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HEAVY METALS IN STREAM SEDIMENTS ADJACENT TO THE EQUITY SILVER MINESITE NEAR HOUSTON, B.C.

Regional Program Report 86-22

By

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ABSTRACT

Sediment samples were collected from streams adjacent to the Equity minesite. In some cases the results reflected contamination due to mine discharges while in other cases the higher metal levels appeared to reflect the presence of the ore body. Future monitoring considerations are discussed.

RÉSUMÉ

On a prélevé des échantillons de sédiments dans des cours d'eau situés tout près de la mine Equity. Dans certains cas on a noté une contamination due aux effluents rejetés par la mine; dans d'autres cas, un accroissement du taux de concentration des métaux semble attester la présence de minerai. Le rapport traite de considérations relatives aux futures enquêtes.

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SUMMARY AND CONCLUSIONS

Sediments were sampled from streams adjacent to the Equity minesite six years after the mine started production. The data form a basis for future comparisons to assess heavy metal loadings to these streams.

Bessemer Creek was found to be contaminated with most metals [e.g. mean copper (368-648 ug/g), mean zinc (317-717 ug/g), mean cadmium (1.9-6.9 ug/g)]. This reflects the discharge of untreated acid mine water earlier on in the mines development and contaminated water presently being discharged.

Buck Creek downstream of Bessemer Creek did not appear to reflect the high level of contamination in Bessemer Creek. Zinc levels were significantly different at site S13 the site nearest Bessemer Creek but copper levels were not. This seemed unusual considering the overall high correlation between copper and zinc levels ($r = 0.98$). The three Foxy Creek sites between Lu Creek and downstream of Berzilius Creek had significantly higher sediment levels of copper and zinc relative to the control site and/or the furthest downstream site. However, the absence of contaminated sediments in Lu Creek plus some evidence of similar levels from one of the sites in 1983 (prior to AMD discharge) suggest the metal levels reflect the presence of the ore body rather than the mine discharge to date.

Future monitoring programs should consider the estimated number of samples required to measure a specified level of metal increase. Examples are provided for Foxy Creek and Buck Creek based on the data collected in this study and measuring 0.5, 1.0 or 2.0 standard deviation increases.

The objective of future studies would be to determine whether sediment metal levels increase beyond existing levels due to mine discharges. The biological significance of any change would require additional considerations.

1 INTRODUCTION

Equity Silver Mines is located approximately 33 km southeast of Houston, B.C. (Figure 1). The mine began production in September 1980. In November 1981 it was determined that waste rock at the mine site was generating acid and untreated acid mine drainage was entering Bessemer Creek. The company constructed a temporary acid mine drainage collection system in Spring 1982 and has continued to make improvements to the collection and treatment system since then. Annual discharges of treated acid mine water began in October 1983 to the Foxy Creek drainage and in May 1985 to the Bessemer Creek drainage.

The Environmental Protection Service (EPS) conducted a stream sediment survey in October 1985 to determine existing metal levels and form a data base for future evaluations. This report presents an analysis of the sediment survey results.

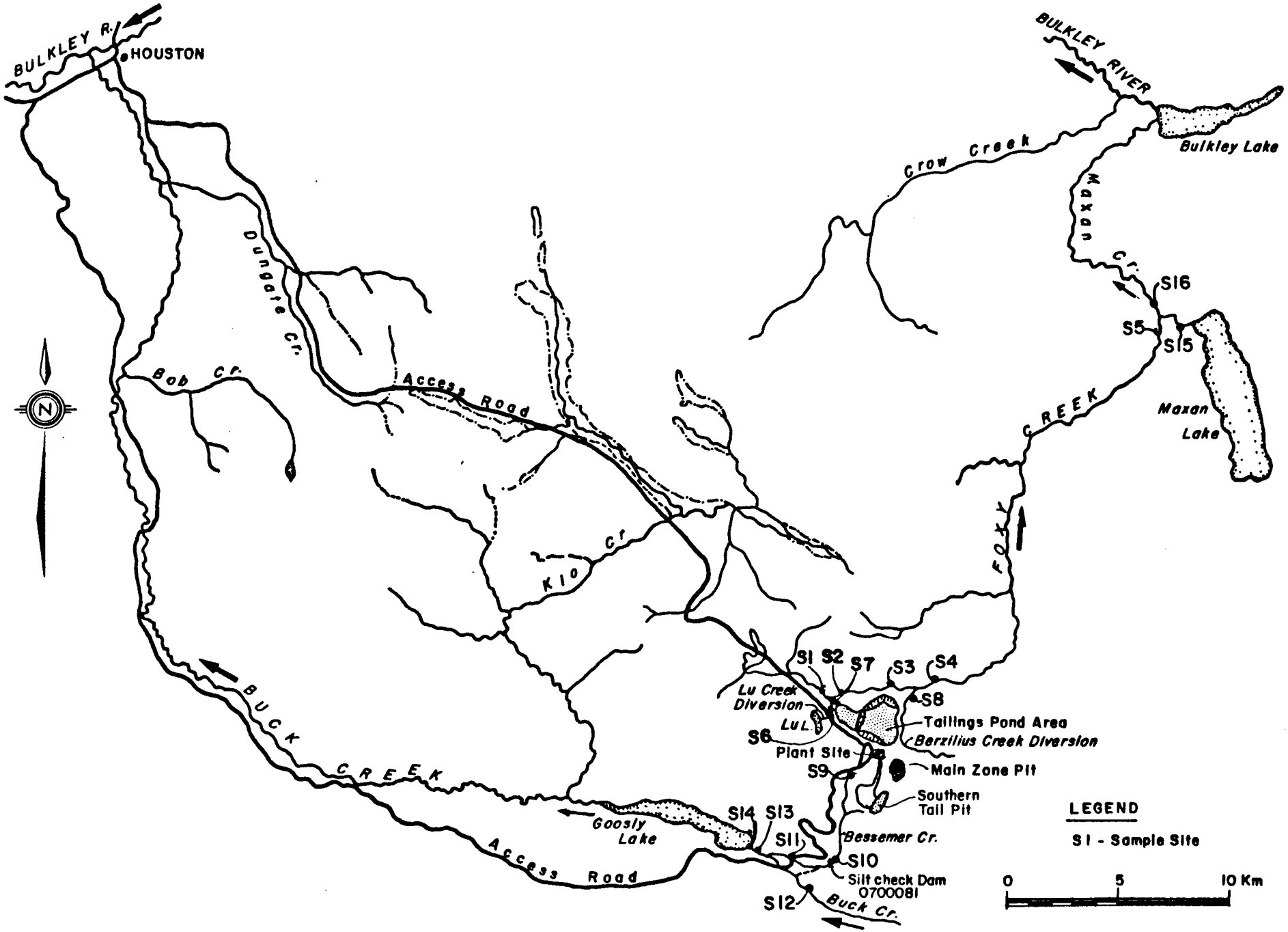


FIGURE 1 EQUITY SILVER MINE - EPS SEDIMENT MONITORING STATIONS

2 DESCRIPTION OF STUDY AREA

The Equity Silver minesite is centered on the Foxy Creek and Bessemer Creek watersheds. Foxy Creek is a tributary of Maxan Creek which flows into Bulkley Lake. Treated acid mine water is discharged into a collection ditch which runs into Lu Creek which in turn discharges into Foxy Creek (Figure 2). Bessemer Creek is a tributary of Buck Creek upstream of Goosly Lake. Treated acid mine water is discharged into a collection ditch which discharges into Upper Bessemer Creek downstream of the acid mine water collection system (Figure 2). Buck Creek downstream of Goosly Lake flows into the Bulkley River at Houston (Figure 1).

Sixteen sites were sampled and the stations are described in Appendix I and shown on Figures 1 and 2.

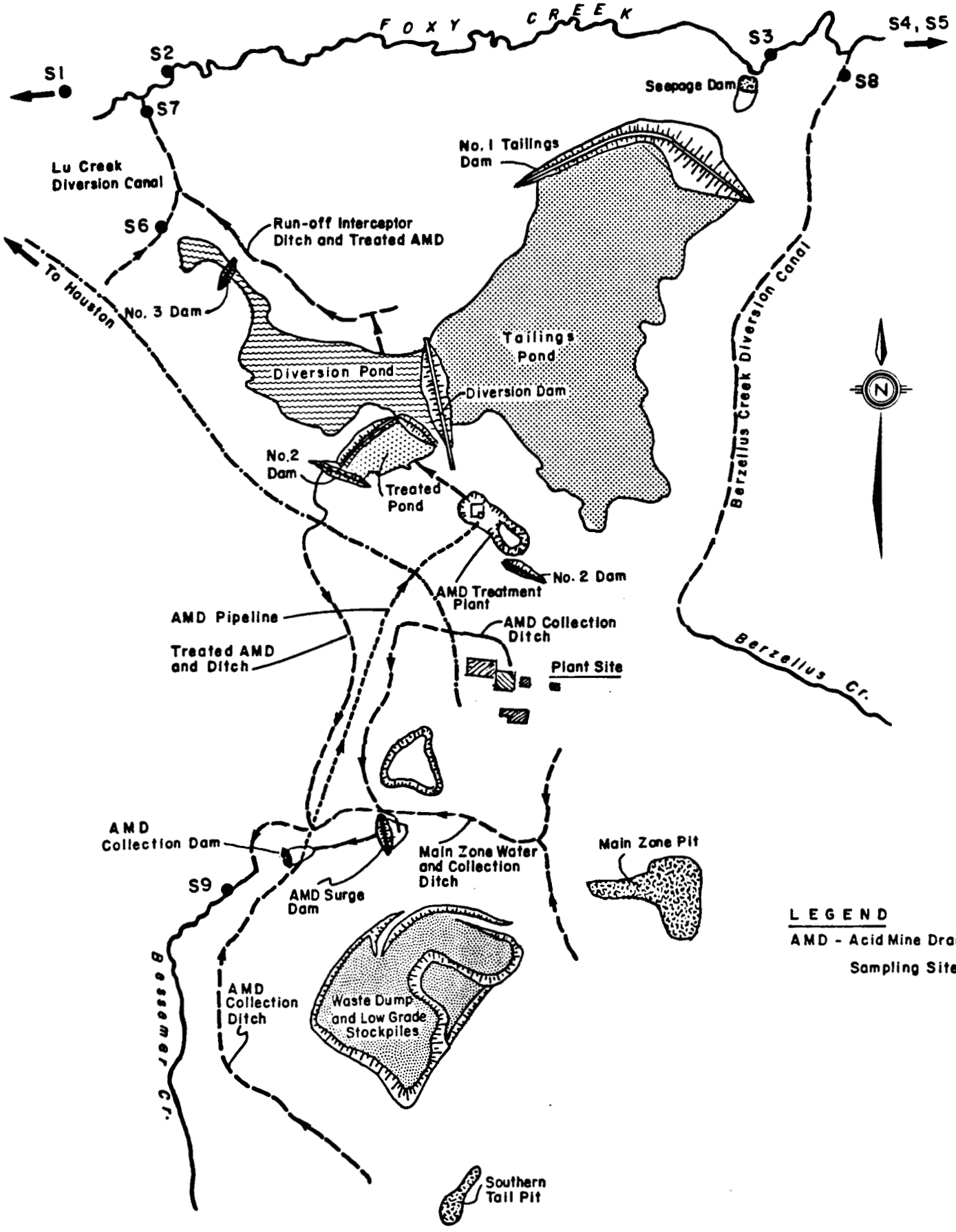


FIGURE 2 EQUITY SILVER MINES LTD. - SITE PLAN

3 MATERIALS AND METHODS

3.1 Sampling

At sites with typical clastic stream sediments, samples were obtained using a 600 ml capacity stainless steel syringe (Derksen, 1985). The probe was worked into the substrate to a depth of 15-20 cm. A sample was drawn up and evacuated into a clean 2 litre polyethylene sample bottle. Four replicates were collected in most cases. Each replicate consisted of a composite of three syringe samples, one each from both sides and the center of the stream (Appendix I). To obtain the final sample, the bottle was left to settle overnight, the water was decanted and then the sediment was spooned into a kraft sediment bag. The only difficulty in obtaining a syringe sample was for Buck Creek. Due to the fine nature of the sediment, core sample methods would have been appropriate.

At the sites where the syringe sampler was not used, a clean acrylic tube (4.76 cm I.D.) was pushed approximately 6-8 cm into the substrate. The core was extruded with a wood dowl into a kraft sediment bag.

The samples were kept frozen until preparation for analysis.

3.2 Analytical Methods

3.2.1 Stream Samples. All analyses were performed at the EPS laboratory in West Vancouver (Anon, 1979). Analyses were made on the < 150 um size fraction and the analytical procedures are outlined in Appendix II. Mercury was analyzed on a Pharmica Mercury Monitor Model 100, silver by atomic absorption spectrometry and the other metals by Inductively Coupled Argon Plasma (ICAP) Atomic Emission Spectrometry.

Percent organic content was determined from a volatile sediment residue analysis. The prepared sample (1-10 gm) was air dried at 90°C overnight followed by drying at 103°C for one hour. The sample was then muffled at 550°C for one hour.

3.2.2 Reference Samples. National Research Council reference samples BCSS1 and MESS1 were tested to evaluate the analytical methods. National Bureau of Standards reference sample NBS1641 was also analyzed for mercury. Reference samples were not analyzed for silver. The reverse aqua regia digest used is not considered a total digest for silica associated or refractory compounds.

4 RESULTS AND DISCUSSION

4.1 Reference Samples

For copper and zinc, the percent recovery based on mean values was 91-99% and 99-101% respectively of the reference sample means (Table 1). Arsenic levels were reported as below detectable levels (< 8 ug/g) although both reference samples had measureable arsenic (^ 11 ug/g). Lowest recovery was for aluminum and was 32-37% of the reference sample means. Three reference samples were analyzed for mercury and recovery ranged from 99-139% of the reference sample means. There were no reference materials analyzed for silver.

4.2 Metal and Organic Content of Sediments - General Observations

Sediment silver, arsenic, cadmium, copper, mercury, lead, zinc and percent organic content are summarized in Table 2. The results for these and the other metals analyzed (Al, Ca, Fe, Mg, Mn, Ni) are reported in Appendix III.

The data indicate some readily apparent elevated levels in Bessemer Creek and to a lesser degree in Foxy Creek (relative to Foxy Creek control).

Bessemer Creek sediments appear to be contaminated with all metals other than mercury relative to the other sites (Table 2). This is not unexpected since the creek received untreated acid mine water prior to a collection and treatment system being installed in 1982 (Patterson, 1986). The creek still receives metal inputs but a general trend in improved effluent quality being discharged through Bessemer Creek is evident over 1981 to 1985 (Table 3). Copper and zinc both reflect the degree of acid mine water contamination. Treated acid mine drainage (AMD) was not discharged into Bessemer Creek until May 1985 (Table 4). Bessemer Creek drains into a diffuse wetland area downstream of site S11 before draining into Buck Creek. During Spring runoff, some of the Bessemer Creek flow apparently bypasses the wetland area. Metal levels in Buck Creek did not reflect the high level of contamination in Bessemer Creek.

Foxy Creek sediments from site S2 in the area downstream of the Lu Creek diversion to site S4 downstream of Berzilius Creek indicated higher

TABLE 1 REFERENCE SAMPLES

METAL	NRC MESS 1	EPS (n = 3)	RELATIVE % DIFFERENCE*	NRC BCSS 1	EPS (n = 2)	RELATIVE % DIFFERENCE*	NBS 1641	EPS (n = 4)	RELATIVE % DIFFERENCE*
	$\bar{x}$	$\bar{x}$ (SD)		$\bar{x}$	$\bar{x}$ (SD)		$\bar{x}$	$\bar{x}$ (SD)	
As (ug/g)	10.6 ± .02	< 8 (0)	-	11.1 ± 1.4	< 8 (0)	-	-	-	-
Cd (ug/g)	.59 ± .10	.60 (.01)	-	.25 ± .04	< .3 (0)	-	-	-	-
Co (ug/g)	10.8 ± 1.9	13.9 (2.1)	129	11.4 ± 2.1	11.9 (.5)	104	-	-	-
Cu (ug/g)	25.1 ± 3.8	24.8 (1.1)	99	18.5 ± 2.7	16.9 (.9)	91	-	-	-
Mn (ug/g)	513 ± 25	386 (9.3)	75	229 ± 15	230 (3)	100	-	-	-
Ni (ug/g)	29.5 ± 2.7	24 (2)	81	55.3 ± 3.6	53 (1)	96	-	-	-
Pb (ug/g)	34.0 ± 6.1	37 (5)	109	22.7 ± 3.4	23 (2)	101	-	-	-
Zn (ug/g)	191 ± 17	190 (6)	99	119 ± 12	120 (1)	101	-	-	-
Al (%)	5.84 ± .20	1.85 (.07)	32	6.26 ± .22	2.31 (.03)	37	-	-	-
Fe (%)	3.05 ± .17	2.62 (.08)	86	3.29 ± .10	3.09 (.04)	94	-	-	-
Ca (ug/g)	4820 ± 457	2460 (50)	51	5430 ± 529	4520 (35)	83	-	-	-
Mg (ug/g)	8680 ± 542	7130 (290)	82	1.47 ± .16	1.33 (.01)	90	-	-	-
Hg (ug/g)	.171 ± .014	.203 (.016)	119	.129 ± .012	.179 (.027)	139	1.49 ± .04	1.47 (.08)	99
Ag (ug/g)	-	-	-	-	-	-	-	-	-

* relative difference in sample means, reference sample mean value taken as 100%

TABLE 2 SUMMARY OF SEDIMENT METAL LEVELS

CREEK	SITE #	n	METAL (ug/g)							ORGANIC CONTENT %	
			Ag	As	Cd	Cu	Hg	Pb	Zn		
			$\bar{x}$ (SD)	$\bar{x}$ (SD)	$\bar{x}$ (SD)	$\bar{x}$ (SD)	$\bar{x}$ (SD)	$\bar{x}$ (SD)	$\bar{x}$ (SD)	$\bar{x}$	(SD)
(Foxy Drainage)											
Foxy	S1	4	.20 (.06)	< 8 (0)	< .3 (0)	48.4 (5.3)	.09 (.02)	29 (3)	121 (8)	3.5	(1.0)
	S2	4	.25 (.05)	< 8 (0)	1.2 (.7)	100 (24.7)	.10 (.01)	31 (2)	172 (32)	4.7	(1.5)
	S3	4	.28 (.08)	< 8 (0)	1.0 (.3)	68.5 (8.3)	.13 (.05)	33 (3)	184 (13)	5.7	(.4)
	S4	4	.25 (.05)	< 8 (0)	.5 (.2)	85.3 (3.3)	.17 (.12)	36 (2)	193 (6)	4.5	(.5)
	S5	4	.09 (.01)	< 8 (0)	< .3 (0)	40.9 (3.3)	.09 (.02)	28 (3)	108 (5)	3.6	(.8)
Maxan	S15	4	.12 (.03)	< 8 (0)	< .3 (0)	28.9 (1.6)	.08 (.03)	22 (2)	101 (5)	5.1	(1.1)
	S16	4	.11 (.01)	< 8 (0)	< .3 (0)	33.8 (3.1)	.08 (.02)	26 (2)	98.4 (2.7)	4.6	(.6)
Lu	S6	3	.18 (.12)	< 8 (0)	< .3 (0)	42.7 (5.8)	.09 (.05)	27 (6)	99.4 (18.4)	.9	(.1)
	S7	3	.13 (.02)	< 8 (0)	< .3 (0)	53.9 (5.6)	.14 (.03)	27 (2)	127 (9)	1.8	(.6)
Berzilius	S8	4	.26 (.06)	< 8 (0)	< .3 (0)	91.7 (1.4)	.10 (.01)	40 (3)	181 (14)	3.5	(.5)
(Buck Drainage)											
Buck	S12	4	.13 (.05)	< 8 (0)	< .3 (0)	46.4 (10.6)	.11 (.03)	32 (5)	111 (4)	2.8	(.8)
	S13	4	.20 (.08)	< 8 (0)	< .3 (0)	52.0 (3.8)	.24 (.22)	34 (2)	147 (7)	1.8	(.4)
	S14	4	.15 (.05)	< 8 (0)	< .3 (0)	41.6 (10.8)	.09 (.01)	28 (3)	117 (8)	2.7	(1.9)
Bessemer	S9	4	5.2 (2.9)	87 (16)	6.9 (1.4)	648 (106)	.21 (.02)	192 (29)	717 (91)	2.4	(1.8)
	S10	4	1.1 (.13)	14 (7)	1.9 (.7)	368 (38)	.14 (.01)	94 (6)	317 (25)	4.8	(.9)
	S11	3	.88 (.46)	< 8 (0)	4.2 (2.3)	544 (197)	.15 (.02)	79 (13)	547 (227)	15.3	(23.5)

TABLE 3 BESSEMER CREEK COPPER AND ZINC LEVELS AT SITE 0700081 OVER 1981 TO 1985

YEAR	n	MEAN (SD)	MINIMUM	MAXIMUM	MEDIAN	25th PERCENTILE	75th PERCENTILE
COPPER (ug/l)							
1981*	5	1016 (481)	180	1400	1160	1090	1160
1982	36	509 (1398)	2	7710	84	56	155
1983	50	121 (85)	16	350	96	57	160
1984	52	206 (283)	13	1420	105	62	210
1985	51	61 (73)	12	350	33	19	63
ZINC (ug/l)							
1981*	4	1642 (514)	1180	2367	1510	1295	1989
1982	36	468 (867)	5	4220	180	145	250
1983	48	250 (128)	64	650	230	150	310
1984	52	234 (308)	5	1250	140	85	190
1985	51	86 (86)	16	450	58	32	86

* Results for November and December only, other years for January to December inclusive, data summarized from Patterson, 1986. Site 0700081 was established as a silt check dam in 1984.

TABLE 4 TREATED AMD DISCHARGE LOADINGS

DATE	VOLUME (m^3/month)	n	$\bar{x}$ T. Cu (ug/l)	LOADING (kg)	n	$\bar{x}$ T. Zn (ug/l)	LOADING (kg)
FOXY CREEK							
1983							
October	11 700	4	125	1.46	2	300	3.51
November	7 900	5	102	.81	5	338	2.67
December	5 400	4	158	.85	4	290	1.57
1984							
April 18	30 100	2	45	1.35	2	54	1.63
May	230 800	5	66	15.23	5	62	14.31
June	589 000	4	15	8.84	4	29	17.03
July	207 200	5	22	4.56	5	31	6.42
August	149 400	4	27	4.03	4	23	3.44
September	197 100	4	9	1.77	4	12	2.36
October	125 700	5	9	1.13	5	12	1.51
November	71 000	4	19	1.35	4	35	2.48
December 28	11 600	4	61	.71	4	107	1.24
1985							
May 9	146 500	3	45	6.59	3	102	14.94
June	321 800	4	26	8.37	4	95	30.57
July	76 700	5	39	2.99	5	81	6.21
August	12 300	4	61	.75	4	101	1.24
September	29 700	5	59	1.75	5	93	2.76
October	27 100	4	47	1.27	4	77	2.09
November 27	19 900	4	35	.70	4	99	1.97
TOTAL 1983-1985				64.51			117.95
BESSEMER CREEK							
1985							
May 27	33 400	-	-	-	-	-	-
June	169 500	3	35	5.93	3	120	20.34
July 25	53 600	4	162	8.68	4	185	9.92
TOTAL				14.61			30.26

* Data from Patterson, 1986

levels of cadmium, copper and zinc relative to the control site S1 and the furthest downstream site (S5) (Table 2). Foxy Creek has received an 'indirect' discharge (via Lu Creek) of treated acid mine drainage since October 1983 (Table 4). Lu Creek (S7) sediments downstream of the treated AMD discharge channel reflect somewhat higher mean copper and zinc levels but not cadmium. A single factor analysis of variance indicated these differences were not significant (α = .05). A set of sediment samples collected in July 1983 (by the same method) from Foxy Creek in the vicinity of Foxy Creek site S3 had a copper concentration [$\bar{x}$ (SD)] of [58 (2) ug/g], a zinc concentration of [157 (3) ug/g] and a cadmium concentration of [1.0 (.1) ug/g]. These levels are similar to the values reported in this study at site S3 for copper [68.5 (8.2) ug/g], zinc [184 (13) ug/g] and cadmium [1.0 (.3) ug/g]. The absence of heavily contaminated sediments in Lu Creek plus comparable metal levels at site S3 prior to the discharge of treated AMD to Lu Creek indicate metal levels at sites S2 to S4 reflect the presence of the ore body rather than the mine discharge to date.

Berzilius Creek had copper and zinc but not cadmium concentrations comparable to the higher levels in Foxy Creek (Table 2). The creek at the point of discharge into Foxy Creek was not its natural channel. Berzilius Creek did receive some acid water generated from riprap along the diversion channel (pers. comm., Bob Patterson).

4.2.1 Correlation Between Metals and Organic Matter. There was no statistically significant (α= .05) correlation between any of the metals and sediment organic content. The strongest statistically significant correlation existed between copper and zinc (r = .98) followed by silver and zinc (r = .82) and silver and copper (r = .79).

4.3 Statistical Assessment of Copper and Zinc Levels

The Kolmogorov-Smirnov test was used to test for goodness of fit to a normal distribution. For Foxy Creek and Buck Creek, the hypothesis that the samples came from a normal distribution was accepted in all cases (α= .05) (Zar, 1984).

Analyses of variance were followed by multiple comparisons of sediment elemental values by Tukey's test (Zar, 1984). Statistical comparisons were made on a Hewlett Packard model HP9133 computer. All tests for significance were made at $p < .05$ unless otherwise stated.

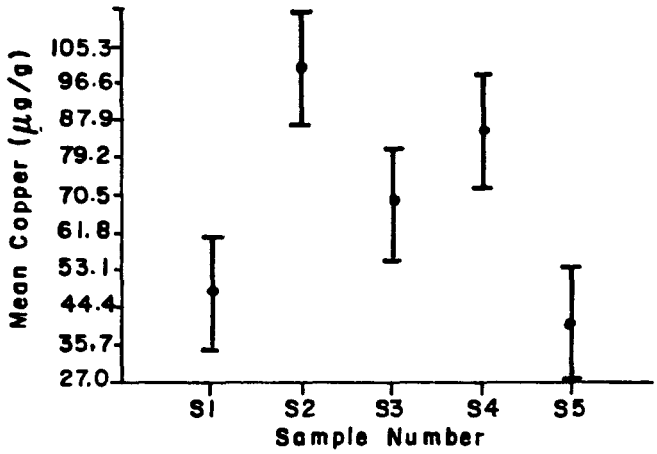
4.3.1 Foxy Creek. An analysis of variance indicated that the hypothesis that all station mean copper and zinc levels were equal was rejected. Tukey's test indicated that for copper, the control site (S1) was not different from site S3 or site S5 (Figure 3). Sites S2 and S4 were not different from one another but both were different from the control site and the furthest downstream site (S5). Site S3 was different from site S5. For zinc, the control site (S1) was not different from the furthest downstream site (S5). Sites S2, S3 and S4 were not different from one another but they were all different from sites S1 and S5 (Figure 1).

4.3.2 Buck Creek. An analysis of variance indicated that while the hypothesis was accepted for all station mean copper levels being equal, it was rejected for zinc. Mean copper levels are shown on Figure 4. For zinc, the control site (S12) was not different from site S14 at Goosly Lake (Figure 4). Site S13 was different from both site S12 and S14. This site was nearer the point at which the Bessemer Creek wetland area emerges to drain into Buck Creek. Considering the strong correlation between copper and zinc ($r = .98$) it seems unusual that if the higher zinc levels were related to the influence of Bessemer Creek, copper would not also be elevated.

4.4 Future Monitoring Considerations

The sediment data collected in this study represents what can be considered a baseline for future comparisons. As comparable data does not exist prior to the mines operation, it is not clear what influences existing discharges may have had on Foxy Creek or Buck Creek. There is obvious contamination of Bessemer Creek sediments.

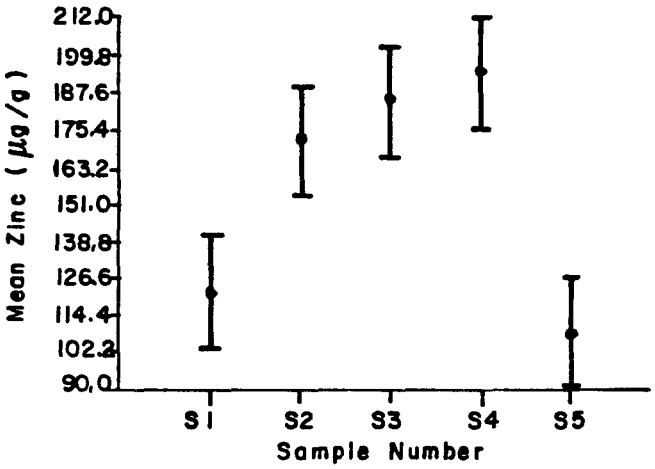
For future studies, 'contamination' might be defined as increases in sediment metal levels (e.g. copper, zinc) that are statistically significantly greater than those measured in this study. There is a



(a) MEAN COPPER

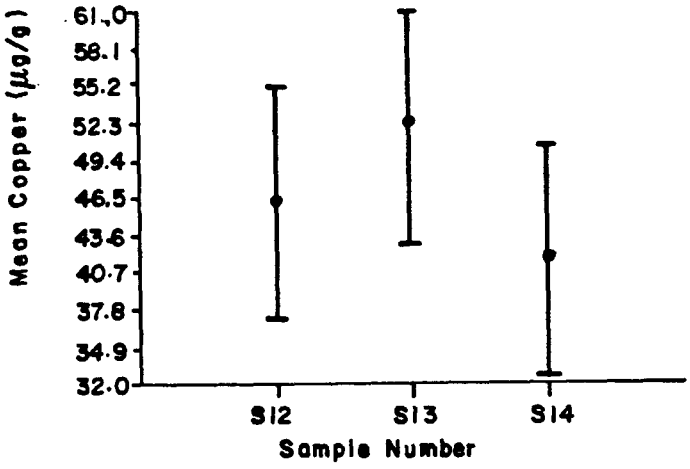
LEGEND

95% Confidence Limits

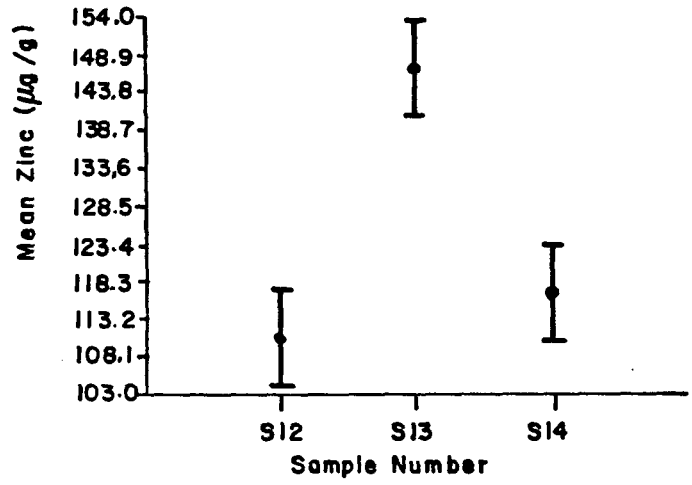


(b) MEAN ZINC

FIGURE 3 FOXY CREEK - TUKEY'S MULTIPLE COMPARISON FOR (a) MEAN COPPER AND (b) MEAN ZINC CONCENTRATIONS



(a) MEAN COPPER



(a) MEAN ZINC

FIGURE 4 BUCK CREEK - TUKEY'S MULTIPLE COMPARISON FOR (a) MEAN COPPER AND (b) MEAN ZINC CONCENTRATIONS

continuous loading of metals into the system (Tables 3 and 4) and the challenge is to determine whether these loadings over time become reflected in the receiving stream sediments. The assessment of the significance of any measureable increases on the biological community requires other considerations and is not addressed here.

Hawkes and Webb, 1962 reported that for a single population of values that are distributed symmetrically (normally or lognormally), the threshold for that material may be conventionally taken as the mean plus twice the standard deviation. In a geochemical sense then, concentrations that fall between the mean plus twice the standard deviation and the mean plus three times the standard deviation are possibly anomalous values (Hawkes and Webb, 1962). In order to detect a specified change with a specified level of confidence, it is necessary first to decide on the level of acceptable change and secondly determine how many samples are required at a given confidence level.

For example, Foxy Creek stations S2, S3 and S4 were significantly different than either the control site S1 or the furthest downstream site S5. Using Hawkes and Webb's definition of anomalous ($\bar{x}$ + 2 S.D.) then in order to measure this level of change in the stretch of creek between S2 and S4 the required number of samples has to be estimated. Zar 1984 presents formula to do this. The number of samples required to measure a more conservative 0.5 and 1.0 standard deviation increase as well as a two standard deviation increase are presented in Table 5. For stations S2 to S4 combined, if the overall mean copper concentration (85 ug/g) is considered representative of this reach of the creek, then for a 90% chance of detecting a mean significantly (α = .05) different by as little as one standard deviation (19 ug/g), 12 samples are required. Approximately three samples are required to measure a two standard deviation increase. However, to measure a 10 ug/g difference at the same level of confidence, the estimated sample size would be approximately 44.

The overall mean copper concentration for Buck Creek stations S12 to S14 combined (47 ug/g) could be considered to be representative of this reach of the creek considering there were no statistically significant differences in mean copper levels. The number of samples estimated to

TABLE 5 ESTIMATED SAMPLE SIZE TO MEASURE A SPECIFIED LEVEL OF CHANGE IN FOXY CREEK SEDIMENTS

FOXY CREEK (S2 + S3 + S4)	PERCENT CHANCE OF DETECTING A MEAN SIGNIFICANTLY DIFFERENT BY A SPECIFIED LEVEL*		ESTIMATED SAMPLE SIZE		
			GUESSED SAMPLE SIZE		ESTIMATED SAMPLE SIZE
	% CHANCE	LEVEL	n =	v =	$n = \frac{S^2}{(\text{level})^2} (t_{0.05(2),\,v} + t_{0.10(1),\,v})^2$
Copper $\bar{x}$ = 85 ug/g SD = 19 2 SD = 38	90	10 ug/g	20	19	$n = \frac{370}{(10)^2} (2.093 + 1.328)^2 = 43.3$
	90	10 ug/g	19	18	$n = \frac{370}{(10)^2} (2.101 + 1.330)^2 = 43.5$
	90	19 ug/g	20	19	$n = \frac{370}{(19)^2} (2.093 + 1.328)^2 = 11.9$
	90	19 ug/g	19	18	$n = \frac{370}{(19)^2} (2.101 + 1.330)^2 = 12.1$
	90	38 ug/g	20	19	$n = \frac{370}{(38)^2} (2.093 + 1.328)^2 = 3.0$
	90	38 ug/g	19	18	$n = \frac{370}{(38)^2} (2.101 + 1.330)^2 = 3.1$

* Estimation of required sample size to test Ho:U = Uo, α = 0.05 (Zar, 1984, pg. 110)

TABLE 6 ESTIMATED SAMPLE SIZE TO MEASURE A SPECIFIED LEVEL OF CHANGE IN BUCK CREEK SEDIMENTS

BUCK CREEK (S12+ S13+ S14)	PERCENT CHANCE OF DETECTING A MEAN SIGNIFICANTLY DIFFERENT BY A SPECIFIED LEVEL*		ESTIMATED SAMPLE SIZE		
			GUESSED SAMPLE SIZE		ESTIMATED SAMPLE SIZE
	% CHANCE	LEVEL	n =	v =	$n = \frac{S^2}{(\text{level})^2} (t_{0.05(2),\,v} + t_{0.10(1),\,v})^2$
Copper	90	9 ug/g	20	19	$n = \frac{85}{(9)^2} (2.093 + 1.328)^2 = 12.3$
$\bar{x}$ = 47 ug/g SD = 9 ug/g 2 SD = 18 ug/g S^2 = 85 ug/g	90	9 ug/g	19	18	$n = \frac{85}{(9)^2} (2.101 + 1.330)^2 = 12.4$
	90	18 ug/g	20	19	$n = \frac{85}{(18)^2} (2.093 + 1.328)^2 = 3.0$
	90	18 ug/g	19	18	$n = \frac{85}{(18)^2} (2.101 + 1.330)^2 = 3.1$

* Estimation of required sample size to test Ho:U = Uo, α = 0.05 (Zar, 1984, pg. 110)

measure a 1.0 and 2.0 standard deviation change were approximately twelve and three respectively. Thus, to measure a 9 ug/g increase with a 90% chance (α = .05) the downstream sample size should be increased from four per station to twelve. For a 18 ug/g increase the sample size used in this study would be adequate.

Prior to any future sediment monitoring programs, the sample size should be estimated based on the above considerations. For Foxy Creek, additional stations between site S4 and S5 could be added to determine where sediment metal levels first return to background. Samples should be collected during the same time of the year to minimize potential seasonal affects (Sakai et al., 1986; Derksen, 1985). In addition the particle size fraction and extraction scheme should be consistent (Sakai et al., 1986; Forstner and Wittman, 1979; Hickey and Kittrick, 1984). Laboratory methods should ideally be compared in future comparisons and this could be documented by the use of reference samples. If laboratory procedures are different then the method should be clearly stated. It is recommended that reference sample material should routinely be used to assess differences due to methodology changes or differences in laboratories. This will help ensure changes in sediment quality are real and not due to other sources.

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APPENDIX I

SAMPLE STATION DESCRIPTION

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STATION	DESCRIPTION	SAMPLE TYPE
FOXY CREEK		
S1	- Control site approximately 140 m u/s of Lu Cr. Diversion confluence. - Substrate clean, gravel to cobble material.	- Syringe sampler (4, 3)*
S2	- Approximately 135 m d/s of Lu Cr. Diversion confluence. - Substrate visibly sedimented over and prolific algal growth on rocks in this area. - Gravel to cobble material.	- Syringe sampler (4, 3)
S3	- Approximately 50 m d/s of bend in creek at seepage pond. - Gravel to cobble material with interspersed boulders.	- Syringe sampler (4, 3)
S4	- Approximately 300 m d/s of main Berzilius Cr. confluence. - Gravel to cobble material with interspersed boulders.	- Syringe sampler (4, 3)
S5	- Approximately 40 m u/s of Maxan Lake road bridge. - Gravel to cobble material.	- Syringe sampler (4, 3)
LU CREEK DIVERSION		
S6	- Approximately 10 m u/s of confluence with interceptor ditch that contains seasonal treated AMD discharge. - Gravel material overlying fine sediments.	- Core sampler (3, 2)
S7	- Lower end of Lu Cr. diversion prior to entering Foxy Creek, d/s of interceptor ditch that contains seasonal treated AMD discharge. - Gravel to cobble size material overlying fine sediments.	- Core sampler (3, 2)

*(# of replicates, # of samples per replicate)

CONTINUED...

APPENDIX I (Continued)

STATION	DESCRIPTION	SAMPLE TYPE
BERZILIUS CREEK DIVERSION		
S8	- Lower end of Berzilius Cr. diversion, approximately 40 m u/s of Foxy Cr. confluence. - Gravel to boulder material, hard to sample with syringe.	- Syringe sampler (3, 3)
BESSEMER CREEK		
S9	- Upper Bessemer Creek just d/s of flow weir, d/s of mine surface water drainage collection system and ditch with seasonal treated AMD discharge. - Gravel to cobble material interspersed with sandy material.	- Core sampler (3, 2)
S10	- Section of creek immediately u/s of silt check dam. - Gravel to cobble substrate but highly compacted with fine material, hard to sample with syringe.	- Syringe sampler (4, 3)
S11	- At road crossing, sampled just u/s of road and at 90 m and 200 m d/s of road. - Gravel material u/s of road crossing, changing to silty/muddy material downstream.	- Core sampler (3, 2)
BUCK CREEK		
S12	- Control site approximately 145 m u/s of large wooden flow weir, 40 m u/s of blue flagging ribbon. - Gravel material but alot of fines, hard to sample with syringe.	- Syringe sampler (4, 3)
S13	- Approximately 400 m u/s of Goosly Lake inlet, at blue flagging ribbon. - Gravel material but alot of fines, hard to sample with syringe.	- Syringe sampler (4, 3)

*(# of replicates, # of samples per replicate

CONTINUED...

APPENDIX I (Continued)

STATION	DESCRIPTION	SAMPLE TYPE
BUCK CREEK (Continued)		
S14	- At delta formed at Goosly Lake inlet, sampled across delta. - Coarse, sandy material.	- Core sampler (4, 2)
MAXAN CREEK		
S15	- Upstream of Foxy Creek and access at Maxim Indian Reserve. Creek blocked by beaver dams. - Sampled gravel to cobble section that was flowing and looked like main creek channel.	- Syringe sampler (4, 3)
S16	- Approximately 150 m d/s of Foxy Cr. confluence and beaver dam blocking Maxan Cr.	- Syringe sampler (4, 3)

*(# of replicates, # of samples per replicate

APPENDIX II

SEDIMENT SAMPLE PREPARATION AND REVERSE AQUA REGIA DIGEST PROCEDURE

APPENDIX II SEDIMENT SAMPLE PREPARATION AND REVERSE AQUA REGIA DIGEST PROCEDURE

1) Transfer sample material into labelled KRAFT soil sample envelopes, dry samples @ 60°C., until completely dry.

2) When samples are dry, disaggregate the sample material by rapping the sample bag with a rubber mallet. Occasionally, the sample bag may split, this usually occurs when the samples are marine sediments or if the bags are hit too hard. If particle sizing has been requested, split the sample material on a riffle - a normal split is ¼ for metals and ¾ for particle sizing. Ensure that the sample splits are done in a manner that minimizes biasing of the subsamples. If the particle sizing request is for only the +/- 100 mesh (0.150 mm) fractions sample splitting is not required.

3) Sieve samples through a 100 mesh (.150 mm) stainless steel screen, store the fine fraction in a labelled vial, retain the coarse fraction if requested.

4) Weigh 0.30 to 0.32 g of sieved sample into calibrated 50 ml test tubes. Replicate samples, reference materials, and reagent blanks must be included with every set of samples. Normally one reference material and one blank should be run with every set of 30 or less samples, the number of replicates should be at least the square root of the number of samples in a given lot. Use computer program "SEDWT" to set up a weight file and take weights directly from the balance.

5) Add 4.5 ml concentrated NITRIC acid, 1.5 ml concentrated HYDROCHLORIC acid, swirl solution vigorously, allow to react for 30 minutes, then add 10.0 ml DI water. Reagents should be dispensed with automatic pipettors, use only "BAKER - INSTRA-ANALYZED" acids (used for trace metal analysis).

6) Place test tubes into pre-heated block and heat for three hours. Sample solutions should boil gently during the digestion period - exercise care with very fine grained samples, they are likely to cause bumping problems. Bring volume of sample down to approximately 12 ml in order to compromise for equal matrix of reagents, as are used in ICP and GFAA analysis.

7) Remove test tubes and allow to cool before diluting sample solutions to 50.0 ml. Cap test tubes and mix well, allow sample solutions to settle out overnight. Carefully decant sample solutions into 30 ml acid washed poly bottles, ensureing that particulate material is not transferred to the sample bottles.

8) Analyze sample solutions by ICAP and/or GFAA. Use computer program to calculate final results. Analyze mercury on Pharmacia Mercury Monitor Model 100.

APPENDIX III

EQUITY SILVER SEDIMENT DATA (1985)

Title - Equity Silver Sediment Data (1985).
Printout Range : 1 - 20 *

Data Listing Foxy Creek

Entry	Station	As	Cd	Cu	Pb	Zn	Ag	Hg
1	1	8.0	.3	53.8	30.0	124.0	.22	.10
2	1	8.0	.3	50.3	31.0	131.0	.26	.10
3	1	8.0	.3	48.1	30.0	118.0	.18	.11
4	1	8.0	.3	41.3	25.0	112.0	.13	.06
5	2	8.0	2.3	134.0	33.0	214.0	.28	.11
6	2	8.0	1.0	103.0	31.0	181.0	.28	.09
7	2	8.0	.6	83.8	32.0	151.0	.25	.09
8	2	8.0	1.0	80.0	28.0	143.0	.18	.10
9	3	8.0	1.0	75.3	34.0	191.0	.31	.10
10	3	8.0	1.5	75.8	37.0	200.0	.20	.13
11	3	8.0	.7	62.8	30.0	174.0	.38	.20
12	3	8.0	.9	60.0	31.0	173.0	.22	.09
13	4	8.0	.3	83.3	36.0	189.0	.20	.15
14	4	8.0	.6	90.1	38.0	202.0	.32	.11
15	4	8.0	.6	82.9	35.0	190.0	.24	.08
16	4	8.0	.6	84.9	34.0	192.0	.23	.36
17	5	8.0	.3	41.4	26.0	107.0	.08	.08
18	5	8.0	.3	45.0	32.0	115.0	.10	.11
19	5	8.0	.3	37.0	28.0	105.0	.09	.06
20	5	8.0	.3	40.1	26.0	106.0	.10	.09

Entry	Station	Al	Ca	Fe	Mg	Mn	Ni	SVR
1	1	25500.0	9810.0	42400.0	8720.0	1080.0	51.0	4.3
2	1	28200.0	10200.0	44300.0	9430.0	1140.0	46.0	4.2
3	1	26700.0	9750.0	42200.0	8790.0	1090.0	41.0	3.1
4	1	23200.0	9340.0	40100.0	7990.0	1090.0	41.0	2.5
5	2	26300.0	11200.0	43400.0	8270.0	3020.0	54.0	6.9
6	2	25500.0	10900.0	42900.0	7890.0	2090.0	46.0	4.2
7	2	24500.0	10700.0	41600.0	7750.0	1540.0	44.0	4.2
8	2	23200.0	10300.0	40100.0	7560.0	1030.0	45.0	3.5
9	3	24400.0	11200.0	43600.0	7850.0	2920.0	48.0	6.0
10	3	24700.0	11100.0	42900.0	7760.0	3080.0	51.0	5.6
11	3	23300.0	10400.0	41600.0	7440.0	2420.0	49.0	5.2
12	3	24500.0	11000.0	42000.0	7580.0	2640.0	51.0	6.0
13	4	23700.0	10500.0	46500.0	7940.0	1860.0	64.0	4.6
14	4	24400.0	11000.0	47300.0	8120.0	2240.0	58.0	4.6
15	4	22400.0	10800.0	45700.0	8210.0	2140.0	63.0	3.7
16	4	21700.0	10400.0	44900.0	7880.0	2230.0	59.0	5.0
17	5	20900.0	10600.0	43200.0	8850.0	1370.0	39.0	4.4
18	5	23500.0	11500.0	45600.0	9420.0	1760.0	50.0	3.5
19	5	22700.0	11400.0	44000.0	9210.0	1240.0	43.0	2.5
20	5	22900.0	11300.0	44000.0	9280.0	1140.0	47.0	4.1

*metals as ug/g, SVR as %

Appendix III

Title - Equity Silver Sediment Data (1985).
Printout Range : 21 - 28 *

Data Listing Maxan Creek

Entry	Station	As	Cd	Cu	Pb	Zn	Ag	Hg
21	15	8.0	.3	27.0	23.0	106.0	.11	.07
22	15	8.0	.3	31.0	23.0	97.9	.11	.07
23	15	8.0	.3	28.6	20.0	95.7	.17	.06
24	15	8.0	.3	29.0	20.0	104.0	.10	.12
25	16	8.0	.3	32.8	26.0	95.8	.09	.10
26	16	8.0	.3	32.0	29.0	98.7	.11	.06
27	16	8.0	.3	38.4	25.0	102.0	.12	.07
28	16	8.0	.3	32.0	25.0	97.2	.11	.08

Entry	Station	Al	Ca	Fe	Mg	Mn	Ni	SVR
21	15	21500.0	10500.0	46100.0	10400.0	779.0	53.0	5.7
22	15	21000.0	9970.0	43900.0	8840.0	843.0	56.0	5.9
23	15	22100.0	10100.0	39300.0	8390.0	944.0	50.0	5.3
24	15	20500.0	10100.0	45000.0	9950.0	751.0	46.0	3.4
25	16	20900.0	10700.0	42800.0	8990.0	975.0	41.0	3.8
26	16	22100.0	11000.0	46500.0	9070.0	1560.0	46.0	4.9
27	16	23100.0	11200.0	45200.0	9440.0	1120.0	50.0	4.3
28	16	22100.0	11100.0	43600.0	9190.0	1120.0	45.0	5.2

* metals as ug/g, SVR as %

Appendix III

Title - Equity Silver Sediment Data (1985).
Printout Range : 29 - 37 *

Data Listing Lu Creek and Berzilius Creek

Entry	Station	As	Cd	Cu	Pb	Zn	Ag	Hg
29	6	8.0	.3	43.5	29.0	112.0	.31	.14
30	6	8.0	.3	48.1	31.0	108.0	.16	.10
31	6	8.0	.3	36.5	20.0	78.3	.08	.04
32	7	8.0	.3	60.0	29.0	137.0	.12	.13
33	7	8.0	.3	52.9	27.0	125.0	.15	.12
34	7	8.0	.3	48.9	25.0	119.0	.11	.17
35	8	8.0	.3	93.1	43.0	175.0	.22	.11
36	8	8.0	.3	90.3	40.0	172.0	.24	.09
37	8	8.0	.3	91.7	38.0	197.0	.33	.10

Entry	Station	Al	Ca	Fe	Mg	Mn	Ni	SVR
29	6	22000.0	11600.0	39600.0	8180.0	786.0	33.0	1.1
30	6	21000.0	12700.0	40700.0	8430.0	1180.0	35.0	2.2
31	6	14900.0	13800.0	39700.0	7080.0	1180.0	33.0	2.1
32	7	24300.0	13400.0	42500.0	10300.0	1340.0	41.0	.9
33	7	22700.0	13300.0	42000.0	9380.0	1420.0	35.0	.9
34	7	23100.0	10600.0	41700.0	9330.0	748.0	35.0	1.0
35	8	22100.0	10100.0	50800.0	7540.0	1470.0	76.0	3.7
36	8	21700.0	9890.0	49500.0	7630.0	1370.0	63.0	3.9
37	8	22400.0	9980.0	51400.0	7660.0	1510.0	58.0	2.9

* metals as ug/g, SVR as %

Appendix III

Title - Equity Silver Sediment Data (1985).
Printout Range : 49 - 60 *

Data Listing Buck Creek

Entry	Station	As	Cd	Cu	Pb	Zn	Ag	Hg
49	12	8.0	.3	60.8	38.0	116.0	.19	.15
50	12	8.0	.3	47.8	34.0	111.0	.13	.13
51	12	8.0	.3	38.6	29.0	109.0	.10	.10
52	12	8.0	.3	38.4	27.0	106.0	.09	.08
53	13	8.0	.3	56.9	35.0	156.0	.31	.58
54	13	8.0	.3	52.9	35.0	150.0	.14	.17
55	13	8.0	.3	49.7	35.0	141.0	.15	.12
56	13	8.0	.3	48.4	31.0	141.0	.18	.11
57	14	8.0	.3	48.9	28.0	117.0	.09	.09
58	14	8.0	.3	46.4	31.0	125.0	.20	.11
59	14	8.0	.3	45.6	28.0	119.0	.16	.09
60	14	8.0	.3	25.6	24.0	106.0	.15	.08

Entry	Station	Al	Ca	Fe	Mg	Mn	Ni	SVR
49	12	24800.0	12500.0	81500.0	7840.0	2710.0	51.0	3.3
50	12	22300.0	11400.0	72700.0	8230.0	2090.0	79.0	1.7
51	12	19600.0	9850.0	56000.0	7890.0	1290.0	65.0	1.7
52	12	19200.0	9520.0	52900.0	7260.0	1340.0	52.0	2.0
53	13	17400.0	10700.0	76200.0	6850.0	2380.0	45.0	1.7
54	13	17400.0	10100.0	66600.0	6770.0	2650.0	77.0	1.6
55	13	20000.0	9790.0	51900.0	6880.0	3040.0	49.0	2.3
56	13	18400.0	9830.0	58000.0	6760.0	3090.0	72.0	1.6
57	14	17500.0	7300.0	38400.0	6230.0	467.0	25.0	1.3
58	14	18300.0	8060.0	42400.0	6730.0	688.0	27.0	2.6
59	14	18900.0	7380.0	38600.0	6170.0	676.0	23.0	5.4
60	14	13700.0	6880.0	36800.0	5470.0	414.0	21.0	1.4

* metals as ug/g, SVR as %

Appendix III
Title - Equity Silver Sediment Data (1985).
Printout Range : 38 - 48 *

Data Listing Bessemer Creek

Entry	Station	As	Cd	Cu	Pb	Zn	Ag	Hg
38	9	109.0	8.6	802.0	232.0	841.0	9.30	.20
39	9	88.0	6.3	624.0	170.0	655.0	3.60	.22
40	9	78.0	7.6	597.0	195.0	730.0	2.90	.19
41	9	74.0	5.3	567.0	173.0	642.0	4.90	.21
42	10	23.0	1.9	374.0	102.0	343.0	1.30	.14
43	10	9.0	1.6	419.0	93.0	335.0	1.10	.13
44	10	16.0	1.2	335.0	94.0	296.0	1.10	.15
45	10	8.0	2.8	342.0	88.0	296.0	1.00	.16
46	11	8.0	6.8	771.0	92.0	807.0	1.40	.18
47	11	8.0	2.3	430.0	66.0	385.0	.66	.13
48	11	8.0	3.6	431.0	80.0	449.0	.57	.16

Entry	Station	Al	Ca	Fe	Mg	Mn	Ni	SVR
38	9	19700.0	14200.0	43300.0	8270.0	1550.0	33.0	2.4
39	9	20800.0	11900.0	46900.0	7730.0	1660.0	38.0	1.4
40	9	18700.0	13300.0	46000.0	7830.0	1510.0	36.0	.9
41	9	18200.0	10800.0	44300.0	6420.0	1380.0	36.0	4.9
42	10	19700.0	8120.0	45400.0	6370.0	1270.0	45.0	4.2
43	10	21800.0	8560.0	49800.0	6630.0	1470.0	55.0	6.0
44	10	18900.0	8130.0	45500.0	6130.0	1170.0	47.0	4.2
45	10	19200.0	8160.0	45800.0	6330.0	1200.0	54.0	4.6
46	11	27600.0	10200.0	59900.0	8720.0	2840.0	126.0	1.5
47	11	23000.0	9210.0	49300.0	6760.0	1540.0	56.0	1.9
48	11	21400.0	14600.0	74800.0	6160.0	2910.0	60.0	42.4

* metals as ug/g, SVR as %