007488

ECOLOGICAL ENGINEERING

AND

BIOLOGICAL POLISHING

FOR DRAINAGE FROM THE FARO

WASTE ROCK DUMPS

prepared by

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LIST OF FIGURES

LIST OF TABLES

LIST OF MAPS

LIST OF PLATES

SUMMARY

The objective of this investigation was to ascertain whether a natural means of reducing or removing contaminants could be identified for the mining wastes of the Faro operation. Such measures are collectively referred to as **Ecological Engineering** and **Biological Polishing.**

Water monitoring data were evaluated and a field trip was carried out in March 1990 to obtain an understanding of the physical conditions of the site.

The water characteristics suggest that the most effective means of controlling contaminant release from the tailings and the waste rock would be by enhancement of permafrost and a general encouragement of low temperatures. The manner in which colder temperatures could be encouraged warrants investigation.

It is likely that natural contaminant removal processes are occurring in the form of precipitation, biological adsorption, or a combination of microbial H_2S production and precipitation. **Ecological Engineering** and **Biological Polishing** techniques could enhance the already present contaminant removal processes. Laboratory tests at Boojum Research Ltd. indicate that the macrophytic alga *Chara vulgaris* can adsorb significant concentrations of zinc. This, coupled with the fact that other algae and cyanobacteria present at Faro can also concentrate heavy metals such as zinc, provide enough information to suggest that **Ecological Engineering** and **Biological Polishing** will significantly reduce contaminant loadings in Faro waste water if properly applied to this site.

1.0 INTRODUCTION

Waste materials (waste rock and tailings) associated with the former Cyprus Anvil operations at Faro, Yukon Territory, were first produced between 1969 and 1982. Except for some stripping of waste, the operation was dormant until 1986 when milling resumed at a rate of 13,500 tons per day. The Zone II pit has already been mined out and backfilled with waste rock. By 1991, the Faro pit (Zone I/III pit) will be exhausted. The tailings produced since 1986 have been deposited in impoundments below the earlier tailings in Rose Creek valley.

Environmental concerns have been associated with this mining operation prior to 1986. These concerns range from high copper and cyanide concentrations, to depression of dissolved oxygen, and finally, elevated zinc concentrations in the water (EPS Reports 81 to 85). Some of the concerns associated with milling practices have already been addressed, but metal leaching due to weathering of waste rock presents a complex long-term problem.

At present, treatment of all effluents takes place in the mill and in the tailings pond where, through addition of lime and provision of sufficient retention time, contaminants are removed prior to effluent discharge. Environmental concern has been raised with respect to the post-mining operation phase. Conventional technology, including the installation of water treatment plants and till and water covers over tailings to reduce infiltration of oxygen, are very expensive and the environmental benefits are not readily apparent or quantifiable.

In the continued search for an environmentally acceptable long-term solution, Boojum Research Limited was retained to examine the existing information from the Cyprus Anvil/Faro site and to identify those potential avenues within the Ecological Engineering approach which may be used to increase the effectiveness of conventional technology. Ecological Engineering methods are based on an understanding of the natural processes which lead to contaminant generation and those which assist in repairing or counteracting environmental degradation.

In order to utilize the natural repair mechanisms, a determination of the long-term effluent characteristics is essential, namely their improvement, deterioration or reaching steady state. With this information at hand, measures can be taken towards an environmentally sound closure approach. The long-term performance of acceptable measures for closure can only be determined if the controlling factors of contaminant generation are understood. Furthermore, those factors which assist in the natural removal of contaminants from the water column have to be identified. If the rate of contaminant generation is controlled by infiltration of oxygen and water, then the effectiveness of a cover can be determined through quantification of the reduction of oxygen and water infiltration. If, on the other hand, contaminant generation is controlled by temperature, measures which would enhance low temperature regimes for the waste material would provide an effective long-term management strategy.

The objective of Phase 1 of this project is to identify options for the closure plan which are based on an understanding of the natural processes of contaminant generation and removal which may exist in the drainage basin. These natural processes are collectively referred to as "Ecological Engineering and Biological Polishing".

Through a review of monitoring data from the relevant areas (the waste rock dumps and the tailings), and a site visit to become familiar with conditions of the site, some of these processes can be identified. Furthermore, through toxicity tests with the algal family Characeae, (a known biological polishing agent for alkaline waste water), the applications of the *Chara* process can be evaluated.

In Section 2, the background data are reviewed in order to identify the relevant factors which control contaminant release. The impressions obtained during a field trip carried out in March 1990, and their relevance to biological systems for the site, are presented in Section 3. Section 4 gives the results of the *Chara* toxicity tests and an assessment of other potential biological polishing mechanisms. Section 5 outlines those components of Ecological Engineering which could be usefully developed for the Faro site.

2.0 BACKGROUND DATA EVALUATION

Relevant information was extracted from reports and data listings made available by Curragh Resources Inc. These are summarized below. Data are presented, along with comments and recommendations regarding future measurements, sample analyses and data interpretation which would be required to better understand the key factors driving contaminant mobilization and its removal.

List of Reports and Data Sources

1. Kerr-AEX Grum Joint Venture, 1975. Biophysical and Socio-Economic Program. Monenco.

2. Environmental Quality of Rose Creek as Affected by Cyprus Anvil Mining Corp. Ltd. EPS Regional Program Report. 79-25.

3. Compliance Evaluation of Cyprus Anvil Mine, FARO, Yukon. EPS Regional Program Report. 81-15.

4. Examination of the Impact of the Discharges from Cyprus Anvil Mine on the Aquatic Environmental Quality of Rose Creek, Yukon. EPS Regional Program Report. 81-25.

5. Oxidation of Yukon Mine Tailings. EPS Regional Program Report. 84-15.

6. Tailings Abandonment Development Program (TADP) Annual Report. S.R.K. July 1989.

7. Faro Pits and Rock Waste Dumps, 1987 and 1988 Seep Surveys. Report No. 60612.

8. Faro Mine Abandonment Plan, Curragh Resources Inc., April 1988. Prepared by R. McLenehan and J. Bowers.

2.1 Waste Rock and Existing Tailings

Available sulphur analyses of various waste-rock types from the Faro mine are listed in Table 1a, together with acid-generation potential (AGP), acid-neutralization potential (ANP) and net AGP values (in kg $CaCO_3$ per tonne of waste). Table 1b lists estimated total quantities of waste-rock, and estimated total net acid-generation potential (12.6 million tonnes), based on mean net AGP equal to 550 kg/tonne. These estimates indicate the dimensions of the problem, if all pyritic material were converted to sulphuric acid. Although this acid generation potential exists, its environmental impact is dependant on the rate at which the net acid generation proceeds. Available information indicates that weathering would proceed slowly.

Table 1a: Waste Rock Data

A. ANALYSES

WASTE-ROCK TYPE	Code	pH	% S	A.G.P. kg/tonne	A.N.P. kg/tonne	NET A.G.P. kg/tonne
1975 samples (corrected from Table 7B)						
Sandy pyrite	2EO	6	52.70	1645.4	24.5	1621
Biotite schist	1DO	9.2	0.09	2.8	13.6	-11
Quartz/muscovite schist	1D4	6.4	3.60	112.4	33.6	79
Muscovite schist	1CD	7.9	0.09	2.8	18.1	-15
Calc-silicate	3D	9.4	0.46	14.4	65.8	-51
JANUARY 1987 samples (Table 7A)						
Barren massive sulfide	2E	5.9	30.90	965.6	2.8	963
Biotite/andalusite schist	1DO	7.5	1.14	35.6	10.4	25.2
Quartz/muscovite schist	1D4	7.2	4.09	127.8	18.3	110
Calc-silicate gneiss	3D	8.9	0.42	13.2	212.7	-200
Calc-silicate breccia	3DBX	8.5	0.79	24.7	17.9	6.8
ROCK DRAIN and CAUSEWAY samples (means from Table 16)						
Biotite/andalusite schist	1DO	8.3	0.288	9.0	59.9	-50.9
Calc-silicate breccia	3DBX	9.1	0.20	6.1	79.40	-73.3

From: Faro Mine Abandonment Plan, CRI, April 1988.
AGP and ANP in kg $CaCO_3$ equivalent per tonne material.

Table 1b: Waste Rock Data

B. QUANTITIES

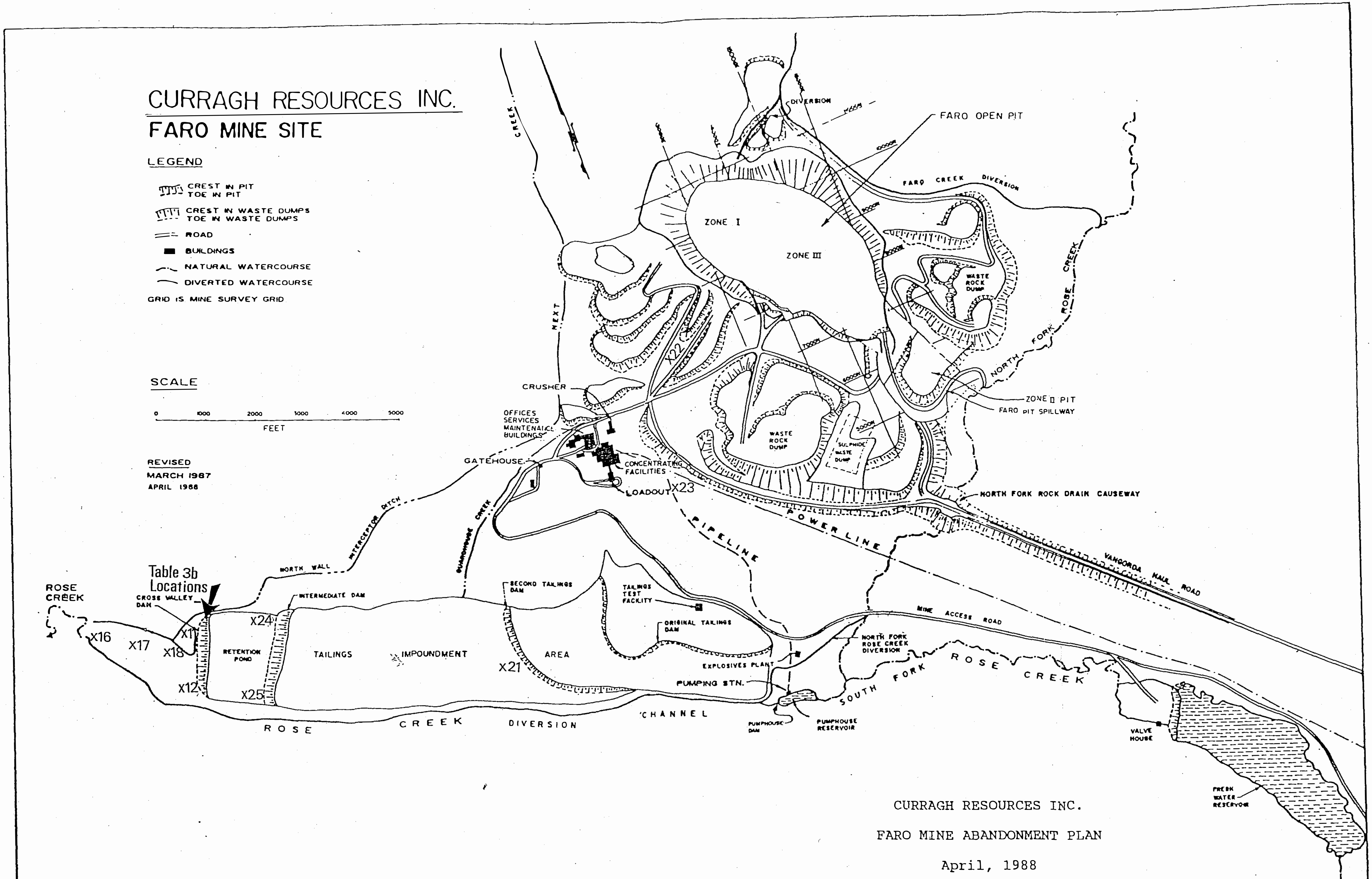
	ULTIMATE QUANTITY	CALC-SIL. GNEISS	BIOTITE SCHIST	MUSCOV. SCHIST	DIORITE	ACID-GENERATING WASTE ROCK
In millions of cubic meters						
FARO MAIN DUMPS	56.00	18.48	16.24	10.64	5.04	5.60
UPPER NORTHWEST DUMPS	5.00	1.75	1.50	1.00	0.50	0.25
EAST SIDE DUMPS	23.00	8.05	6.90	4.60	2.30	1.15
VANGORDA HAUL ROAD	5.00	2.00	1.50	1.00	0.50	0.00
PIT DUMPS	3.00	0.60	0.54	0.36	0.18	1.32
TOTALS	92.00	30.88	26.68	17.60	8.52	8.32
In milions of tonnes, assuming bulking = 30%						
FARO MAIN DUMPS	116.31	38.38	33.73	22.10	10.47	15.51
UPPER NORTHWEST DUMPS	10.38	3.63	3.12	2.08	1.04	0.69
EAST SIDE DUMPS	47.77	16.72	14.33	9.55	4.78	3.18
VANGORDA HAUL ROAD	10.38	4.15	3.12	2.08	1.04	0.00
PIT DUMPS	6.23	1.25	1.12	0.75	0.37	3.66
TOTALS	191.07	64.13	55.42	36.56	17.70	23.04

H2SO4 12,672,000 TONNES

This rate will differ for the tailings where the AGP is estimated based on data presented in Tables 2a and 2b. Available sulphur analyses for the tailings are listed together with AGP, ANP and net AGP values (in kg H_2SO_4 per tonne). The net AGP values range from a minimum of 259 kg/tonne to a maximum of 1516 kg/tonne, with a mean of 849 kg/tonne. Using this mean value and a total quantity of about 40 million tonnes of tailings, the total net AGP for the present tailings deposit would be about 32 million tonnes. Rates of contaminant generation can be derived if data exists which facilitates such calculations. The availability of data from which a time series can be derived and a complete accounting of those possible oxidation products is essential.

Chemical analyses of water collected in the period 1986 - 1989 from various groundwater sampling sites are listed in Tables 3a and 3b. The groundwater sampling sites for the requirements of the water license are presented in Table 3a. The monitoring data differentiate between unaffected ground water (X16A,B - X17A,B) and water which is affected by the tailings deposit. The differences in concentrations in Mn, Fe, Na and sulphate make these elements worthy parameters for data interpretation.

In Table 3b, additional ground water sampling sites are summarized. Those show the same pattern as the X sampling series where the presence of tailings is indicated by the elements Mn, Fe, Na and sulphate. One series of samples (ID 4S, ID 4D and the series 81-04D to K12) shows erratic zinc concentration fluctuations along with a wide range of pH values.



CURRAGH RESOURCES INC.

FARO MINE ABANDONMENT PLAN

April, 1988

Map 1: Water Sampling Stations

Table 2a: Tailings Analyses

Source +sample #	Depth m	TOTAL S %	Sulfate S %	Sulfide S %	AGP H2SO4 kg/t	ANP H2SO4 kg/t	NET AGP H2SO4 kg/t
FARO TAILINGS (%)							
EPS 84-15		24.55		24.6	751.2	13.5	737.7
SRK Pits1-2		25.9	0.09	25.8	789.8	32.5	757.3
3-4		36.3	0.15	36.2	1106.1	34.8	1071.3
5-8		28.4	0.23	28.2	862.0	16.2	845.8
9		37.9	0.27	37.6	1151.4		1151.4
10		31.9	0.12	31.8	972.4		972.4
11		30.9	0.15	30.8	940.9	14.5	926.4
13		27.2	0.15	27.1	827.7	17.2	810.5
14		21.4	0.11	21.3	651.5		651.5
19		31.1	0.53	30.6	935.4	17.6	917.8
22		35.2	0.17	35.0	1071.9		1071.9
27		22.5	0.33	22.2	678.4	7.6	670.8
28-30		22.1	0.10	22.0	673.2		673.2
33		29.4	0.20	29.2	893.5	41.9	851.6
34-40		28.2	0.14	28.1	858.6	19.4	839.2
43		26.5	0.17	26.3	805.7	36.3	769.4
45		36.5	0.14	36.4	1112.6	18.8	1093.8
46		28.1	0.07	28.0	857.7		857.7
48		29.6	0.11	29.5	902.4		902.4
49		22.8	0.12	22.7	694.0		694.0
SRK DRILLHOLES							
2.3 Plug dam hole 1							
	0.0	24.1	0.038	24.1	736.3		736.3
	1.5	34.4	0.027	34.4	1051.8	22.5	1029.3
	3.0	35.1	0.19	34.9	1068.2	25.7	1042.5
	3.0	39.2	0.064	39.1	1197.5	16.4	1181.1
soil	8.0	0.67	0.011	0.7	20.2		
soil	14.0	0.21	0.006	0.2	6.2	25.0	
2.1 Original dam hole 1							
	0.0	23.1	2.43	20.7	632.5		632.5
	0.5	49.9	0.23	49.7	1519.8	3.7	1516.1
	2.0	41.9	0.062	41.8	1280.2	23.5	1256.7
	2.0	41.7	0.076	41.6	1273.6	24	1249.6
	3.5	41.6	0.12	41.5	1269.2	30.6	1238.6
	6.0	40.0	0.13	39.9	1220.0		1220.0
	9.0	38.9	0.041	38.9	1189.0	26	1163.0
	13.5	32.6	0.056	32.5	995.8	38	957.8
soil	26.0	1.69	0.015	1.7	51.3	12.5	
soil	32.0	0.08	0.012	0.1	2.1	39.7	
2.2 1974 dam Hole							
	1.0	18.6	0.25	18.4	561.5		561.5
	1.5	24.8	0.34	24.5	748.4	27.9	720.5
	1.5	21.5	0.03	21.5	657.0	26	631.0
	2.5	25.5	0.22	25.3	773.5	24.5	749.0
	9.1	13.6	0.097	13.5	413.2	44.4	368.8
	18.3	13.6	0.37	13.2	404.8	0	404.8

Table 2b: Tailings Analyses

Source +sample #	Depth m	TOTAL S %	Sulfate S %	Sulfide S %	AGP H2SO4 kg/t	ANP H2SO4 kg/t	NET AGP H2SO4 kg/t
2.2 1974 dam hole 2							
soil	25.9	8.6	0.13	8.5	259.2	0	259.2
soil	30.5	1.74	0.034	1.7	52.2	11.3	
2.4 H1 hole 1							
	0.0	32.6	1.56	31.0	949.8		949.8
	0.5	10.8	0.72	10.1	308.4	9.3	299.1
	2.0	32.7	0.42	32.3	987.7	16.9	970.8
	2.0	32.4	0.26	32.1	983.4	25	958.4
	3.5	38.7	0.16	38.5	1179.3	16.9	1162.4
	6.1	38.4	0.13	38.3	1171.0	37.2	1133.8
	12.2	25.7	0.047	25.7	785.0	37.2	747.8
soil	19.8	0.38		0.4	11.6	8.8	
2.5 H1 hole 1							
	0.0	18.4	1.2	17.2	526.3		526.3
	0.5	13.1	0.89	12.2	373.6	5.9	367.7
	1.5	15.1	0.23	14.9	455.0	26.7	428.3
	1.5	16.6	0.28	16.3	499.4	23.8	475.6
	2.5	17.9	0.35	17.6	537.0		537.0
	6.1	34.2	0.026	34.2	1045.7	22.5	1023.2
	10.7	40.8	0.012	40.8	1248.1	19.6	1228.5
soil	15.2	0.83		0.8	25.4	13	
MAX		49.9	2.4	49.7	1519.8	44.4	1516.1
MEAN		25.3	0.3	25.1	766.8	21.7	848.9
MIN		0.08	0.01	0.07	2.08	0.00	259.17

Table 3a: Licence Groundwater Sample Sites

SITE #	LOCATION	DATE	pH	Cu mg/L	Pb mg/L	Zn mg/L	Mn mg/L	Fe mg/L	Na mg/L	SO4 mg/L
X16A	BY ROSE CREEK, DOWNSTREAM	09-Jun-87	7.45	0.008	0.011	0.045	0.208		3.4	46
X16A	OF CROSS VALLEY DAM	01-Oct-87	7.16	0.002	0.032	0.087	0.305		2.8	118
X16A	A - 5 M	12-Oct-88	7.8	0.005	-0.005	0.019	0.125	0.190	2.1	35
X16A		08-Aug-89	7.80	0.003	-0.005	0.016	0.089	0.087	2.1	55
X16A		21-Sep-89	7.95	0.003	-0.005	0.021	0.447	0.650	1.7	17
X16B	B - 30 M	09-Jun-87	7.75	0.005	0.006	0.021	0.008		3.5	9
X16B		01-Oct-87	7.78	-0.002	0.007	0.014	0.005		4.0	21
X16B		12-Oct-88	8.0	0.002	-0.005	0.009	0.005	0.020	2.4	10
X16B		08-Aug-89	7.50	0.005	-0.005	0.070	0.021	0.035	2.6	17
X16B		21-Sep-89	9.47	0.003	-0.005	0.018	-0.002	0.015	2.0	12
X17A	DOWNSTREAM OF CROSS	09-Jun-87	7.7	0.004	0.005	0.016	0.005		4.0	14
X17A	VALLEY DAM	01-Oct-87	7.83	-0.002	0.005	0.020	0.007		4.6	26
X17A	A - 5 M	12-Oct-88	7.9	-0.002	-0.005	0.003	0.025	0.045	3.2	13
X17A		08-Aug-89	8.35	-0.002	-0.005	0.006	0.004	0.031	2.7	18
X17A		21-Sep-89	9.49	0.002	-0.005	0.011	0.217	0.195	2.2	18
X17B	B - 20 M	09-Jun-87	7.76	0.004	0.006	0.013	0.147		3.3	20
X17B		01-Oct-87	7.75	-0.002	-0.005	0.009	0.132		3.2	25
X17B		12-Oct-88	7.8	-0.002	-0.005	0.005	0.160	0.070	3.1	16
X17B		08-Aug-89	8.12	-0.002	-0.005	0.006	-0.002	0.025	2.7	20
X17B		21-Sep-89	7.81	0.003	0.006	0.017	0.229	1.140	10.0	19
X18A	N. OF CROSS VALLEY DAM	08-Aug-89	6.74	-0.002	-0.005	0.020	0.420	0.380	45.5	186
X18A	A - 10 M	22-Sep-89	7.88	0.003	-0.005	0.008	0.690	0.850	36.5	225
X18B	B - 20 M	10-Jun-87	7.03	0.004	-0.005	0.026	0.424		35.5	281
X18B		01-Oct-87	7.54	0.002	0.011	0.024	0.284		25.0	188
X18B		12-Oct-88	7.5	-0.002	-0.005	0.008	0.295	0.530	30.0	200
X18B		08-Aug-89	7.35	-0.002	-0.005	0.022	0.297	1.700	32.0	211
X18B		22-Sep-89	8.22	0.002	-0.005	0.016	0.276	4.510	36.0	245
X21A	BY OLD TAILINGS POND DECANT	10-Jun-87	6.68	0.004	-0.005	1.55	28.50		92.0	1175
X21A	A - 10 M	13-Oct-88	7.4	0.012	0.160	0.750	14.20	5.500	62.0	469
X21A		27-Sep-89	8.79	0.002	-0.005	0.012	2.73	0.493	*****	510
X21B	B - 27 M	10-Jun-87	7.54	0.003	0.007	0.021	0.66		13.1	127
X21B		13-Oct-88	7.6	0.003	0.026	0.150	2.080	0.015	23.5	212
X21B		27-Sep-89	8.36	-0.002	-0.005	0.042	0.275	2.240	*****	332
X21C	C - 40 M	10-Jun-87	7.09	0.004	-0.005	0.219	8.85		28.0	444
X21C		13-Oct-88	7.5	0.002	-0.005	0.084	3.80	0.710	19.0	173
X21C		27-Sep-89	8.40	-0.002	-0.005	0.006	0.126	0.062	31.5	332

Table 3a continued:

SITE #	LOCATION	DATE	pH	Cu mg/L	Pb mg/L	Zn mg/L	Mn mg/L	Fe mg/L	Na mg/L	SO4 mg/L
X24A	INTERMEDIATE DAM: NORTH	15-May-86		-0.005	-0.005	-0.005	1.010		50.0	326
X24A	A - SHALLOW	15-Oct-86	7.40	-0.005	0.002	0.040	1.560		65.5	451
X24A		01-Oct-87	7.66	0.004	-0.005	0.024	3.20		98.0	474
X24A		13-Oct-88	7.7	0.003	-0.005	0.008	3.35	0.070	98.0	384
X24B	B - DEEP	15-May-86		-0.005	-0.005	-0.005	2.360		52.0	324
X24B		15-Oct-86	7.30	-0.005	0.010	0.030	1.870		60.0	416
X24B		01-Oct-87	7.37	0.003	-0.005	0.022	1.90		87.0	532
X24B		13-Oct-88	7.9	0.002	-0.005	0.007	2.85	0.025	75.0	322
X25A	INTERMEDIATE DAM: SOUTH	15-May-86		-0.005	-0.005	-0.005	0.720		9.0	233
X25A	A - SHALLOW	15-Oct-86	7.20	-0.005	0.030	0.080	0.140		11.1	238
X25A		09-Jun-87	7.56	0.004	-0.005	0.31	2.83		78.0	718
X25A		01-Oct-87	7.36	0.003	-0.005	0.026	0.185		14.1	224
X25A		13-Oct-88	7.5	0.002	-0.005	0.003	0.325	0.150	13.0	186
X25A		22-Sep-89	7.27	0.002	-0.005	0.013	0.685	0.085	14.7	282
X25B	B - DEEP	15-May-86		-0.005	-0.005	-0.005	0.280		5.0	28
X25B		15-Oct-86	7.50	-0.005	0.030	0.040	0.240		4.4	27
X25B		09-Jun-87	7.49	0.014	0.007	0.013	3.05		74.0	753
X25B		01-Oct-87	7.56	-0.002	-0.005	0.01	0.61		4.4	81
X25B		13-Oct-88	7.8	-0.002	-0.005	0.003	0.345	0.030	4.8	67
X25B	*	22-Sep-89	7.56	0.002	-0.005	0.010	0.469	0.326	7.6	366

NOTE: Less then = (-)

* NO SAMPLE TAKEN IN AUGUST DUE TO DAM CONSTRUCTION

Table 3b: Additional Groundwater Sample Sites

SITE	LOCATION	DATE	pH	Cu mg/L	Pb mg/L	Zn mg/L	Mn mg/L	Fe mg/L	Na mg/L	SO4 mg/L
CVDC 4S	CROSS VALLEY DAM	01-Oct-87	7.2	0.003	-0.005	0.023	4.22		69.0	495
CVDC 4S	CREST NORTH	12-Oct-88	7.6	0.004	0.005	0.023	2.50	0.120	64.0	387
CVDC 4S	S - SHALLOW	09-Aug-89	8.13	0.003	-0.005	0.022	0.014	0.051	21.7	360
CVDC 4S		21-Sep-89	7.53	0.010	-0.005	0.064	0.011	0.019	21.0	66
CVDC 4D	D - DEEP	01-Oct-87	7.68	-0.002	0.005	0.046	0.036		9.1	215
CVDC 4D		12-Oct-88	7.9							
CVDC 7S	CROSS VALLEY DAM	01-Oct-87	7.56	0.002	-0.005	0.016	4.51		56.0	314
CVDC 7S	CREST MID	12-Oct-88	7.6	0.003	0.005	0.012	6.00	0.150	88.0	372
CVDC 7S	S - SHALLOW	09-Aug-89	7.71	0.003	-0.005	0.028	5.55	0.560	82.0	365
CVDC 7S		21-Sep-89	7.39	0.007	0.012	0.262	6.10	0.140	67.0	449
CVDC 7D	D - DEEP	01-Oct-87	7.46	0.003	-0.005	0.022	4.40		83.0	617
CVDC 7D		12-Oct-88	7.6	0.002	0.013	0.017	4.25	0.005	84.0	428
CVDC 7D		09-Aug-89	8.05	0.003	-0.005	0.008	3.93	0.198	88.0	456
CVDC 7D		21-Sep-89	7.48	0.012	0.009	0.138	3.85	0.048	82.0	350
CVDC 9S	CROSS VALLEY DAM	01-Oct-87	7.77	-0.002	-0.005	0.028	0.04		8.6	78
CVDC 9S	CREST SOUTH	12-Oct-88	7.7	0.004	-0.005	0.021	0.025	0.035	14.5	127
CVDC 9S	S - SHALLOW	09-Aug-89	7.79	0.003	-0.005	0.023	0.035	0.169	25.0	226
CVDC 9S		21-Sep-89	8.50	0.004	-0.005	0.016	0.098	0.035	28.0	256
CVDC 9D	D - DEEP	01-Oct-87	7.7	0.002	-0.005	0.017	0.078		17.4	163
CVDC 9D		12-Oct-88	7.8	0.002	-0.005	0.011	0.125	0.670	18.0	174
CVDC 9D		09-Aug-89	8.01	0.003	-0.005	0.016	0.112	0.276	25.0	155
CVDC 9D		21-Sep-89	8.41	0.003	-0.005	0.007	0.059	0.052	23.0	149
CVDT 1	CROSS VALLEY DAM	01-Oct-87	7.9	0.002	-0.005	0.011	3.92		84.0	456
CVDT 1	TOE NORTH	13-Oct-88	7.6	0.004	0.005	0.008	5.50	0.260	100.0	439
CVDT 1		09-Aug-89	8.36	0.003	-0.005	0.009	4.46	0.028	98.0	421
CVDT 1		21-Sep-89	7.44	0.003	-0.005	0.020	3.24	0.009	64.0	343

Table 3b continued:

SITE	LOCATION	DATE	pH	Cu mg/L	Pb mg/L	Zn mg/L	Mn mg/L	Fe mg/L	Na mg/L	SO4 mg/L
CVDT 2	CROSS VALLEY DAM	01-Oct-87	7.11	0.003	-0.005	0.016	2.22		68.0	417
CVDT 2	TOE SOUTH	13-Oct-88	7.6	0.003	-0.005	0.003	2.800	0.025	80.0	428
CVDT 2		09-Aug-89	8.10	0.003	-0.005	0.016	0.810	0.030	72.0	420
CVDT 2		21-Sep-89	7.39	0.005	-0.005	0.030	0.655	0.011	72.0	432
ID 4S	INTERMEDIATE DAM MID	01-Oct-87	7.31	0.006	-0.005	0.044	6.75		67.0	487
ID 4S	S - SHALLOW	13-Oct-88	7.2	0.004	-0.005	0.013	16.80	0.140	88.0	520
ID 4D	D - DEEP	01-Oct-87	7.71	0.004	-0.005	0.017	0.083		71.0	609
ID 4D		13-Oct-88	7.8	0.003	-0.005	0.007	0.590	0.330	72.0	433
FVWD-H	FARO VALLEY WASTE DUMP	15-Aug-89	7.40	0.005	-0.005	0.267	0.199	0.990	2.7	23
P81-09	N. OF PUMPHOUSE POND	09-Jun-87	7.59	0.023	0.007	0.03	0.01		3.6	11
P81-09		01-Oct-87	7.54	0.005	0.019	0.073	0.017		2.6	23
81-04D	OLD TAILINGS DAM, DEEP	01-Oct-87	6.85	0.003	0.023	0.072	12.4		100	335
83-2B	ORIGINAL TAILINGS POND	01-Oct-87	9.22	0.002	0.009	0.009	0.008		38	37
83-2C	ORIGINAL TAILINGS POND	01-Oct-87	7.5	0.009	0.027	0.074	0.072		175	506
83-3A	OLD TAILINGS POND	01-Oct-87	5.42	0.011	0.4	165	35.1		195	1940
83-3B	OLD TAILINGS POND	01-Oct-87	3.15	0.71	1.7	52.5	14.9		263	1670
83-4B	OLD TAILINGS POND	01-Oct-87	7.53	0.008	0.117	0.79	0.175		91	116
K10	ORIGINAL TAILINGS POND	01-Oct-87	6.23	0.006	0.137	2.34	0.67		28	
K12	ORIGINAL TAILINGS POND	01-Oct-87	7.06	0.002	0.044	0.355	0.092		48	119

With few exceptions (pH between 3.15 and 6.85 in the old tailings dam and pond), pH values are generally higher than 7.0, indicating that any acid produced is neutralized by dissolution of calcite in the waste-rock dumps, and by the free lime which is discharged from the mill to the tailings. Metal concentrations are generally relatively low, except locally in the old tailings.

Assuming that all sulphate in the water samples represents oxidation of sulphide minerals, an equivalent amount of Cu, Fe, Pb and Zn is expected in the water samples. Comparison of the sum of the metal concentrations with the sulphate concentration in samples for which both Fe and Zn values are available revealed "excess" sulphate ranging from 88.9 to 99.9% of the total sulphate. This suggests that most of the Iron (Fe) resulting from the oxidation of pyrite and pyrrhotite is being precipitated as Ferric-hydroxide inside the waste-rock dumps and tailings, due to neutralization. It is likely that some Mn and Zn are co-precipitated with Ferric-hydroxide.

The relatively low sulphate concentrations overall may be due to low oxidation rates, to dilution, or to loss of sulphate through precipitation of gypsum. The latter would occur if sufficient calcium were produced during the acid-neutralization process to supersaturate the water with respect to gypsum. This could not be checked, due to the absence of Ca^{++} concentration data.

Selective data from stations X22 and X23 (Tables 3a, 3b and 3c) were plotted to highlight seasonal and long-term trends. In Figure 1, the concentrations of Mn and Na are presented for the period of January 1987 to September 1989. The same data for station X23 are shown in Figure 2. For Na, some seasonal trends appear to be present; concentrations are lower in winter than in summer. For X23, on the other hand, a seasonal trend is less evident. Concentration shifts occur for both Mn and Na in the same fashion.

The water at station X22 is basically that water collecting in the Zone I/III pit, and thus represents a collection of all the wall seeps. These wall seeps are Faro creek water and Faro Valley ground water which has run through different geological formations and waste rock sites upstream from the pit. The water characteristics of X23 reflect the changes in water as X22 water runs through a major portion of the waste rock. Water sampling station X23 is the seepage emerging from waste dumps in the Faro stream valley downstream from the pit. It represents precipitation from the dumps plus seepage losses from the unlined ditch conveying X22 water over the dumps. Therefore, X22 can be considered partly the recharge for X23. Comparison of the two types of water shows that the concentration of Na averages slightly lower, and that of Mn, slightly higher in X23 than in X22. It could be hypothesized that this subtle shift is due to acid generation and subsequent neutralization with disseminated carbonates and silicate minerals (Rhodochrosite - $MnCO_3$ is probably present). The noted shifts in concentrations of Na and Mg could also be brought about by different interactions of precipitation in the dumps of various ages. Or, alternatively, particularly explaining 1987 trends, the large water volumes which were passing through the system as the pit was dewatered may have caused some of these shifts.

Figure 1: Manganese and Sodium Concentrations in Faro X22

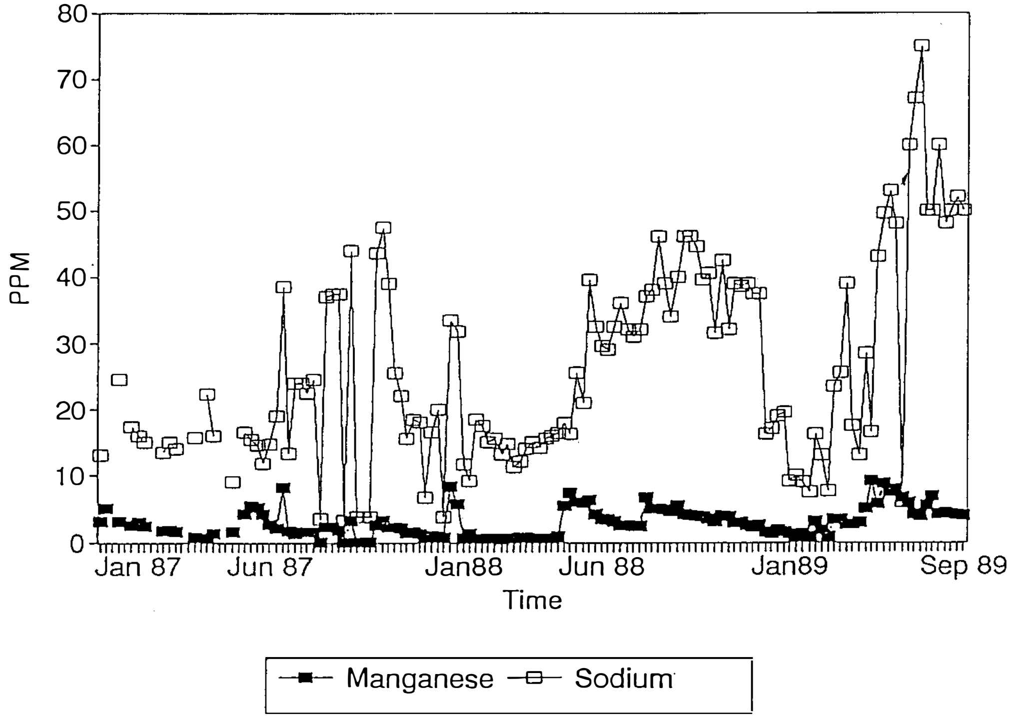
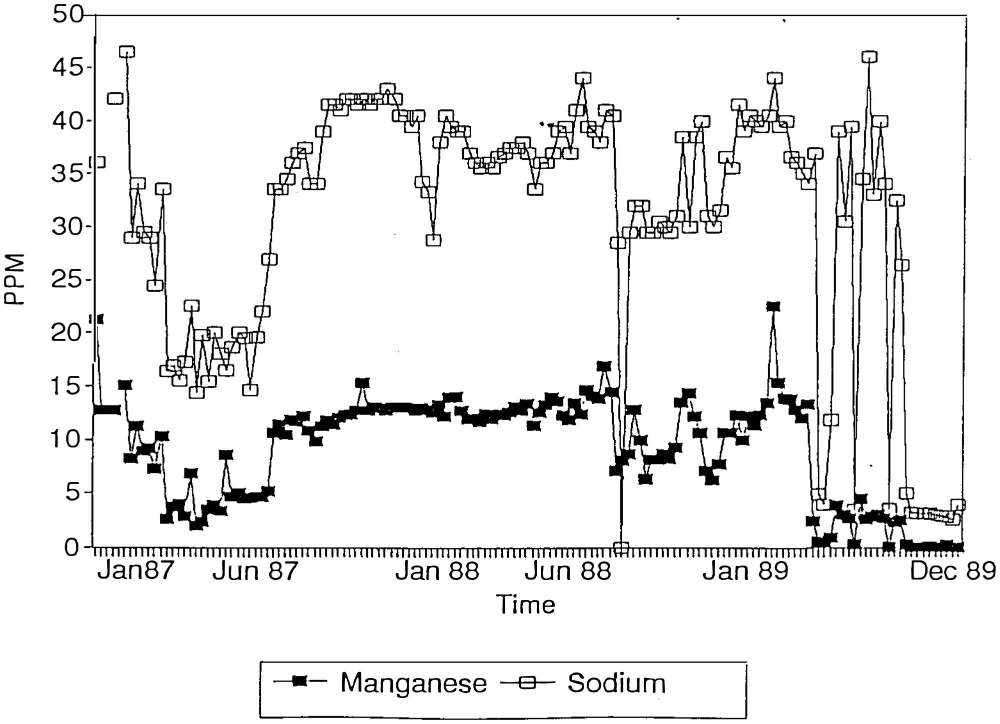


Figure 2: Manganese and Sodium Concentrations in Faro X23



Acid-generation in the waste rock dumps followed by neutralization could proceed to different degrees in different sections of the waste rock pile. This should be detectable from the sulphate concentrations in X23 and X22 (Figure 3 and Figure 4). If temperature is a major controlling factor, AMD would be expected to be more extensive in the waste rock pile than in the wall seeps which collect in the pits. The waste rock pile is expected to reach higher temperatures due to the breathing phenomenon of waste rock piles. At X23, sulphate concentrations are in fact higher (around 1400 mg/l) than those of X22, generally ranging between 400 and 800 mg/l.

Interpretation of X23 seepage water sulphate is confounded by the fact that ore stockpiles are located above the X23 site. Seepage from the ore stockpiles must contribute to the water quality at X23. It is interesting to note that the ore stockpiles were at an all time low in the winter of 1989 when sulphate concentrations at X23 were low. An 800,000 tonne oxidized ore stockpile was screened and coarse fraction processed between September 1986 and March 1987. The fines remain stockpiled above station X23.

Assuming that oxidation of pyritic material is driven mainly by temperature, then a decrease in sulphate would be expected during winter. This phenomenon should be more pronounced in X22 than in X23, given that the X23 water is more insulated inside waste rock pile. Seasonal trends are evident, indicating a drop during the winter and a slight increase in summer. A significant drop in sulphate concentrations in the winter of 1989 from about 1600

Figure 3: Sulphate Concentrations in Faro X23

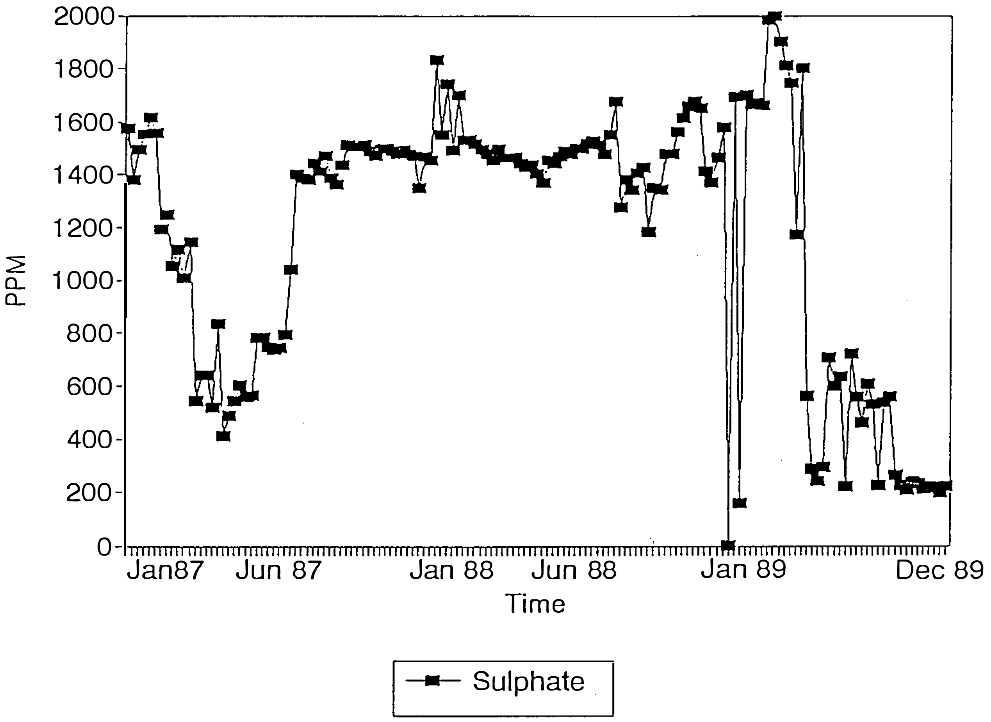
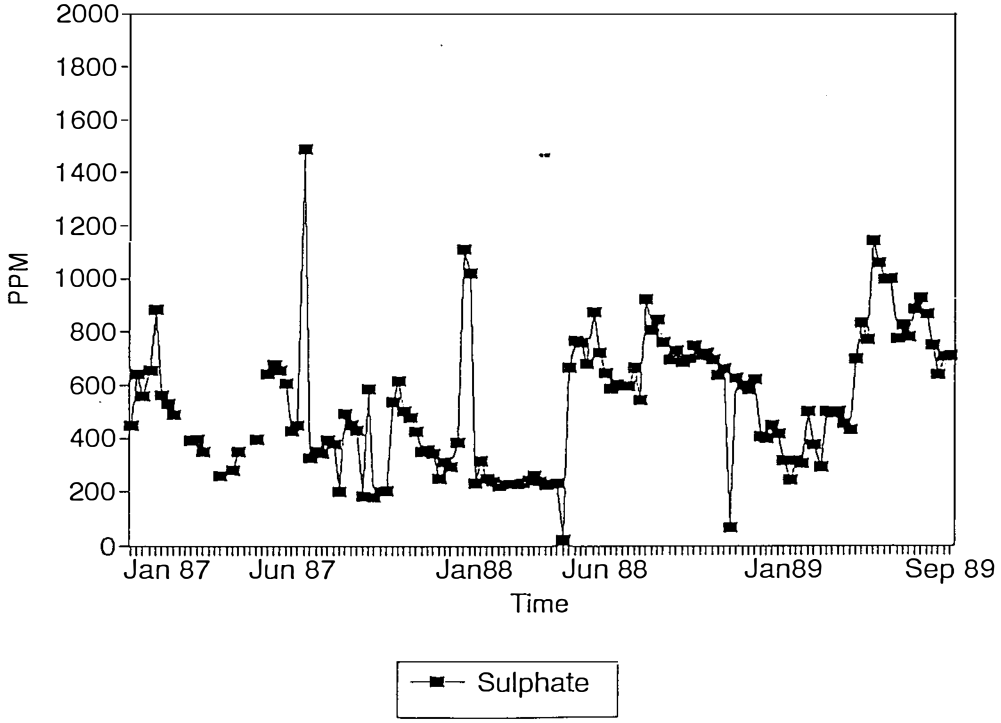


Figure 4: Sulphate Concentrations in Faro X22



mg/l to about 500 mg/l has occurred at X23. It cannot be determined if this is attributable to the temperature regime in the waste rock pile or if it is due to changes in the flow pattern of the X23 seepage. Analyses by Assayers Ontario Ltd. of water collected by Boojum Research Ltd. from station X23 for a) *Chara* toxicity tests and b) for the determination of the distribution of elements in suspended particulate form collected in March and April 1990, are given in Table 4. These results suggest that the sulphate concentrations remained around the higher level and did not drop as indicated by Curragh Resources monitoring data. From these data, it is also evident that some fraction of the Na and Fe in the water is present in the suspended form (compare March 90 filter paper to filtered acidified in Table 4). All other elements occur essentially as dissolved components. The same conclusion has to be reached when the three April 1990 samples are evaluated (Table 4). The Fe concentrations are erratic, as the total acidified water has lower concentrations than the filtered-acidified water to which no acid was added. This essentially indicates that Fe numbers are erratic due to formation of iron-rich flocculants and the variable adherence of iron to storage container walls prior to analysis. Overall, these observations confirm that Fe is precipitated in the waste rock pile as the acid generated is neutralized.

Table 4: Dissolved and Suspended Elements in X23

SAMPLE DATE ASSAYERS CODE	March 90 1565	March 90 1575	April 90 1648	April 90 1652	April 90 1659
SAMPLING LOCATION	Faro X23 Filtered Acidified	Faro X23 Filter Paper	Faro X23 Total Acidified	Faro X23 Filtered Acidified	Faro X23 Total No Acid
pH					6.2
Cond. (umhos)					350
Ferric (ppm)					0
Ferrous (ppm)					10
ELEMENTS(PPM) Ag	< 0.01	0.0012	< 0.01	0.01	0.01
Al	0.1	0.06784	0.2	0.2	0.2
As	< 0.01	0.0004	0.06	0.1	0.1
B	< 0.01	0.038	0.1	0.2	0.03
Ba	< 0.01	0.0004	0.03	0.03	0.04
Bi	0.09	0.0012	0.05	0.06	0.06
Ca	648	0.00852	481	485	504
Cd	0.05	0.0364	0.2	0.3	0.3
Ce	< 0.01	0.0004	0.2	0.02	0.02
Co	< 0.01	0.04	0.4	0.6	0.6
Cr	< 0.01	0.018	0.1	0.1	0.1
Cu	< 0.01	0.0104	0.01	0.01	0.01
Fe	2.6	3.094	14.3	31	31
K	< 0.01	0.00332	15.2	16	16
La	< 0.01	< 0.1	0.03	0.03	0.04
Mg	214	0.0024	267	271	272
Mn	11	0.014476	8.6	8.7	9.2
Mo	0.1	0.0168	0.02	0.04	0.04
Na	47	1.06264	69	71	70
Nb	< 0.01	0.0036	0.04	0.06	0.06
Ni	0.1	0.0076	0.7	0.7	0.8
P	0.8	0.11968	1.5	2.2	2.2
Pb	< 0.01	0.0236	0.3	0.5	0.5
S	586	0.72	728	694	740
Sb	0.1	< 0.1	0.03	0.04	0.04
Se	0.1	0.002	0.02	0.05	0.05
Si	9.9	0	6.9	7.1	7.3
Sn	0.05	< 0.1	0.06	0.09	0.1
Th	3.7	< 0.1	1.2	1.2	1.2
Te	0.06	0.0016	0.09	0.1	0.1
Th	< 0.01	< 0.1	0.09	0.09	0.09
Ti	< 0.01	0.005848	0.01	0.01	0.01
U	< 0.01	0.0004	0.02	0.02	0.02
V	< 0.01	0.0004	0.03	0.05	0.04
W	0.05	0.0008	0.1	0.1	0.1
Zn	19	0.068	34	34	36
Zr	< 0.01	0.002	0.04	0.04	0.05

The drainage from the waste rock pile (X23) enters the tailings area and eventually emerges as X11 and X12 at the foot of the Cross Valley dam in addition to the outflow of the decant tower at the dam. The sulphate concentrations, flow, and sulphate loading in the water are presented in Figure 5 for X11 (north seepage) and Figure 6 for X12 (south side seepage). An interesting aspect emerges, when comparing the two seeps. The sulphate concentrations in X12 are related to the flow, where decreasing flows produce increasing sulphate concentration, reflecting a constant rate of sulphate production. The increase in sulphate concentration, however, does not result in an increase of sulphate loading. This behaviour of the seepage at X12 is likely related to seasonal changes in the water flow in the Rose Creek diversion ditch. Water flow in the ditch then drives the flow rate through leaks reaching the X12 flow path prior to the emergence of the X12 seepage. At the X11 station, no significant seasonal pattern of sulphate loading has been noted, and the higher sulphate concentrations found likely reflect the input from the old tailings, X22, and X23. These considerations, although based on circumstantial evidence, indicate that the supply of oxygen and water from the Rose Creek diversion to the flow path prior to X12 do not appear to increase acid generation in the new tailings significantly. Both seeps' average temperatures remain basically the same (Figure 7). The concentrations of Mn and Fe at stations X11 and X12 are given in Figures 8 and 9. Seasonal variations in concentrations are not evident at either station. However, both Mn and Fe concentrations are consistently higher in X11 water compared to X12 water. In X12 water, more oxygen is available for acid generation, followed by precipitation of Fe and Mn.

Figure 5: Sulphate and Loading/Flow Rate for Faro X11 (north side).

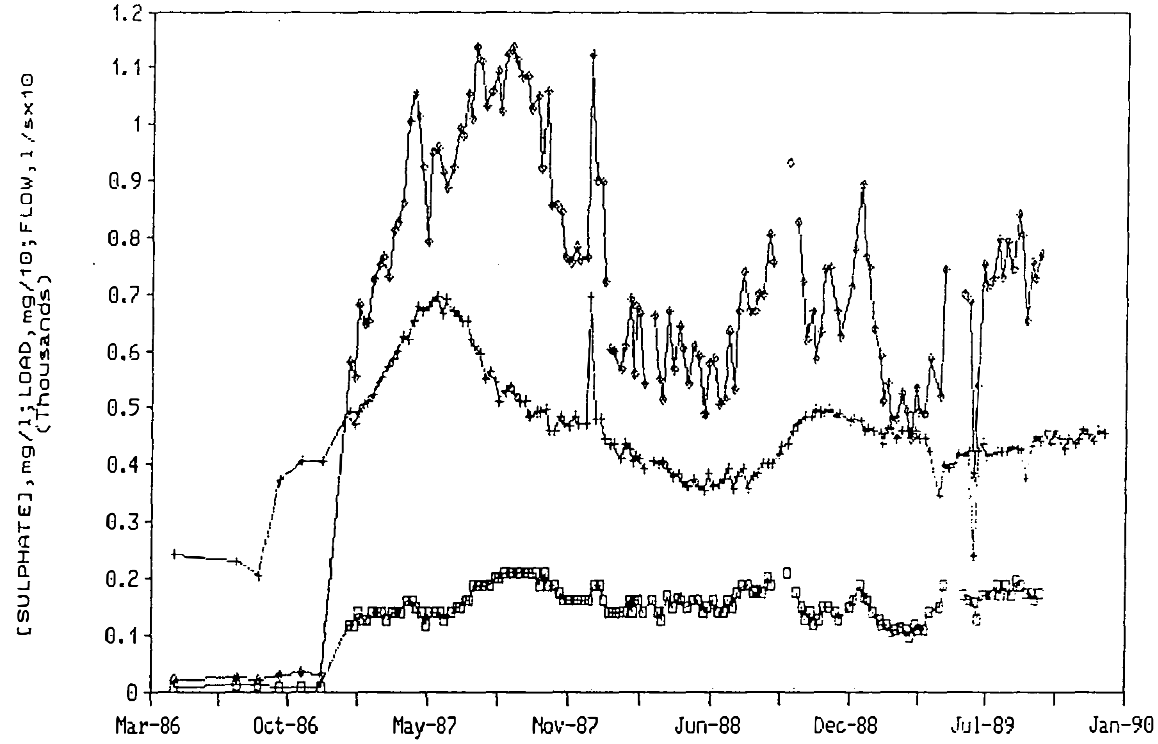


Figure 6: Sulphate and Loading/Flow Rate for Faro X12 (south side).

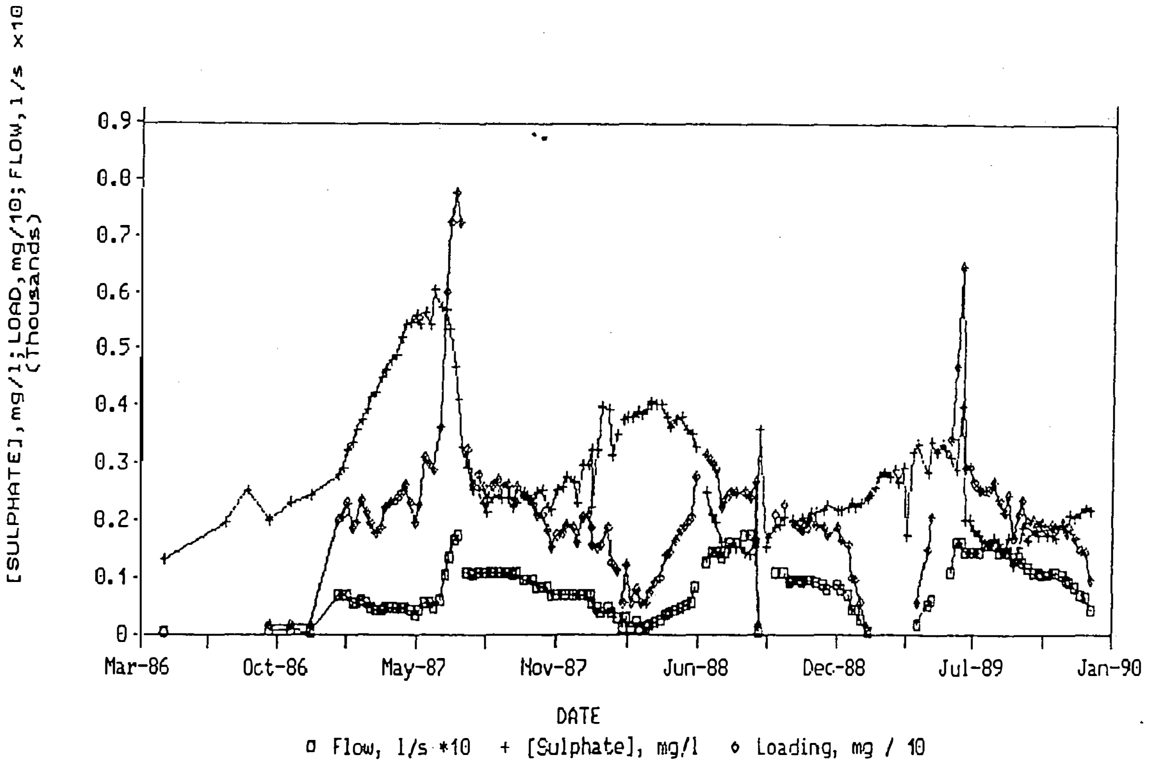
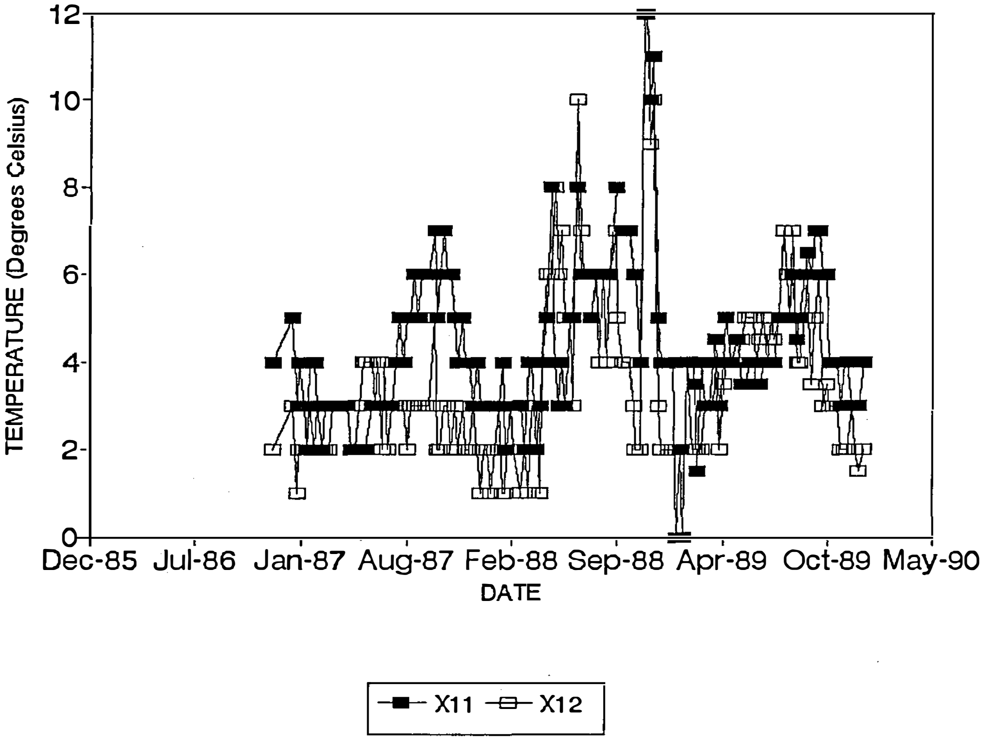


Figure 7: Field Water Temperatures for X11, X12 (north and south sides).



The flow pattern between X11 and X12 seeps is different. Seep X12 receives more oxygenated water due to leaks in the Rose Creek diversion ditch, even though the acid generation rates in both flow paths are comparable. Overall, the main rate-limiting factor for acid generation in these tailings is temperature, while variation in oxygenated water entering the tailings does not appear to affect acid generation rates.

There has also been a gradual increase in sulphate concentrations since the operation of the tailings basin resumed in 1986. It should be noted that the concentrations of sulphate at seeps X11 and X12, at the time when monitoring started in early 1987, were at approximately the same low level (around 200 mg/l). During the time of shutdown the difference in flow regimes between the two seeps likely continued. The long-term implications of these sulphate concentration increases should be further investigated.

There is some indication that, at the time of shutdown, the seeps from the waste rock will create more acidity than seepage from the tailings. Assuming that temperature is the main controlling factor, acid generation is occurring at a higher rate in waste rock than in the tailings, probably due to the insulation against heat loss provided by the waste rock pile. However, the oxygen content is also higher in the waste rock pile due to the breathing phenomenon, and/or the waste rock pile may have less neutralizing capacity. While the acid generation potential of the tailings is higher than that of the waste rock pile, the factors dictating the rate at which both materials will liberate contaminants will not be the same.

Currently, it appears that as water passes through the waste rock pile, sulphate concentrations increase. However, upon passing through the tailings, sulphate concentrations do not increase. This pattern may be maintained through dilution by water with lower sulphate concentrations or it may be that excess sulphate may precipitate within the tailings as gypsum. Although a more thorough investigation of the data is required, the evaluation of the monitoring data suggests that a long-term measure for the reduction of acid-generation rates could be achieved by a reduction of the temperatures in the tailings and the waste rock pile.

Figure 8: Manganese and Iron for Faro X11 (north side).

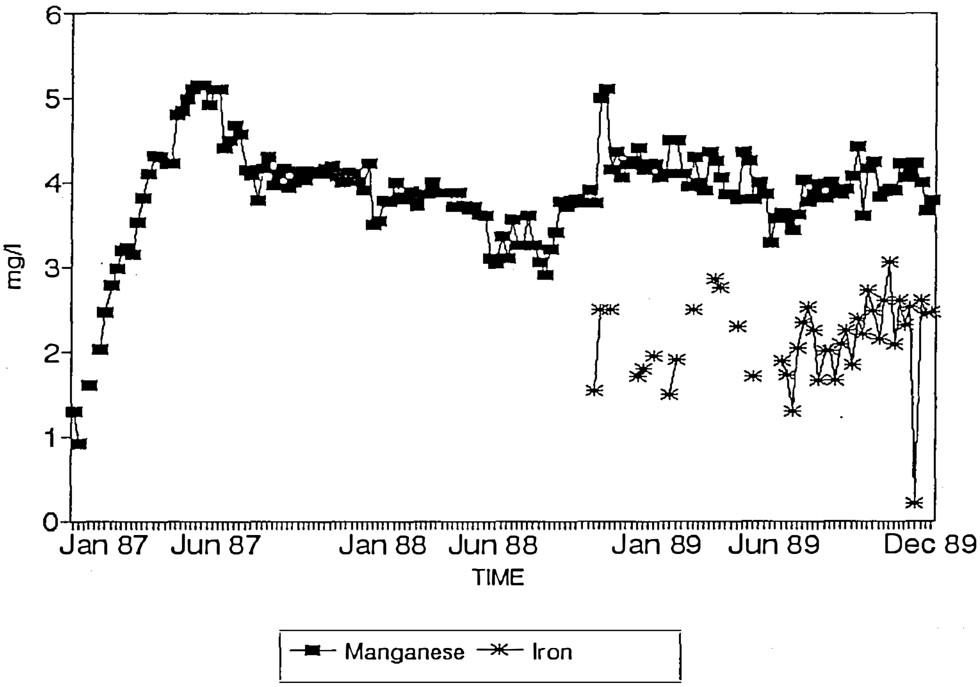
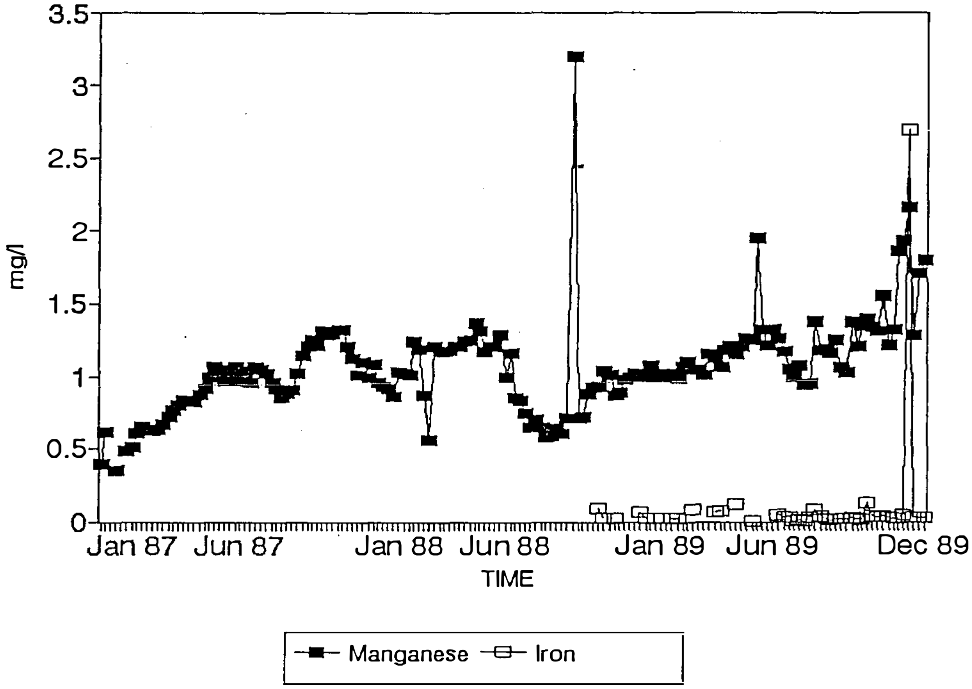


Figure 9: Manganese and Iron for Faro X12 (south side).



3.0 SITE ASSESSMENT FOR BIOLOGICAL POLISHING

A field visit was carried out in mid March 1990 by M. Kalin to gain an understanding of the lay-out of the site, particularly with respect to the conditions of the seeps described in Report 60612, 1987 and the 1988 Seep Survey.

3.1 Winter Seep Characteristics

In Table 5, the water characteristics of the North Fork of Rose Creek (#1) are compared to seep 5/6, which probably represents the flow from the Faro creek diversion ditch (sample #2) and a pit wall seep (sample #4). For each water sample, the concentrations of elements present in dissolved form (FA, filtered acidified) and the total sample concentration (W) is given. The difference indicates the suspended fraction. In samples #1 and #2, differences in concentrations of Fe, Na, Mn, and S are indicated between these two forms. In the pit wall seep, these differences between dissolved and suspended concentrations are the most pronounced for iron. It is likely that these differences are related to the acid generation/neutralization process which results in formation of an iron precipitate. The highest concentrations of Ca, Mg, and S are present in sample #2. This sample represents characteristics of water which has passed through an area of more intensive acid

Table 5: Water Characteristics of the North Fork of Rose Creek

SAMPLE DATE		Mar 19 90	Mar 19 90	Mar 19 90	Mar 19 90	Mar 19 90	Mar 19 90
SAMPLE VOLUME		250 ml		250 ml	250 ml	250 ml	250 ml
ASSAYERS CODE		1618	1625	1616	1627	1615	1629
SAMPLING LOCATION		Faro # 1 FA	Faro # 1 W	Faro #2 FA	Faro #2 W	Faro #4 FA	Faro #4 W
Temp.							
pH		6.6		6.7		7.5	
Cond. (umhos)		160		600		300	
Ferric (ppm)		0		10		0	
Ferrous (ppm)		0		0		15	
ELEMENTS mg/l	Ba	0.1	0.08	0.04	0.04	0.05	0.05
	Ca	48	47	139	152	56	57
	Co	0.02	0.2	0.1	< 0.01	0.2	0.01
	Cr	< 0.01	0.06	0.07	< 0.01	0.08	< 0.01
	Cu	< 0.01	< 0.01	0.03	< 0.01	0.03	< 0.01
	Fe	1.9	23	20	< 0.01	25	3.4
	K	5.1	3.8	8.1	10	9.9	12
	La	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
	Mg	13	14	91	105	43	48
	Mn	0.01	0.04	0.07	0.03	0.09	0.03
	Mo	< 0.01	0.02	0.02	< 0.01	0.02	< 0.01
	Na	8.4	11	17	24	21	29
	Nb	< 0.01	0.03	0.03	< 0.01	0.04	< 0.01
	P	0.07	1.1	0.7	< 0.01	1.2	0.01
	Pb	< 0.01	< 0.01	< 0.01	< 0.01	0.07	< 0.01
	S	4.8	7.6	128	143	29	28
	Se	0.01	0.02	< 0.01	< 0.01	< 0.01	0.01
	Si	8.9	8.4	6.5	7.1	5.1	5.2
	SR	0.1	0.1	0.3	0.3	0.2	0.2
	Te	< 0.01	0.05	0.03	< 0.01	0.06	< 0.01
	Ti	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
	Zn	< 0.01	< 0.01	0.5	0.3	0.4	0.3
	Zr	0.01	0.01	0.02	< 0.01	0.02	< 0.01
Lab Alkalinity		230		220		180	

generation than water from the pit wall seep (# 4), which flows through the gravel bed of the Faro creek. The low concentrations of zinc (the main element of concern) in the seeps are of long term concern. Both seeps have significantly lower concentrations of zinc than X23, suggesting that the mechanisms and sources of zinc loading to X23 should be determined. The concentrations in the North Fork of Rose Creek (#1) are background concentrations, unaffected by any acid generation/neutralization.

3.2 Locations for Biological Polishing

There are several areas which could be considered for the establishment of a biological polishing system and these are briefly discussed.

The area below the mill, which receives X23 seepage, initially appeared to be a reasonable location to be used for this purpose. The physical aspects of this location seemed ideal. Seepage could be ponded between X23 and X7, the culvert along the road, as X23 flows all year around. However, the close proximity of the mill and the concentrate loading facility would mask any experimental results. Concentrate would enter the system and thus influence zinc concentrations and conditions to a degree that would not be representative of conditions at closure. Remedial measures for this area would be required and could be provided by adsorption surfaces utilizing, for instance, the dead wood in the spill area.

An area below the seepage 5/6 running into the zone II diversion ditch may also have potential for ponding some seepage water. Viewing the overall pit seepage situation, however, and in light of the pit closure scenario, it appears that both these locations are not representative of conditions which would prevail at close-out.

Locations at which biological polishing capacity could be usefully applied at closure are in the seepage from the pile along the north east side of the waste rock pile and the North Fork of Rose Creek. This area was investigated on foot, searching for flowing seeps along the mountain side. It is likely that most of these seeps freeze up during the winter, and only the North Fork of Rose Creek has generated flow. The same condition holds for the Faro Creek diversion ditch, where several attempts were made to find flowing water, without success.

In general, it has to be concluded that, given the fractured nature of the terrain, attempts to contain water in constructed impoundments would be ineffective. This is demonstrated by the leakages in both the Faro Creek diversion ditch and that of Rose Creek. It is therefore suggested that natural depressions be sought as experimental areas, along the North Fork of Rose Creek and below the tailings discharge. By regulating the flow, it may be possible to create experimental areas in which the capacity for biological polishing can be established. Once some reduction of contaminants has been achieved in such an experimental setting, locations downstream from Rose Creek could be identified for the waste rock dump.

4.0 ALKALINE BIOLOGICAL POLISHING WITH *CHARA*

The attached macrophytic algal group Characeae has been studied extensively and the employment of these algae in underwater meadows as polishing agents for alkaline mine effluents, removing Ra^{226} and uranium, is being tested on a commercial level (Smith and Kalin, 1989). Some work has been carried out with the algae to remove zinc from the water column in situations where lime treatment is not achieving the desired concentrations for discharge of the effluent. Given the alkaline nature of the effluents from the waste rock dumps at Faro and the tailings, employment of this algal group as biological polishing agents could assist in improving effluent characteristics. Thus, the first step was to test the growth of these species in the laboratory in waste water from the site.

4.1 Objective of Growth Tests

The objective of these experiments was to examine whether either of the two species of *Chara*, *C. vulgaris* and *C. buckelli*, would survive and grow in the laboratory when cultured in solutions overlaying substrate collected from both the X22 and X23 seepages.

The results of this study will be used to assess the feasibility of introducing and promoting characean populations in seeps from the Faro waste rock dump and the tailings.

4.2 Materials and Methods

Plant Material:

Chara vulgaris: Plant material was collected on February 16, 1990 from a natural population in a pond near Ballantrae, Ontario. New plant shoot production was promoted in the laboratory by culturing the biomass in aquaria under fluorescent lighting. The aquaria contained a layer of sediment from the biomass source site overlain with silica sand and filled with tap water.

Chara Buckelli: Plant material was collected during September 1989 from a natural population in Waldsea Lake, Saskatchewan. Good growth is routinely produced in the laboratory by culturing the plants in aquaria under fluorescent lighting. In this case, aquaria contain a layer of sediment from the *C. vulgaris* source sites, overlain with silica sand and filled with a prepared medium containing macronutrients at concentrations similar to averages in Waldsea Lake. Both cultures were prepared by February 20, 1990.

On March 2, 1990, plant biomass was removed from the aquaria and new shoots 5 to 10 cm long consisting of 3 to 4 whorls were cut from the biomass. Five shoots were set aside for set-up of each treatment.

Solutions and Substrate: The X22 and X23 solutions arrived in the laboratory on February 21, 1990 and were stored at room temperature.

Industrial grade silica sand was used in several treatments. Material used as sediment and amendment treatments was of Ballantrae *Chara* population origin.

Control solutions were tap water (T-H_2O) and Artificial Waldsea Lake Water (AWW).

Growth Chamber: Growth trials are performed at room temperature (21 to 24° C) beneath cool white fluorescent light banks.

Culture Set-up: All treatments were set up in new 2 litre, wide-mouth glass jars. Each treatment had one of two substrate types; sand or sediment. All substrates were added before the water and plants.

In sand treatments, a 5 cm thick layer of washed silica sand was added. In the sediment treatment, 4 cm of screened, homogenized sediment was added, overlain by a 1 cm thick layer of sand.

After substrate addition, 1.8 l of the solution was added carefully to the jars so as not to disturb the stratification.

Using forceps, 5 shoots were implanted vertically into the substrate , burying the shoots to the lowermost whorl. All precautions were taken so as not to damage or kill the cells comprising the shoots' axes.

Water levels were adjusted with distilled water to compensate for evaporation.

Overall Experimental Design:

	Control				X22		X23	
	T-H_2O		AWW		Sol'n		Sol'n	
	Cv	Cb	Cv	Cb	Cv	Cb	Cv	Cb
Sand	S,G	S,G	D	S,G	D	D	S,G	S
Sand Sediment	S,G	S,G	D	S,G	D,R	D	S,G	S

D = apical shoots died
S = apical shoots survived
G = apical shoots grew
R = regenerated from basal shoot

Parameters being Examined: The pH, conductivity and temperature of the solutions were recorded every 4 days. Shoot colour, axis and branchlet cell survival, and the development of new whorls from the apical and lateral meristems were recorded every 4 days.

4.3 Chara Toxicity Tests

Both species survived and grew well in the control treatments with tap water and sand or sediment substrate. Interestingly, *Chara vulgaris* did not survive in artificial pond water (AWW) with sand or sediment substrate. Survivability was low for both species of *Chara* in X22 water with sand or sediment as substrate. However, some new basal shoots of *Chara vulgaris* were regenerated within the sediment in the X22-sediment treatment after 14 days. On the other hand, *Chara vulgaris* shoots in X23 solutions with either sand or sediment not only survived but grew at rates equivalent to the tap water controls (Plate 1). Some cells in the *Chara buckellii* shoots remained alive in X23 water, but no growth was observed. According to assay data, X23 water contained significantly higher levels of Mn, S, and Zn than X22 water. *Chara vulgaris* appears tolerant of, and capable of growing well in X23 solution. It is not clear why growth of growth of *Chara* was better in X23 (with higher levels of heavy metals) than in X22.

Biological polishing agents are capable of accumulating elevated concentrations of sulphates, calcium, magnesium and zinc. Table 6 lists the concentrations of elements of interest in the

Faro waste water together with those concentrations obtained in the *Chara* shoots which grew. The first and second columns represent X22 and X23 water concentrations, while the third column represents *Chara* tissue accumulations in control water, i.e. plants grown in their natural background water. The last four columns are the concentrations (accumulations) in *Chara* tissues grown in X23 water. It is evident, when the concentrations of the control plants are compared to those grown in waste water, that zinc, when present in solution, is accumulated. Accumulations of 10 to 300 fold are noted, compared to the control plants. These results suggest the possibility of the application of this algal group as a biological polishing agent for the seepage from the Faro waste dump. Personal communications with biologists in Whitehorse (Skeeter Verlaine-Wright, of Biotic Interactions) indicated that populations of these algae have been reported in the vicinity. Field tests with these algae would therefore be beneficial, if populations can be established in appropriate locations.

Plate 1: *Chara* growth experiments at Boojum Research Ltd.

Plate 2: Green algae and cyanobacterial mats at X11.

Table 6: Concentrations of Elements in Faro Waste Water and accumulation of elements in *Chara* tissues.

SAMPLE DATE	March 1990						
ASSAYERS CODE	1564	1565	1663	1664	1662	1666	1665
SAMPLING LOCATION	Faro X 22 Water	Faro X 23 Water	Faro Control T Water CV Sand/Sed	Faro X 22 Solution CV Sand/Sed	Faro X 23 Solution CV Sand/Sed	Faro X 23 Solution CV Sand	Faro X 23 Solution CB Sand/Sed
Elements Ca mg/l	89	648	110760	111470	69580	31950	69580
Cu	< 0.01	< 0.01	37	40	18	82	105
Fe	0.3	2.6	2447	2724	699	1888	1328
Mg	23	214	4200	4800	5400	3120	6180
Mn	0.01	11	847	693	3696	6468	2926
Na	3.7	47	222	296	888	74	518
S	93	586	5000	6000	7000	7000	9000
Pb	< 0.01	< 0.01	27	47	27	1473	53
Zn	5.5	19	34	347	4467	9146	3260

4.4 Other Biological Polishing Agents

Extensive growth of cyanobacteria (blue-green alga: *Oscilliatoria),* diatoms and green filamentous algae (*Stigeoclonium*) were noted in the seepage from X11, Plate 2. These organisms have also been shown to be effective biological polishers. These algae have been shown to effectively remove zinc and provide organic matter in tailings ponds (Kalin and Mallory, 1989). Algae and/or cyanobacteria could be utilized in the ponded water on the Faro tailings, or in pools formed on the abandoned waste rock pile. Furthermore, if tailings deposition from the VanGorda -Grum development is considered in the old Zone I/III pit rather than the existing tailings ponds, cyanobacteria as polishing agents may make a significant contribution to the reduction of zinc loading.

Biomass from the X11 seep was collected, dried, and analyzed for elemental composition (Table 7). The water concentrations from X11 and X12, at the time of sampling, are presented in Table 8. The accumulation of the elements Al, Ca, Fe Mg, Mn, Na, S in the precipitate and the biomass is high when compared to the concentrations of the same elements in the seepage water. For example, Al and Ni were present at detection limits (<0.01 mg/l) in the seepages, but the concentrations in the biomass were as high as 1.6 and 0.01 % of the dry weight, respectively. The existence of these precipitation/bioaccumulation systems in this seepage during the winter suggests that through a better understanding of these natural

Table 7: Elemental Composition of Biomass from X11

SAMPLE DATE	Mar 19 90	Mar 19 90	Mar 19 90	Mar 19 90	Mar 19 90
ASSAYERS CODE	1636	1637	1638	1639	1640
SAMPLING LOCATION	Faro W2 X11 Fungi SS	Faro ROCKS PCIP SS	Faro W2 X11 GR SOLIDS SS	Faro GREEN FILAMEN SS	Faro BLUE GREEN SS
ELEMENTS(PPM) Ag	0.3	0.8	10	< 10	< 10
Al	16430	1590	3180	3710	42930
As	1253	1304	901	673	119
B	900	600	300	300	200
Ba	1877	1870	873	1232	1734
Bi	13	16	< 10	< 10	< 10
Ca	36920	26270	50410	17750	17040
Cd	45	61	30	24	< 10
Co	42	72	23	29	19
Cr	59	39	191	35	66
Cu	116	10	29	13	44
Fe	316400	424200	207200	286300	134400
K	4150	830	830	2490	14940
La	58	26	30	46	14
Mg	4800	600	4800	1200	4800
Mn	2310	4620	2310	770	1540
Na	11111	740	5920	1480	9620
Nb	10	12	< 10	< 10	< 10
Ni	106	114	76	63	62
P	1320	440	1760	3080	880
Pb	242	143	81	114	172
S	13000	1000	11000	3000	2000
Sn	< 10	< 10	37	< 10	< 10
Sr	299	258	311	189	231
Te	18	21	10	13	< 10
Ti	860	< 10	< 10	< 10	3440
U	24	30	18	19	< 10
V	40	10	< 10	10	86
W	12	< 10	< 10	10	12
Y	39	24	21	31	14
Zn	323	91	87	93	216
Zr	47	30	22	25	53

Table 8: Elemental Concentrations in X11 and X12 Water.

SAMPLE DATE	Mar 19 90	Mar 19 90	Mar 19 90	Mar 19 90
SAMPLE VOLUME	250 ml	250 ml	250 ml	250 ml
ASSAYERS CODE	1617	1626	1614	1628
SAMPLING LOCATION	Faro W2 X11 FA	Faro W2 X11 W	Faro X 12 FA	Faro X 12 W6 W
Temp.	2.3		1.4	
pH	7.1		7.2	
Cond. (umhos)	600		600	
Ferric (ppm)	0		0	
Ferrous (ppm)	0		0	
ELEMENTS mg/l Ba	0.1	0.1	0.1	0.1
Ca	167	162	105	117
Co	0.04	0.02	0.01	< 0.01
Cr	0.02	< 0.01	< 0.01	< 0.01
Cu	< 0.01	< 0.01	< 0.01	< 0.01
Fe	6.5	3.2	1.1	< 0.01
K	10	13	6.6	10
La	0.01	< 0.01	< 0.01	
Mg	37	40	36	41
Mn	3.7	3.4	1.1	1.1
Mo	< 0.01	< 0.01	< 0.01	< 0.01
Na	164	226	127	178
Nb	0.01	< 0.01	< 0.01	< 0.01
P	0.08	0.03	< 0.01	< 0.01
Pb	< 0.01	< 0.01	< 0.01	< 0.01
S	191	200	117	134
Se	0.01	0.01	< 0.01	< 0.01
Si	7.9	7.9	5.7	6.1
SR	0.2	0.2	0.2	0.2
Te	0.01	< 0.01	< 0.01	< 0.01
Ti	< 0.01	< 0.01	< 0.01	< 0.01
Zn	< 0.01	< 0.01	< 0.01	< 0.01
Zr	0.02	< 0.01	< 0.01	< 0.01
Lab Alkalinity			200	

processes, some means of enhancing these self-cleansing mechanisms could be applied. It should be noted that the zinc accumulation in the biomass is not as species specific with these biota as it was for the alga, *Chara*. Thus, an Ecologically Engineered biological polishing system for the Faro seeps will consist of a combination of natural polishing agents for the waste water.

Natural contaminant removal processes are also probably present. These processes may be suspected from the results of a series of samples collected by Curragh Resources from the Grum Adit. Water from the adit, developed during exploration in 1975, is leaving through a small pond in which some removal of contaminants takes place. In Table 9, analyses of water collected during the winter are presented. Notes from Curragh personnel (Arno Hamalainen) indicated that the location of the discharge sample did not represent the discharge, but was taken at the fringe of the pond above the discharge. This is indeed confirmed by the analytical results in which the concentrations of the key indicator elements, such as Ca, Fe, S, Si and Zn, are basically identical for the water from the Grum Adit and the discharge. Most interesting, however, are the concentrations of the same elements in the water collected from the pond, where a significant reduction in proportions of some of these elements is noted. For example, Ca and S are reduced by half, whereas iron appears to have been reduced by an order of magnitude. Magnesium and Na are also reduced, though at different rates. The reduction of elements in unequal proportions in the water suggests that the removal

Table 9: Analysis of Water Collected During Winter from Grum Adit

SAMPLE DATE ASSAYERS CODE	March 90 1651	March 90 1654	March 90 1658	March 90 1649	March 90 1653	March 90 1657	March 90 1650	March 90 1655	March 90 1656
SAMPLING LOCATION	Faro Grum Adit Filtered Acidified	Faro Grum Adit Total Acidified	Faro Grum Adit Total No Acid	Faro Adit Pond Filtered Acidified	Faro Adit Pond Total Acidified	Faro Adit Pond Total No Acid	Faro Discharge Filtered Acidified	Faro Discharge Total Acidified	Faro Discharge Total No Acid
pH			6.2			7.08			7.1
Cond. (umhos)			350			400			350
Ferric (ppm)			0			0			0
Ferrous (ppm)			0			5			0
ELEMENTS mg/l Al	0.2	0.4	0.08	0.07	1.3	0.4	0.2	0.5	0.2
As	0.09	0.1	0.01	< 0.01	< 0.01	0.09	0.08	0.09	0.1
B	0.2	0.1	< 0.01	0.3	0.2	0.01	0.2	0.1	0.01
Ba	0.07	0.1	0.08	0.09	0.1	0.1	0.07	0.1	0.08
Bi	0.06	0.06	< 0.01	< 0.01	< 0.01	0.06	0.04	0.05	0.06
Ca	110	107	111	47	50	53	103	104	106
Cd	0.2	0.3	< 0.01	< 0.01	< 0.01	0.3	0.2	0.2	0.3
Ce	0.01	0.01	< 0.01	< 0.01	< 0.01	0.01	0.01	0.01	0.01
Co	0.2	0.3	0.03	< 0.01	< 0.01	0.2	0.2	0.2	0.3
Cr	0.1	0.1	0.03	0.01	0.01	0.1	0.1	0.1	0.1
Fe	25	32	4.4	0.9	0.6	26	27	27	30
K	4.4	5.3	3.7	2.4	3.3	4.7	4.7	5.4	5.4
La	0.02	0.01	0.01	< 0.01	< 0.01	0.01	0.01	0.01	0.01
Mg	75	77	79	15	16	17	73	75	75
Mn	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.2
Mo	0.03	0.04	< 0.01	< 0.01	< 0.01	0.03	0.03	0.03	0.04
Na	20	24	23	6.4	7.3	8.4	23	25	25
Nb	0.05	< 0.01	0.01	< 0.01	< 0.01	0.05	0.04	0.05	0.05
Ni	0.1	0.1	0.06	0.01	0.01	0.07	0.09	0.1	0.1
P	1.8	2.1	0.1	0.07	0.02	1.9	1.7	1.9	2.1
Pb	0.3	0.7	0.1	0.02	0.08	0.3	0.3	0.6	0.4
S	56	58	58	27	29	37	55	59	60
Sb	0.03	0.03	0.01	< 0.01	< 0.01	0.03	0.03	0.03	0.03
Se	0.03	0.04	0.02	< 0.01	< 0.01	0.04	0.04	0.03	0.05
Si	7.2	8.1	7.3	1.1	4.6	1.7	6.8	8.3	7.1
Sn	0.07	0.08	0.04	0.01	0.01	0.07	0.07	0.07	0.1
Th	0.4	0.4	0.5	0.1	0.1	0.1	0.4	0.4	0.4
Te	0.1	0.1	0.01	< 0.01	< 0.01	0.1	0.1	0.1	0.1
Th	0.04	0.04	0.03	< 0.01	< 0.01	0.02	0.03	0.03	0.04
Ti	0.01	0.03	< 0.01	< 0.01	0.08	0.01	0.01	0.04	0.01
U	0.01	0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.01	0.01	0.01
V	0.02	0.04	0.01	< 0.01	0.01	0.04	0.03	0.04	0.04
W	0.05	0.06	0.01	< 0.01	< 0.01	0.06	0.05	0.05	0.07
Zn	1.5	2.1	1.5	0.1	0.3	0.2	1.3	1.9	1.1
Zr	0.03	0.03	0.01	< 0.01	0.01	0.02	0.03	0.03	0.03
Alkalinity			240			80			180

is unlikely due to dilution, although this possibility cannot be entirely excluded. A natural precipitation process however, appears to be taking place which should be investigated further. If, for example, biological sulphate reduction takes place in the pond, decreases in zinc concentrations from 1.5 mg/l to 0.3 mg/l could be explained and could represent a further potential biological cleansing process for use during closure.

In summary, these preliminary data suggest that natural removal processes are present in association with the conditions of the Faro site. A detailed understanding of these processes and their application could result in significant improvement of the effluents produced by future mining activities at Faro and Grum Vangorda.

5.0 ECOLOGICAL ENGINEERING FOR THE CLOSURE OF MINING WASTES FOR FARO TAILINGS AND WASTE ROCK

It is possible that Ecological Engineering measures and Biological Polishing can be applied to the improvement of the quality of the seepage from the waste rock dumps and from the tailings basin. An understanding of the precipitation processes and natural biological accumulation parameters however, must be obtained beforehand.

The monitoring data, discussed in Section 2, indicated that temperature is the main factor controlling the rates of acid generation. The most effective means of controlling the environmental impact of the waste material, therefore, would be by utilizing the low temperatures in the Yukon. If a compacted till cover is to be placed over the tailings, it can be assumed that the cover will reduce the rates of penetration of water and oxygen into the tailings. Such a cover would be less effective than expected however, if drying were to lead to the development of dehydration cracks in the till. However, the comparison of data concerning the seeps of X11 and X12 suggests that fluctuations in oxygen/water supply to the tailings, normally considered the worst case scenario for acid generation, did not produce an increase in sulphate concentrations. Thus, any cover should be designed in such a way as to produce maximum insulation from heating during the summer months, thereby encouraging low temperatures and permafrost.

A vegetation cover would increase the insulating capacity. It is well known that by removing vegetation, permafrost is disturbed. Accordingly, the placement of a vegetation cover should encourage expansion of permafrost. This is due to the ability of vegetation to intercept sunlight and thereby shield the ground from infra-red. Furthermore, the low thermoconductivity of a vegetation cover can be expected, as increased air entrapment would provide better insulation during the summer months than a till cover alone. During the winter, moisture retention by the vegetation increases thermoconductivity, a requirement for the reduction of heat. The most effective vegetation cover which can be envisaged is a vegetation cover dominated by moss. Biological polishing measures are generally referred to submerged aquatic populations acting as filtration agents to clean the water. However, biological systems can also be utilized in terrestrial settings to curtail surface water contamination by preventing or curtailing erosion and water penetration into the tailings.

Inactive tailings are frequently invaded by indigenous moss covers, and some work has been carried out by Boojum Research to encourage growth of indigenous moss. Given the reduction in temperature expected from a moss/vegetation cover that experiments towards this end should be conducted on the inactive Faro tailings. A vegetation cover which would encourage low temperatures in the tailings only makes sense if the tailings are amenable to permafrost induction in their present state. A brief preliminary evaluation of temperature data available for the tailings has been carried out in conjunction with the climate data.

Air-temperature and precipitation data are available from two weather stations in the area, at Faro (1971 - 1977, at Faro Airport since 1978), and at the mine site (since 1967). Climate normals for these stations are given in Table 10. The mean annual air temperature is below freezing for both stations, suggesting that permafrost may exist in at least some locations in the area where vegetation, winter snow cover, soil moisture and slope conditions are favourable. Low temperature and low precipitation rates restrict the rate of sulphide oxidation and the transport of oxidation products. Sub-zero Celsius temperatures will severely restrict the oxidation process during more than half the year.

Thermistor strings have been installed in a number of boreholes in the tailings area in 1981, 1985 and 1988. Permafrost was found to exist in some locations, particularly in north-facing slopes. In at least two locations, the measurements indicate that permafrost is thawing (Figure 10). Unfortunately, the varying frequency of measurements and the often long intervals between successive measurements (up to 2 years; Figure 11) make it difficult to distinguish between natural temperature variations and changes due to deterioration of the thermistors. The latter commonly occurs as a result of the saturation of cable insulation with water. Figure 11 demonstrates the improvement in information quality that resulted from recently increased measurement frequency. The 1989/90 part of Figure 11 provides a much improved representation of the ground thermal regime, allowing at least preliminary estimates of both the phase shift and the attenuation of the temperature cycle with depth. Figure 12 demonstrates that measurement intervals should be no longer than 4 weeks, and preferably no longer than two.

The present ground temperature regime allows existence of permafrost, but permafrost will likely not develop naturally in new areas. It may be possible, however, to promote permafrost development, e.g. through careful manipulation of the vegetation, soil moisture, and snow cover.

Table 10: Climate Data for Faro Airport and Faro Mine site

A. ANVIL, Yukon

Established:	1967
Location :	62°22'N 133°23'W
Elevation :	1158 m

CLIMATE NORMALS 1951-1980

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Precipitation and rain in mm; snow in cm													
RAINFALL	0.0	0.2	0.0	0.5	10.7	34.8	45.6	41.6	29.6	2.6	0.1	1.2	166.9
SNOWFALL	27.7	16.7	18.3	10.7	13.1	0.0	0.0	0.7	3.8	29.5	30.9	27.8	179.2
TOTAL	26.0	22.4	30.4	15.5	16.3	41.6	49.7	41.5	32.9	36.9	29.9	24.6	367.7
ST.DEV.	19.5	9.2	14.5	5.8	10.3	19.1	23.6	20.1	25.2	19.0	12.7	14.7	77.6
Mean Temperatures in degree C													
DAILY MAX.	-15.1	-8.3	-5.3	2.2	9.3	16.0	17.5	15.2	9.6	1.6	-7.0	-12.6	1.9
DAILY MIN.	-24.9	-18.8	-17.3	-8.7	-1.8	3.0	5.0	3.3	-0.9	-8.1	-16.7	-22.4	-9.0
DAILY MEAN	-19.8	-13.9	-11.2	-3.2	4.0	9.9	11.5	9.5	4.6	-3.1	-11.6	-17.2	-3.4

PRECIPITATION EXTREMES - 24 hours (10-14 years)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
RAIN	0.0	0.0	0.0	3.8	12.2	19.3	23.0	36.8	15.7	10.7	0.5	2.5	36.8
SNOW	21.3	11.8	14.2	10.7	15.5	0.0	0.0	5.6	13.7	15.2	14.0	16.8	21.3
PRECIP.	21.3	11.8	7.6	10.7	17.8	19.3	23.0	36.8	15.7	15.2	7.9	16.8	36.8

Mean Annual Precipitation		367.7 mm
Mean Annual Lake Evaporation		240 mm
Mean Annual Evapotranspiration		190 mm
Mean Annual Runoff	(A)	128 mm
	(B)	178 mm

Table 10 continued:

B. FARO, Yukon

Established:	1971	
Location :	62°14'N 133°21'W	CLIMATE NORMALS 1951-1980
Elevation :	694 m	

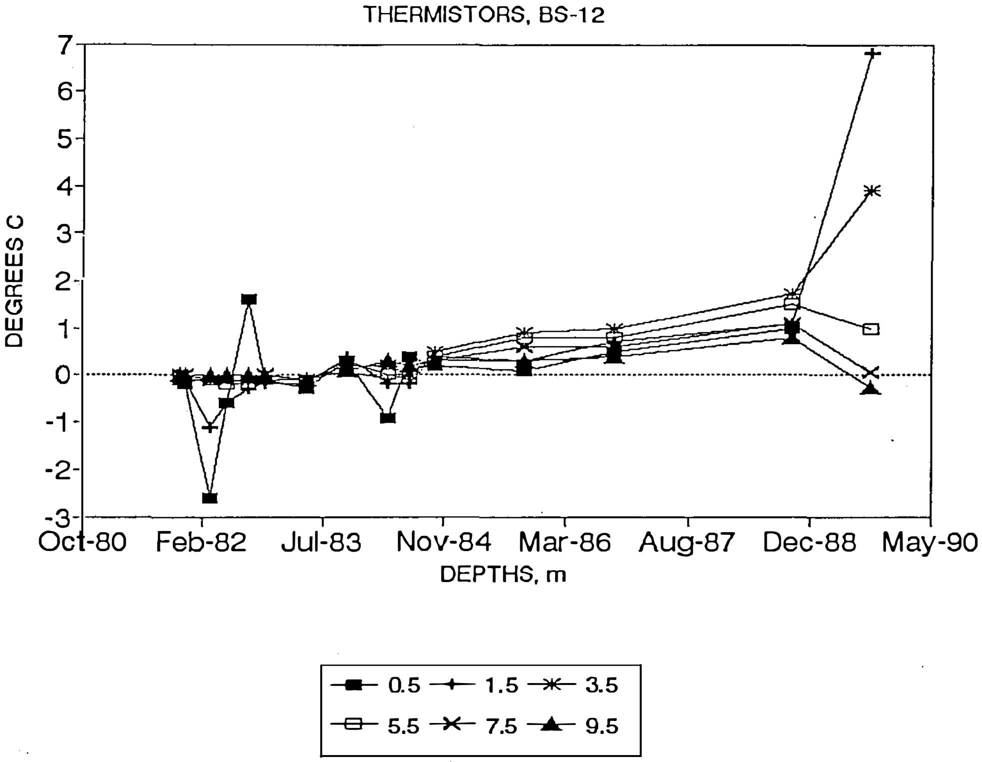
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Precipitation and rain in mm; snow in cm													
RAINFALL	0.0	0.0	0.4	0.6	12.2	23.2	28.7	26.3	22.5	6.0	1.0	0.0	120.9
SNOWFALL	15.5	12.9	26.8	5.9	2.4	0.0	0.0	0.4	4.2	15.7	24.5	17.6	125.9
TOTAL	21.0	14.4	24.6	7.6	17.4	50.4	28.7	26.3	31.1	21.7	27.0	18.6	288.8
ST.DEV.	16.4	8.9	5.1	3.5	13.6	7.3	18.7	18.5	14.0	10.2	6.7	6.2	80.1
Men Temperatures in degree C													
DAILY MAX.	-20.4	-10.7	-3.4	5.5	13.3	18.9	21.2	18.9	12.6	3.5	-10.4	-17.8	2.6
DAILY MIN.	-28.5	-20.9	-16.7	-7.0	0.8	6.1	8.6	5.8	1.5	-4.3	-17.2	-25.6	-8.1
DAILY MEAN	-24.5	-15.8	-10.1	-0.8	7.1	12.5	14.9	12.4	7.1	-0.4	-13.8	-21.7	-2.8

PRECIPITATION EXTREMES - 24 hours (5 - 6 years)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
RAIN	0.0	0.0	0.0	1.8	11.7	16.5	46.7	28.4	12.2	4.8	0.8	0.0	46.7
SNOW	16.3	10.4	12.2	7.4	6.1	0.0	0.0	5.3	10.2	10.9	9.4	6.6	16.3
PRECIP.	16.3	10.4	7.6	7.4	17.8	16.5	46.7	28.4	12.2	10.9	7.9	6.6	46.7

Mean Annual Precipitation		288.8	mm
Mean Annual Lake Evaporation		285	mm
Mean Annual Evapotranspiration		189	mm
Mean Annual Runoff	(A)	4	mm
	(B)	100	mm

Figure 10: Thermistor Readings from Boreholes in Tailings Area



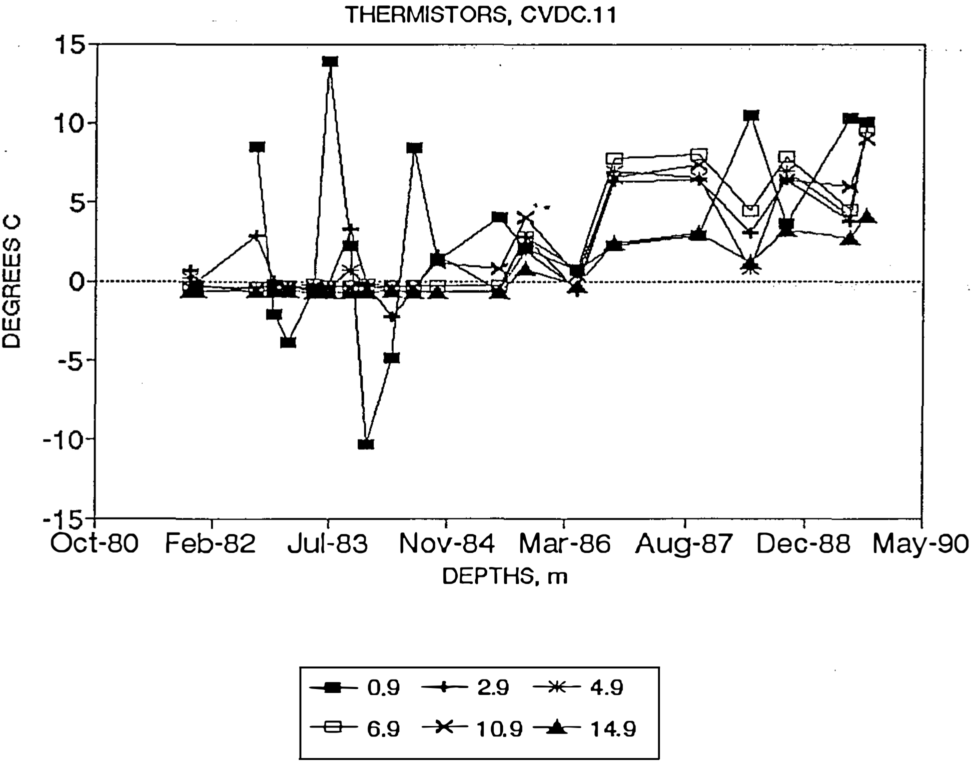


Figure 11: Thermistor Readings at Long Intervals

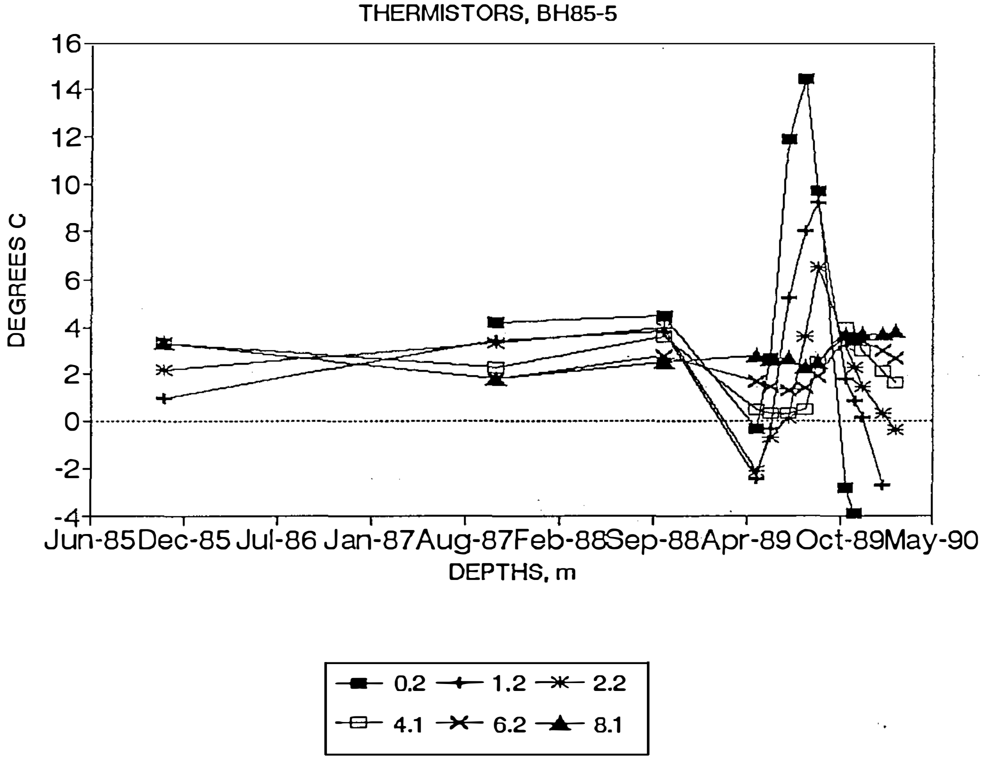
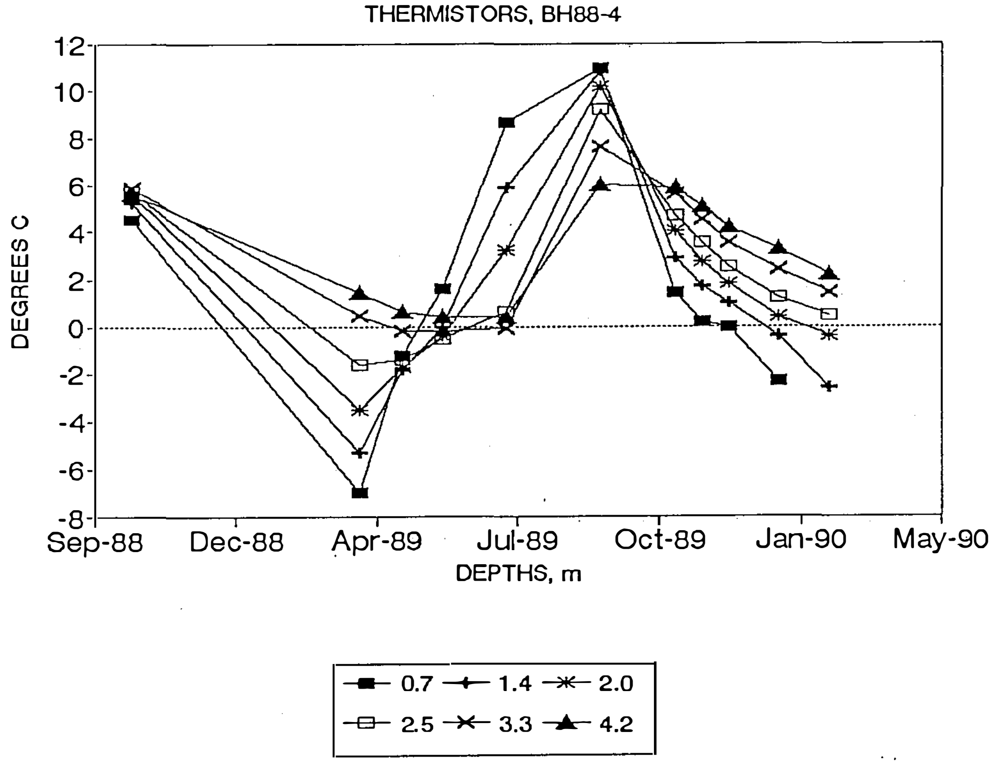
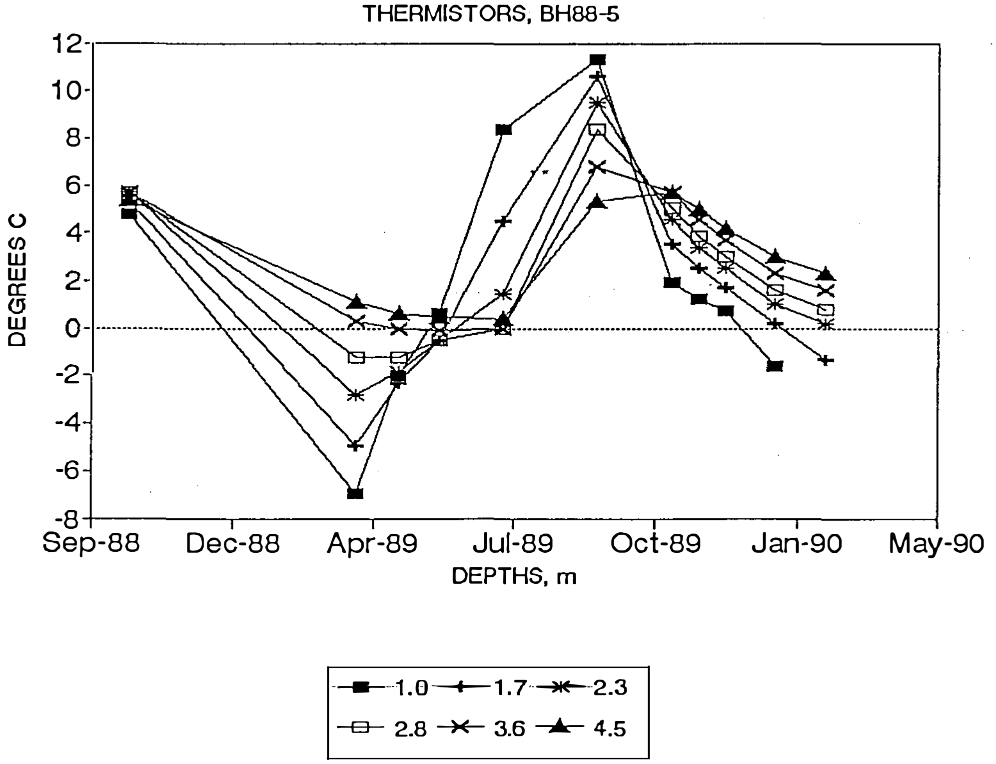


Figure 12: Thermistor Readings at 4 Week Intervals





6.0 MINING VANGORDA-GRUM AND DECOMMISSIONING

The environmental problems of decommissioning the Cyprus Anvil waste rock and tailings should be addressed using the economic resources created by mining the Vangorda Grum deposit. For example, when mining of the Vangorda and Grum deposits gets underway, the old tailings area could receive part or all of the estimated 32 million tonnes of tailings that will result from processing of the Vangorda and Grum ores.

Those tailings are expected to differ from the Faro tailings in several respects. They will be finer (ore ground to 80% $<50\mu m$); they will contain less pyrite and much less pyrrhotite, and they will contain barium sulphate. The finer material will present a larger surface area for sulphide oxidation which will to some extent be counteracted by the lower pyrite and pyrrhotite contents. If the finer material is spread out over the existing tailings, the lowered permeability may reduce the infiltration of water and the transport of oxidation products. As it is likely that the temperature of the tailings is the main factor limiting the rate of acid generation, the new tailings from the Grum Vangorda deposit, with the characteristics described above, could also be deposited into the old Zone I/III pit. Thus the tailings should be deposited while maintaining a constant water cover. The excess water can be reclaimed. During closure of the pit, water from the Faro creek could, in effect, form a lake over the tailings.

Such a lake could be amenable to some Ecological Engineering measures. With appropriate tailings disposal methods, the temperature stratification which is likely to develop in the pit will separate the water leaving the pit from that in contact with the tailings. Further assessment of the temperature stratification expected in the pit will be required if this path is chosen.

Biological Polishing capacity, with cyanobacteria, algae and *Chara*, may be developed for the seeps and for those parts of the Faro tailings cover where water will remain pooled. If permafrost can indeed be induced and promoted in the tailings through the development of a vegetation cover, and contaminant loadings from the waste rock seeps can be polished biologically, both in the pit and in ponded water on the tailings, a reduction in contaminant loadings to Rose Creek can be expected.

In conclusion, the assessment of the background data and a site visit indicated that some natural processes which clean the water are at work in the drainage basin. These coupled with standard Ecological Engineering and Biological Polishing methods should be explored to curtail contaminant release and promote natural contaminant removal.

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