of 2 ug/L. The lead concentration of 0.80 ug/L was also the second highest in the study, but also below the hardness corrected water quality standard of 5 ug/L. All sampled metals were detected during low-flow conditions in the downstream sample, and all metals increased from the upstream to the downstream sample site. Similarly, all sampled metals had increased concentration from high-flow to low-flow conditions at the downstream site. A replicate water sample for metals was collected at this site (Table 30). The results showed good agreement, with a maximum difference of 7% for hardness, while most metals had 0% difference.

Evaluation of Sediment Samples

In the downstream sediment sample, cadmium, nickel, zinc, and lead concentrations exceeded sediment quality guidelines (Table 31). These metals increased in concentration downstream from nearly 3-fold to over 23-fold over the upstream concentration. The downstream cadmium concentration of 5.5 mg/Kg exceeded the Consensus-Based threshold effect guideline of 0.99 mg/Kg. The downstream zinc concentration of 6,960 mg/Kg far exceeded the Consensus-Based probable effect guideline of 459 mg/Kg and the Washington State-based guideline of 520 mg/Kg. These concentrations of cadmium and zinc were the highest found in this study.

The downstream lead concentration of 186 mg/Kg exceeded the Consensus-Based probable effect value of 128 mg/Kg. The downstream nickel concentration of 44 mg/Kg exceeded the Consensus-Based threshold of 23 mg/Kg. The lead and nickel concentrations were the second highest found in this study. The copper concentration did not exceed sediment quality guidelines but increased by 2-fold from upstream to downstream. The concentration of mercury increased by over 10-fold in the downstream sample but did not exceed the sediment guidelines.

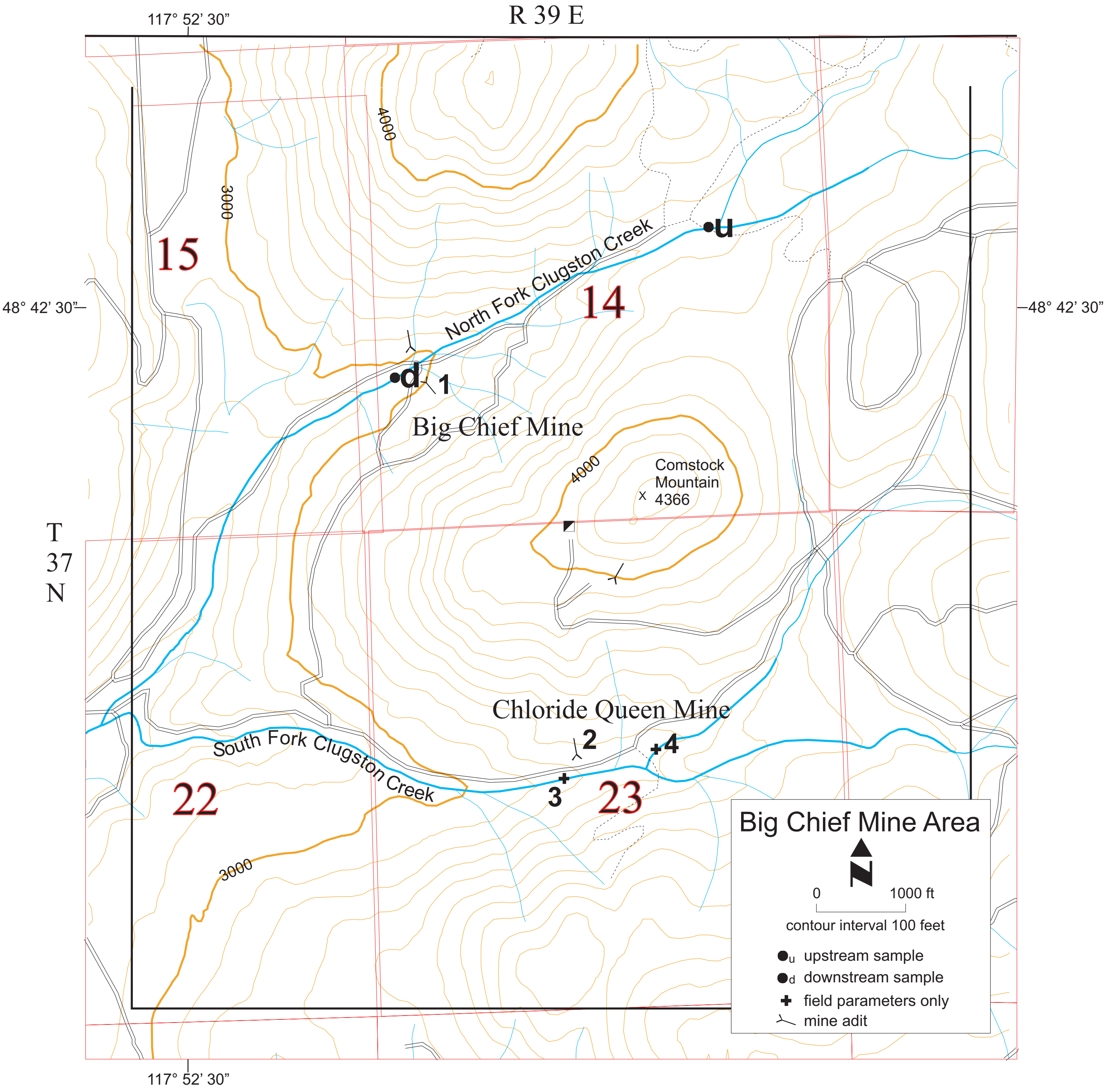

Figure 8. Location of Water and Sediment Samples Collected in North Fork of Clugston Creek, Big Chief Mine Area

Table 27. Field Measurements and General Chemistry Results for Big Chief Mine Area Water Samples Collected October 2000 and May 2001

Sample Location	Flow (cfs) High Flow	Flow (cfs) Low Flow	Temp. (^oC) High Flow	Temp. (^oC) Low Flow	pH (units) High Flow	pH (units) Low Flow	Cond. (umho/cm) High Flow	Cond. (umho/cm) Low Flow	Hardness (mg/L) High Flow	Hardness (mg/L) Low Flow
N Fk Clugston Crk Upstream	1.5J	0.6J	4.2	4.3	8.43	8.02	392	405	219	233
N Fk Clugston Crk Downstream	2J	1J	5.9	6.8	8.49	8.19	410	451	226	263

Sample Location	TDS (mg/L) High Flow	TDS (mg/L) Low Flow	TSS (mg/L) High Flow	TSS (mg/L) Low Flow	Turbidity (NTU) High Flow	Turbidity (NTU) Low Flow	Sulfate (mg/L) High Flow	Sulfate (mg/L) Low Flow
N Fk Clugston Crk Upstream	251	254	2J	2	0.5UJ	0.5UJ	9.71	7.61
N Fk Clugston Crk Downstream	256	281	1J	5	0.5UJ	0.8J	14.9	19.5

J = estimated value
UJ = not detected at or above the reported estimated value

Table 28. Miscellaneous Field Measurements in the Big Chief Mine Area Collected October 2000 and May 2001

Sample Location	Map Key	Temp. (^oC) High Flow	Temp. (^oC) Low Flow	pH (units) High Flow	pH (units) Low Flow	Cond. (umho/cm) High Flow	Cond. (umho/cm) Low Flow
Big Chief Mine adit drainage	1	9.1	8.8	7.44	7.35	477	486
Chloride Queen waste rock seepage	2	10.3	8.3	8.15	7.46	289	561
S Fk Clugston Crk below Chloride Queen	3	4.9	4.4	8.33	7.98	167	270
S Fk Clugston Crk above Chloride Queen	4	4.3	3.2	8.38	7.62	200	202

Table 29. Metals Concentrations in Big Chief Mine Area Water Samples Collected October 2000 and May 2001 (ug/L)

Sample Location	Aluminum (total recoverable) High Flow	Aluminum (total recoverable) Low Flow	Iron (total recoverable) High Flow	Iron (total recoverable) Low Flow	Copper (dissolved) High Flow	Copper (dissolved) Low Flow	Zinc (dissolved) High Flow	Zinc (dissolved) Low Flow
N Fk Clugston Crk Upstream	**55J**	**20**	20U	**26**	**0.13**	**0.11**	0.2U	**0.50**
N Fk Clugston Crk Downstream	50UJ	**65**	20U	**34**	**0.14**	**0.31**	**177**	**335***

Sample Location	Arsenic (total recoverable) High Flow	Arsenic (total recoverable) Low Flow	Cadmium (dissolved) High Flow	Cadmium (dissolved) Low Flow	Lead (dissolved) High Flow	Lead (dissolved) Low Flow	Mercury (total recoverable) High Flow	Mercury (total recoverable) Low Flow
N Fk Clugston Crk Upstream	**0.37**	0.50U	0.020U	0.02U	0.020U	0.020U	0.002U	0.002U
N Fk Clugston Crk Downstream	**0.55**	**0.57**	**0.072**	**0.14**	**0.454**	**0.803**	0.002U	**0.0026**

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

Table 30. Results from Field Replicates on Water Samples in Big Chief Mine Area Collected May 2001 (ug/L)

Location	N. Fk. Clugston Creek - Downstream				
Date	09-May-01				
Sample No.	1980221		198028		RPD
TSS (mg/L)	1	J	1	UJ	0%
TDS (mg/L)	**256**		**255**		0%
Sulfate (mg/L)	**15**		**15**		0%
Turbidity (mg/L)	0.5	UJ	0.5	UJ	0%
Iron (ug/L)	20	U	20	U	0%
Aluminum "	50	UJ	50	UJ	0%
Zinc "	**177**		**177**		0%
Copper "	**0.14**		**0.14**		0%
Arsenic "	**0.55**		**0.54**		2%
Cadmium "	**0.072**		**0.072**		0%
Lead "	**0.45**		**0.43**		5%
Mercury "	0.002	U	0.002	U	0%
Hardness (mg/L)	**226**		**210**		7%

Note: Metals detections highlighted in **BOLD**
J = estimated
U = not detected at or above reported value
UJ = not detected at or above the reported estimated value
RPD = relative percent difference (range as percent of duplicate mean)

Table 31. Grain Size and Metals Concentrations in Big Chief Mine Area District Sediment Samples Collected October 2000 (mg/Kg, dry)

Sample Location	% Gravel	% Sand	% Silt	% Clay	Al	Sb	Be
N Fk Clugston Crk Upstream	50.4	47.9	1.5	0.2	**6030**	5UJ	1U
N Fk Clugston Crk Downstream	22.5	73.6	2.8	1.1	**6710**	5UJ	1U

Sample Location	Cd	Cr	Cu	Fe	Mn	Ni	Ag
N Fk Clugston Crk Upstream	**0.57**	**12.1**	**5.1**	**23400**	**223**	**12.6**	1U
N Fk Clugston Crk Downstream	**5.55***	**9.37**	**10.2**	**11600**	**348**	**44.5***	**1.5**

Sample Location	Zn	As	Pb	Hg	Se	Tl
N Fk Clugston Crk Upstream	**41.8**	**7.26**	**7.58**	0.004U	0.40U	0.30U
N Fk Clugston Crk Downstream	**6960***	**4.31**	**186***	**0.043**	**0.77**	**0.33**

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

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8. Morton Cinnabar District, Lewis County

Geology and Historical Mining Operations and Practices

Mining at the Roy and Barnum-McDonnell mines took place during intermittent periods of production from 1926 to 1940, with the peak year being 1929 (Mackin, 1944). The Morton District had the most significant mercury production in the state, with over 4,000 flasks of mercury produced (Huntting, 1956). Cinnabar mineralization, probably related to the emplacement of subsurface igneous bodies, occurred in discontinuous lenses and brecciated zones in Eocene Puget Group sandstone and shale sediments (Mackin, 1944). The combined development work, including adits and production stopes on both properties, totaled 9,400 feet on ten levels (Huntting, 1956). For practical purposes, the mines have been inoperative since 1940. The mines yielded a total of $509,717 (historic value) of mercury. Various retort furnaces operated on the properties between 1914 and 1940. A 300-ton/day flotation mill was constructed at the mouth of the Barnum-McDonnell no. 6 haulage tunnel (Wolff et al., 2001).

Eocene Puget Group sediments consisting of folded and faulted sandstone, shale, and interbedded coal seams are intruded by Eocene basic sills and dikes (Schasse, 1987). The folding and faulting occurred during the Tertiary Period (Gard, 1968). Ore mineralization was controlled by varying degrees of permeability within the sediments and localized in brecciated zones along fault planes (Mackin, 1944). Cinnabar was the only ore mineral (Derkey et al., 1990).

Evaluation of Water Samples

Low-flow and high-flow water samples and low-flow sediment samples were collected in Chapman Creek, which was intended to represent the upstream or background water quality in the district. Chapman Creek does not drain the majority of the district, and as a result the downstream sample was collected in water draining from a culvert under the highway east of Morton below a steep embankment (Figure 9). The two sampling sites were about 1½ miles apart. Based on maps of the district, the drainage from the culvert may be from the Barnum-McDonnell Mine, which has apparently been covered by the highway. The apparent mine drainage flows toward the adjacent Davis Lake Wildlife Refuge. The overgrown foundation of a large mercury retort was located nearby but was not sampled for water or sediment quality. Staff from DNR subsequently conducted a more detailed geologic and physical hazards investigation of this district (Wolff et al., 2001).

Field measurements of conductivity (Table 32) showed that there was a greater than 15-fold increase in conductivity from the upstream to the downstream samples for both high-flow and low-flow conditions. pH stayed about the same between upstream and downstream locations during low flow. During high flow, pH increased by nearly one standard unit downstream. The pH upstream decreased about 0.6 standard unit during high-flow compared to the low-flow value, while the downstream pH had little change between high flow and low flow. For general chemistry (Table 32), sulfate concentration increased downstream by 22-fold during low-flow and 38-fold during high-flow conditions. Similarly, the concentration of TDS increased downstream by over 8-fold during low flow and nearly 10-fold during high flow. These concentrations were the highest values obtained for any district in this study, further confirming the assumption that the downstream sample is from mine drainage. Sulfate concentration increased from low flow to high flow while TDS decreased from low flow to high flow. Hardness showed about a 25-fold increase downstream during both low flow and high flow. Hardness was slightly lower during high flow than low flow, the same pattern as for TDS and the opposite of sulfate.

Field parameters were also measured in the discharge from an adjacent but somewhat higher level culvert under the highway (Table 33). The contrast in pH and conductivity measurements in the discharge from this culvert, and the pH and conductivity measurements obtained from the assumed Barnum-McDonnell drainage, tends to affirm the conclusion that the lower culvert contains mine drainage and the upper culvert represents barrow ditch water. Field parameter measurements were also made in Minnie Creek which showed similar water quality to Chapman Creek.

Water quality results showed that copper and zinc concentrations increased between 3- and 4-fold between the upstream and downstream sites during both low-flow and high-flow conditions (Table 34). Concentrations were lower during high flow than during low flow. Lead increased concentration downstream about 4-fold during low flow but only slightly during high flow. High-flow concentration was lower than low flow. Although this was a mercury mining district, mercury was only detected during low flow in the upstream sample. Mercury was not detected in either the high-flow or low-flow downstream samples.

Evaluation of Sediment Samples

The concentration of mercury, lead, zinc, chromium iron, copper, and nickel in the downstream sediment sample exceeded sediment quality guidelines (Table 35). The downstream mercury concentration of 99 mg/Kg increased 700-fold from the upstream sample and was substantially above the Consensus-Based probable effect guideline of 5.0 mg/Kg and the Washington State - based apparent effects guideline of 0.56 mg/Kg. The water quality results of no change in mercury concentration from upstream to downstream do not reflect the sediment quality results. Lead concentration increased downstream to 117 mg/Kg which was an increase of over 30-fold from the upstream result and exceeded the Consensus-Based probable effects guideline of 128 mg/Kg. Zinc concentration increased 10-fold downstream, from 39 mg/Kg to 412 mg/Kg. The downstream concentration exceeded the Consensus-Based effects threshold guideline of 121 mg/Kg.

Chromium increased from 13 mg/Kg upstream to 82 mg/Kg downstream which exceeded the Consensus-Based effects threshold of 43 mg/Kg. Iron increased more than 2-fold downstream to 57,300 mg/Kg which exceeded the proposed severe effect level of 40,000 mg/Kg (Persaud et al., 1993). The concentration of copper at 60 mg/Kg in the downstream sample increased more than 3-fold above the upstream sample and exceeded the Consensus-Based threshold of 32 mg/Kg. Nickel increased nearly 6-fold to a concentration in the downstream sample of 61 mg/Kg which exceeded the Consensus-Based probable effects guideline of 49 mg/Kg and the Washington State-based guideline of 46 mg/Kg. Aluminum, and arsenic increased in concentration by 2-fold downstream but did not exceed sediment quality guidelines.

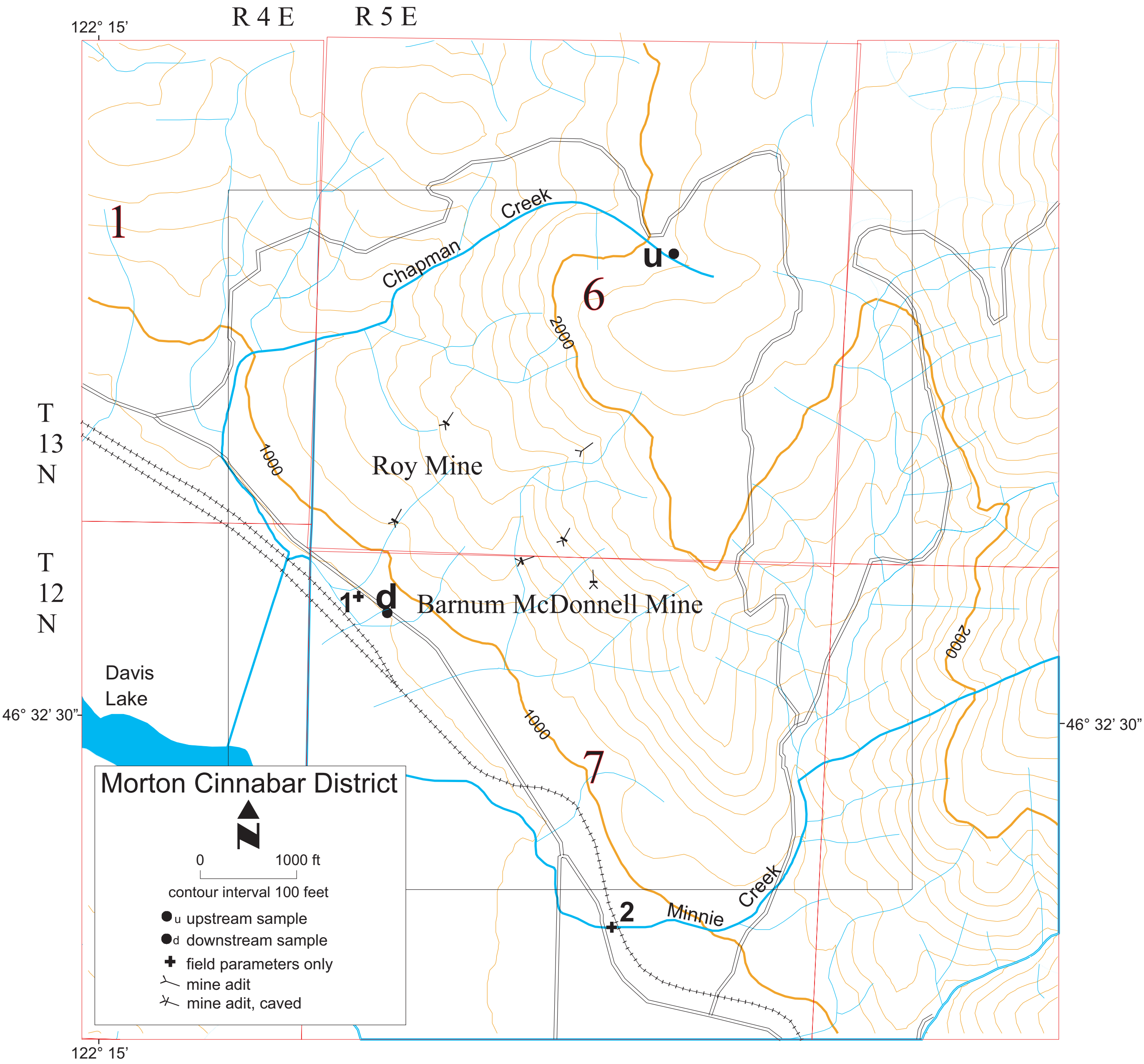

Figure 9. Location of Water and Sediment Samples Collected in Chapman Creek/ Barnum-McDonnell Mine?, Morton Cinnabar District

Table 32. Field Measurements and General Chemistry Results for Morton Cinnabar District Water Samples Collected October 2000 and April 2001

	Flow (cfs)		Temp. (^oC)		pH (units)		Conductivity (mS/cm)		Hardness (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Chapman Crk Upstream	0.06J	0.03J	5.9	9.9	6.60	7.21	33	32	8.94	11.1
Barnum-McDonnell Mine? Downstream	0.05J	0.03J	10.1	10.1	7.39	7.30	524	569	248	284

	TDS (mg/L)		TSS (mg/L)		Turbidity (NTU)		Sulfate (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Chapman Crk Upstream	31	42	1U	1U	0.5UJ	0.9J	1.07	1.31
Barnum-McDonnell Mine? Downstream	305	363	1U	1U	0.5UJ	0.5UJ	42.6	30.8

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

Table 33. Miscellaneous Field Measurements in the Morton Cinnabar District Collected April 2001

		Temp. (^oC)		pH (units)		Cond. (umho/cm)	
Sample Location	Map Key	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Borrow ditch culvert	1	8.4	NM	7.85	NM	74	NM
Minnie Creek	2	6.2	NM	7.74	NM	58	NM

NM = not measured

Table 34. Metals Concentrations in Morton Cinnabar District Water Samples Collected October 2000 and April 2001 (ug/L)

	Aluminum (total recoverable)		Iron (total recoverable)		Copper (dissolved)		Zinc (dissolved)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Chapman Crk Upstream	**63**	**27**	20U	**20**	**0.13**	**0.22**	**0.28**	**0.4**
Barnum-McDonnell Mine? Downstream	**52**	**20**	**22**	**23**	**0.49**	**0.84**	**0.88**	**1.3**

	Arsenic (total recoverable)		Cadmium (dissolved)		Lead (dissolved)		Mercury (total recoverable)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Chapman Crk Upstream	0.2U	0.5U	0.02U	0.02U	0.020U	0.020U	0.002U	**0.002**
Barnum-McDonnell Mine? Downstream	0.2U	0.5U	0.02U	0.02U	**0.032**	**0.089**	0.002U	0.002U

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

Table 35. Grain Size and Metals Concentrations in Morton Cinnabar District Sediment Samples Collected October 2000 (mg/Kg, dry)

Sample Location	% Gravel	% Sand	% Silt	% Clay	Al	Sb	Be
Chapman Crk Upstream	48.5	48.8	1.1	1.5	**11000**	5UJ	1U
Barnum-McDonnell Mine? Downstream	54	43.7	1.1	1.2	**27000**	5UJ	1U

Sample Location	Cd	Cr	Cu	Fe	Mn	Ni	Ag
Chapman Crk Upstream	0.5U	**12.5**	**17.0**	**19400**	**496**	**10.3**	1U
Barnum-McDonnell Mine? Downstream	5U	**82.2***	**60.3***	**57300***	**680**	**60.6***	**1.7**

Sample Location	Zn	As	Pb	Hg	Se	Tl
Chapman Crk Upstream	**39**	**1.90**	**3.7**	**0.141**	**0.43**	0.3U
Barnum-McDonnell Mine Downstream	**412***	**3.86**	**117***	**99.2***	0.40U	0.3U

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. Mineral Creek Area, Lewis County

Geology and Historical Mining Operations and Practices

The Mineral Creek deposit began production in 1903 and shipped 1,000 tons of arsenic ore (Huntting, 1956). The main adit was about 400 feet long. A retort was constructed near the confluence of Mineral and Arsenic creeks.

Host rocks at the Mineral Creek deposit are in a sequence of Eocene to Oligocene basaltic andesite and andesite flows (Schasse, 1987). Rocks of the Mineral Creek Mine Area are the earliest stages of Cascade magmatic arc volcanism (Walsh et al., 1987; Swanson et al., 1989). Mineralization occurs as veins and fractures filled with realgar and orpiment. Ore minerals are sphalerite, galena, and realgar.

Evaluation of Water Samples

Water quality and sediment samples were collected in Mineral Creek upstream and downstream of its confluence with Arsenic Creek (Figure 10) during high-flow and low-flow conditions. Low-flow samples were obtained in October 2000, and high-flow samples were obtained in April 2001. The upstream and downstream samples are separated by about ¼ mile. Casual inspection revealed visible arsenic mineralization in the sediments of Arsenic Creek above Mineral Creek, and at least one small unmapped mine working was found on the north bank of Arsenic Creek about ¼ mile above the confluence with Mineral Creek.

Nothing of interest was noted between the upstream and downstream locations for field parameters and general chemistry parameters (Table 36). During high flow, pH was noted to be slightly higher and the concentration of general chemistry parameters slightly lower than during low flow at both the upstream and downstream sites. The uniformity between upstream and downstream samples is most likely the product of the diluting effect from the flow in Mineral Creek that substantially exceeds the flow from the tributaries which actually drain the mining district.

Conductivity and pH were measurement in Arsenic Creek, just above the confluence with Mineral Creek and at an unnamed mine adit upstream of the confluence (Table 37). The pH measurements were similar, while the conductivity increased slightly downstream. More undocumented mine workings may be present in the area. Additional field parameters were measured in Gallup Creek, a large tributary to Mineral Creek outside the mining district, to obtain additional regional background data. These measurements were similar to the upstream measurements in Mineral Creek. During low flow, field parameters were measured at a seep below an outcrop of arsenic mineralization adjacent to Mineral Creek. The pH at this location was about 0.5 unit lower than the downstream sample site, and the conductivity increased about 6-fold over the downstream sample. The seep could not be reached during high-flow conditions.

The water sample analyses for metals showed that arsenic concentration increased more than 11-fold during low flow and more than 80-fold during high-flow conditions and was the highest recorded in this study (Table 38). This is most likely due to an increased flow contribution to Mineral Creek from Arsenic Creek. The concentration of iron increased more than 10-fold during high flow and exceeded the Canadian water quality guideline of 300 ug/L in the downstream sample. During low flow, there was no increase between the upstream and downstream samples. Zinc concentration increased by 4-fold between the upstream and downstream samples during high flow but was not detected during low flow. Aluminum concentration increased by 6-fold during high flow and decreased during low flow from upstream to downstream. The only other metal that was detected was copper, which increased slightly downstream and decreased slightly from low-flow to high-flow conditions. State water quality standards were not exceeded for any metal.

Evaluation of Sediment Samples

Arsenic concentration of 108 ug/Kg was an increase of more than 15-fold downstream and exceeded the Consensus-Based probable effects concentration of 33 mg/Kg and the Washington State-based guideline of 40 mg/Kg (Table 39). Despite the presence of visible arsenic mineralization in Arsenic Creek sediments, this result was only the third highest arsenic concentration among the districts in this study, again pointing to the diluting effect of Mineral Creek. The concentration of mercury increased about 3-fold downstream but did not exceed the guideline. Analyses of other metals showed little variation in concentration between upstream and downstream samples.

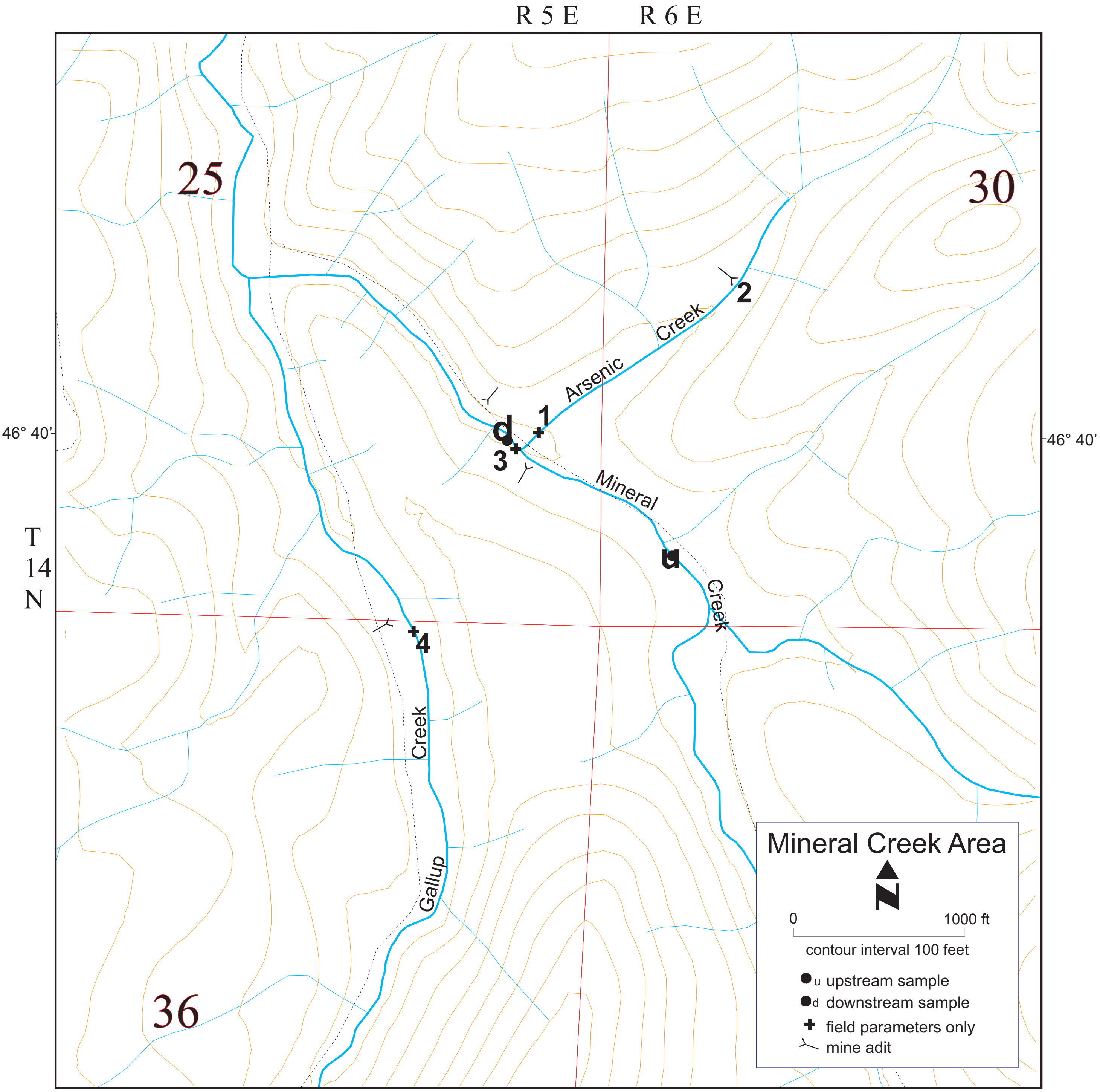

Figure 10. Location of Water and Sediment Samples Collected in Mineral Creek, Mineral Creek Area

Table 36. Field Measurements and General Chemistry Results for Mineral Creek Area Water Samples Collected October 2000 and April 2001

	Flow (cfs)		Temp. (^oC)		pH (units)		Cond. (umho/cm)		Hardness (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Mineral Crk Upstream	NM	NM	4.0	7.7	7.74	7.35	41	70	14.7	21.5
Mineral Crk Downstream	NM	NM	3.9	7.9	7.63	7.36	41	61	15.3	24.1

	TDS (mg/L)		TSS (mg/L)		Turbidity (NTU)		Sulfate (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Mineral Crk Upstream	41	63	1U	1U	0.5J	0.5UJ	1.14	1.60
Mineral Crk Downstream	39	66	1U	1U	0.5UJ	0.5UJ	1.33	1.79

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

Table 37. Miscellaneous Field Measurements in the Mineral Creek Area Collected October 2000 and April 2001

		Temp. (^oC)		pH (units)		Cond. (umho/cm)	
Sample Location	Map Key	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Arsenic Crk abv road	1	4.0	8.0	7.65	7.33	57	80
Adit in Arsenic Creek	2	NM	8.9	NM	7.23	NM	62
Mineral Crk @ As outcrop	3	NM	7.2	NM	6.88	NM	375
Gallup Crk abv old adit	4	4.0	6.7	7.68	7.33	33	98

NM = not measured

Table 38. Metals Concentrations in Mineral Creek Area Water Samples Collected October 2000 and April 2001 (ug/L)

	Aluminum (total recoverable)		Iron (total recoverable)		Copper (dissolved)		Zinc (dissolved)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Mineral Crk Upstream	**106**	**24**	**48**	**25**	**0.16**	**0.29**	**0.26**	0.40U
Mineral Crk Downstream	**675**	**20**	**500***	**25**	**0.27**	**0.32**	**1.03**	0.40U

	Arsenic (total recoverable)		Cadmium (dissolved)		Lead (dissolved)		Mercury (total recoverable)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Mineral Crk Upstream	0.2U	0.5U	0.02U	0.02U	0.02U	0.02U	0.002U	0.002U
Mineral Crk Downstream	**16.1**	**8.8**	0.02U	0.02U	0.02U	0.02U	0.002U	0.002U

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

Table 39. Grain Size and Metals Concentrations in Mineral Creek Area Sediment Samples Collected October 2000 (mg/Kg, dry)

Sample Location	% Gravel	% Sand	% Silt	% Clay	Al	Sb	Be
Mineral Crk Upstream	60.7	37.9	0.9	0.4	**28700**	5U	1U
Mineral Crk Downstream	40.8	52.0	6.8	0.4	**33200**	5U	1U

Sample Location	Cd	Cr	Cu	Fe	Mn	Ni	Ag
Mineral Crk Upstream	5U	**39.8**	**56.6***	**49400***	**608**	**20.9**	**1.2**
Mineral Crk Downstream	5U	**28.8**	**67.1***	**45500***	**624**	**20.6**	**1.0**

Sample Location	Zn	As	Pb	Hg	Se	Tl
Mineral Crk Upstream	**88.5**	**6.93**	**2.5**	**0.011**	0.4U	0.3U
Mineral Crk Downstream	**87.9**	**108***	**3.4**	**0.030**	**0.47**	0.3U

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

10. Gold Creek Area, Okanogan County

Geology and Historical Mining Operations and Practices

The first record of activity in the Gold Creek Area was in 1907 at the Antimony Queen Mine. Total amount of workings was about 1,000 feet. About 1,050 tons of stibnite ore and antimony oxide prepared at the site were shipped from 1907 to 1941 and assayed at 27% antimony (Huntting, 1956). The mine has been inactive since 1941. Commodities were antimony, gold, lead, zinc, tungsten, and silver.

The geology of the mine area is composed of irregularly bedded complexly folded and faulted argillites and graywacke and is part of the Newby Group of Barksdale (Purdy, 1951; Barksdale, 1975). Bedding attitudes are characteristically steep and are widely varied in strike. The formation is structurally weak; its component beds, especially those composed of argillaceous rock, are tightly folded. Age of the Newby Group is Jurassic-Lower Cretaceous (Barksdale, 1975). The mine workings of the Antimony Queen trend along the eastward striking quartz vein system and extend from Gold Creek to an elevation of 383 feet above the creek (Purdy, 1951).

Ore minerals were stibnite, jamesonite, arsenopyrite, chalcopyrite, pyrite, galena, sphalerite, and scheelite. Significant non-ore sulfides are pyrite and pyrrhotite (Derkey et al., 1990).

Evaluation of Water Samples

High-flow and low-flow water samples and a low-flow sediment sample were collected in Foggy Dew Creek to represent upstream water quality in the area. The downstream samples were collected in Gold Creek below the confluence with Foggy Dew Creek and below the Antimony Queen Mine to represent downstream water and sediment quality (Figure 11). Low-flow samples were collected in October 2000 and the high-flow samples in April 2001. The two sample sites are separated by about one mile. The Antimony Queen, the largest mine in the area, does not discharge directly into Gold Creek, although the lower adit is filled with water and is near the south creek bank.

For field parameters (Table 40), pH was noted to be slightly higher during low flow than during high flow. Little difference was noted between the upstream and downstream sites during high flow, but about 0.6 standard unit rise in pH was noted downstream during low flow. Conductivity was little changed between low flow and high flow or between the upstream and downstream locations. Sulfate concentration increased between the upstream and downstream sites during low flow, but did not change during high flow (Table 40). The downstream concentration during low flow was higher than the concentration during high flow. Similarly, hardness increased by nearly 5-fold downstream during low flow but showed little change during high flow.

Conductivity and pH measurements were made at the Antimony Queen Mine (Table 41). Two adits are present near the south bank of Gold Creek. The upper adit was dry with no evidence of mine drainage. The lower adit was mostly collapsed at the portal with the rubble forming a dam to impound mine drainage. The pH of this water was near neutral during both high- and low-flow conditions. Conductivity measurements at high flow and low flow were about the same, but were substantially elevated above both upstream and downstream measurements in Foggy Dew Creek and Gold Creek.

In the water quality samples, arsenic increased by more than 2-fold during low flow and by more than 4-fold during high flow between the upstream and the downstream locations (Table 42). High-flow and low-flow concentrations were about the same. Zinc increased by about 2-fold during high flow at the downstream site. Copper and aluminum showed increased concentration during high flow compared to low flow. State water quality standards were not exceeded for any metal.

Evaluation of Sediment Samples

Arsenic concentration in the steam sediments increased 4-fold between the upstream and downstream samples but did not exceed the sediment quality guideline (Table 43). Copper increased nearly 2-fold downstream and also did not exceed the guideline. Most other metals showed only slight increases downstream. Despite the known mineralogy of the Antimony Queen Mine, antimony was not found in the stream sediments although the laboratory spike recoveries for antimony were noted to be low.

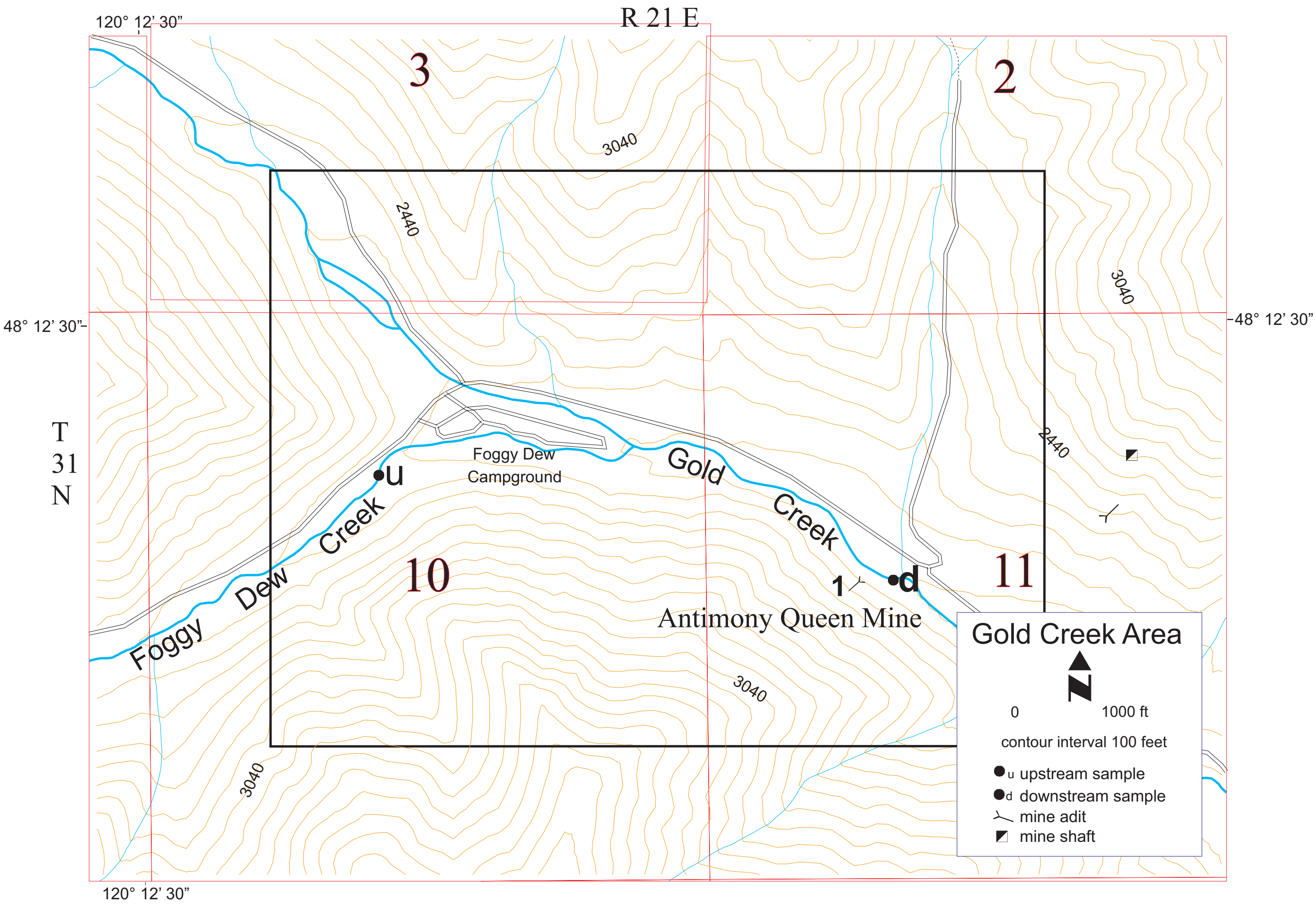

Figure 11. Location of Water and Sediment Samples Collected in Foggy Dew Creek/ Gold Creek, Gold Creek Area

Table 40. Field Measurements and General Chemistry Results for Gold Creek Area Water Samples Collected October 2000 and April 2001

Sample Location	Flow (cfs) High Flow	Flow (cfs) Low Flow	Temp. (^oC) High Flow	Temp. (^oC) Low Flow	pH (units) High Flow	pH (units) Low Flow	Cond. (umho/cm) High Flow	Cond. (umho/cm) Low Flow	Hardness (mg/L) High Flow	Hardness (mg/L) Low Flow
Foggy Dew Creek Upstream	4J	2J	3.5	5.2	8.16	7.58	170	185	84.9	21.8
Gold Creek Downstream	10J	6J	5.9	6.6	8.36	8.23	187	201	94.8	102

Sample Location	TDS (mg/L) High Flow	TDS (mg/L) Low Flow	TSS (mg/L) High Flow	TSS (mg/L) Low Flow	Turbidity (NTU) High Flow	Turbidity (NTU) Low Flow	Sulfate (mg/L) High Flow	Sulfate (mg/L) Low Flow
Foggy Dew Creek Upstream	114	127	1U	1U	0.9J	0.5UJ	9.15	10.1
Gold Creek Downstream	115	158	1	1U	0.5UJ	0.5UJ	9.95	21.0

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

Table 41. Miscellaneous Field Measurements in the Gold Creek Area Collected October 2000 and April 2001

Sample Location	Map Key	Temp. (^oC) High Flow	Temp. (^oC) Low Flow	pH (units) High Flow	pH (units) Low Flow	Cond. (umho/cm) High Flow	Cond. (umho/cm) Low Flow
Antimony Queen lower adit	1	8.6	7.5	7.61	7.31	620	630

Table 42. Metals Concentrations in Gold Creek Area Water Samples Collected October 2000 and April 2001 (ug/L)

Sample Location	Aluminum (total recoverable) High Flow	Aluminum (total recoverable) Low Flow	Iron (total recoverable) High Flow	Iron (total recoverable) Low Flow	Copper (dissolved) High Flow	Copper (dissolved) Low Flow	Zinc (dissolved) High Flow	Zinc (dissolved) Low Flow
Foggy Dew Creek Upstream	50U	**20**	20U	**20**	**0.18**	**0.19**	0.20U	0.40U
Gold Creek Downstream	**51**	**20**	20U	**20**	**0.18**	**0.12**	**0.43**	0.40U

Sample Location	Arsenic (total recoverable) High Flow	Arsenic (total recoverable) Low Flow	Cadmium (dissolved) High Flow	Cadmium (dissolved) Low Flow	Lead (dissolved) High Flow	Lead (dissolved) Low Flow	Mercury (total recoverable) High Flow	Mercury (total recoverable) Low Flow
Foggy Dew Creek Upstream	**0.30**	0.5U	0.02U	0.02U	0.02U	0.02U	0.002U	0.002U
Gold Creek Downstream	**1.36**	**1.2**	0.02U	0.02U	0.02U	0.02U	0.002U	0.002U

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

Table 43. Grain Size and Metals Concentrations in Gold Creek Area Sediment Samples Collected October 2000 (mg/Kg, dry)

Sample Location	% Gravel	% Sand	% Silt	% Clay	Al	Sb	Be
Foggy Dew Creek Upstream	39.0	60.8	0.1	0.1	**3850**	5UJ	1U
Gold Creek Downstream	30.3	69.1	0.4	0.2	**5180**	5UJ	1U

Sample Location	Cd	Cr	Cu	Fe	Mn	Ni	Ag
Foggy Dew Creek Upstream	**0.5**	**14.0**	**3.60**	**7350**	**113**	**7.2**	1U
Gold Creek Downstream	0.5U	**16.5**	**7.12**	**10000**	**142**	**7.7**	1U

Sample Location	Zn	As	Pb	Hg	Se	Tl
Foggy Dew Creek Upstream	**20.8**	**1.60**	**1.4**	.004U	0.40U	0.3U
Gold Creek Downstream	**26.6**	**6.45**	**1.5**	.004U	**0.42**	0.3U

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

Discussion

Low-Level Metals Sampling

This project used low-level metals sampling and analysis procedures to obtain water quality information in waterbodies where no metals data were available or where detection levels in previous studies were higher than state water quality standards. In many of the areas included in this study, very low hardness values result in very low criteria for hardness-dependent metals such as cadmium, copper, lead, and zinc. The technique of low-level sampling for these metals yields data that would be useful to initially document baseline water quality conditions for watershed planning. These data could also be the basis for identifying water quality impaired waterbodies and as a step forward in the total maximum daily load (TMDL) process.

Seasonality of Water Quality Impacts

One objective of this study was to further explore and document the potential issue of seasonality of water quality impacts by discharges from mines, waste rock, and tailings on adjacent waterbodies. This issue is of interest for guiding future water quality studies in mining districts and to assist in the interpretation of water quality data obtained in previous sampling projects. To accomplish this objective, this study and the previous study were designed to collect water quality samples and measure field parameters during low flow and again during high flow at the same locations.

The seasonality of water quality impacts proposed in the previous study was based on the model of cyclic development and flushing of acid salts from mines, waste rock, and tailings through oxidation of pyrite and sulfide ore-bearing minerals. During the annual period of low precipitation and infiltration, typically summer through late winter, efflorescent minerals, or acid salts, form and precipitate on fracture faces in mines, or on the surface of waste rock and tailings material. These acid salts are then remobilized by infiltration of snowmelt and rain through fractures or percolation through waste rock and tailings material during spring freshet and can be flushed into an adjacent stream. The conclusion reached from analyzing the data in the previous study was that this model of seasonality of water quality impacts from the mining districts was demonstrable at the downstream sample sites in the nearby streams.

The results from the present study were less clear and could be partly interpreted to contradict the findings from the previous study. General chemistry parameters that were preferentially selected as likely indicators of ARD, sulfate, and TDS in particular, occurred at lower concentration during high flow than low flow at most downstream sites. That outcome was contrary to the expectation from the previous study results. No difference was noted between the high-elevation stations and the low-elevation stations. The previous study noted a persistent decrease in pH and an increase in TSS during high flow. Those results were not supported in this study. pH uniformly increased during high flow and, where a difference was measurable, TSS concentrations tended to be higher during low flow than high flow. At most stations there was no change in TSS concentrations between high-flow and low-flow conditions.

For metals, the downstream results were mixed in their support of the model. Aluminum and arsenic concentrations tended to increase at a slight majority of the downstream stations during high-flow compared to the low-flow measurements. The concentration of mercury increased at three stations, decreased at one, and stayed the same at six stations when comparing high flow and low flow at the downstream sample site. Zinc was routinely found at higher concentration during high flow in the previous study. In this study, zinc concentrations decreased by at least half from high flow to low flow at all but two districts. At the Big Chief Mine Area, zinc concentration decreased from 335 ug/L at low flow to 177 ug/L at high flow. The rest of the metals did not indicate a clear trend when comparing high-flow and low-flow concentrations. Notably, the concentration of copper at the St Helens District, which was the highest copper concentration measured during this study, was measured at 38 ug/L at both high flow and low flow.

The previous study concentrated on lower-elevation, eastern Washington mining districts in contrast with the present study. By design, an extended test of the model of seasonality of ARD formation and detection was created for this study. More than half of the samples in this study came from high elevation or western Washington mining districts, where precipitation amounts and patterns were expected to be different than in the districts included in the previous study. The expectation was that the variation in precipitation would not affect the ARD model of cyclic formation and flushing of efflorescent minerals. The results from this study apparently do not support the model, although extenuating circumstances may have interfered with the data collected.

One explanation for the departure from the expected results is that the seasonality test in this study was frustrated by drought conditions that interfered with spring runoff. As a result, the expected variations in precipitation amount and annual distribution did not occur. Record low spring runoff conditions occurred throughout the area covered by this study. The low snowpack may have resulted in either minimal formation and flushing of the efflorescent minerals, or flushing may have occurred slowly.

The lack of snowpack also influenced the sampling plan. The highest elevation mining districts, such as Mazama, Monte Cristo, Slate Creek, and St Helens, were not included in the original sampling plan for both fall and spring samples, because in a normal year they would not be accessible during the budget cycle that dictated all sampling must be completed in June. As a result, as shown by the sampling dates in Appendix J, what was termed the fall sampling event at these high-elevation districts actually occurred in August since only one event was planned. The other stations were sampled in October for low-flow conditions in the expectation that they would be readily resampled during high-flow, spring-freshet conditions. In fact, all districts were accessible and resampled within the project time constraints.

In spite of the low spring runoff, dilution may still have influenced the results. Under this circumstance, drought conditions may have inhibited the formation of the efflorescent minerals by limiting the amount of water percolating through the rocks. Subsequent flushing by a small volume of infiltrating snowmelt and precipitation would result in a low volume of contaminated water that then would be mixed with a relatively larger volume of snowmelt in the receiving water. This would result in more dilution than might occur under normal snowpack conditions. Dilution is also discussed in the following section.

Fingerprinting Acid Rock Drainage (ARD)

A third area of investigation for this study was the continuation of the work toward establishing a process to fingerprint ARD. Analysis of data from the previous study resulted in the recommendation that elevated concentrations of total dissolved solids (TDS) and sulfate should be used as primary indicators for ARD leachate in nearby receiving waters. Further, that study recommended consideration and further investigation of a SO_4:TDS ratio of 0.20 as the ARD fingerprint. pH was considered at best a secondary indicator of ARD.

The authors can suggest only mixed results as the outcome from this study, probably in part due to the drought conditions as outlined above. Sulfate and TDS concentrations depend on seasonal flushing of the efflorescent minerals from mines, waste rock, and tailings. If that seasonal process is not operative or is ineffective, the primary effect would be to limit the volume of any leachate generated. Water percolating into mine workings could be insufficient in volume to generate significant discharges to nearby receiving waters, and dilution would mask impacts. This scenario is supported in the data from this study by the very low concentrations of both TDS and sulfate compared to the previous study. For example, sulfate concentrations did not exceed 5 mg/L in nine of the 20 downstream samples and only two samples exceeded 25 mg/L. By contrast, the previous study results included six downstream samples that did not exceed a sulfate concentration of 5 mg/L but ten samples that exceeded 25 mg/L.

Water Quality and Sediment Quality

Varying impacts to receiving waters were identified in this project by sampling water quality upstream and downstream in the selected mining districts. Sediments were also sampled upstream and downstream during low-flow conditions only. Mining district impacts were identified by both methods of investigation. None were identified by pH, confirming the limited role that pH alone plays in ARD identification. The water quality standards for total suspended solids (TSS) and turbidity were not exceeded in any of the mining districts.

The sediment quality guidelines were exceeded with greater frequency than the water quality standards. Sediments are less subject to seasonal and drought conditions, and impacts are sustained under seasonally low-flow conditions.

Table 44 has a summary of the extent of water quality and sediment quality impacts using various comparison criteria. For the St Helens District, column 2 shows that the concentration of aluminum and copper in the downstream sample was more than twice the concentration in the upstream sample. As shown in column 4, the state water quality standard for copper was exceeded at both the upstream and downstream sample sites in the St Helens District. As shown in column 6, the sediment quality guidelines were exceeded in the upstream sample for copper, while the downstream sample exceeded the guidelines for copper, arsenic, and mercury. These results tie in well with the mineralogy of the district, which reportedly contains a large copper reserve.

Table 44. Summary of Water and Sediment Quality Impacts Identified in Mining Districts During Present Study

Location	>2-fold metals increase	>10-fold metals increase	State metals standards exceeded	Iron guideline exceeded	Sediment guidelines exceeded
St Helens District					
Upstream sample			Cu		Cu
Downstream sample	Al, Cu		Cu		As, Cu, Hg
Mazama District					
Goat Creek Upstream					As
Goat Creek Downstream	Cu				Cu
Slate Creek District					
Bonita Creek Upstream					As, Cu
Bonita Creek Downstream					As, Cu
Monte Cristo District					
Glacier Creek Upstream					Sb, As, Cu, Pb, Hg, Zn
Glacier Creek Downstream	As, Cu, Cd, Fe, Zn	As, Cu, Zn			Sb, As, Cu, Pb, Zn
Royal Reward Mine Area					
Green River Upstream					Fe
Green River Downstream					As, Cu
Deer Trail District					
Alder Creek Upstream					
Alder Creek Downstream	As, Cu, Fe, Pb, Zn	Fe, Pb		Fe	As, Cd, Cu, Pb, Mn, Ag, Zn
Big Chief Mine Area					
N Fk Clugston Crk Upstream					
N Fk Clugston Crk Downstream	Al, Cd, Cu, Pb, Zn	Pb, Zn	Zn		Cd, Pb, Ni, Zn
Morton Cinnabar District					
Chapman Creek Upstream					
Barnum-McDonnell Mine? Downstream	Cu, Pb, Zn				Cu, Cr, Fe, Pb, Hg, Ni, Zn
Mineral Creek Area					
Mineral Creek Upstream					Cu, Fe
Mineral Creek Downstream	As, Al, Fe, Zn	As, Fe		Fe	As, Cu, Fe
Gold Creek Area					
Foggy Dew Creek Upstream					
Gold Creek Downstream	As, Zn				

The downstream water sample in the North Fork of Clugston Creek at the Big Chief Mine Area exceeded the state water quality standard for zinc during low flow, increasing from 0.5 ug/L at the upstream sample to 335 ug/L downstream. During high flow, the concentration of zinc increased from the upstream value of less than 0.2 ug/L to 177 ug/L. The downstream concentration did not exceed the water quality standard, but clearly illustrates the water quality impact from the district. Sediment quality guidelines were exceeded for cadmium, lead, nickel, and zinc, metals known to be associated with the ore mined in the district.

The sampling for this study was mostly in streams that were somewhat distant from the inactive and abandoned mines that could potentially discharge metals. In view of the low discharge from these mines into the adjacent streams during the drought, dilution was expected to influence the water quality results, and the importance of subtle changes in concentrations were potentially significant.

With this in mind, in Table 44 the authors also listed sites where there was at least a 2-fold increase in metals concentration downstream compared to the upstream sample. By this analysis, zinc, copper, and arsenic had the most frequent increases in downstream concentration. The table shows that all of the districts, except the Slate Creek District and the Royal Reward Mine Area, had an impact on the water quality of the receiving stream.

In four districts, the downstream concentration of some metals exceeded the upstream concentration by more than 10-fold: in the Monte Cristo District, arsenic, zinc, and copper had more than 10-fold increases; in the Deer Trail District, iron and lead increased more than 10-fold; in the Big Chief Mine Area, lead and zinc increased more than 10-fold; and in the Mineral Creek Area, arsenic and iron had more than 10-fold downstream concentration increases. The study found that the water quality guideline for iron was exceeded in the Deer Trail District and in the Mineral Creek Area.

Comparing sediment quality results with water quality results suggested that sediment quality was a better indicator of the mining district impacts on the receiving waters than the water quality parameters. Metals in sediment samples compared well with the mineralogy of the ore deposits mined in the districts. Sediment quality guidelines were exceeded for at least one metal in all districts except the Gold Creek Area.

The Morton Cinnabar District had the highest mercury concentration in sediments found in a downstream sample during this study. The highest concentration of arsenic in sediments was found in the three districts where arsenic was well documented as a major constituent of the ore. The highest arsenic concentration, 543 mg/Kg, was found at the Monte Cristo District where arsenic was documented in the ore. At the Royal Reward Mine Area, where arsenic was the primary material mined, the upstream sample concentration was 6 mg/Kg while the downstream sample concentration was 166 mg/Kg. In the Mineral Creek Area, where visible arsenic mineralization occurred, the arsenic concentration was 7 mg/Kg in the upstream sample. The downstream sample concentration was 108 mg/Kg.

An exception to the sediment indicator occurred in the Gold Creek Area, where antimony was mined. No antimony was found in the sediments downstream of this district, although low recoveries for antimony were reported in the laboratory spike.

Table 45 contains numerous miscellaneous field measurements of pH, conductivity, and temperature. The measurements were taken in various mining districts not included in this present study and where no water samples were collected. They may be considered reconnaissance measurements.

Appendix H includes the field measurements at the sites where water samples were collected during this present study as well as measurements at nearby mines and streams where no water samples were collected. The results are reported in this study for background purposes to compare to future measurements, if additional water quality sampling is conducted in these mining districts. The data are also a contribution to information being compiled in the DNR mining database.

Table 45. Field Measurements in Miscellaneous Mining Districts

Sample Location	Temp. (^oC) High Flow	Temp. (^oC) Low Flow	pH (units) High Flow	pH (units) Low Flow	Cond. (umho/cm) High Flow	Cond. (umho/cm) Low Flow
Snoqualmie District (King Co.)						
Clipper (middle) adit seepage	NM	6.8	NM	7.02	NM	78
Hardscrabble Crk above Mid Fk Snoq R	NM	7.1	NM	6.77	NM	10
Mid Fk Snoq R above Hardscrabble Crk	NM	6.5	NM	6.78	NM	22
Mid Fk Snoq R near Condor-Hemlock	NM	7.0	NM	6.73	NM	23
Morse Creek District (Yakima Co.)						
Small Crk east of Morse Crk Copper mine	NM	8.4	NM	6.46	NM	100
Morse Crk Copper adit (ARD)	6.7	6.6	6.84	6.20	150	177
Morse Crk below Boston Claim	10.2	8.3	7.47	6.80	29	63
Trib to Morse Crk below Boston Claim	10.6	10.0	7.42	6.65	105	112
Above Elizabeth Gold Hill dump	6	5.6	7.49	6.78	69	192
Below Elizabeth Gold Hill dump	8.8	7.7	7.94	7.03	163	189
Morse Crk near Scout Claim	NM	8.1	NM	7.34	NM	53
Flowing well @ cabin	7.2	6.5	7.83	6.98	138	189
Morse Crk upstream @ footbridge	12.6	8.7	7.57	7.34	15	26
Spring near trailhead	4.5	4.2	7.49	7.53	57	68
Deep Lake Area Mines (Stevens Co.)						
Below Shoemaker Mine	4.6	NM	8.30	NM	119	NM
Below Bechtol Mine	8.2	NM	8.54	NM	507	NM
Deep Lake (east shore)	11.8	NM	8.50	NM	373	NM
Republic Area (Ferry Co.) (Raforth et al, 2000)						
Eureka Crk	10.2	8.2	7.25	7.77	908	1208
Granite Crk @ Lilly Crk Rd	9.5	5.9	7.48	7.93	162	263
Swamp Crk (upstream sample)	11	8.7	6.93	7.40	149	388
Republic Area (Ferry Co.) (This study)						
Eureka Crk	10.7	NM	8.50	NM	1164	NM
Granite Crk @ Lilly Crk Rd	9	NM	8.31	NM	177	NM
Swamp Crk (upstream sample)	13.5	NM	7.73	NM	527	NM

Table 45 (continued)

Sample Location	Temp. (^oC) High Flow	Temp. (^oC) Low Flow	pH (units) High Flow	pH (units) Low Flow	Cond. (umho/cm) High Flow	Cond. (umho/cm) Low Flow
Colville Area (Stevens Co.)						
Old Dominion adit discharge	11	10.7	7.55	7.39	408	484
Stream below Old Dominion adit	10.8	7.8	7.9	7.96	405	454
Admiral Mine seepage	7.9	NM	8.72	NM	732	NM
Admiral Mine downstr. below waste rock	5.9	NM	8.34	NM	190	NM
Admiral Mine upstream	5.6	NM	8.31	NM	173	NM
Copper King Mine, middle adit discharge	NM	7.7	NM	7.54	NM	650
Bonanza adit discharge (strong H_2S)	NM	11.4	NM	6.72	NM	2220
Blue Ridge Mine adit drainage	NM	6.2	NM	7.59	NM	587
Orient District (Stevens County)						
First Thought Mine seep	NM	4.8	NM	7.25	NM	680

NM = not measured

Recommendations

The value of sampling and analysis using the EPA ultra low-level method has been reaffirmed by this study. The ability of the method to yield results at concentrations not previously attained is valuable for assessing water quality impacts in receiving waters where previous data were constrained by detection limits. This EPA method should be part of future studies.

At least two of the mining districts should be investigated further based on the water quality data from this study. The North Fork of Clugston Creek, adjacent to the Big Chief Mine, had the highest concentration of zinc during both low flow and high flow. The mine was not sampled in this study. The unnamed stream in the St Helens District exceeded the water quality standard for copper. Additional samples should be collected from that stream as well as from other streams and mines that were not sampled in this study.

Some districts substantially exceeded one sediment quality guideline, and other districts exceeded several guidelines. Additional sediment sampling should be conducted in other streams that drain those districts to determine the extent of sediment quality impacts. The districts where additional sampling should occur are: St Helens (copper, arsenic, and mercury), Slate Creek (arsenic), Monte Cristo (arsenic), Deer Trail (cadmium, copper, silver, zinc, and lead), Big Chief Mine Area (cadmium, zinc, and lead), Morton Cinnabar District (zinc, lead, and mercury), and the Mineral Creek Area (arsenic).

The following field parameters should continue to be measured in future studies: pH, conductivity, and temperature. Flow measurements should also be continued, even though flows were considered estimates in this study due to the rough substrate encountered in the streams.

The general chemistry parameters in this study are considered the minimum that should be included in future studies. Although this study did not document water quality exceedences for turbidity or total suspended solids, these parameters should be carried forward for water quality impacts assessment.

Sulfate and total dissolved solids should be retained in future projects as an extension of the Acid Rock Drainage (ARD) fingerprinting process investigation using the SO_4:TDS ratio. This ratio is still considered an indicator for ARD. Additional data are necessary to determine a threshold value for this ratio. Concurrent sampling for metals should be continued as confirmation of the utility of this concept. The importance of concurrent sampling was illustrated at the Big Chief Mine where the mine discharge was tested only with field parameters. The mine discharge had neutral pH and low specific conductance, but the concentration of zinc in the receiving water downstream of the mine exceeded the water quality standard.

This study documents the role of dilution introduced by taking a regional sampling approach to assessing water quality impacts from mine discharges. When water quality sampling is conducted at widely spaced locations, cumulative impacts are measured. However, impacts are masked from individual mines discharges that may have significant local effect. Mine drainage should be sampled from one or more mines and compared to results in the receiving water.

The potential role of low snowpack and low runoff, and the linkage to water quality impacts, cannot be foreseen in a project like this. Data obtained under such conditions should be viewed with the idea that water quality impacts are minimized but sediment quality is not affected. A lower threshold of the definition of what constitutes water quality impacts should be used when comparing upstream and downstream results.

This study was a continuation of the inventory process for inactive and abandoned mines that is maintained by DNR. Water quality and sediment quality documentation are an integral part of that inventory. Studies of this type should be routinely conducted to assess metals mining impacts on receiving waters. Future studies should use the DNR database to identify candidate districts. Important information in the database includes documentation of any mine drainage, extent of mining activity, and mineralogy of the ore and host rock. An example of the information available in the database is found in the Washington Division of Geology and Earth Resources Open File Report 2001-1 (Wolff et al., 2001).

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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 for Water Samples (ug/L)

Date	13-Oct-00		10-May-01	
Sample No.	418627	418626	198027	198026
Blank Type	Bottle Blank[a]	Filter Blank[b]	Bottle Blank	Filter Blank
Iron	20 U	na	20 U	na
Aluminum	20 U	na	50 UJ	na
Zinc	na	0.4 U	na	0.21
Copper	na	0.05 U	na	0.05 U
Cadmium	na	0.02 U	na	0.02 U
Lead	na	0.02 U	na	0.02 U
Mercury	0.002 U	na	0.002 U	na

na = not analyzed
U = not detected at or above reported value
UJ = not detected at or above the reported estimated value

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

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

Appendix C. Results from Field Replicates on Water Samples

Location	Glacier Creek - Downstream			N. Fk. Clugston Creek - Downstream		
Date	18-Aug-00			09-May-01		
Sample No.	348074	348076	RPD	1980221	198028	RPD
TSS (mg/L)	na	na	- -	1 J	1 UJ	0%
TDS (mg/L)	na	na	- -	256	255	0%
Sulfate (mg/L)	na	na	- -	15	15	0%
Turbidity (mg/L)	na	na	- -	0.5 UJ	0.5 UJ	0%
Iron (ug/L)	20 U	95	>130%	20 U	20 U	0%
Aluminum "	20 U	20 U	0%	50 UJ	50 UJ	0%
Zinc "	5.6	5.6	0%	177	177	0%
Copper "	0.28	0.26	7%	0.14	0.14	0%
Arsenic "	9.2	9.3	1%	0.55	0.54	2%
Cadmium "	0.041	0.036	13%	0.072	0.072	0%
Lead "	0.02 U	0.02 U	0%	0.45	0.43	5%
Mercury "	0.002 U	0.002 U	0%	0.002 U	0.002 U	0%
Hardness (mg/L)	6.8	na	- -	226	210	7%

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

Appendix D. Results on Laboratory Splits for General Chemistry (mg/L)

Parameter	Location	Date	Sample Number	Analysis #1	Analysis #2	RPD
TSS	Green River - Downstream	4-Apr-01	148025	2	2	0%
	Gold Creek - Downstream	9-Apr-01	158001	1	1	0%
	Alder Creek - Upstream	9-May-01	198022	38 J	41 J	8%
	Bonita Creek - Downstream	17-Aug-00	348070	3 J	3 J	0%
	N.F. Clugston Cr. - Upstream	5-Oct-00	408612	2	2	0%
TDS	Chapman Creek - Upstream	3-Apr-01	148022	28	33	16%
	Foggy Dew Creek - Upstream	9-Apr-01	158000	110	118	7%
	Alder Creek - Downstream	9-May-01	198023	199	204	2%
	Goat Creek - Upstream	19-Jun-01	258006	14	15	7%
	Bonita Creek - Upstream	17-Aug-00	348068	43 J	40 J	7%
	N.F. Clugston Cr. - Downstream	5-Oct-00	408610	280	279	0%
	Chapman Creek - Upstream	11-Oct-00	418614	39	44	12%
Sulfate	Mineral Creek - Upstream	3-Apr-01	148020	1.1	1.1	0%
	Alder Creek - Upstream	9-May-01	198022	3.9	3.8	3%
	St. Helens Creek - Upstream	14-Jun-01	248040	8.4	8.2	2%
	N.F. Clugston Cr. - Downstream	4-Oct-00	408610	20	20	0%
	Chapman Creek - Upstream	11-Oct-00	418614	1.3	1.3	0%
Turbidity	Mineral Creek - Upstream	3-Apr-01	148020	0.5 J	0.5 J	0%
	Alder Creek - Downstream	9-May-01	198023	3.3 J	3.2 J	3%
	St. Helens Creek - Downstream	14-Jun-01	248041	0.5 J	0.5 J	0%
	Glacier Creek - Upstream	18-Aug-00	348072	0.6 J	0.7 J	15%
	N.F. Clugston Cr. - Downstream	5-Oct-00	408610	0.7 J	0.7 J	0%
	Chapman Creek - Upstream	11-Oct-00	418614	0.9 J	0.9 J	0%

J = estimated

RPD = relative percent difference (range as percent of duplicate mean)

Appendix E. Results on Laboratory Splits for Metals and Hardness in Water Samples

Location	Glacier Creek - Downstream			N. Fk. Clugston Creek - Downstream		
Date	18-Aug-00			05-Oct-00		
Sample No.	348062A	348062B	RPD	408610A	408610B	RPD
Iron (ug/L)	20 U	20 U	0%	34	34	0%
Aluminum "	77	71	8%	55	62	12%
Zinc "	7.1	7.0	1%	339	327	4%
Copper "	38	38	0%	0.29	0.34	16%
Arsenic "	0.2 UJ	0.2 UJ	0%	na	na	- -
Cadmium "	0.045	0.097	73%	0.14	0.15	7%
Lead "	0.02 U	0.02 U	0%	0.81	0.81	0%
Mercury "	na	na	- -	0.002 U	0.004	>67%
Hardness (mg/L)	na	na	- -	264	266	1%

Location	N. Fk. Clugston Creek - Downstream		
Date	09-May-01		
Sample No.	198028A	198028B	RPD
Iron (ug/L)	20 U	34	52%
Aluminum "	50 UJ	50 UJ	0%
Zinc "	177	na	- -
Copper "	0.14	na	- -
Arsenic "	0.54	na	- -
Cadmium "	0.072	na	- -
Lead "	0.43	na	- -
Mercury "	0.002 U	0.002 U	0%
Hardness (mg/L)	210	211	0%

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

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

	Flow (cfs)		Temp. (°C)		pH (units)		Cond. (umho/cm)		Hardness (mg/L)	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
St Helens District										
Upstream sample	0.04J	0.01J	4.3	6.4	7.36	7.70	36	39	13.6	11.6
Downstream sample	0.2J	0.02J	7.3	10.4	7.30	6.85	59	86	21.6	30.7
Mazama District										
Goat Creek Upstream	10J	5J	5.0	12.2	8.03	7.48	85	122	42.5	57.2
Goat Creek Downstream	18J	6.6J	8.1	13.9	8.08	6.92	87	183	44.4	87.5
Slate Creek District										
Bonita Creek Upstream	0.5J	0.1J	6.7	15.8	7.88	6.81	29	56	15.6	24.4
Bonita Creek Downstream	8J	0.7J	8.9	6.8	7.86	5.95	52	77	24.4	36.0
Monte Cristo District										
Glacier Creek Upstream	30J	7.5J	2.5	3.4	7.33	6.78	20	18	8.13	6.92
Glacier Creek Downstream	85J	20J	7.0	7.3	7.15	7.02	19	19	7.38	6.80
Royal Reward Mine Area										
Green River Upstream	NM	NM	7.0	13.1	7.90	6.65	39	46	13.6	17.7
Green River Downstream	NM	NM	6.3	12.3	7.82	6.45	40	50	14.3	19.6
Deer Trail District										
Alder Creek Upstream	.05J	.05J	4.9	5.2	8.20	8.17	80	224	70.7	124
Alder Creek Downstream	.3J	.2J	10.9	6.7	8.52	8.03	288	383	150	196
Big Chief Mine Area										
N Fk Clugston Crk Upstream	1.5J	0.6J	4.2	4.3	8.43	8.02	392	405	219	233
N Fk Clugston Crk Downstream	2J	1J	5.9	6.8	8.49	8.19	410	451	226	263
Morton Cinnabar District										
Chapman Crk Upstream	.06J	0.03J	5.9	9.9	6.60	7.21	33	32	8.94	11.1
Barnum-McDonnell Mine? Downstream	.05J	0.03J	10.1	10.1	7.39	7.30	524	569	248	284
Mineral Creek Area										
Mineral Crk Upstream	NM	NM	4.0	7.7	7.74	7.35	41	70	14.7	21.5
Mineral Crk Downstream	NM	NM	3.9	7.9	7.63	7.36	41	61	15.3	24.1
Gold Creek Area										
Foggy Dew Creek Upstream	4J	2J	3.5	5.2	8.16	7.58	170	185	84.9	21.8
Gold Creek Downstream	10J	6J	5.9	6.6	8.36	8.23	187	201	94.8	102

Appendix F. (continued)

Sample Location	TDS (mg/L)		TSS (mg/L)		Turbidity (NTU)		Sulfate (mg/L)		Sulfate:TDS	
	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
St Helens District										
Upstream sample	30J	34J	1UJ	1 UJ	.5UJ	0.5UJ	8.33	7.74J	28%	23%
Downstream sample	48J	73J	1UJ	1 UJ	.5UJ	0.5UJ	16.2	25.3J	34%	35%
Mazama District										
Goat Creek Upstream	255	79J	3J	1 UJ	.5UJ	0.5UJ	3.29	3.4J	1%	5%
Goat Creek Downstream	86	116J	1J	1 UJ	.5UJ	0.5UJ	3.03	12.2J	4%	11%
Slate Creek District										
Bonita Creek Upstream	24	42J	1U	1 J	.5U	0.5UJ	2.69	4.17J	11%	10%
Bonita Creek Downstream	36	53J	1U	3 J	.5U	0.5UJ	3.61	5.16J	10%	10%
Monte Cristo District										
Glacier Creek Upstream	14	19J	1U	1 UJ	.5UJ	0.7J	1.44	1.32J	10%	7%
Glacier Creek Downstream	15	21J	1U	1 J	.5UJ	0.5UJ	2.09	1.72J	14%	8%
Royal Reward Mine Area										
Green River Upstream	36	110	2	8J	1.2	4.4J	1.37	1.96	4%	2%
Green River Downstream	38	53	2	3J	1.2	2.1J	1.48	2.16	4%	4%
Deer Trail District										
Alder Creek Upstream	108	174	40	2J	1.3J	1.0J	3.88	3.35	4%	2%
Alder Creek Downstream	202	254	19	12J	3.3J	5.2J	23.9	24.8	12%	10%
Big Chief Mine Area										
N Fk Clugston Crk Upstream	251	254	2J	2	.5UJ	.5UJ	9.71	7.61	4%	3%
N Fk Clugston Crk Downstream	256	281	1J	5	.5UJ	.8J	14.9	19.5	6%	7%
Morton Cinnabar District										
Chapman Crk Upstream	31	42	1U	1U	.5UJ	.9J	1.07	1.31	3%	3%
Barnum-McDonnell Mine? Downstream	305	363	1U	1U	.5UJ	.5UJ	42.6	30.8	14%	8%
Mineral Creek Area										
Mineral Crk Upstream	41	63	1U	1U	.5J	.5UJ	1.14	1.60	3%	3%
Mineral Crk Downstream	39	66	1U	1U	.5UJ	.5UJ	1.33	1.79	3%	3%
Gold Creek Area										
Foggy Dew Creek Upstream	114	127	1U	1U	.9J	.5UJ	9.15	10.1	8%	8%
Gold Creek Downstream	115	158	1	1U	.5UJ	.5UJ	9.95	21.0	9%	13%

U = Not detected at or above the reported result.
J = Estimated result
UJ = Estimated value below the detection limit
NM = Not Measured

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

	Total Recoverable Aluminum		Total Recoverable Iron		Dissolved Copper		Dissolved Zinc	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
St Helens District								
Upstream sample	20U	20U	20UJ	20U	**4.69**	**5.98**	**4.9**	**6.11**
Downstream sample	**84**	**74**	**21J**	20U	**38***	**38.1***	**4.6**	**7.07**
Mazama District								
Goat Creek Upstream	**77**	**89**	**27**	20U	**0.55**	**0.16**	0.2U	**0.63J**
Goat Creek Downstream	**64**	**130**	**23**	20U	**0.31**	**0.40**	0.2U	**0.43J**
Slate Creek District								
Bonita Creek Upstream	50U	**46**	**23J**	20U	**0.50**	**0.852**	0.2U	**0.52J**
Bonita Creek Downstream	50U	**69**	20UJ	20U	**0.38**	**0.506**	**0.37**	**0.95J**
Monte Cristo District								
Glacier Creek Upstream	50U	20U	20UJ	20U	.02U	**0.264**	**0.2**	**1.8J**
Glacier Creek Downstream	50U	20U	20UJ	**95**	**0.3**	**0.27**	**5.04**	**5.75**
Royal Reward Mine Area								
Green River Upstream	**122**	**318**	**75**	**299**	**0.18**	**0.33**	**0.22**	0.4U
Green River Downstream	**109**	**130**	**85**	**140**	**0.17**	**0.31**	.2U	**0.61**
Deer Trail District								
Alder Creek Upstream	140J	**77**	**64**	**42**	**0.20**	**0.16**	0.2U	0.4U
Alder Creek Downstream	**163J**	**70**	**218**	**775***	**0.60**	**0.39**	**0.53**	**0.93**
Big Chief Mine Area								
N Fk Clugston Crk Upstream	**55J**	**20**	20U	**26**	**0.13**	**0.11**	0.2U	**0.50**
N Fk Clugston Crk Downstream	50UJ	**65**	20U	**34**	**0.14**	**0.31**	**177**	**335***
Morton Cinnabar District								
Chapman Crk Upstream	**63**	**27**	20U	**20**	**0.13**	**0.22**	**0.28**	**0.4**
Barnum-McDonnell Mine? Downstrear	**52**	**20**	**22**	**23**	**0.49**	**0.84**	**0.88**	**1.3**
Mineral Creek Area								
Mineral Crk Upstream	**106**	**24**	**48**	**25**	**0.16**	**0.29**	**0.26**	0.4U
Mineral Crk Downstream	**675**	**20**	**500***	**25**	**0.27**	**0.32**	**1.03**	0.4U
Gold Creek Area								
Foggy Dew Creek Upstream	50U	**20**	20U	**20**	**0.18**	**0.19**	0.2U	0.4U
Gold Creek Downstream	**51**	**20**	20U	**20**	**0.18**	**0.12**	**0.43**	0.4U

Appendix G. (continued)

	Total Recoverable Arsenic		Dissolved Cadmium		Dissolved Lead		Total Recoverable Mercury	
Sample Location	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
St Helens District								
Upstream sample	0.2U	0.2UJ	**0.043**	**0.039**	**0.033**	0.02U	**0.0044**	0.002U
Downstream sample	0.2U	0.2UJ	**0.042**	**0.071**	0.02U	0.02U	**0.0053**	0.002U
Mazama District								
Goat Creek Upstream	**0.62**	0.2UJ	0.02U	0.02U	0.02U	0.02U	**0.0026**	0.002U
Goat Creek Downstream	**0.94**	0.2UJ	0.02U	0.02U	0.02U	0.02U	0.002U	0.002U
Slate Creek District								
Bonita Creek Upstream	**9.29**	**7.15**	0.02U	0.02U	0.02U	0.02U	**0.0061**	0.002U
Bonita Creek Downstream	**7.42**	**6.00**	0.02U	0.02U	0.02U	0.02U	**0.0049**	0.002U
Monte Cristo District								
Glacier Creek Upstream	**0.28**	**4.52**	0.02U	0.02U	0.02U	**0.032**	**0.0042**	0.002U
Glacier Creek Downstream	**7.37**	**9.24**	**0.041**	**0.039**	**0.020**	0.02U	**0.0058**	0.002U
Royal Reward Mine Area								
Green River Upstream	**0.37**	**0.77**	0.02U	0.02U	0.02U	0.02U	0.002U	0.002U
Green River Downstream	**0.44**	**0.66**	0.02U	0.02U	0.02U	0.02U	0.002U	0.002U
Deer Trail District								
Alder Creek Upstream	**0.74**	**0.98**	0.02U	0.02U	0.02U	0.02U	0.002U	0.002U
Alder Creek Downstream	**1.67**	**1.60**	0.02U	0.02U	**0.19**	**0.218**	**0.0024**	**0.0023**
Big Chief Mine Area								
N Fk Clugston Crk Upstream	**0.37**	0.5U	0.02U	0.02U	0.02U	0.02U	0.002U	0.002U
N Fk Clugston Crk Downstream	**0.55**	**0.57**	**0.072**	**0.14**	**0.454**	**0.803**	0.002U	**0.0026**
Morton Cinnabar District								
Chapman Crk Upstream	0.2U	0.5U	0.02U	0.02U	0.02U	0.02U	0.002U	**0.002**
Barnum-McDonnell Mine? Downstream	0.2U	0.5U	0.02U	0.02U	**0.032**	**0.089**	0.002U	0.002U
Mineral Creek Area								
Mineral Crk Upstream	0.2U	0.5U	0.02U	0.02U	0.02U	0.02U	0.002U	0.002U
Mineral Crk Downstream	**16.1**	**8.8**	0.02U	0.02U	0.02U	0.02U	0.002U	0.002U
Gold Creek Area								
Foggy Dew Creek Upstream	**0.30**	0.5U	0.02U	0.02U	0.02U	0.02U	0.002U	0.002U
Gold Creek Downstream	**1.36**	**1.2**	0.02U	0.02U	0.02U	0.02U	0.002U	0.002U

Note: Detections highlighted in BOLD
*exceeds water quality criterion
U = Not detected at or above the reported result.
J = Estimated result
UJ = Estimated value below the detection limit

Appendix H. Field Measurements for Miscellaneous Mines and Streams

Sample Location	Temp. (°C) High Flow	Temp. (°C) Low Flow	pH (units) High Flow	pH (units) Low Flow	Cond. (umho/cm) High Flow	Cond. (umho/cm) Low Flow
St Helens District						
Polar Star Mine	6.7	12.5	4.52	4.29	1283	488
Stream below Polar Star	8.0	9.5	6.67	6.67	40	41
Green River above bridge	10.2	17.8	6.72	6.54	34	51
Green River @ horse camp	10.1	15.8	6.50	6.48	36	52
Downstream sample	7.3	10.4	7.30	6.85	59	86
Discharge from collapsed adit	7.1	9.0	7.68	7.13	56	121
Creek upstream of collapsed adit	6.8	9.7	7.80	7.20	59	91
Discharge from adit	5.5	6.8	7.31	7.24	147	142
Creek upstream of adit	5.5	9.3	7.72	7.30	40	45
Upstream sample	4.3	6.4	7.36	7.70	36	39
Mazama District						
Goat Crk @ bridge (downstream sample)	8.1	13.9	8.08	6.92	87	183
Goat Spring	NM	16.3	NM	7.24	NM	167
Stream below Chinaman Mine	NM	12.3	NM	7.26	NM	136
Goat Crk @ Vanderpool Crossing (upstream sample)	5.0	12.2	8.03	7.48	85	122
Goat Crk below Montana Crk	NM	14.1	NM	7.9	NM	147
Montana Crk above Goat Crk	NM	11.6	NM	7.47	NM	303
Slate Creek District						
Bonita Crk downstream sample	8.9	6.8	7.86	5.95	52	77
Bonita Crk upstream sample	6.7	15.8	7.88	6.81	29	56
Spring @ toe of Western Gold dump	5.8	NM	7.10	NM	38	NM
Western Gold adit	6.0	NM	7.56	NM	199	NM
Creek adjacent to Western Gold adit	9.2	11.8	7.94	5.97	58	91
New Light Mine	4.3	14.3	7.75	6.45	97	230
New Light middle adit	3.7	NM	7.62	NM	86	NM
Creek near Mammoth Mine	9.7	NM	8.02	NM	82	NM
Mammoth Mine seepage	5.5	NM	8.16	NM	268	NM
Monte Cristo District						
Glacier Crk upstream sample	2.5	3.4	7.33	6.78	20	18
Glacier Crk below waste rock	4.4	3.9	7.80	6.56	18	23
Glacier Crk downstream sample @ bridge	7.0	7.3	7.15	7.02	19	19
Stream draining waste rock	10.4	NM	6.88	NM	111	NM
Royal Reward Mine Area						
Green River upstream sample	7.0	13.1	7.90	6.65	39	46
Green River downstream sample	6.3	12.3	7.82	6.45	40	50

Appendix H. (continued)

Deer Trail District						
Alder Creek upstream sample	4.9	5.2	8.20	8.17	80	224
Alder Creek downstream sample	10.9	8.7	8.52	7.50	288	510
Flowing drill hole casing	NM	6.8	NM	7.77	NM	342
Mine adit drainage	5.1	6.4	7.73	7.65	111	355
Tailings pond	13.5	NM	8.28	NM	288	NM
Tailings pond inlet	7.8	NM	8.34	NM	172	NM
Turk Mine seepage	7.2	NM	7.79	NM	118	NM
Stream below Turk, stream	4.0	NM	8.09	NM	175	NM
Keystone Mine adit drainage	NM	7.6	NM	8.05	NM	304
Queen Seal mill drainage (from pvc pipe)	NM	7.2	NM	7.55	NM	607
Queen Seal adit drainage (from pvc pipe)	NM	8.3	NM	7.43	NM	672
Big Chief Mine Area						
N Fk Clugston Crk upstream sample	4.2	4.3	8.43	8.02	392	405
N Fk Clugston Crk downstream sample	5.9	6.8	8.49	8.19	410	451
Big Chief Mine adit drainage	9.1	8.8	7.44	7.35	477	486
Chloride Queen waste rock seepage	10.3	8.3	8.15	7.46	289	561
S Fk Clugston Crk below Chloride Queen	4.9	4.4	8.33	7.98	167	270
S Fk Clugston Crk above Chloride Queen	4.3	3.2	8.38	7.62	200	202
Morton Cinnabar District						
Chapman Crk upstream sample	5.9	9.9	6.60	7.21	33	32
Barnum-McDonnell Mine?	10.1	10.1	7.39	7.30	524	569
Mineral Creek Area						
Mineral Crk upstream sample	4.0	7.7	7.74	7.35	41	70
Mineral Crk downstream sample	3.9	7.9	7.63	7.36	41	61
Arsenic Crk above road	4.0	8.0	7.65	7.33	57	80
Mineral Crk @ As outcrop	NM	7.2	NM	6.88	NM	375
Gallup Crk above old adit	4.0	6.7	7.68	7.33	33	98
Gold Creek Area						
Foggy Dew Crk upstream sample	3.5	5.2	8.16	7.58	170	185
Gold Creek downstream sample	5.9	6.6	8.36	8.23	187	201

NM = not measured

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

Sample Location	Al	Sb	Be	Cd	Cr	Cu	Fe	Mn	Ni	Ag	Zn	As	Pb	Hg	Se	Tl
St Helens District																
Upstream sample	3570	5UJ	0.2U	0.5U	5.9	251*	10400	119	5.5	1U	33.2	2.20	2.28	0.013	0.30	0.3UJ
Downstream sample	6400	5UJ	0.2U	0.5U	5.9	844*	19800	306	7.5	1U	35.0	28.1*	5.95	0.298*	0.78	0.3UJ
Mazama District																
Goat Creek Upstream	12900	7U	0.2U	0.7U	16.8	20.6	25100	404	9.5	1U	53.4	17.5*	5.08	0.021	0.30	0.3UJ
Goat Creek Downstream	11600	5UJ	0.2U	0.5U	19.5	33.3*	22800	350	10.9	1U	43.9	9.05	4.05	0.019	0.30	0.3UJ
Slate Creek District																
Bonita Creek Upstream	7300	5UJ	0.2U	0.5U	12.7	74.5*	13500	195	4.3	1U	27.2	70.2*	3.94	0.008	0.54	0.3UJ
Bonita Creek Downstream	15600	7UJ	0.2U	0.7U	25.5	59.8*	31900	379	15.4	1U	102	84.2*	18.7	0.061	0.32	0.3UJ
Monte Cristo District																
Glacier Creek Upstream	10500	6.2J*	0.2U	0.52	17.7	33.3*	25000	1190	13.4	1U	172*	251*	86.6*	0.254*	0.30	0.3UJ
Glacier Creek Downstream	12700	12J*	0.2U	0.5U	21.2	84.5*	29600	915	12.7	1U	190*	543*	76.3*	0.066	0.30	0.3UJ
Royal Reward Mine Area																
Green River Upstream	28000	5UJ	1.5U	5U	19.2	25.8	40300*	769	11.0	1.6	77.2	5.43	5.26	0.056	0.4U	0.3U
Green River Downstream	21500	5UJ	1U	2.5U	15.7	32.9*	39800	864	14.9	1.2	62.9	166*	4.21	0.042	0.47	0.3U
Deer Trail District																
Alder Creek Upstream	12500	5UJ	1U	0.5U	7.2	7.2	16800	399	3.2	1U	41.2	3.63	6.9	0.004U	0.55	0.41
Alder Creek Downstream	18000	5UJ	1U	2.9*	18.2	111*	31900	3980*	12.7	10.9*	452*	21*	447*	0.021	0.48	0.3U
Big Chief Mine Area																
N Fk Clugston Crk Upstream	6030	5UJ	1U	0.57	12.1	5.1	23400	223	12.6	1U	41.8	7.26	7.58	0.004U	0.4U	0.3U
N Fk Clugston Crk Downstream	6710	5UJ	1U	5.55*	9.37	10.2	11600	348	44.5*	1.5	6960*	4.31	186*	0.043	0.77	0.33
Morton Cinnabar District																
Chapman Crk Upstream	11000	5UJ	1U	0.5U	12.5	17.0	19400	496	10.3	1U	39	1.90	3.7	0.141	0.43	0.3U
Barnum-McDonnell Mine? Downstream	27000	5UJ	1U	5U	82.2*	60.3*	57300*	680	60.6*	1.7	412*	3.86	117*	99.2*	0.4U	0.3U
Mineral Creek Area																
Mineral Crk Upstream	28700	5U	1U	5U	39.8	56.6*	49400*	608	20.9	1.2	88.5	6.93	2.5	0.011	0.4U	0.3U
Mineral Crk Downstream	33200	5U	1U	5U	28.8	67.1*	45500*	624	20.6	1.0	87.9	108*	3.4	0.030	0.47	0.3U
Gold Creek Area																
Foggy Dew Creek Upstream	3850	5UJ	1U	0.5	14.0	3.60	7350	113	7.2	1U	20.8	1.60	1.4	.004U	0.4U	0.3U
Gold Creek Downstream	5180	5UJ	1U	0.5U	16.5	7.12	10000	142	7.7	1U	26.6	6.45	1.5	.004U	0.42	0.3U

*exceeds sediment quality guidelines

U = Not detected at or above the reported result.

J = Estimated result

UJ = Not detected at or above the reported estimated result

Appendix J. Key for Water and Sediment Samples

	Sample Number			GPS Location		Elevation	Sample Date	
	Fall 2000		Spring 2001					
Sample Location	Water	Sediment	Water	North	West		Fall 2000	Spring 2001
St Helens District								
Upstream sample	348060	348061	248040	46.3598	122.0784	4000	15-Aug	14-Jun
Downstream sample	348062	348063	248041	46.3551	122.0758	3185	15-Aug	14-Jun
Mazama District								
Goat Creek Upstream	348064	348065	198024	48.6566	120.3268	4000	16-Aug	10-May
Goat Creek Downstream	348066	348067	198025	NM	NM	2311	16-Aug	10-May
Filter Blank			198026					10-May
Bottle Blank			198027					10-May
Slate Creek District								
Bonita Creek Upstream	348068	348069	258008	48.7665	120.7181	6300	17-Aug	20-Jun
Bonita Creek Downstream	348070	348071	258009	48.7582	120.7158	5340	17-Aug	20-Jun
Monte Cristo District								
Glacier Creek Upstream	348072	348073	258006	47.9798	121.3616	4410	18-Aug	19-Jun
Glacier Creek Downstream	348074	348075	258007	47.9871	121.3931	2721	18-Aug	19-Jun
Glacier Creek Downstream Replicate	348076						18-Aug	
Royal Reward Mine Area								
Green River Upstream	408602	408603	148024	47.3225	121.8993	780	2-Oct	4-Apr
Green River Downstream	408600	408601	148025	47.3194	121.9323	580	2-Oct	4-Apr
Deer Trail District								
Alder Creek Upstream	408604	408605	198022	48.0353	118.0958	3580	4-Oct	9-May
Alder Creek Downstream	408606	408607	198023	48.0373	118.0942	3400	4-Oct	9-May
Big Chief Mine Area								
N Fk Clugston Crk Upstream	108612	408613	198020	48.7083	117.8501	3572	5-Oct	9-May
N Fk Clugston Crk Downstream	408608	480609	198021	48.7038	117.8605	2989	5-Oct	9-May
N Fk Clugston Crk Downstream Replicate	408610		198028				5-Oct	9-May
Morton Cinnabar District								
Chapman Crk Upstream	418614	418615	148022	46.5555	122.2263	2120	11-Oct	3-Apr
Barnum-McDonnell Mine? Downstream	418616	418617	148023	46.5455	122.2372	1120	11-Oct	3-Apr
Mineral Creek Area								
Mineral Crk Upstream	418620	418621	148020	46.6642	122.1039	2107	12-Oct	3-Apr
Mineral Crk Downstream	418618	418619	148021	46.6661	122.1078	2063	12-Oct	3-Apr
Gold Creek Area								
Foggy Dew Creek Upstream	418622	418623	158000	NM	NM	2160	13-Oct	9-Apr
Gold Creek Downstream	418624	418625	158001	NM	NM	1950	13-Oct	9-Apr
Filter Blank	418626						13-Oct	
Bottle Blank	418627						13-Oct	

NM = not measured

Appendix K. List of Minerals Referred to in this Report

Anglesite: $PbSO_4$ ---- 68.32% Pb (MW = 303.26 gm)
Argentite: Ag_2S ---- 87.06% Ag (MW = 247.80 gm)
Arsenopyrite: FeAsS ---- 46.01% As (MW = 162.83 gm)
Azurite: $Cu_3(CO_3)_2(OH)_2$ ---- 55.31% Cu (MW = 344.67 gm)
Biotite: $K(Mg,Fe^{2+})_3(Al,Fe^{3+})Si_3O_{10}(OH,F)_2$
Calcite: $CaCO_3$ ---- 40.04% Ca (MW = 100.09 gm)
Cerussite: $PbCO_3$ ---- 77.54% Pb (MW = 267.21 gm)
Chalcocite: Cu_2S ---- 79.85% Cu (MW = 159.16 gm)
Chalcopyrite: $CuFeS_2$ ---- 34.63% Cu (MW = 183.53 gm)
Dolomite: $CaMg(CO_3)_2$ ---- 21.73% Ca (MW = 184.40 gm)
Epidote: $Ca_2(Fe^{3+},Al)_3(SiO_4)_3(OH)=Ca_2(Fe,Al)Al2(SiO4)(Si2O7)O(OH)$
Electrum: an alloy of gold with silver
Fluorite: CaF_2 ---- 48.67% F (MW = 78.07 gm)
Galena: PbS ---- 86.60% Pb (MW = 239.27 gm)
Hematite: Fe_2O_3 ---- 69.94% Fe (MW = 159.69 gm)
Limonite: $Fe^{3+}O(OH)$
Magnetite: $Fe^{2+}Fe^{3+}{}_2O_4$ ---- 72.36% Fe (MW = 231.54 gm)
Malachite: $Cu_2(CO_3)(OH)_2$ ---- 57.48% Cu (MW = 221.12 gm)
Molybdenite: MoS_2 ---- 59.94% Mo (MW = 160.07 gm)
Naumannite: Ag_2Se ---- 26.79% Se (MW = 294.70 gm)
Polybasite: $(Ag,Cu)_{16}Sb_2S_{11}$
Pyrargyrite: Ag_3SbS_3 ---- 22.48% Sb (MW = 541.55 gm)
Pyrite: FeS_2 ---- 46.55% Fe (MW = 119.98 gm)
Pyrrhotite: Fe(1-x)S(x=0-0.17) ---- 62.33% Fe (MW = 85.12 gm)
Quartz: SiO_2 ---- 46.74% Si (MW = 60.08 gm)
Realgar: AsS ---- 70.03% As (MW = 106.99 gm)
Scheelite: $CaWO_4$ ---- 63.85% W (MW = 287.93 gm)
Sericite: (Muscovite) $KAl_2(Si_3Al)O_{10}(OH,F)_2$ ---- 9.82% K (MW = 398.31 gm)
Sphalerite: (Zn,Fe)S ---- 67.10% Zn (MW = 97.46 gm)
Stephanite: Ag_5SbS_4 ---- 68.33% Ag (MW = 789.36 gm)
Stibnite: Sb_2S_3 ---- 71.68% Sb (MW = 339.70 gm)
Tellurides: A combination of a metal and tellurium (such as Hessite, Ag_2Te)
Tetrahedrite: $(Cu,Fe)_{12}Sb_4S_{13}$
Umangite: Cu_3Se_2 ---- 54.69% Cu (MW = 348.56 gm)

Appendix L. Glossary of Geologic and Mining Terms

adit: A nearly 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, which 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 50-200C.

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.

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.

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

greenschist: Schist characterized by green color. Product of regional metamorphism. (Green color is imparted by mineral chlorite.)

greenschist facies: Assemblage of minerals formed between 150 and 250º C during regional metamorphism.

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, CaCO3, 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 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 deposits 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 a 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.

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.

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

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.

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.

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

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

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.