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Water and Sediment Quality in the Vicinity of Cleveland Mine, Hunters Creek Drainage, Stevens County

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Water and Sediment Quality in the Vicinity of Cleveland Mine, Hunters Creek Drainage, Stevens County

by
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Abstract

Water and sediment quality were assessed in a small unnamed tributary to the North Fork of Hunters Creek in Stevens County. The stream largely consists of drainage from two abandoned mine portals at the Cleveland Mine site. The Bureau of Land Management is undertaking a cleanup of tailings piles at the mine.

Because of buffering by limestone, the portal discharges are not acidic and metals concentrations generally met state standards during the summer/fall period. Due to the presence of tailings, high concentrations of iron, zinc, lead, arsenic, cadmium, silver, and antimony occur in stream sediments from the mine to the North Fork of Hunters Creek. The level of sediment contamination would be expected to have severe adverse effects on benthic organisms.

Recommendations include additional water sampling during spring runoff conditions, assessing the downstream extent of sediment contamination in Hunters Creek, and evaluating options for sediment cleanup on non-BLM land.

Acknowledgements

The access to the study site given by property owners is very much appreciated. Field samples were collected with the assistance of Clarence George and Sherman Spencer, Ecology Eastern Regional Office, Toxics Cleanup Program. The good work of Manchester Laboratory staff in analyzing the samples is gratefully acknowledged, especially Dickey Huntamer, Jim Ross, Randy Knox, and Sally Cull.

This report benefited from review comments by Dave George, Jake Jakabosky, Will Kendra, and Matt Kadlec.

Summary

Plans for a Bureau of Land Management (BLM) cleanup of tailings piles at the Cleveland Mine site in Stevens County prompted a survey by the Washington State Department of Ecology to assess the extent of contamination in the North Fork Hunters Creek watershed due to continued discharge from two abandoned mine portals. The portal discharges account for most of the flow in a small unnamed stream running from the mine to the North Fork. The tailings cleanup is scheduled for completion by September or October 2000, and may include stream sediments on BLM land.

Water, sediment, and/or tailings samples were collected on August 9 - 10, 1999 at 15 sites between the upper mine portal and the confluence of the North and South Forks of Hunters Creek. A second set of water samples was collected at the mine portals and at a site immediately downstream of the tailings piles on October 26, 1999.

Results showed the lower portal was the primary contributor to poor water quality, but that, due to buffering by the limestone ore body, state water quality standards for metals were generally met in the drainage. Mercury slightly exceeded the state chronic standard in the lower portal and in the nearest downstream water sample. Iron exceeded EPA or more recent and restrictive Canadian aquatic life criteria from below the portals to the North Fork, a distance of about 1½ miles. Concentrations of dissolved (0.45 μm filtered) aluminum slightly exceeded British Columbia chronic water quality down to the South Fork confluence (there are no state standards or EPA criteria for dissolved aluminum).

While most metals decreased in concentration going downstream, dissolved arsenic and lead showed gradual increases from below the mine portals to the North Fork confluence, suggesting the presence of sources in addition to the portals. The tailings piles did not appear to be having a significant effect on metals concentrations or general water quality parameters at the time of this survey. Within the North Fork, drainage from the Cleveland Mine site caused dissolved arsenic, zinc, and lead to increase by factors of >12 to 18 and dissolved aluminum by a factor of 2.

Data collected by BLM during March 1998 document exceedances of the state acute standard for dissolved zinc and the state chronic standard for dissolved cadmium, both above and below the tailings piles. This could be an indication of significant seasonal differences in metals concentrations.

Sediments in most parts of the Cleveland Mine drainage have concentrations of iron, zinc, lead, arsenic, cadmium, silver, and antimony far above levels where adverse effects on benthic organisms would be expected to occur. Microscopic analysis and microchemical tests showed metallic grains from the tailings are the principal source of the zinc, lead, cadmium, and silver, while arsenic may primarily occur adsorbed onto iron hydroxide coatings on the sediment particles.

If stream sediments are included in the BLM cleanup of the tailings piles area, recontamination will gradually occur from the approximately 0.3 miles of contaminated upstream sediments. If upstream sediments are controlled, recontamination will primarily come from deposition of iron

from the lower portal. Iron deposits appeared weak downstream of the mine portals, so may not constitute a serious impact to the stream bed.

It is recommended that:

- Additional water samples be collected to assess metals concentrations during spring runoff conditions.

- Sediment sampling be conducted further downstream in Hunters Creek between the North Fork and Lake Roosevelt (Columbia River).

- Options be evaluated for sediment cleanups on non-BLM land.

Background

The Cleveland Mine site is located at the head of Hunters Creek watershed on the east shore of Franklin D. Roosevelt Lake (Figure 1). The mine began operation around 1917, producing silver, lead, copper, gold, antimony, and zinc. Work continued sporadically until 1970 when the mine caved in. The mill was demolished in 1973. Some minor mining activity continues at the site.

The ore deposits are in dolomitic limestone (Purdy, 1951). Minerals include galena (PbS), boulangerite ($5PbS.2Sb_2S_3$), sphalerite (ZnS), tetrahedrite ($3Cu_2S.Sb_2S_3$), chalcopyrite ($CuFeS_2$), stibnite (Sb_2S_3), cerrussite ($PbCO_3$), anglesite ($PbSO_4$), bindheimite ($Sb\ (OH)_x$), mimetite ($3Pb_3As_2O_8.PbCl_2$), and valentinite (Sb_2O_3).

Two adits, upper and lower, discharge to an unnamed stream feeding the North Fork of Hunters Creek. During summer and fall, drainage from the mine portals is the major source of flow in the creek.

Tailings were dumped in the streambed in two piles downstream of the mill. The upstream pile is approximately 0.4 acres with a depth of 1.6 - 4+ feet. The downstream pile is approximately 2.2 acres with a depth of 0.5 - 8.4 feet (BLM, 1998a). Partially breached dams act as retaining walls at the downstream end of each pile. The stream channel generally follows the west side of the tailings. The distance from the downstream pile to the North Fork is approximately 1 mile. There is also a small tailings impoundment at the old mill site below the lower portal.

The tailings piles are located on land administered by the Bureau of Land Management (BLM). Other parts of the drainage, including the mine portals and old mill sites, are on private land. BLM is undertaking a cleanup of the tailings piles. They asked the assistance of the Washington State Department of Ecology (Ecology) in addressing upstream sources that could continue to recontaminate public land after cleanup actions were taken (BLM, 1998b). The Ecology Eastern Regional Office (ERO) therefore requested that Ecology's Environmental Assessment Program (EAP) survey the extent of contamination in Hunters Creek drainage in the vicinity of the mine. EAP and ERO conducted the field work on August 9 - 10, 1999, with some follow-up sampling by Dave George and Sherman Spencer of ERO on October 26, 1999. The results from these efforts are described here.

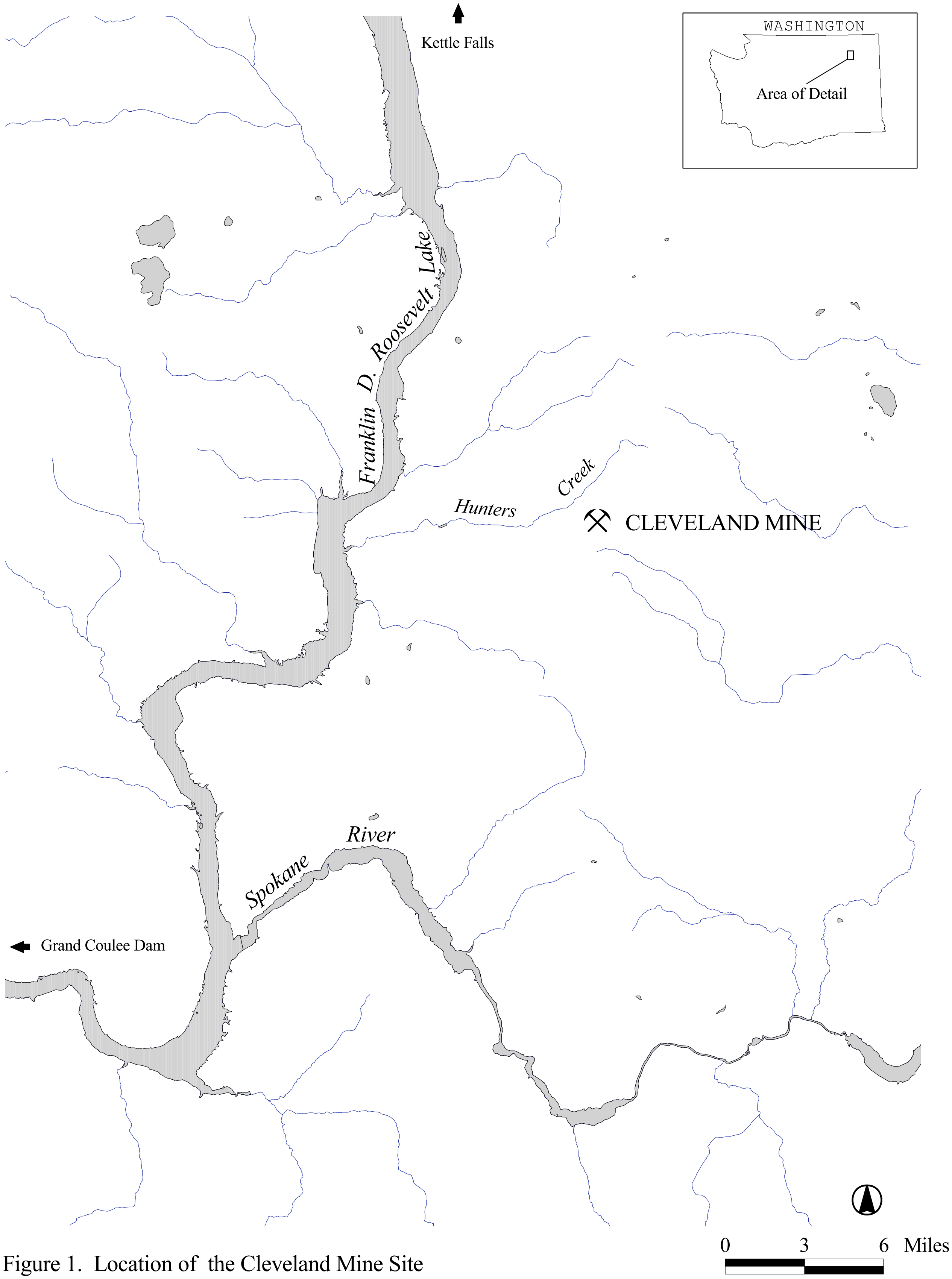

Figure 1. Location of the Cleveland Mine Site

BLM Cleanup

The cleanup action involves a consolidation of the material at each of the two tailings sites to make a smaller footprint. Engineering design will attempt to hydraulically isolate the consolidated tailings from ground water flow atop the bedrock and from the stream surface water flow.

ERO recently proposed that BLM remove additional contaminated sediments along the stream course on BLM land. These sediments would be added to the two tailings areas during consolidation. If accomplished, pending Dangerous Waste and Hydraulics Permit approval, this action will further reduce contact of the stream with contaminated sediments on BLM land.

During the fall of 1999, BLM contractors began some of the work to consolidate the tailings piles and divert the stream past them. The cleanup is scheduled to be completed in September or October 2000 (Jakabosky, 2000).

Sampling Plan

Table 1 shows the sampling plan for the August 1999 field work. Water, sediment, and/or tailings samples were collected at 15 sites between the upper mine portal and the North Fork of Hunters Creek above its confluence with the South Fork (Figures 2 and 3). A small tributary drainage* (site #1) that enters from the northeast, about 300 hundred yards below the upper mine portal, was sampled to obtain data on background water and sediment quality in the Cleveland Mine area. Water samples were collected from both mine portals (sites #2 and #4). Tailings samples were obtained from the upper and lower piles, and from the small impoundment at the old mill (sites #8, #10, and #5, respectively).

Sampling was not carried out as originally planned for four sites (not shown in Figure 1):
Site #7, above the upper tailings pile, was dropped because of its proximity to samples collected below the portals at site #6. A sediment sample was planned for a site #15 on the North Fork of Hunters Creek between the Cleveland Mine drainage and the South Fork. However, because the gradient was steep and access difficult, no depositional areas could be located for sampling. Because of a rocky stream bed, no sediment samples were collected at the North Fork above the South Fork confluence (site #16). Finally, the property owner where South Fork Hunters Creek samples were to have been taken (site #17) could not be contacted, so no sampling was done.

At each water sampling site, field measurements were made of temperature, pH, dissolved oxygen (D.O), and flow. Water samples were collected for specific conductivity, hardness, alkalinity, turbidity, color, sulfate, total suspended solids (TSS), cyanide, iron, aluminum, arsenic, zinc, copper, lead, cadmium, silver, and mercury. Total recoverable metals (whole water) were analyzed for the mine portals. Dissolved metals (filtered water) were analyzed in downstream samples, except for iron and mercury which were total recoverable. The metals analyzed were either identified as a concern in BLM (1998a) or were considered likely to be a concern under these circumstances. Cyanide analysis was limited to water samples near the mine to confirm BLM data showing that none is detectable.

The same metals were analyzed in sediment samples, with the addition of antimony, chromium, nickel, thallium, beryllium, and selenium. Grain size was also determined. Subsamples were examined microscopically and subjected to microchemical tests to identify the presence of tailings in the sediments and provide an estimate of the amount.

The follow-up sampling on October 26, 1999 was done to determine how representative the August data were of low-flow conditions. A second set of field measurements and water samples were obtained at each of the mine portals and below the lower tailings pile (site #11)*. These samples were analyzed for the same parameters as in August. Streamflow was also measured at the downstream end of the Cleveland Mine drainage and on the North Fork above Cleveland Mine.

* The origin of the water in this drainage is uncertain. BLM contents it is the discharge from a collapsed adit (Jakabosky, 2000). Ecology has been unable to verify this and considers the source to be unknown at this time (George, 2000)

Table 1. Sampling Plan for Cleveland Mine Survey, August 9-10, 1999

Site No.	Location	Field Measurements[a]	Chemistry Samples Water[b]	Chemistry Samples Sediment[c]
1	Tributary Drainage	x	x	x
2	Upper Mine Portal	x	x	
3	Below Upper Mine Portal			x
4	Lower Mine Portal	x	x	
5	Tailings @ Lower Mill			x
6	Below Portals & Mill Sites[d]	x	x	x
7	Above Tailings	------------no samples collected------------		
8	Upper Tailings Pile			x
9	Between Tailings Piles	x	x	
10	Lower Tailings Pile			x
11	Below Lower Tailings Pile	x	x	
12a	0.2 Mile Below Tailings Piles			x
12b	0.6 Mile Below Tailings Piles			x
13	Above North Fork Confluence[d]	x	x	x
14	North Fork above Cleveland	x	x	x
15	North Fork below Cleveland	------------no samples collected------------		
16	North Fork above South Fork Confluence	x	x	
17	South Fork above North Fork Confluence	------------no samples collected------------		

[a] flow, temperature, pH, D.O.

[b] analyzed for conductivity, hardness, alkalinity, turbidity, color, sulfate, total suspended solids (TSS), cyanide, iron, aluminum, arsenic, zinc, copper, lead, cadmium, silver, and mercury.

[c] analyzed for iron, aluminum, arsenic, zinc, copper, lead, cadmium, silver, mercury, antimony, chromium, nickel, thallium, beryllium, selenium, grain size, and particle ID.

[d] replicate water samples and duplicate (split) sediment samples at these sites.

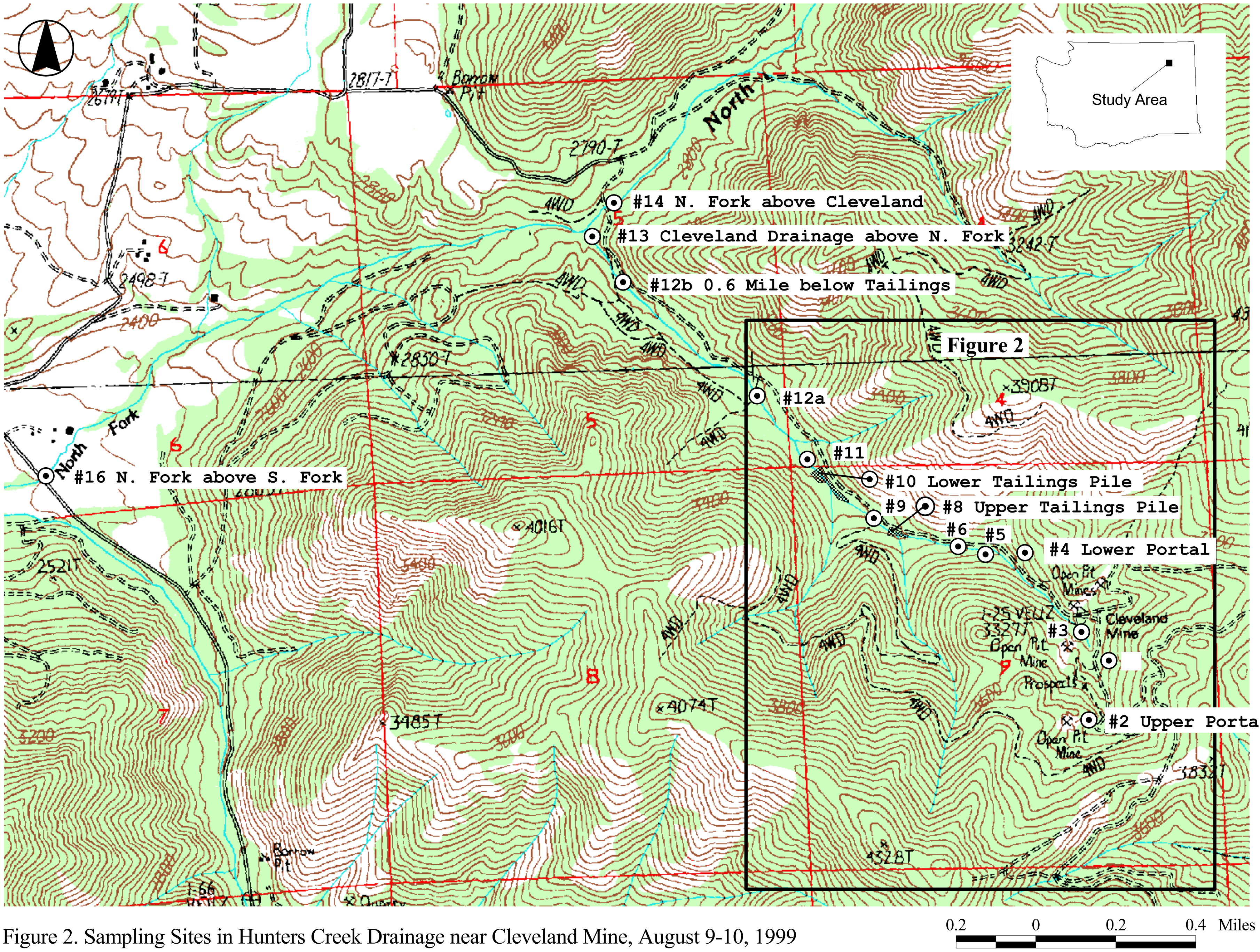

Figure 2. Sampling Sites in Hunters Creek Drainage near Cleveland Mine, August 9-10, 1999

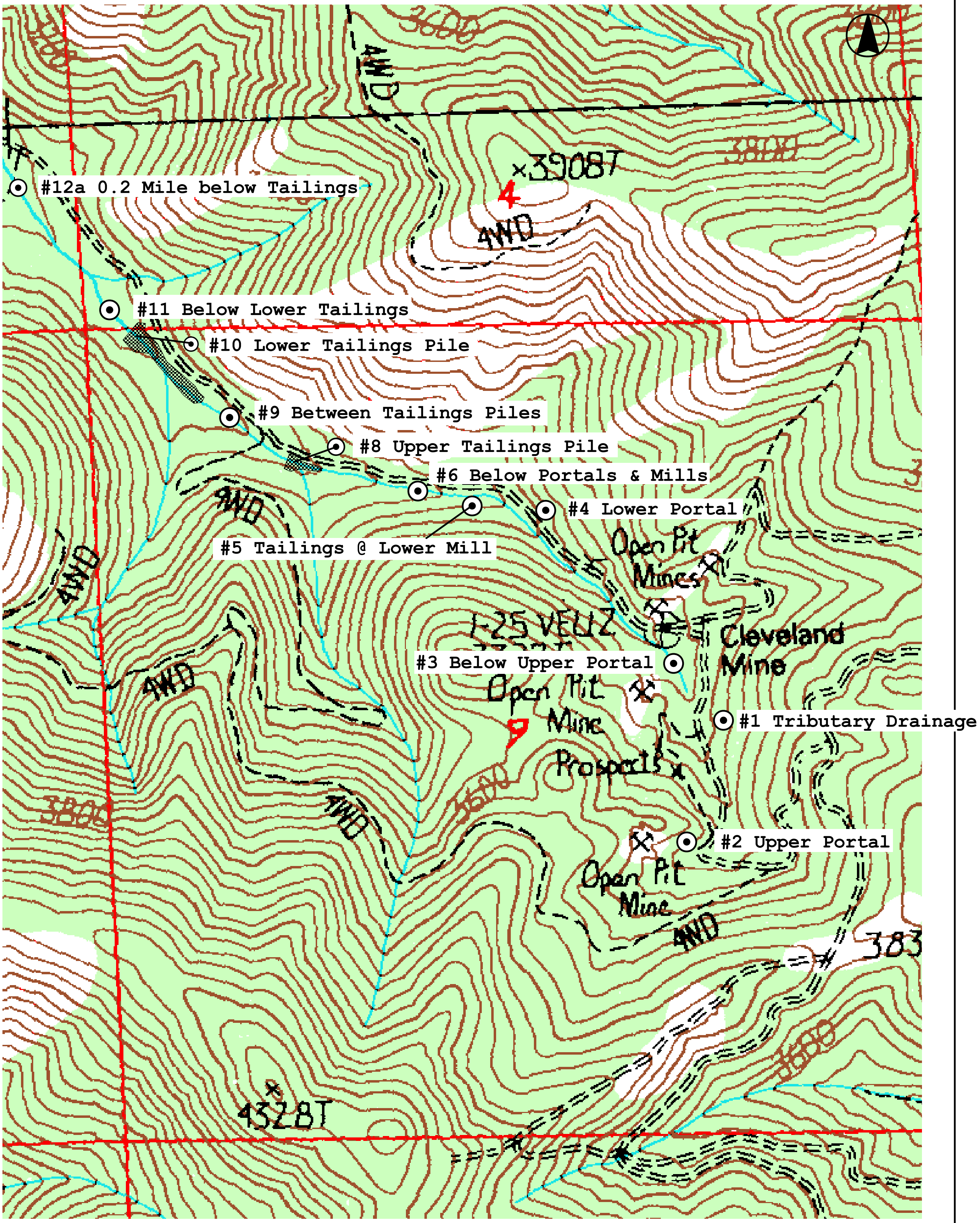

Figure 3. Sampling Sites at Cleveland Mine, August 9 - 10, 1999

Methods

Field

All water samples were collected as simple grabs. EPA (1995) clean sampling procedures were used for metals. Metals samples were taken directly in pre-cleaned 500 mL teflon bottles. Samples for dissolved metals were vacuum-filtered in the field through a disposable 0.45 µm cellulose-nitrate filter (#450-0045, type S). The filtering was done in a polyethylene glove box. 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 other water quality parameters are described in MEL (1999).

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.

pH measurements were obtained with an Orion Model 250A meter. For the August survey, the pH meter was two-point calibrated prior to use at the upper portal and re-calibrated for downstream sites after use at the lower portal. In October, the meter was two-point calibrated before first use. Dissolved oxygen was analyzed with the azide modification of the Winkler method. Temperature was measured with a precision thermometer or taken from the pH meter. Streamflows were gauged with a Marsh-McBirney flowmeter and top-setting rod. Latitude and longitude were recorded from a hand-held GPS (not differentially corrected); the coordinates are in Appendix A.

Sediment samples were composites of multiple grabs taken with stainless steel scoops and homogenized in the field in stainless steel beakers. Sampling equipment was cleaned by washing with Liquinox detergent and sequential rinses with tap water, dilute nitric acid, and DI water. The homogenate was split into glass jars with teflon lid liners, cleaned to EPA QA/QC specifications (EPA, 1990), or put in twist-lock bags for grain size.

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

Laboratory

Sample analysis was conducted at Manchester, except for grain size which was done by Rosa Environmental & Geotechnical Laboratory, Seattle. The methods used are listed in Table 2.

Water samples for total recoverable metals were digested with nitric acid by EPA method 200.2, modified for ICP/MS. Dissolved samples were not digested. Water samples for mercury were digested as described in method 245.7. In sediment samples, metals other than mercury were digested with nitric and hydrochloric acid by EPA method 3050. The mercury digestion is described in method 245.5.

Table 2. Analytical Methods for Cleveland Mine Survey

Analysis	Method	Number
Water Samples		
Ag,Cd,Cu,Pb,Zn	ICP/MS	200.8
As	GFAA	206.2
Al	ICP	200.7
Fe	ICP	200.7
Hg	CVAA	245.7
Conductivity	Wheatstone bridge	120.1
Hardness	EDTA titrimetric	SM2340B
Total Suspended Solids	Filter, Grav. 103-105^{o}C	160.2
Turbidity	Nephelometric	180.1
Color	Spectrophotometric	110.1
Sulfate	Ion chromatography	300.0
Cyanide (weak acid dissociable)	Automated colorimetric	335.2
Sediment Samples		
Al,Sb,As,Be,Cd,Cr,Cu,Fe,Pb,Ni,Ag,Zn	ICP	SW6010
Se	ICP	SW7740
Tl	ICP	SW7841
Hg	CVAA	245.5
Grain Size	Seive & pipette	PSEP Method
Particle ID	Microscopy/microchemisty	in house

Data Quality

Manchester staff prepared written reviews on the quality of the chemical data for this project. The reviews include an assessment of sample condition on receipt at the laboratory, compliance with holding times, instrument calibration, procedural blanks, laboratory control samples, standard reference material, matrix spike and matrix spike duplicate recoveries, and duplicate sample analyses. Copies of the reviews and complete chemical data are available from the author.

Overall, the quality of the data is good. A few of the analyses for the August sample set failed to meet all QA/QC criteria: (1) Color was analyzed one day over the two-day holding time, (2) antimony data on sediment were qualified as an estimate (J flag) due to low recoveries of matrix spikes and in laboratory control samples, and (3) thallium sediment data were qualified as estimates due to low matrix spike recoveries. Table 3 summarizes supporting QA/QC data for the August metals analyses.

Several problems were encountered in analyzing the October metals samples from the mine portals: (1) Spike recoveries were low for copper, arsenic, and mercury, (2) lead was detected in the procedural blank, and (3) the holding time was also exceeded for mercury. As a result the October copper, arsenic, mercury, and lead data on the portals were qualified as estimates. The stream data did not require qualification.

The variability (field + laboratory) of the metals and general chemistry data on water can be gauged from results on replicate samples collected approximately 5 minutes apart at sites #6 and #13 during the August survey (Table 4). For most parameters, results agreed within 20% or better. The replicate data were averaged for use in the remainder of this report.

Because sediment samples were collected as composites of multiple grabs from each site, replicate sampling was not done to evaluate field variability. Analytical precision can be estimated from results on two samples split at the laboratory (Table 5). Different degrees of precision were achieved in the two splits, with the site #6 sample appearing to be less homogeneous than the site #13 sample. The duplicate average is used in this report.

Table 3. Summary of Metals QA/QC Data for August 9-10, 1999 Samples

	Method Blank	Stand. Ref. Material[a] Results	Stand. Ref. Material[a] Certified	Lab Control Sample	Matrix Spike[b]	Spike Duplicate[b]
Water Samples (µg/L)						
Iron	40U	na	- -	102%	106%	108%
Aluminum	20U	na	- -	103%	107%	na
Arsenic	1.5U	na	- -	96%	107%	118%
Zinc	1U	1.19	1.04	102%	nc	nc
Copper	0.10U	1.53	1.35	105%	91%	91%
Lead	0.02U	0.055	0.068	94%	120%	116%
Cadmium	0.02U	0.02U	0.013	95%	120%	114%
Silver	0.02U	0.02U	- -	91%	110%	105%
Mercury	0.002U	na	- -	94%	73%	81%
Sediment Samples (mg/Kg)						
Aluminum	10U	na	- -	98%	nc	nc
Antimony	5U	na	- -	27%	39%	0%
Arsenic	5U	na	- -	112%	nc	nc
Beryllium	0.1U	na	- -	111%	97%	97%
Cadmium	0.5U	na	- -	108%	nc	nc
Chromium	0.5U	na	- -	107%	94%	97%
Copper	0.5U	na	- -	106%	91%	93%
Iron	10U	na	- -	79%	nc	nc
Lead	5U	na	- -	105%	nc	nc
Nickel	1U	na	- -	107%	95%	97%
Silver	1U	na	- -	102%	86%	76%
Zinc	1U	na	- -	105%	nc	nc
Thallium	0.2U	na	- -	105%	41%	53%
Selenium	0.15U	na	- -	124%	82%	84%
Mercury	0.005U	na	- -	107%	123%	125%

[a] SLRS-3 (River Water Reference Material for Trace Metals, Nat. Res. Council Canada)

[b] Water sample no. 328287; sediment sample no. 328310

U = not detected at or above reported value

na = not analyzed

nc = not calculated (native concentration greater than spiking level)

Table 4. Variability Between Field Replicate Water Samples

Location:	Site #6 - Below Portals & Mill Sites			Site #13 - Above N. Fork Confluence		
Sample No.:	328283	328284	RPD	328287	328288	RPD
General Chemistry						
Conduct. (µmhos/cm)	395	397	0.5%	360	359	0.3%
Hardness (mg/L)	219	217	0.9%	196	195	0.5%
Alkalinity (mg/L)	188	187	0.5%	172	171	0.6%
Turbidity (NTU)	6.3	6.2	2%	7.1	7.5	6%
Color (units)	20	30	40%	20	20	0%
Sulfate (mg/L)	34	34	0%	28	28	1%
TSS (mg/L)	5	4	22%	8	8	2%
Cyanide (mg/L)	0.01U	0.01U	nd	na	na	- -
Metals (µg/L)						
Iron	3,220	3,220	0%	575	584	2%
Aluminum	85	99	15%	83	69	18%
Arsenic	26	26	2%	141	140	0.7%
Zinc	117	123	5%	88	90	2%
Copper	1.1	1.2	10%	0.83	0.86	4%
Lead	0.28	0.30	7%	1.4	2.3	49%
Cadmium	0.83	0.86	4%	0.26	0.25	4%
Silver	0.02U	0.02U	nd	0.02U	0.02U	nd
Mercury	0.020	0.011	58%	0.002U	0.002U	nd

RPD = Relative Percent Difference (range as percent of duplicate mean)
U = not detected at or above reported value
nd = not detected
na = not analyzed

Table 5. Variability Between Duplicate (laboratory split) Sediment Samples

Location:	Site #6 - Below Portals & Mill Sites			Site #12a - 0.2 Mi. Below Tailings Piles		
Sample No.:	328303	328304	RPD	328310a	328310b	RPD
Grain Size (%)						
Gravel	34.1	32.7	4%	79.1	79.1	0%
Sand	59.7	62.9	5%	36.1	31.4	14%
Silt	5.9	4.0	38%	57.5	59.8	4%
Clay	2.1	2.2	5%	5.0	7.3	37%
Solids	83.1	80.0	4%	1.5	1.5	0%
Metals (mg/Kg, dry weight)						
Iron	78,200	64,800	19%	51,200	51,000	0.4%
Aluminum	6,480	7,980	21%	9,450	10,300	9%
Zinc	25,900	20,300	24%	10,600	10,400	2%
Lead	14,800	9,470	44%	2,620	2,660	2%
Arsenic	6,850	4,200	48%	3,230	3,400	5%
Antimony	514J	315J	48%	74	77	4%
Cadmium	237	177	29%	77	75	3%
Copper	117	113	4%	54	57	5%
Chromium	18	19	5%	22	22	0%
Nickel	17	19	11%	17	18	6%
Silver	28	17	49%	5.4	5.7	5%
Thallium	0.8UJ	1.2J	>40%	2.1J	na	- -
Beryllium	1U	1U	nd	1	1U	>0%
Mercury	0.37	0.10	115%	0.11	0.11	0%
Selenium	0.15U	0.15U	nd	0.15U	0.15U	nd

RPD = Relative Percent Difference (range as percent of duplicate mean)
U = not detected at or above reported value
nd = not detected
na = not analyzed

Results and Discussion

General Water Quality Conditions

Table 6 shows the field measurements and general chemistry results for August. Flow rates for the upper and lower mine portals were similar at 0.14 and 0.16 cubic feet per second (cfs), respectively. The tributary side drainage (site #1) coming in below the upper portal was about half that at 0.07 cfs. The flow measurement below the confluence of these three discharges was 0.29 cfs (site #6), which agrees reasonably well with upstream readings. Flow increased to 0.91 cfs by the confluence with North Fork Hunters Creek.

There were substantial differences in the quality of the mine discharges, with the lower portal being much worse in terms of turbidity, color, TSS, and other parameters. Sulfate concentrations in the lower portal were 73 mg/L vs. only 2.2 mg/L at the upper portal. Because the ore body is limestone (Purdy, 1951) both discharges are well buffered, with pH values of 8.35 in the upper portal and 7.77 in the lower portal.

Water quality in the upper portal was as good or better than in the side drainage entering at site #1. All three of these headwater sources were within Class A standards for temperature, pH, turbidity, and D.O. No cyanide was detectable, here or in downstream samples, consistent with findings by BLM (1998a).

Sulfate, from oxidation of sulfide minerals, is a conservative tracer of drainage from sulfide ore mines (Gray, 1997). Sulfate levels decreased slightly from below the mine portals to the North Fork, from 34 to 28 mg/L. There was no evidence that the tailings piles were having an adverse effect on general water quality parameters.

A pulse of turbid water from an unidentified upstream source was observed as samples were about to be collected at site #11 below the lower tailings pile. Sampling was delayed until the stream cleared up, but the turbidity and TSS data for this site show conditions had not returned to normal. There was no indication of this plume in results for downstream samples collected 1½ hour later at site #13.

Compared to the North Fork, drainage entering from the Cleveland Mine site was more turbid, 7.3 vs. 1.8 NTU, and had higher TSS, 8 vs. 3 mg/L, and, especially, sulfate, 28 vs. 2.9 mg/L. Color values were similar at 20 units each. With dilution in the North Fork, only sulfate concentrations were significantly affected downstream.

Results from re-sampling the mine portals in October were nearly identical for both flow and general water quality parameters (Table 7). Sulfate concentrations, for example, were 2.1 vs. 2.2 mg/L in the upper portal and 73 mg/L on both occasions in the lower portal. Slightly lower but above neutral pH values were recorded in both portals. As in August, the lower portal had the lower pH. The relative size of the North Fork and Cleveland Mine drainage was similar to August, at approximately 2:1.

Table 6. Field Measurements and General Chemistry Results for Cleveland Mine/Hunters Creek Water Samples Collected August 10, 1999

Location	Site No.	Sample No.	Time	Flow (cfs)	Temp. (^oC)	pH (units)	D.O. (mg/L)	Conduct. (µmhos/cm)
Tributary Drainage	1	328281	0945	0.07	8.2	8.17	10	472
Upper Mine Portal	2	328280	0830	0.14	8.3	8.35	9.9	270
Lower Mine Portal	4	328282	1050	0.16	7.9	7.77	10.4	462
Below Portals & Mill Sites	6	328283/84	1150	0.29	10.5	8.27	9.6	396
Between Tailings Piles	9	328285	1410	nm	11.2	8.25	8.2	377
Below Lower Tailings Pile	11	328286	1335	0.5	12.2	8.12	9.2	374
Above N. Fork Confluence	13	328287/88	1510	0.91	13.8	8.25	8.8	360
North Fork ab. Cleveland	14	328289	1440	2.5*	17.6	7.74	>8	102
North Fork ab. South Fork	16	328290	1610	1.4	17.2	8.14	na	220

Location	Site No.	Hardness (mg/L)	Alkalinity (mg/L)	Turbidity (NTU)	Color (units)	Sulfate (mg/L)	TSS (mg/L)	Cyanide (mg/L)
Tributary Drainage	1	274	272	0.7	30	4.2	2	0.01U
Upper Mine Portal	2	149	145	0.5U	0	2.2	1U	0.01U
Lower Mine Portal	4	260	184	9.5	60	73	6	0.01U
Below Portals & Mill Sites	6	218	188	6.2	30	34	4	0.01U
Between Tailings Piles	9	208	178	6.7	30	32	5	0.01U
Below Lower Tailings Pile	11	212	178	23	30	30	47	0.01U
Above N. Fork Confluence	13	196	172	7.3	20	28	8	na
North Fork ab. Cleveland	14	48	50	1.8	20	2.9	3	na
North Fork ab. South Fork	16	116	106	1.2	10	9.4	1	na

U = not detected at or above reported value
nm = not measured
na = not analyzed
*flow estimated from sulfate/flow data for sites 13, 14, and 16

Table 7. Field Measurements and General Chemistry Results for Cleveland Mine/Hunters Creek Water Samples Collected October 26, 1999

Location	Site No.	Sample No.	Time	Flow (cfs)	Temp. (°C)	pH (units)	D.O. (mg/L)	Conduct. (µmhos/cm)
Upper Mine Portal	2	438000	942	0.14	8.5	7.71	na	272
Lower Mine Portal	4	438002	1105	0.16	7.7	7.10	na	460
Below Lower Tailings Pile	11	438004	1145	0.47	7.0	7.30	na	395
Above N. Fork Confluence	13	- -	1323	0.51	na	na	na	na
North Fork ab. Cleveland	14	- -	1310	0.98	na	na	na	na

Location	Site No.	Hardness (mg/L)	Alkalinity (mg/L)	Turbidity (NTU)	Color (units)	Sulfate (mg/L)	TSS (mg/L)	Cyanide (mg/L)
Upper Mine Portal	2	139	147	2.8	0	2.1	5	na
Lower Mine Portal	4	239	182	7.7	70	73	7	na
Below Lower Tailings Pile	11	210	168	65	100	61	58	na
Above N. Fork Confluence	13	na	na	na	na	na	na	na
North Fork ab. Cleveland	14	na	na	na	na	na	na	na

na = not analyzed

BLM contractors were working on the tailings piles when the October samples were collected. There was some disturbance of the stream, resulting in elevated levels of turbidity, TSS, and sulfate below the tailings (site #11, Table 7).

Metals in Water Samples

Results from the metals analysis of the August water samples are shown in Table 8. Metals concentrations in the upper portal were low and generally similar to those in the nearby tributary drainage and in the North Fork of Hunters Creek above Cleveland Mine. Arsenic, zinc, and lead were slightly elevated in this portal.

The lower portal had a high level of iron at 5,230 µg/L. Most (98%) of the iron was in particulate form (Ross, 2000). Iron staining, ferric hydroxide from oxidation and deposition of the iron in pyrite, was evident in the streambed (Figure 4). Little or no staining was observed in the upper portal. Relative to upstream waters, arsenic, zinc, copper, lead, cadmium, and mercury were substantially elevated in the lower portal.

Table 8. Metals Concentrations in Cleveland Mine/Hunters Creek Water Samples Collected August 10, 1999 (µg/L)

Portal data are for total recoverable metals. Stream data are for dissolved metals (0.45 µm *filtered), except Fe and Hg are total recoverable.*

Location	Site No.	Sample No.	Time	Fe	Al	As	Zn
Tributary Drainage	1	328281	0945	40	97	2.9	1 U
Upper Mine Portal	2	328280	0830	40	77	5.2	2.7
Lower Mine Portal	4	328282	1050	5,230	76	27	47 J
Below Portals & Mill Sites	6	328283	1150	3,220	96	26	122
Between Tailings Piles	9	328285	1410	1,800	61	50	139
Below Lower Tailings Pile	11	328286	1335	11,400	77	70	153
Above N. Fork Confluence	13	328287	1510	580	76	140	89
North Fork ab. Cleveland	14	328289	1440	130	26	1.6	1 U
North Fork ab. South Fork	16	328290	1610	67	59	29	12
Bottle Blank	- -	328293	1545	40	20 U	1.5 U	1 U
Filter Blank	- -	328294	1545	na	20 U	1.5 U	1 U

Location	Site No.	Cu	Pb	Cd	Ag	Hg
Tributary Drainage	1	0.10	0.02 U	0.02 U	0.02 U	0.002 U
Upper Mine Portal	2	0.10 U	0.39	0.02 U	0.02 U	0.002 U
Lower Mine Portal	4	2.5	1.5	0.82	0.02 U	0.035
Below Portals & Mill Sites	6	1.2	0.29	0.84	0.02 U	0.016
Between Tailings Piles	9	1.4	0.44	0.99	0.02 U	0.0033
Below Lower Tailings Pile	11	1.4	1.0	0.88	0.02 U	0.0033
Above N. Fork Confluence	13	0.82	1.8	0.26	0.02 U	0.002 U
North Fork ab. Cleveland	14	0.44	0.02 U	0.02 U	0.02 U	0.002 U
North Fork ab. South Fork	16	0.13	0.35	0.02 U	0.02 U	0.002 U
Bottle Blank	- -	0.10 U	0.02 U	0.02 U	0.02 U	0.002 U
Filter Blank	- -	0.10 U	0.02 U	0.02 U	0.02 U	na

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

Figure 4. Lower Portal, Cleveland Mine, August 10, 1999

Except for arsenic and lead, metals concentrations decreased from the portals to the North Fork. Dissolved arsenic gradually increased in this reach from 26 to 50 to 70 to 140 µg/L and dissolved lead from 0.29 to 0.44 to 1.0 to 1.8 µg/L, suggesting sources in addition to the mine portals. The iron spike below the lower tailings pile is likely due to the transient upstream disturbance that affected this site, as previously mentioned. This may also be responsible for the increase in dissolved zinc seen at this location.

Drainage from the Cleveland Mine site was having a measurable effect on metals concentrations in the North Fork. Compared to samples collected above Cleveland, dissolved arsenic, lead, and zinc were elevated at site #16 above the South Fork by factors of >12 to 18 and dissolved aluminum by a factor of 2. There was a loss of iron in this reach, possibly from precipitating out on the stream bed.

The metals concentrations measured in the portals and below the tailings piles in October are shown in Table 9. The October results for the portals are comparable to those obtained in August. The only large discrepancy was for zinc in the lower portal which was at 318 µg/L in the October sample vs. 47 µg/L in August.

Table 9. Metals Concentrations in Cleveland Mine/Hunters Creek Water Samples Collected October 26, 1999

Portal data are for total recoverable metals. Stream data are for dissolved metals (0.45 µm filtered), except Fe and Hg are total recoverable.

Location	Site No.	Sample No.	Time	Fe	Al	As	Zn
Upper Mine Portal	2	438000	942	35	36	4.7	3.2
Lower Mine Portal	4	438002	1105	4,640	60	59	318
Below Lower Tailings Pile	11	438004	1145	5,660	180	181	338

Location	Site No.	Cu	Pb	Cd	Ag	Hg	Sb
Upper Mine Portal	2	0.25 UJ	1.5 J	0.25 U	0.25 U	0.05 UJ	0.5 U
Lower Mine Portal	4	5.9 J	2.4 J	1.0	0.25 U	0.05 UJ	13
Below Lower Tailings Pile	11	3.2	17	1.3	0.02 U	0.045	93

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

The work being conducted on the tailings piles while the October samples were being collected resulted in elevated levels of a number of dissolved metals downstream of the tailings at site #11, including arsenic, zinc, lead, mercury, and antimony.

The metals data from the August and October surveys are compared in Table 10 to data reported by BLM (1998a). BLM collected a sample from the lower portal in July 1994, in response to a request from Ecology. Miners had been in the adit causing the stream to run red (Jakabosky, 2000). Metals concentrations were high compared to portal samples collected by Ecology.

BLM analyzed dissolved metals in samples collected above and below the tailings piles in March 1998. Their results are higher than Ecology's summer/fall samples for arsenic, zinc, cadmium, lead, and copper. This suggests the possibility of significant seasonal fluctuations in dissolved metals concentrations in response to runoff.

Table 10. Comparison of BLM[a] and Ecology Metals Data on Water Samples from Cleveland Mine Site
Portal data are for total recoverable metals. Stream data are for dissolved metals (0.45 μm filtered), except Fe and Hg are total recoverable.

Location:	Lower Portal		Above Upper Tailings Pile		Below Lower Tailings Pile	
Investigator:	BLM	Ecology	BLM	Ecology	BLM	Ecology
Sampling Date:	May-94	Aug-99/Oct-99	Mar-98	Aug-99	Mar-98	Aug-99
Site No.:	- -	#4	- -	#6	- -	#11
Fe	na	5,230/4,640	nd	3,220	nd	11400
Al	na	76/60	nd	96	nd	77
As	508	27/59	63	26	28	70
Zn	1,610	47/318	449	122	495	153
Cu	13	2.5/5.9	nd	1.2	nd	1.4
Pb	23	1.5/2.4	2	0.29	3	1.0
Cd	7.7	0.82/1.0	4	0.84	6	0.88
Ag	na	0.02/<0.25	nd	0.02	nd	0.02
Hg	na	0.035/<0.05	nd	0.016	nd	0.0033
Sb	na	na/13	na	na	na	na

[a] BLM (1998a)
na = not analyzed
nd = not detected (detection limit not reported)

Water Quality Standards/Criteria for Metals

Tables 11 (lower portal samples) and 12 (August stream samples) compare Ecology's metals data to state water quality standards for protection of aquatic life (WAC 173-201A). For metals that have hardness dependent criteria (zinc, copper, lead, cadmium, and silver), the lowest hardness recorded for the sample group in question was used to calculate the standard. Metals toxicity generally increases with decreasing hardness. Formulas for calculating metals standards are provided in Appendix B.

Because there are no state standards for iron or aluminum, EPA (1999) recommended national water quality criteria are shown in the tables. EPA's 1,000 µg/L criterion for iron (from the 1979 Red Book) may not be sufficiently protective. Canada has a more recent recommended guideline of 300 µg/L that takes into account that acute toxicity to aquatic insects can occur down to 320 µg/L (CCREM, 1987).

Table 11. Metals Concentrations in Lower Mine Portal Samples Compared to Water Quality Standards and Criteria (µg/L)

Total recoverable metals, except Hg acute criterion is for dissolved.

	Lower Portal		Water Quality Standards/Criteria	
	10-Aug-99	26-Oct-99	acute	chronic
Fe	**5,230**	**4,640**	- -	1,000[a]
Al	76	60	750[a]	87[a]
As	27	59	359[b]	189[b]
Zn	47	**318**	219[b]	221[b]
Cu	2.5	5.9	40[b]	25[b]
Pb	1.5	2.4 J	248[b]	9.7[b]
Cd	0.82	1.0	10[b]	2.4[b]
Ag	0.02 U	0.25 U	18[b]	na[b]
Hg	**0.035**	0.05 UJ	2.1[b]	0.012[b]

Exceedances highlighted in **BOLD**

U = not detected at or above reported value

J = estimated value

UJ = not detected at or above reported estimated value

na = not available

[a] EPA (1999) - National Recommended Water Quality Criteria

[b] WAC173-201A - Washington State Standards (@ 239 mg/L hardness, October 26)

Table 12. Metals Concentrations in August 1999 Stream Samples below Cleveland Mine Compared to Water Quality Standards and Criteria (µg/L)

Dissolved (0.45 µm *filtered) metals, except Fe and Hg (other than acute criterion) are total recoverable.*

	North Fork Hunters Cr. (sites #14,16)	Cleveland Mine Drainage (sites #6,9,11,13)	Water Quality Standards/Criteria	
			acute	chronic
Fe	67 - 130	580 - **11,400**	- -	1,000[a]
Al	26 - **59**	**61 - 92**	100[b]	50[b]
As	1.6 - 29	26 - 140	360[c]	190[c]
Zn	1U - 12	89 - 153	61/202[c]	56/185[c]
Cu	0.13 - 0.44	0.82 - 1.4	8.5/32[c]	6.1/20[c]
Pb	0.02U - 0.35	0.29 - 1.8	29/133[c]	1.1/5.2[c]
Cd	0.02U	0.26 - 0.99	1.7/7.7[c]	0.60/1.7[c]
Ag	0.02U	0.02U	0.98/11[c]	NA[c]
Hg	0.002U	0.002U - **0.016**	2.1[c]	0.012[c]

Exceedances highlighted in **BOLD**

U = not detected at or above reported value

[a] EPA (1999) - National Recommended Water Quality Criteria

[b] Butcher (1988) - British Columbia Water Quality Criteria

[c] WAC173-201A - Washington State Standards (@ 48 mg/L hardness for Hunters Creek @ 196 mg/L hardness for Cleveland Mine drainage)

No water quality standards or criteria were exceeded in the upper portal (data not shown) Both samples from the lower portal exceeded EPA's iron criterion by a factor of approximately 5. State standards were exceeded in the lower portal in two instances. The mercury concentration in the August sample, at 0.035 µg/L, exceeded the 0.012 µg/L chronic standard. The detection limit for mercury in the October sample, 0.05 µg/L, was not low enough to determine compliance with the chronic standard. The October results for the lower portal also showed that zinc, at 318 µg/L, exceeded the acute standard of 219 µg/L.

Table 12 shows how metals concentrations in the August stream samples compare to standards and criteria. Because the EPA aluminum criteria are for total recoverable, the table shows only pH-dependent criteria for dissolved aluminum. The pH-dependent criteria for dissolved aluminum were developed to protect British Columbia aquatic species (Butcher, 1988).

No standards were exceeded in the side tributary below the upper portal (data not shown). Except at its mouth, all iron concentrations measured in the Cleveland Mine drainage downstream of this site exceeded the EPA 1,000 µg/L criterion by factors of 2 or more. Although within EPA criteria, the sample at the mouth of the drainage exceeded the Canadian 300 µg/L criterion, again by about a factor of 2. The chronic criterion for dissolved aluminum was exceeded in all parts of the drainage below the mine, 61 - 92 µg/L vs. 50 µg/L. The only exceedance of a state standard (chronic) was for mercury below the mine portals (site #6) where the concentration was 0.016 µg/L, about half the concentration measured in the lower portal.

State standards were not exceeded in the North Fork, above or below Cleveland Mine. The dissolved aluminum concentration measured above the South Fork confluence slightly exceeded the British Columbia (B.C.) chronic criterion, apparently due to the Cleveland Mine discharge.

Figure 5 plots the August data for those metals that approached or exceeded state standards or the EPA/B.C. criteria. Metals concentrations are shown as ratios with the chronic values, adjusted for the hardness in each sample where appropriate. In the few cases where a metal was not detected, the detection limit was used in the ratio. In addition to the exceedances already noted for iron, aluminum, mercury; arsenic, zinc, and cadmium approached but did not exceed state standards.

The relatively low concentrations of dissolved metals in the portals and in drainage downstream of Cleveland Mine are due to the high pH which acts to reduce metals solubility. Iron and aluminum precipitate directly, forming hydrous oxides that are nearly insoluble at neutral pH. Concentrations of other metals are attenuated by adsorption onto the surface of the precipitating minerals. Arsenic, for example, adsorbs over a wide range of pH conditions down to 4 or less. Lead adsorption peaks at approximately pH 5, then precipitates out as lead carbonate as pH increases. The solubilities of zinc, copper, and cadmium begin to decrease around a pH of 6 - 7 (Bethke, 1996; Holmstrom et al., 1999).

Although Ecology's stream data show almost no exceedances of state standards, the BLM samples collected in March 1998 indicate that state standards were not being met for zinc and cadmium above or below the tailings piles. Dissolved zinc concentrations were 449 - 495 µg/L vs. the acute standard of 222 µg/L. Dissolved cadmium concentrations were 4 - 6 µg/L vs. the chronic standard of 1.8 µg/L. pH was not reported.

While the present report refers to the stream below Cleveland Mine as "mine drainage", it appears to be high quality habitat worthy of protection. The stream is well shaded, with numerous small pools. The drainage has a population of small eastern brook trout, observed to occur within 30 feet of the lower tailings pile (Kelly, 1998). A few small (100 mm or less) trout were seen at sites #12a, #12b, and #13 during the field sampling conducted in August 1999.

Stream Sediments and Tailings Samples

The grain size data for the sediment and tailings samples are in Table 13. Differences between samples can be better seen in Figure 6 which is a diagram of percent gravel, sand, and fines (silt + clay).

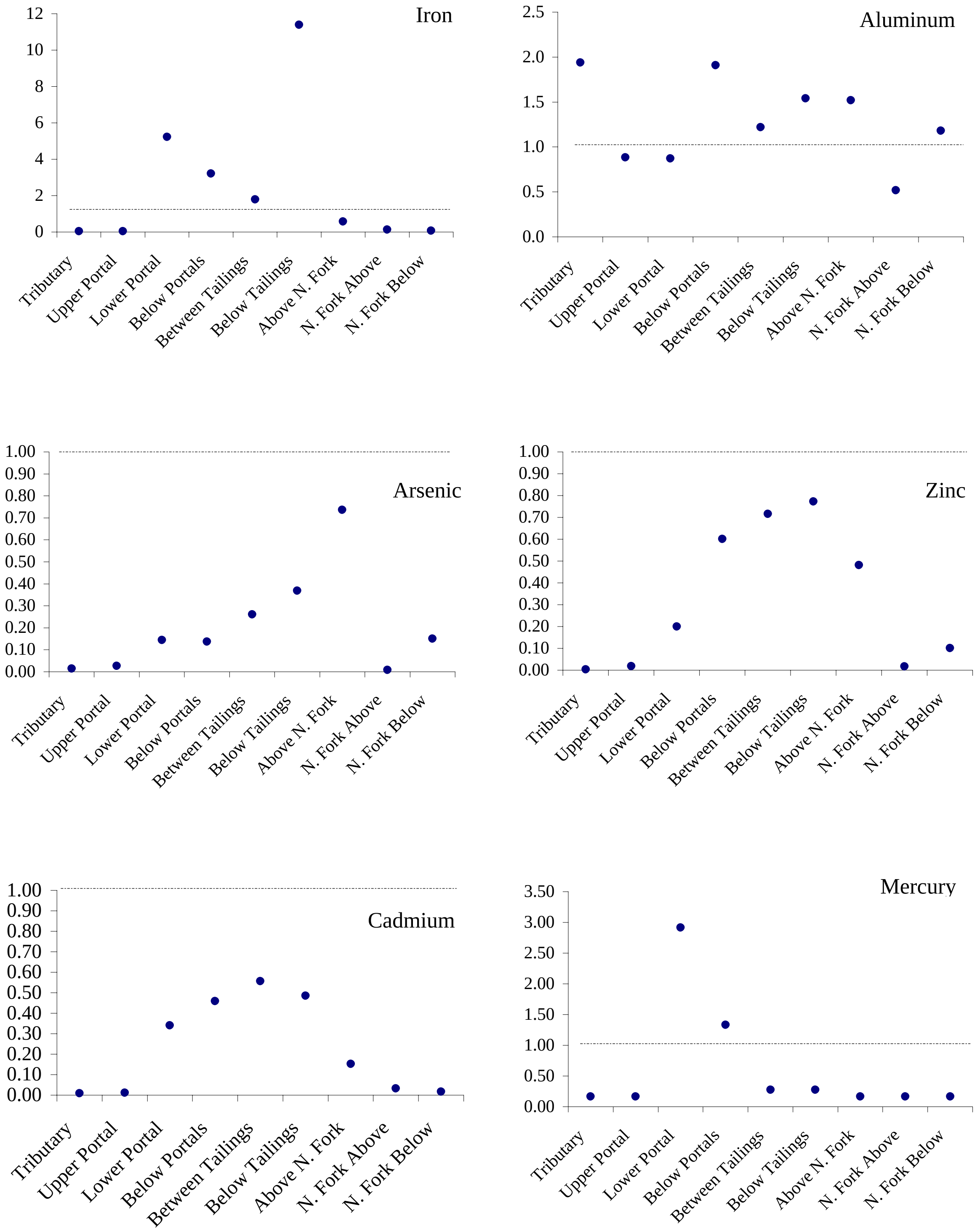

Figure 5. Metals Concentrations Compared to Chronic State Standards or Other Chronic Criteria (iron, aluminum)
[Ratios >1 exceed standards or criteria; August 1999 water data (µg/L).]

Table 13. Grain Size of Cleveland Mine/Hunters Creek Sediment and Tailings Samples Collected August 9-10, 1999

Location	Site No.	Sample No.	Solids (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
Tributary Drainage	1	328300	53.5	20.9	51.9	23.8	3.4
Below Upper Mine Portal	3	328301	40.1	1.5	59.3	34.1	4.9
Tailings @ Lower Mill	5	328302	62.4	31.2	38.3	27.6	3.0
Below Portals & Mill Sites	6	328303	83.1	34.1	59.7	5.9	2.1
Upper Tailings Pile	8	328306	78.1	0.6	78.3	19.2	1.8
Lower Tailings Pile	10	328308	64.7	0.3	50.0	45.9	3.6
0.2 Mile Below Tailings Piles	12a	328310a	79.1	36.1	57.5	5.0	1.5
0.6 Mile Below Tailings Piles	12b	328316	78.5	22.9	70.2	6.1	0.8
Above N. Fork Confluence	13	328311	30.6	0.3	35.6	60.2	3.9
North Fork Above Cleveland	14	328313	83.6	23.3	70.9	4.7	1.0

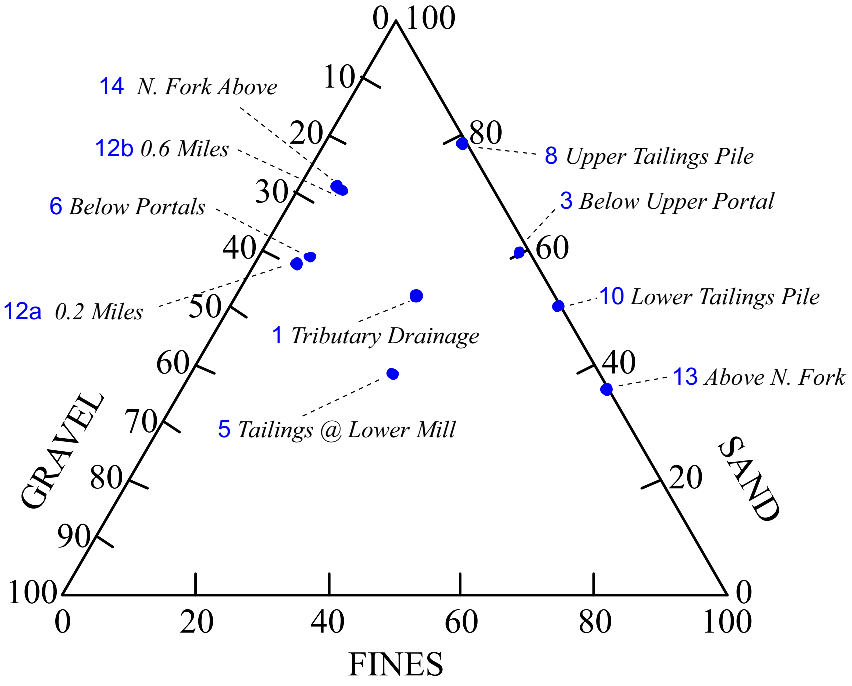

Figure 6. Grain Size Distribution of Sediment and Tailings Samples

Most of the stream sediments were coarse, 21 - 36% gravel and less than 4% fines. Finer material was encountered at site #3 below the upper portal and in the North Fork above Cleveland Mine, which, like the tailings piles, were predominantly sand size. Figure 7 shows a photograph of a portion of the upper tailings pile, taken during the August survey. The tailings sample from the lower mill impoundment was comprised of approximately equal amounts of gravel, sand, and fines.

Table 14 has the metals data on these samples. As already reported by BLM (1998a), the tailings have high concentrations of zinc, lead, arsenic, antimony, and cadmium. Relative to sediments in the upper side tributary and in the North Fork above Cleveland Mine, these same metals are elevated by one or more orders of magnitude in sediments throughout the Cleveland Mine drainage. Smaller elevations are also seen for iron, silver, thallium, and mercury. Judging by results for the North Fork, the upper tributary sediment sample was slightly elevated in lead, arsenic, mercury, and selenium.

A masters thesis (Rabbi, 1992) has additional data on metals concentration in sediments from this area, but it is difficult to determine where samples were collected. The thesis data indicate that manganese levels may also be a concern in the sediments.

Sediment Quality Guidelines for Metals

There are no state standards or EPA aquatic life criteria for metals in freshwater sediments. An Ecology study (Cubbage et al., 1997) has recommended "apparent effects thresholds" (AETs) from an analysis of bioassay and chemical data in the department's FSEDQUAL database on freshwater sediments statewide. These AETs are comparable to sediment quality guidelines that have been developed in Canada (Persaud et al., 1993; Environment Canada, 1994; see Appendix C). Ecology has not officially adopted or proposed to adopt the Cubbage AET values.

Table 15 shows how metals concentrations in the Cleveland Mine and Hunters Creek sediment samples compare to AETs. No AET was available for iron; the table shows a Canadian "severe effects level" for benthic macroinvertebrates (Persaud et al., 1993).

Except for some elevation in mercury, neither of the background sediments (sites #1 and #13) exceeded effects thresholds. All three tailings samples and most of the sediments within Cleveland Mine drainage, including the sample below the upper portal, substantially exceeded AETs for zinc, lead, arsenic, cadmium, silver, and antimony. Iron concentrations were at or above severe effects levels downstream of the lower portal.

The level of sediment contamination in the Cleveland Mine drainage appears exceptionally high when compared to other mining areas. Table 16 shows median and 90th percentile concentrations of metals in creek sediments downstream from eight other mining sites in eastern Washington (Raforth et al., 2000; Johnson et al., 1997). As shown in the table, the median levels of iron, zinc, lead, arsenic, antimony, and cadmium in Cleveland Mine drainage sediments exceed 90th percentile values from other mining districts.

Figure 7. Upper Tailings Pile, Cleveland Mine, August 10, 1999 (mine drainage stream behind camera)

Table 14. Metals Concentrations in Cleveland Mine/Hunters Creek Sediment and Tailings Samples Collected August 9-10, 1999 (mg/Kg, dry weight)

Location	Site No.	Sample No.	Fe	Al	Zn	Pb
Tributary Drainage	1	328300	30,600	18,400	84	20
Below Upper Mine Portal	3	328301	31,400	10,600	1,040	977
Tailings @ Lower Mill	5	328302	84,600	11,300	5,120	3,230
Below Portals & Mill Sites	6	328303/04	71,500	7,230	23,100	12,140
Upper Tailings Pile	8	328306	77,500	2,130	22,600	11,100
Lower Tailings Pile	10	328308	76,200	1,400	9,690	5,160
0.2 Mile Below Tailings Piles	12a	328310a/b	51,100	9,880	10,500	2,640
0.6 Mile Below Tailings Piles	12b	328316	41,000	10,400	7,230	1,530
Above N. Fork Confluence	13	328311	43,400	10,400	8,330	2,500
North Fork Above Cleveland	14	328313	21,700	10,100	51	5 U

Location	Site No.	As	Sb	Cd	Cu	Cr
Tributary Drainage	1	12	10 U	1 U	90	28
Below Upper Mine Portal	3	240	10 UJ	9.0	34	11
Tailings @ Lower Mill	5	2,870	102 J	39	70	19
Below Portals & Mill Sites	6	5,520	415 J	207	115	19
Upper Tailings Pile	8	16,500	826 J	216	99	7.8
Lower Tailings Pile	10	22,400	322 J	89	98	7.2
0.2 Mile Below Tailings Piles	12a	3,320	76 J	76	56	22
0.6 Mile Below Tailings Piles	12b	2,470	22 U	45	38	22
Above N. Fork Confluence	13	3,720	35 J	73	62	21
North Fork Above Cleveland	14	5.7	10 UJ	1 U	21	23

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

Table 14. (continued)

Location	Site No.	Ni	Ag	Tl	Be	Hg	Se
Tributary Drainage	1	21	1.4	0.8 UJ	1 U	0.65	0.53
Below Upper Mine Portal	3	12	1.4	0.8 UJ	1 U	0.21	0.19
Tailings @ Lower Mill	5	29	7.1	7.0 J	1 U	1.9	0.18
Below Portals & Mill Sites	6	18	23	1 J	1 U	0.24	0.15 U
Upper Tailings Pile	8	8.3	20	0.8 UJ	1 U	0.60	0.15 U
Lower Tailings Pile	10	7.2	11	0.8 UJ	1	0.32	0.15 U
0.2 Mile Below Tailings Piles	12a	18	6	2.1 J	1	0.11	0.15 U
0.6 Mile Below Tailings Piles	12b	18	3.0	2.2 J	1 U	0.05	0.15 U
Above N. Fork Confluence	13	20	5.5	5.9 J	1 U	0.20	0.31
North Fork Above Cleveland	14	17	1 U	0.8 UJ	1 U	0.006 U	0.15 U

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

Microscopic Analysis

Manchester further analyzed the tailings and sediment samples microscopically and through microchemical tests, to identify the presence and amount of tailings material in the sediments (Huntamer, 2000). Two types of particles were identified that could be used as tracers of the tailings: metallic grains (usually sulfides) and carbonate grains. The concentrations of cadmium, silver, zinc, and lead in the sediments were strongly correlated (R^2 >0.8) with the amount of metallic grains present. Arsenic did not correlate with metallic grains, but had an R^2 of 0.7 with carbonate grains. It was concluded that arsenic may be primarily present adsorbed to iron hydroxide coatings on the particles, rather than as a specific mineral species.

Table 17 shows the percentage of metallic, carbonate, and other type grains in the samples. Metallic and carbonate grains were not found in any significant numbers in the sediment samples from upper tributary site #1 or in the North Fork above Cleveland Mine. They were also not present in background soils in the vicinity of site #1 and #12b, collected in October 1999. The soils near site #12b were collected three feet above the high water mark, so as not to be influenced by drainage from the Cleveland Mine site.

Table 15. Metals Concentrations in Cleveland Mine/Hunters Creek Sediment Samples Compared to Sediment Quality Guidelines (mg/Kg, dry weight)

	Local Background (sites #1,14)	Tailings (sites #5,8,10)	Downstream Sediments (sites #3,6,12a,12b,13)	Apparent Effects Threshold[a]
Fe	21,700 - 30,600	**76,200 - 84,600**	31,400 - **71,500**	40,000[b]
Al	10,100 - 18,400	1,400 - 11,300	7,230 - 10,600	- -
Mn	na	na	na	1,800
Zn	51 - 84	**5,120 - 22,600**	**1,040 - 23,100**	520
Cu	21 - 90	70 - 99	34 - 115	840
Cr	23 - 28	7.2 - 19	11 - 22	280
Pb	5U - 20	**3,230 - 11,100**	**977 - 12,135**	260
Ni	17 - 21	7.2 - 29	12 - 20	46
As	5.7 - 12	**2,870 - 22,400**	**240 - 5,525**	40
Cd	1U	**39 - 216**	**9.0 - 207**	8
Ag	1U - 1.4	**7.1 - 20**	1.4 - **23**	5
Sb	10U	**102J - 322J**	10UJ - **415J**	3
Hg	.006U - **0.65**	0.32 - **1.9**	.05 - .24	1
Se	.15U - 0.53	0.15U - 0.18	0.15U - 0.31	- -
Be	1U	1U - 1	1U - 1	- -
Tl	0.8UJ	0.8UJ - 7.0J	0.8UJ - 5.9J	- -

Exceedances highlighted in **BOLD**

[a] Cubbage et al. (1997) - Ecology (not adopted or proposed)

[b] Persaud et al. (1993) - Ontario Severe Effects Level

U = not detected at or above reported value

J = estimated value

UJ = not detected at or above reported estimated value

na = not analyzed

Table 16. Concentrations of Selected Metals in Cleveland Mine Downstream Sediments Compared to Downstream Sediments in Other Eastern Washington Mining Areas[a,b]

	Cleveland Mine (n = 5)		Other E. Wash Mines (n = 10-13)	
	median	90th percentile	median	90th percentile
Fe	43,400	63,340	16,100	27,500
Zn	8,330	18,060	113	1,837
Pb	2,500	8,337	4	18
As	3,315	4,803	6	380
Sb	35	279	3	4
Cd	73	155	0.5U	37
Ag	6	16	0.3U	12

[a] Raforth et al. (2000)
[b] Johnson et al. (1977)
U = not detected at or above reported value

Table 17. Percentages of Grain Size Types[a] in Cleveland Mine/Hunters Creek Tailings, Sediment, and Soil Samples Collected August 9-10 and October 26, 1999

Location	Site No.	Sample Type	Grain Types		
			Metallic	Carbonate	Other
Tributary Drainage	1	sediment	0	0	100
"	1a	soil	0	0	100
Below Upper Mine Portal	3	sediment	0.52	2.3	97
Tailings @ Lower Mill	5	tailings	1.1	4	95
Below Portals & Mill Sites	6	sediment	14	20	66
Upper Tailings Pile	8	tailings	9.6	23	67
Lower Tailings Pile	10	tailings	4.5	53	43
0.2 Mile Below Tailings Piles	12a	sediment	3.3	25	72
0.6 Mile Below Tailings Piles	12b	sediment	2.8	9.6	88
"	12c	soil	0	0	100
Above N. Fork Confluence	13	sediment	1.4	27	72
North Fork Above Cleveland	14	sediment	0	0	100

[a] from Huntamer (2000)

The highest percentage of metallic grains was found at site #6 below the old mill, followed closely by the upper tailings pile sample (14% and 9.6%, respectively). These tapered off going downstream to the North Fork confluence, where the percent metallic grains was 1.4. While showing the presence of substantial amounts of tailings in the stream, these percentages are not directly proportional to the total amount. No consistent downstream trend was evident for carbonate grains.

Normalizing the metals data on bulk sediment to metallic grains brings the concentrations of cadmium, silver, zinc, and lead in tailings pile samples and downstream sediments more in line with one another. For example, see Figure 8 which plots the dry weight and normalized data for lead.

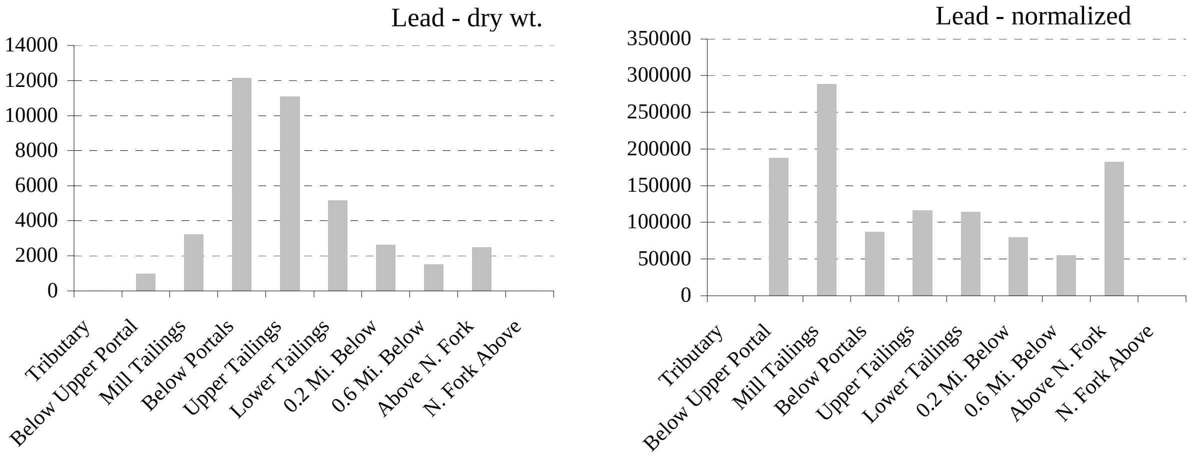

Figure 8. Dry Weight and Normalized Data for Lead Concentrations in Sediment and Tailings Samples (mg/Kg; lead normalized to percent metallic grains)

Recontamination Potential

Results of the present survey show there are approximately 0.3 miles of heavily contaminated sediments in the drainage upstream of BLM land (from site #6 near the BLM boundary to site #3 below the lower portal). If sediments are removed from the stream bed on BLM land, recontamination will occur as upstream sediments are gradually washed into this area.

If upstream sediments are removed or controlled, then the primary source of recontamination would be the lower portal through deposition of iron and aluminum hydroxides and sorption of metals onto this material. Signs of iron deposition, such as staining or flocs, were weak or not observed below the confluence of the two mine portals, so this may not cause a serious impact to the stream bed.

As long as the pH remains high in the portals and drainage stream, state water quality standards should generally continue to be met on BLM land. Iron and, to a much lesser extent, aluminum will continue to be potential water quality problems.

Conclusions

Results from this survey show the lower portal is the primary contributor to poor water quality in drainage from the Cleveland Mine site. Due to good buffering capacity, state water quality standards for metals were generally met during the late summer/fall sampling period. The iron discharge from the lower portal caused aquatic life criteria to be exceeded down to the confluence with the North Fork of Hunters Creek. Sediments in all parts of the Cleveland Mine drainage stream are highly contaminated with iron, zinc, lead, arsenic, cadmium, silver, and antimony, due to the presence of tailings and discharges from the lower portal. The concentrations observed would be expected to have a severe adverse effect on benthic organisms.

Recommendations

- Additional water sampling should be conducted to (1) document conditions after cleanup of the tailings piles and stream sediments on BLM land and (2) more clearly determine if metals concentrations violate state standards during spring runoff.

- Additional sediment sampling should be conducted in Hunters Creek between the North Fork and Lake Roosevelt to determine if there is significant metals contamination.

- Options for cleaning up the sediments on non-BLM land within the Cleveland Mine drainage should be evaluated.

References

Bethke, C.M. 1996. Geochemical Reaction Modeling. Oxford Univ. Press, New York, NY.

BLM. 1998a. Final Draft EECA Report: Cleveland Mill Tailings, Spokane District, Washington. Bureau of Land Management.

BLM. 1998b. Letter to Tony Grover, Department of Ecology Eastern Regional Office, from Joseph Buesing, Bureau of Land Management, Spokane District Office, Spokane, WA.

Butcher, G.A. 1988. Water Quality Criteria for Aluminum: Technical Appendix. British Columbia Ministry of Environment and Parks.

CCREM. 1987 (and updates). Canadian Water Quality Guidelines. Canadian Council of Resource and Environment Ministers, Ottawa, Ontario.

Cubbage, J., D. Batts, and S. Briedenbach. 1997. Creation and Analysis of Freshwater Sediment Quality Values in Washington State. Washington State Dept. Ecology, Olympia, WA. Pub. No. 97-323a.

Environment Canada. 1994 (draft). Interim Sediment Quality Assessment Values. Ecosystem Conservation Directorate Evaluation and Interpretation Branch, Ottawa, Ontario.

EPA. 1990. Specifications and Guidance for Obtaining Contaminant-Free Sample Containers. OSWER Directive #93240.0-05.

EPA. 1995. Method 1669: Sampling Ambient Water for Trace Metals at EPA Water Quality Levels. EPA 821-R-95-034.

EPA. 1999. National Recommended Water Quality Criteria. EPA 822-Z-99-001.

George, D. 2000. Personal communication. Washington State Dept. Ecology, Spokane, WA.

Gray, N.F. 1997. Environmental Impact and Remediation of Acid Mine Drainage: A Management Problem. Environ. Geol. 30(1/2):62-71.

Holmstrom, H., J. Ljungberg, and B. Ohlander. 1999. Role of Carbonates in Mitigation of Metal Release from Mining Waste. Evidence from Humidity Cells. Environ. Geol. 37(4): 267-280.

Huntamer, D. 2000. Identification of Cleveland Mine Tailings Pile Particulate Matter in Hunters Creek Drainage, Stevens County, Washington. Washington State Dept. Ecology, Manchester Laboratory, Manchester, WA.

Jakabosky, J. 2000. Personal communication. Bureau of Land Management, Spokane, WA.

Johnson, A., J. White, and D. Huntamer. 1997. Effects of Holden Mine on the Water, Sediment, and Benthic Invertebrates of Railroad Creek (Lake Chelan). Washington State Dept. Ecology, Olympia, WA. Pub. No. 97-330.

Kammin, W.R., S. Cull, R. Knox, J. Ross, M. McIntosh, and D. Thompson. 1995. Labware Cleaning Protocols for the Determination of Low-level Metals by ICP-MS. American Environmental Laboratory 7(9).

Kelly, J. 1998. Memorandum to George Brown, BLM, on fish species inhabiting waters downstream of the Cleveland Mine site. Bureau of Land Management, Spokane District Office, Spokane, WA.

MEL. 1999. Laboratory Users Manual. Washington State Dept. Ecology, Manchester Environmental Laboratory, Manchester, WA.

Persaud, D., R. Jaagumagi, and A. Hayton. 1993. Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario. Ontario Ministry of Environment and Energy.
ISBM 0-7729-9248-7.

Purdy, C.P. 1951. Antimony Occurrences of Washington. Washington State Dept. Conservation and Development, Olympia, WA. Bull. No. 39.

Rabbi, F. 1992. Trace Element Geochemistry of Polluted Stream Sediments and Water in Hunters and Cleveland Areas of Stevens County, Washington. MS Thesis, Eastern Washington University, Pullman, WA.

Raforth, R., D. Norman, and A. Johnson. 2000. Screening Level Investigation of Water and Sediment Quality Impacts at Ten Eastern Washington Mining Districts, with Emphasis on Metals. Washington State Dept. Ecology and Washington State Dept. Natural Resources. Ecology Pub. No. 00-03-004.

Ross, J. 2000. Personal communication. Washington State Dept. Ecology, Manchester Environmental Laboratory, Manchester, WA.

Appendices

Appendix A. Coordinates of August 9-10, 1999 Sampling Sites

Site No.	Location	Latitude (48^o N)	Longitude (118^o W)
1	Tributary Drainage	07 02	00 04
2	Upper Mine Portal	06 53	01 13
3	Below Upper Mine Portal	not recorded	
4	Lower Mine Portal	07 05	00 57
5	Tailings @ Lower Mill	06 34	01 44
6	Below Portals & Mill Sites	07 11	02 03
7	Above Tailings	no samples	
8	Upper Tailings Pile	07 23	02 21
9	Between Tailings Piles	06 51	02 09
10	Lower Tailings Pile	07 24	02 31
11	Below Lower Tailings Pile	not recorded*	
12a	0.2 Mile Below Tailings Piles	07 19	02 30
12b	0.6 Mile Below Tailings Piles	07 18	03 17
13	Above North Fork Confluence	07 52	03 09
14	North Fork above Cleveland	07 57	03 05
15	North Fork below Cleveland	no samples	
16	North Fork above South Fork Confluence	07 02	04 54
17	South Fork above North Fork Confluence	no samples	

*about 100 feet downstream of lower tailings pile sample, site #10

Appendix B. Metals Criteria 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 C. Guidelines on Metals in Freshwater Sediments (mg/Kg, dry)

	Ontario[a]	Canada[b]	Ecology[c]
Metal	Severe Effects Level	Probable Effects Level	Apparent Effects Threshol
Iron	40,000	- -	- -
Manganese	1,100	- -	1,800
Zinc	820	310	520
Lead	250	91	260
Copper	110	200	840
Chromium	110	90	280
Nickel	75	36	46
Cadmium	10	3.5	7.6
Arsenic	33	17	40
Silver	- -	- -	4.5
Antimony	- -	- -	3.0
Mercury	2.0	0.49	0.56
Selenium	- -	- -	- -
Beryllium	- -	- -	- -
Thallium	- -	- -	- -

[a] Persaud et al. (1993)

[b] Environment Canada (1994)

[c] Cubbage et al. (1997)