BUCHANS: MINING WASTES AND THE ENVIRONMENT

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BUCHANS : MINING WASTES AND THE ENVIRONMENT

1.0 INTRODUCTION AND OBJECTIVE

To arrive at a realistic solution to the overall reclamation of mining wastes, a site must be viewed in its historic context. Information that has been accumulated over several years can be utilized to determine long term trends in water quality. Happily, such data is available for the Buchans waste management area. An analysis of the characteristics of the mine waste material following several years of deposition will indicate trends of either environmental degradation or recovery.

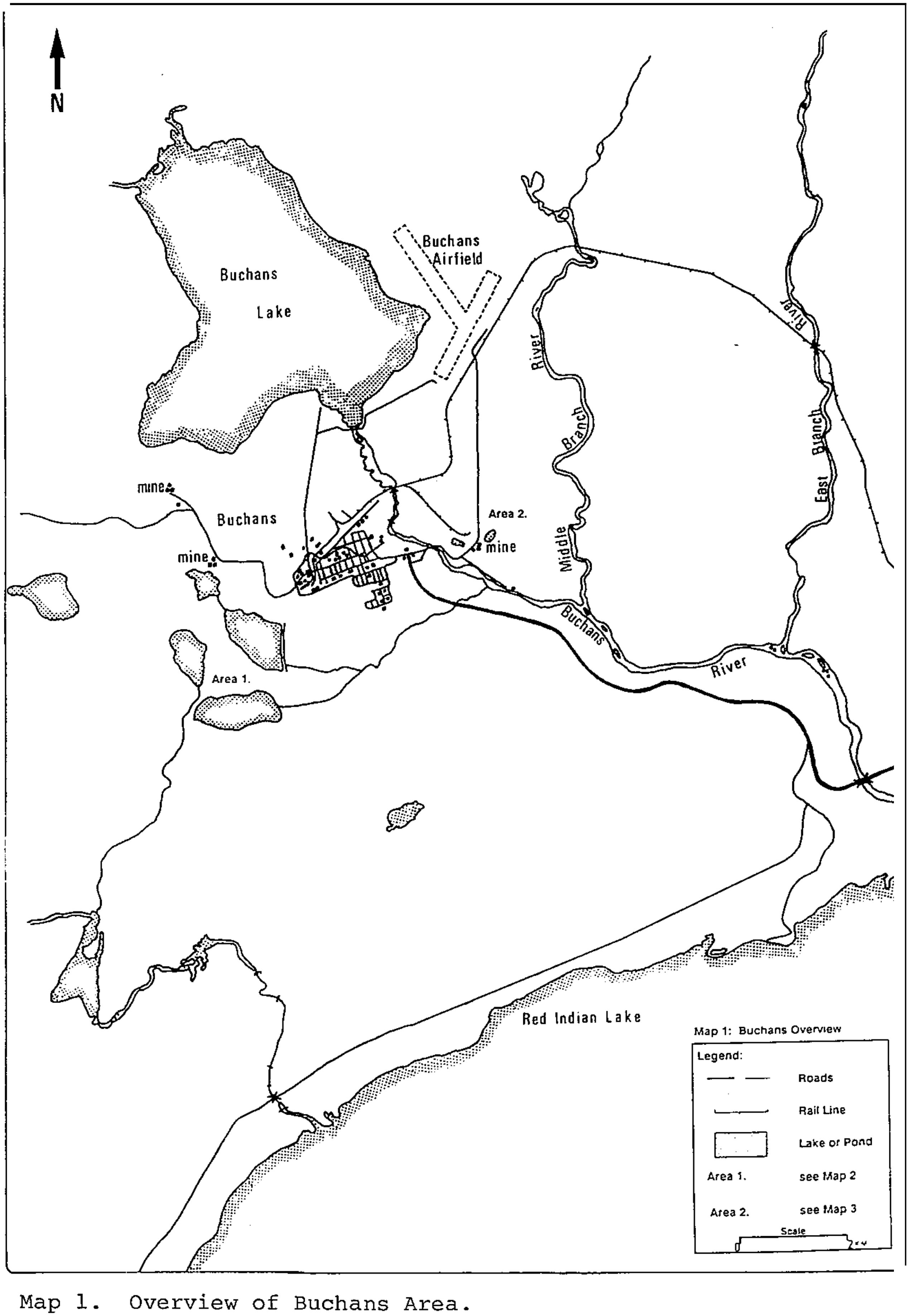
In July, 1988, ASARCO retained Boojum Research Limited to assess the Buchans waste management area which has been dormant since 1984. The objective of this work is to identify, through an intensive field investigation and analysis of historic data, any problems which exist and to suggest an approach for the reclamation and decommissioning of the Buchans waste management area.

Results of the environmental monitoring of the waste streams, carried out by ASARCO, indicate that the concentrations of metals in the water of the pits is high. Therefore, ameliorative measures for the pit effluent should be considered a top priority. The reclamation plan will focus on developing a means of improving the quality of the water leaving the site, prior to its discharge. The socio-economic conditions require that the waste treatment system at Buchans be ultimately maintenance free, i.e. a self-sustaining walk-away solution.

2.0 SITE DESCRIPTION

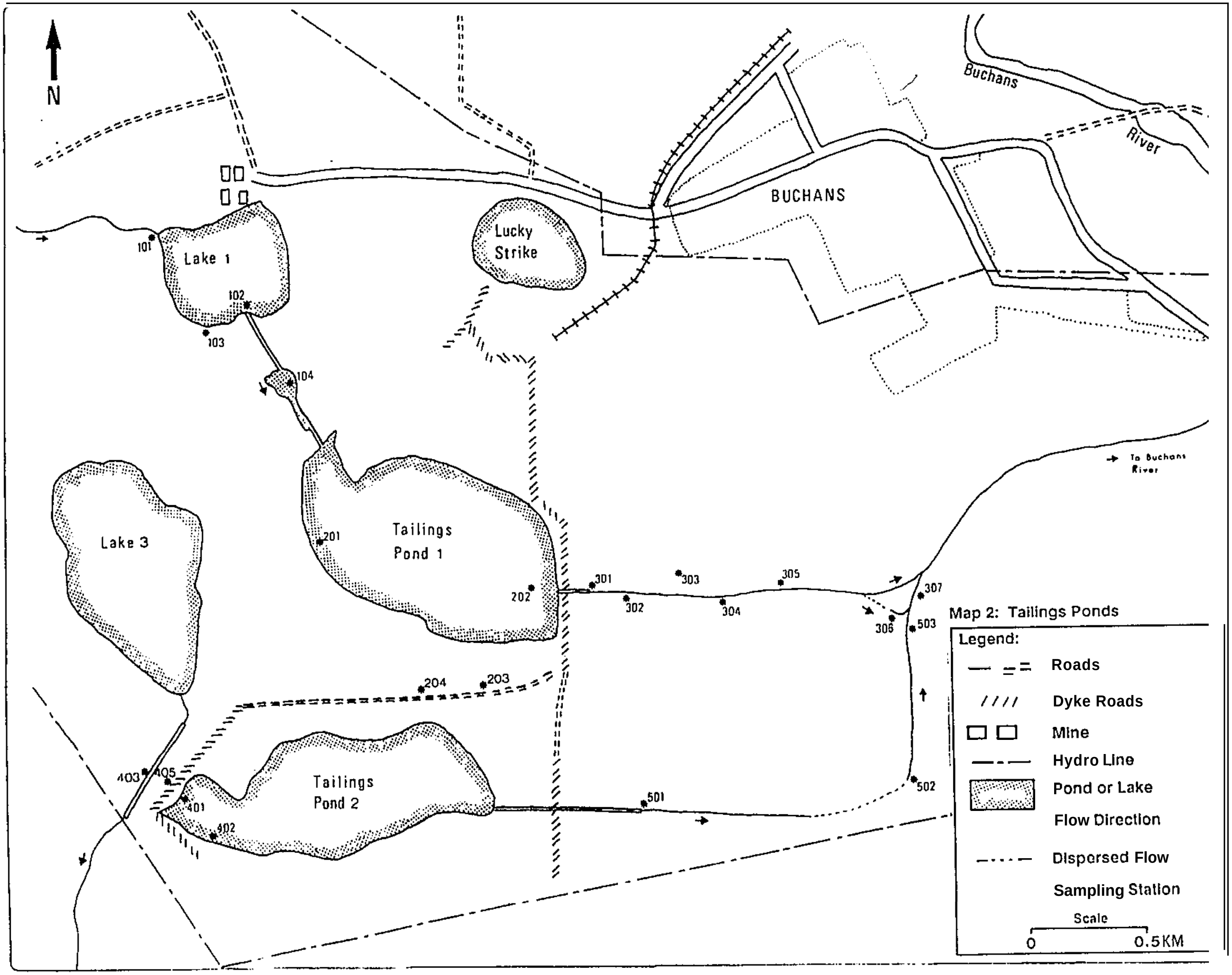
Although a prospect was opened on the shores of Buchans River between 1905 and 1911, production from the Buchans Mines commenced in 1928. Buchans River received the tailings from the mill until 1966, at which time tailings dams were constructed. These tailings dams contained tailings material , first in Lake 2 (Tailings Pond No 1) and later in Lake 4 (Tailings Pond No 2). Lake 1 contains sand slimes from a sand backfill washing operation. Part of lake 4 contains reprocessed tailings after the extraction of barite. It is estimated that at the time of shut down in 1984, there was a total of 2.8 million tons of tailings in the two tailings ponds (Neary, 1988 p.c).

An overview of the area surrounding Buchans is given in Map 1. The tailings and the glory holes are located in the Buchans River drainage basin. The Buchans River, also referred to as Buchans Brook flows into Red Indian Lake. Lake 1 is surrounded by wet meadows, and drains through a channel into Lake 2, also referred to as Tailings Pond 1 (Map 2). A tailings beach merges



Map 1. Overview of Buchans Area.

Map 2. Details of Buchans tailings areas with approximate sampling locations.



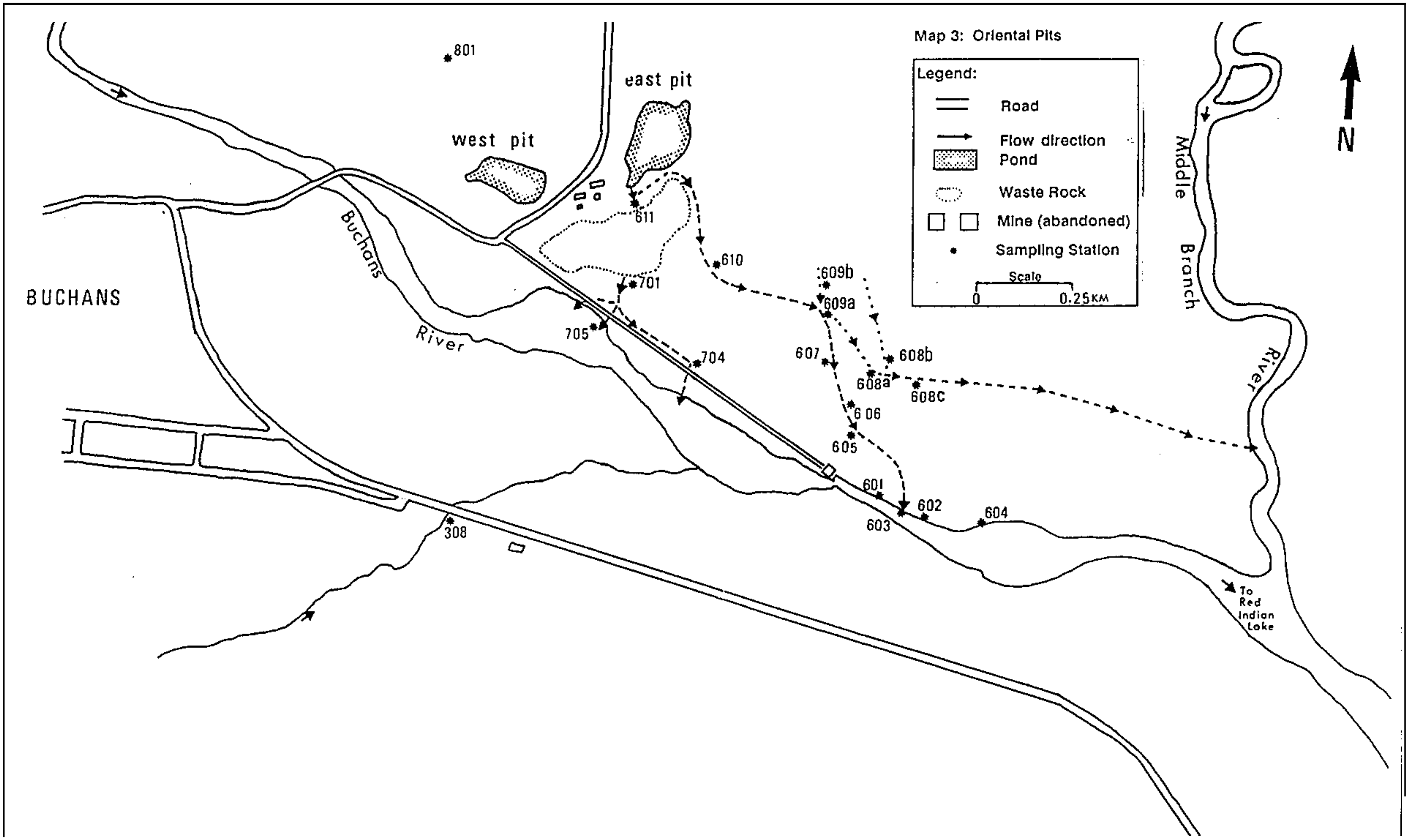
with the tailings pond proper which drains through a decant structure into Simms Brook. The brook flows east, receiving effluent from Tailings Pond 2, then turns northeast, crossing the highway and flowing into the Buchans River.

The Buchans mill was supplied with ore from five mines over the years. Rothermere and MacLean were completely underground, while two other operations, Oriental and Lucky Strike, were mined by a combination of the glory hole system and underground stopes. At the time of shut-down in 1984, all the underground workings were force flooded. The lower pits are at Oriential. The Oriental East Pit, which is the lowest , began to overflow in 1987. At Lucky Strike the glory hole is filling very slowly with present water level about 110 feet below overflow. The run-off from Oriental East now crosses two meadows before entering the Buchans and Middle Branch Rivers (Map 3). Precipitate from the water is being deposited the full length of the first meadow. There is, at present, no surface run-off from the West pit.

3.0 METHODS

3.1 Field methods

Measurement of electrical conductivity for water and saturated materials were recorded using a YSI Model 33 S-C-T Meter with a 10m



Map 3. Details of Oriental Seepage and Pits.

probe. The meter was standardized by dilutions made from a stock solution of 100,000 umhos/cm. Portable pH meter model Corning pH 103 and Orion Research Model S.A. 210 were used, with a combination gel electrode. Readings were taken after calibrating the meter with the probe in standard buffering solutions of pH 4 to 10.

Sediment samples were obtained with an Eckman grab sampler. Water samples were collected either as grab samples from the surface or collected from various depths with a Van Dorn sampler. Vegetation samples were collected and pressed for identification.

Phytoplankton and periphyton samples were collected as grab samples and preserved for identification with Lugols solution. The firm Algatax carried out the identification of the phytoplankton and periphyton, and R. Scribailo of the University of Toronto, Department of Botany, identified the vascular plants.

3.2 Analytical methods

The water samples were filtered through 0.45 um Gelman filters and acidified with concentrated nitric acid. The filtration apparatus was rinsed with tap water between filtrations. After each filtration session, tap water was filtered and kept for analysis. This measure was used to detect potential cross-contamination for each sampling set. The water samples were submitted to a commercial laboratory, Assayers Ontario Limited, for semi-quantitative analysis. Inductively Coupled Plasma Spectrophotometry (ICP) was used to determine the multi-elemental composition of the water. Sulphates were determined colorimetrically, and acidity/alkalinity was determined through titration, followed by a conversion to $CaCO_3$ equivalents.

Solid samples were dried at 60°C in a drying oven until no significant weight change occurred. The samples were then homogenized with a hand mortar and packaged in whirlpacks. Loss on ignition was determined at 1000°C on a 1 g of sample. 1 g was wet oxidized, using nitric acid, followed by perchloric acid. The filtrate was brought to 100 ml for ICP analysis.

4.0 FIELD INVESTIGATION: SITE SELECTION

The field investigation included an extensive sampling program to determine the water characteristics of both tailings ponds and the Oriental glory holes. The water in these two systems is different in character. Surface water flows through the tailings system, whereas ground water and precipitation run-off is collected in the glory holes. In principle, given these differences, the resultant water quality is expected to be different.

A detailed investigation of the tailings ponds and both Oriental pits will reveal the basic interactions of water with tailings and glory holes. These findings can then be applied, in general, to the Buchans site. In the following sections, the findings from the field investigation are summarized for both tailings ponds (Section **4.1)** and for the glory holes (Section **4.2).**

4.1 Tailings ponds

A survey of pH and electrical conductivity was carried out to determine those locations at which chemical changes are taking place in the system. The water samples were then collected on the basis of these changes.

The pH and electrical conductivity values for the tailings system are presented in Table **1.** In Map **2,** the approximate locations of the sampling stations are given. The water which enters Lake 1 has a pH of **6.45** and an electrical conductivity of *220* umhos/cm. The temperature of **15°C** reflects that of surface water. At locations 102 to **104,** lower conductivity values of 30 to **40** umhos/cm, with the same pH value, are reported, indicating that fresh water drainage enters the system from the west. Both stations in Tailings Pond 1 (201 and 202) exhibit pH readings around 6.5 and conductivity of approximately 100 umhos/cm. These values, together with the topography, suggest that the drainage basins of the tailings ponds receive significant volumes of fresh water which determine the characteristics of the effluents.

Table 1. pH, Conductivity and Temperature Readings taken July, 1988

	pH	CONDUCTIVITY (umhos/cm)	TEMPERATURE (C)	COMMENTS
LAKE 1 AND DRAINAGE				
101	6.45	220	15.5	
102	6.23	30	18.0	
103	6.48	40	18.0	
104	6.40	40	18.0	
TAILINGS POND 1				
201	6.54	100	19.0	
202	6.59	100	20.0	
203	6.10	600	13.0	Seepage between
204	6.16	480	14.0	TP1 and TP2
TAILINGS POND 1 DRAINAGE				
301	6.43	90	16.0	
302	6.35	95	15.0	
303	3.20	105	15.0	
304	5.77	95	15.0	
305	5.83	95	14.5	
306	5.21	95	14.5	
307	5.64	125	14.0	
308	6.45	95	14.0	
TAILINGS POND 2				
401	6.05	170	17.0	
402	5.12-5.66	100	15.0	
403	6.56	25	17.0	Between
404	6.18	75	14.0	Lake 3
405	6.53	700	15.0	and TP2
TAILINGS POND 2 DRAINAGE				
501	5.95	180	15.0	
502	5.35	150	14.0	
503	6.23	140	13.5	

The conductivity values in the drainage from Tailings Pond 2 are similar to those in the Tailings Pond 1 system. The values range from 25 to 700 and 30 to 600 umhos/cm, respectively. In the drainage channels through which the water leaves the tailings ponds, the pH and conductivity values do not change.

A pH value of 3.2 was recorded with the same conductivity. This reading was the only low pH reading obtained during the survey, although several locations were measured in unaffected bogs/meadows in the vicinity of the site. These observations suggest that this one low value is likely of an organic nature, probably produced by a pocket of Sphagnum moss. This however, is not representative of the character of the meadows and bogs in the Buchans area.

The bogs are generally of a neutral to slightly acidic nature, frequently referred to as fens. The significant implication therefore, is that the indigenous flora found are not likely to be tolerant to acidification. Acid generation which might occur in the waste material could result in acidification of the effluents and the bogs could accordingly be affected if the conditions in the tailings ponds are altered.

The concentration of those elements which were above the detection limits, i.e. values greater than <0.001 mg/l for most elements, ate summarized in Table 2, in the order of the flow path through the tailings drainage basin (Map 2).

Table 2. Water analysis data of inflow. tailings system and drainage channels towards Buchans River
Data collected: July 16, 1988

	INFLOW & TAILINGS SYSTEM				DRAINAGE TO BUCHANS RIVW				
STATION NO.	101	102	201	202	301	305	306	501	503
Field:									
Temp	15.5	18.0	19.0	20.0	16	14.5	14.5	15	13.5
pH	6.45	6.23	6.54	6.59	6.43	5.83	5.21	5.95	6.23
Cond	220	30	100	100	90	95	95	180	140
Lab:									
pH	4.80	5.57	4.91	4.97	4.95	3.30	4.96	6.17	6.14
ELEMENTS (mg/L)									
Al	0.1	0.1	0.2	0.06	0.1	0.6	0.2	0.1	0.2
Ba	0.02	1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Ca	9.9	5.8	19	18	18	9	20	33	26
CU	(0.01	0.03	0.01	0.03	0.01	0.08	0.02	0.03	0.05
Fe	0.3	0.1	0.1	0.04	0.1	0.2	0.1	0.05	0.02
Mg	0.8	0.5	0.9	0.8	0.9	1.6	1	1.9	1.7
Mn	0.08	0.02	0.2	0.1	0.2	1	0.2	0.3	0.1
P	<0.01	1.7	0.6	(0.01	0.3	0.6	0.6	1.8	1.8
Pb	(0.01	0.07	0.1	0.07	0.1	0.1	0.1	0.1	0.09
S	1.7	1.8	12	10	11	16	11	26	20
Zn	0.01	0.1	1.8	1.7	1.9	4.2	1.7	4.1	2.8
Acidity as CaCO3	10	49	12	36	55	36	19	62	97

Stations 301, 305, 306, 307, 501, 502 and 503 represent the main channel of flow from the tailings basin prior to the final monitoring point at the highway (Simms Brook Stn. 308, Map 3). In the tailings ponds, only the concentrations of calcium, sulphur, zinc and copper increase slightly. The range of the concentrations are within those reported for natural backgrounds, with the exception of Molybdenum which is marginally higher (Table 3). The concentrations of the natural range, or background concentrations, reported in the literature are higher than those recommended by Environment Canada for the protection of aquatic life. The background concentration range for Zn is reported as 0.001 to 1.17 mg/l in natural waters, whereas 0.03 mg/l is the recommended level for the protection of aquatic life.

Table 3. Water characteristics of inflow into tailings basin and Control Bog compared to Rinse Waters

STATION	101	801	RINSE WATER	E.P.S. ref Guideline	Natural Range
ELEMENTS (mg/L)					
Ag	(0.01	<0.01	(0.01	0.0001 *	<0.04 **
Al	0.1	0.1	0.2	0.1 ****	<0.38 ****
AS	<0.01	0.02	0.01	0.05 *	0.05 ***
Ba	0.02	0.1	0.16		0.005-0.1 *****
C	449	1212	1202		
Ca	9.9	5.1	1.9		1-100 *****
Cd	(0.01	0.02	0.02	0.0002 *	(0.01 ***
cu	(0.01	0.04	0.1	0.002 *	0.001-0.068 ****
Fe	0.3	0.1	0.09		0.05-0.1 *****
Hg	<0.1	<0.1	<0.1	0.0001 *	<0.00001 ****
Mg	0.8	0.9	0.4		0.5-20 *****
Mn	0.08	0.03	0.01		0.001-0.08 *****
Mo	(0.01	0.06	0.02		(0.005 ****
Na	1	1.5	1.13		2-100 *****
Ni	0.01	(0.01	0.02	0.025 *	<0.1 **
P	(0.01	1.4	0.9	***	0.005-0.5 *****
Pb	<0.01	0.07	0.07	0.005 *	<0.1 **
S	1.7	4.3	1.13		2-150 *****
U	<0.1	<0.1	<0.1		
Zn	0.01	0.6	0.2	0.05 *	0.001-1.17 ****
Acidity as CaCO3	10	36	65		

Source : * Stewart W. Reeder.
**Kalin, 1985
*** CREM
**** Kalin and Wall 1987
***** Allen et al. 1974

The concentrations in the tailings effluent are not as low as background. Metal levels in waste water streams are expected to be elevated. The important environmental considerations however, are whether these metal levels being discharged from the waste management area are affecting the water quality of the receiving water and thus endangering aquatic life. This determination may be made by evaluating the historic monitoring data of the two elements of concern, namely, Zn and Cu. The concentrations of Zn and Cu in Tailings Ponds 1 and 2, Simms Brook and Buchans River, are presented in Figures la and 1b.

The average annual concentrations of zinc in the Buchans River has shown a very gradual reduction since 1968 while the concentration of copper has remained about the same. The effluents of the tailings therefore, although higher in concentrations of Cu and Zn, have not contributed to an increase in metals in the receiving water, i.e. the Buchans River. Monitoring data between 1968 and 1987 has shown no significant change for copper and a decreasing trend for zinc. The means and standard deviations of 20 years' monitoring in the Buchans River are 0.02 mg/l ± 0.007 for copper, and 0.4 ± 0.09 mg/l for zinc. These are small standard deviations to be associated with a river which has received tailings and tailings effluents for a long time. Although Cu and Zn conc. lie in the upper range of concentrations encountered in natural

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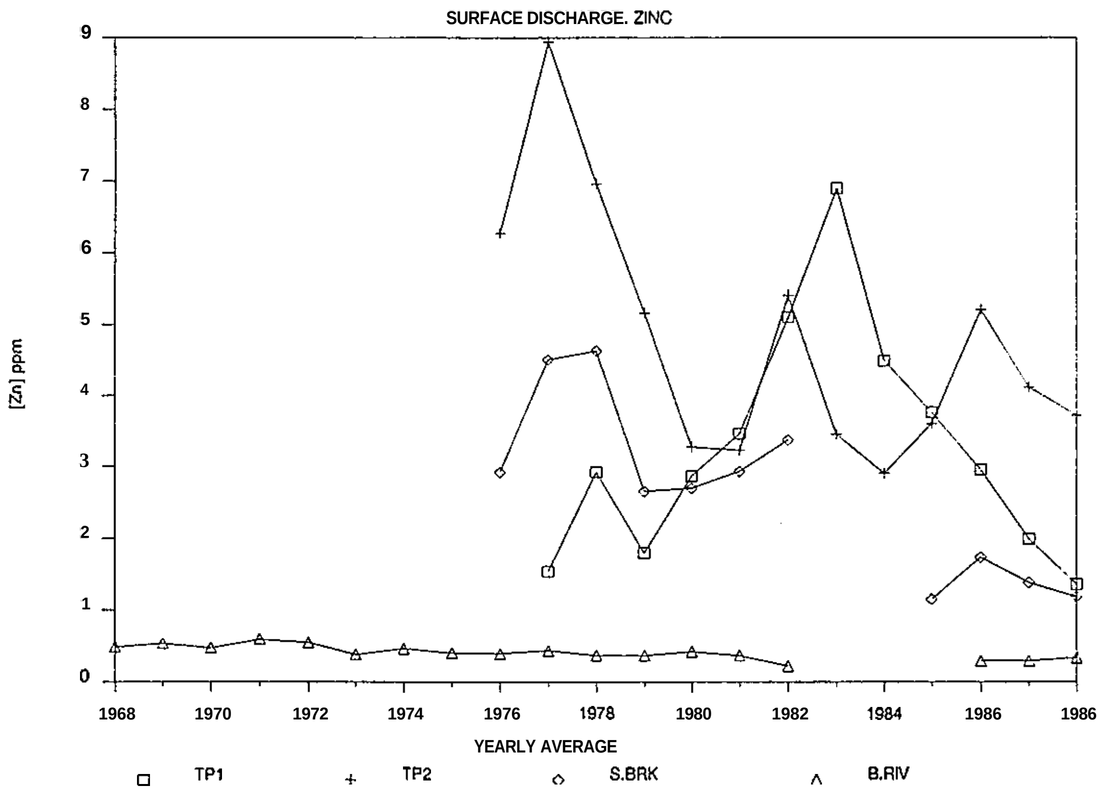

Figure la. Yearlyaverages of Zn concentrations for Tailings Ponds 1 and 2, Simms Brook and Buchans River from 1968 to 1988

ASARCO - BUCHANS UNIT, 1968-1988

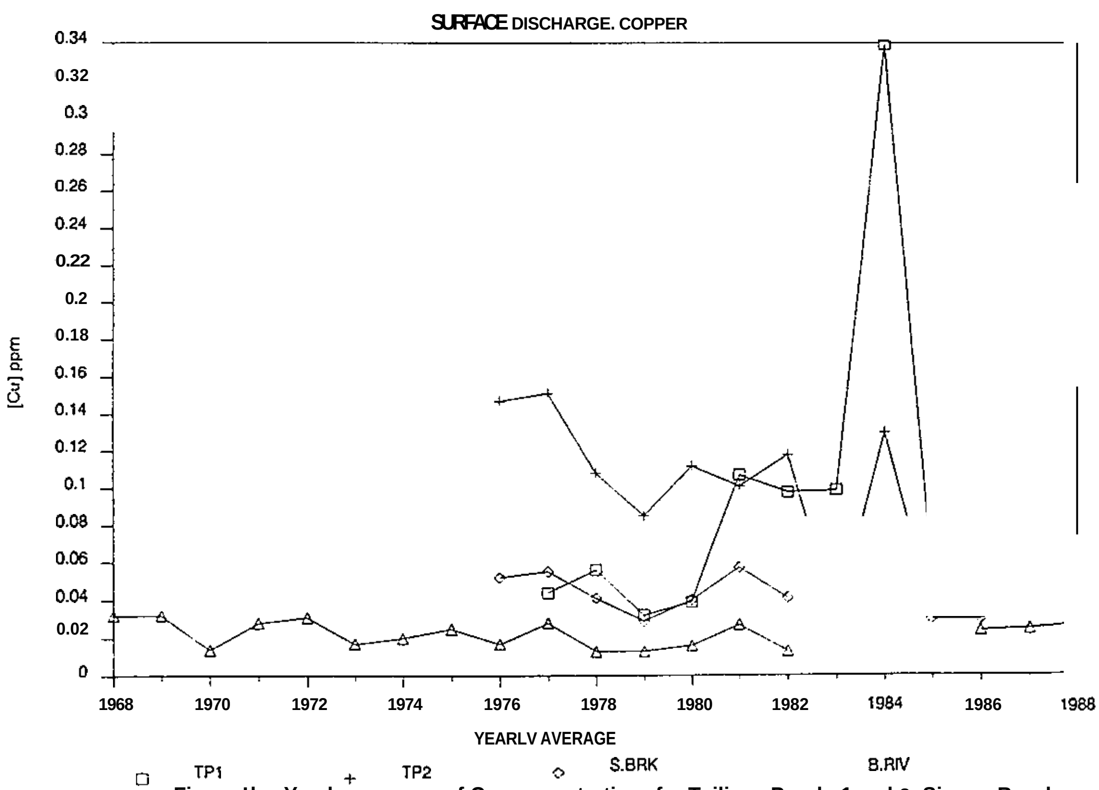

Figure lh. Yearly averages of Cu concentrations for Tailings Ponds 1 and 2, Simms Brook and Buchans River from 1968 to 1988 waters, this is expected as the area is mineralized (Table 3). It is therefore reasonable to suggest that these concentration ranges be considered natural background for this area.

Potential changes in the tailings systems which would affect the long term water quality of the tailings effluents should be evaluated. The behaviour of the tailings effluents, based on annual average concentrations, indicates the following trends:

- the annual average Zn concentration in Tailings Pond 1 increased steadily from 1.5 mg/l to **7** mg/l between **1977** and **1983**, following which a steady decline to 2 mg/l is evident by **1988** (Figure la)

- for copper, the trend is somewhat similar, in that an increase in concentrations was noted in **1977** and **1983**, particularly in Tailings Pond 2, which was followed by a steady decline to the present concentration range. The increases of the copper concentrations were less drastic than those for Zn (Figure lb). These variations in metal concentrations are most likely reflective of activities during mining operations. However, the important observation for the long term is that of the more recent trend of steadily decreasing zinc concentrations and the consistency of the copper concentrations.

As the concentration of zinc decreased in the tailings effluents, a similar decrease was noted in the concentration in Simms Brook after 1982. The concentration in Simms Brook is consistently lower than the tailings pond effluents. The drainage basin through which the water leaves the tailings system appears to provide sufficient dilution resulting in lower annual concentrations in Simms Brook and the Buchans River. A general view of the area of the drainage basin is given in Plate 1.

PLATE 1: General view of drainage basin of the tailings

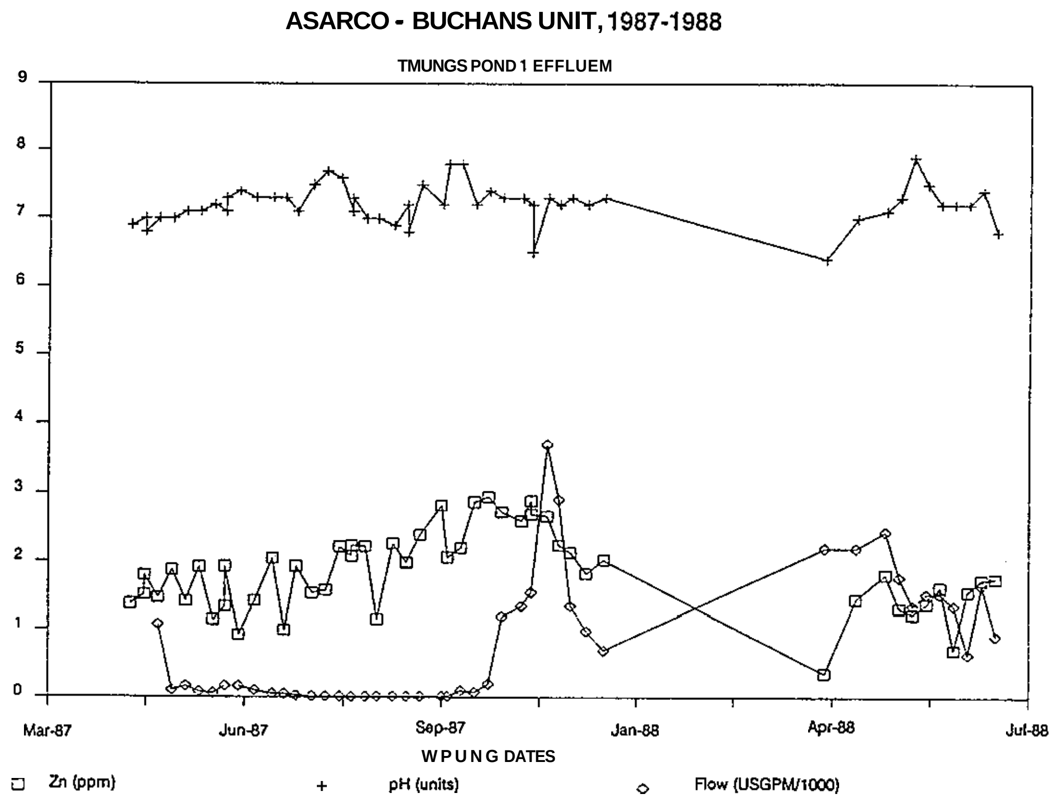

Figure 2a. Seasonal variations of Zn, pH and Flow for Tailings Pond 1 Effluent

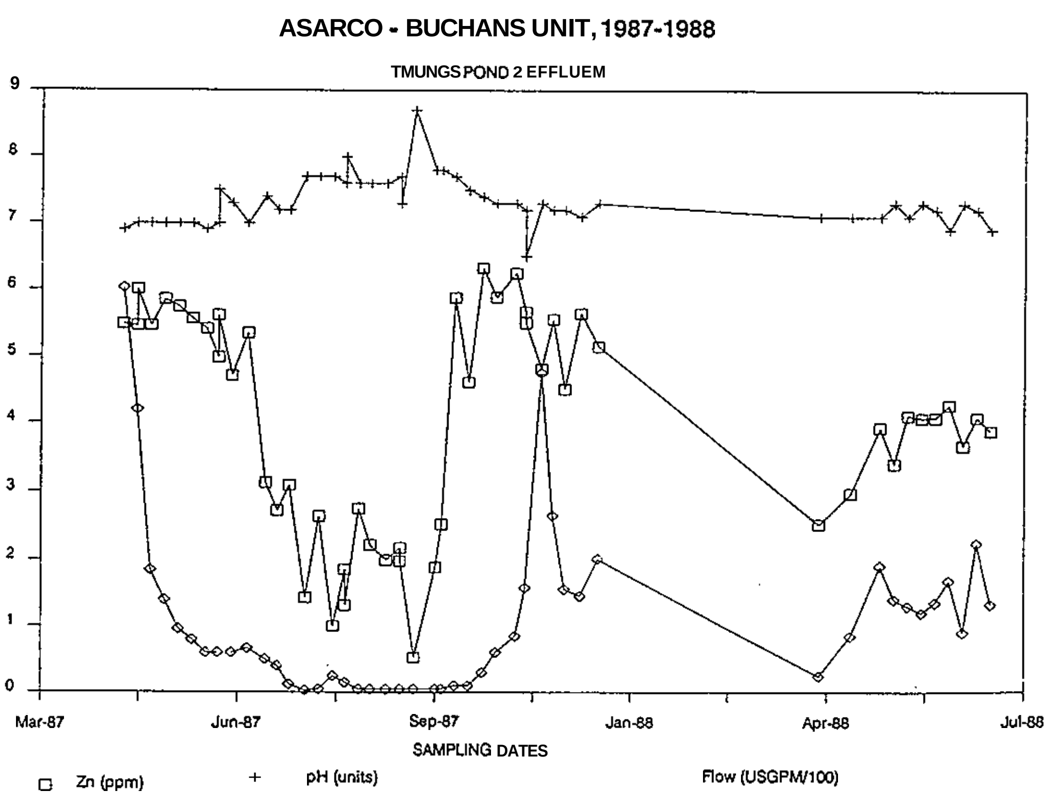

Figure 2b. Seasonal variations of Zn, pH and Flow for Tailings Pond 2 Effluent

and 2b are relatively steady at around 7.

A correlation of the Zn concentration with pH for the two ponds reveals some interesting information (Figures 3a and 3b). No linear relationship is evident between these two variables for Tailings Pond 1. However, a marked trend is noted for Tailings Pond 2, in that higher Zn concentrations are associated with lower pH values between 6.8 and 7.3. Although the difference in pH values between the two ponds is not large, it is however sufficient to affect the hydrolysis of Zn.

Further, the Zn concentrations may be a result of the differences in characteristics of the water flowing through the two tailings ponds. Water which would be representative of the inflow for Tailings Pond 1 was collected at Station 101 where it enters Lake 1. The type of water entering Tailings Pond 2 is characteristic of water from meadows which are unaffected by mining.

In Table 3, the elemental concentrations of the water are presented, as well as the concentration ranges for the protection of aquatic life and the natural concentration ranges summarized from the literature. Sample 801 was collected from a "control" bog north of the Oriental West pit. In addition, in order to provide

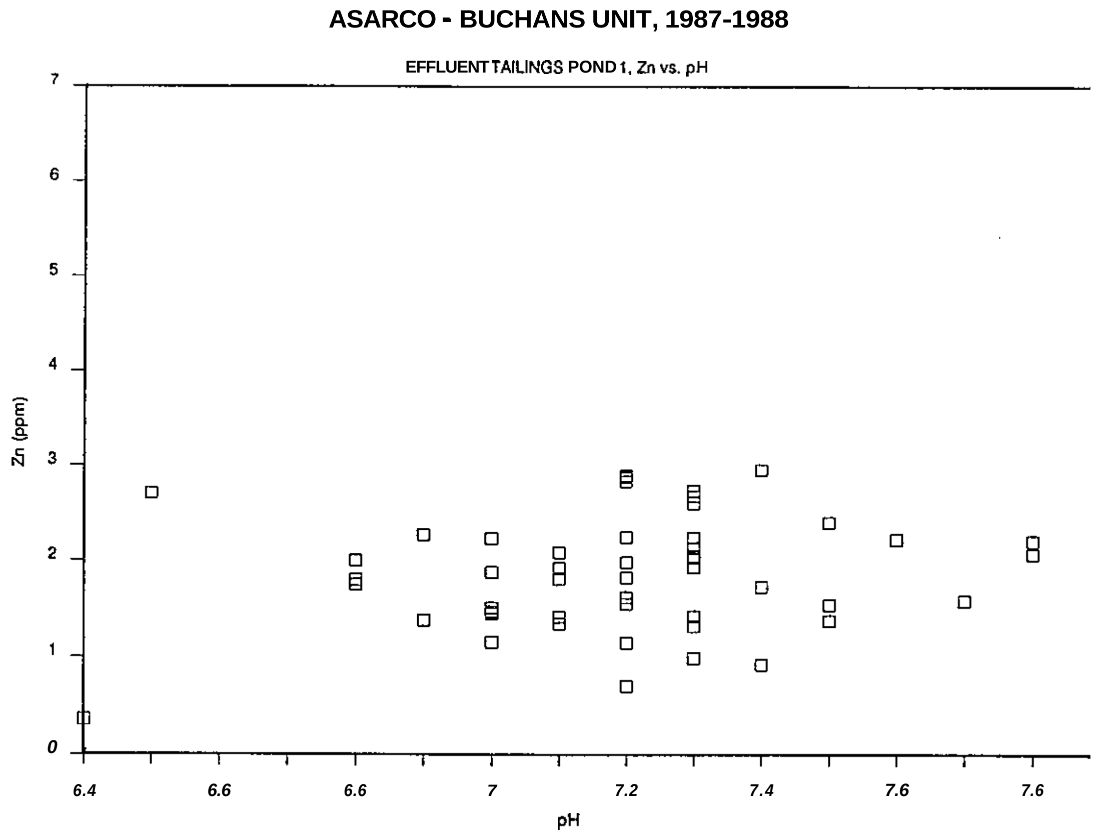

Figure 38. Correlation between Zn and pH for Tailings Pond 1 Effluent

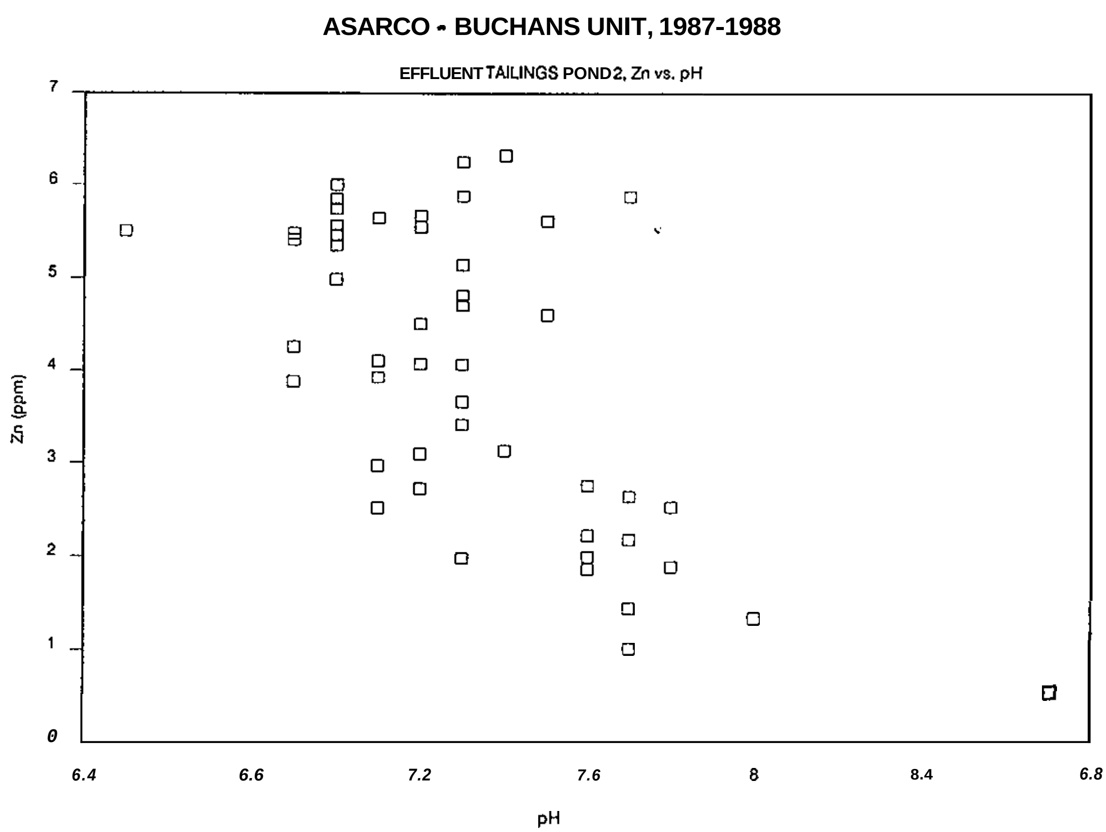

Figure 3b. Correlation between Zn and pH for Tailings Pond 2 Effluent

a larger data set, the concentrations in the water which was used for quality control of the filtration apparatus has been considered to be background water.

The elemental concentrations presented in Table 3 lead to three main observations. Firstly, the samples were not cross-contaminated through filtration, as all elements in the rinse water are present in similar concentration ranges to those found in uncontaminated bog water (801). Secondly, the elements are all present in concentration ranges expected for natural, i.e. unaffected water. Thirdly, the characteristics of the waters entering the tailings pond are similar. The zinc concentrations are between 0.01 mg/l and 0.6 mg/l, and most metals are below the detection limit of 0.01 mg/l, with the exception of Fe, Mg, Mn and Ni. It is interesting to note that the acidities in these background waters range between 10 and 74 $CaCo_3$ mg/l. This range is similar to the acidity determined for the tailings system (Table 2), between 12 and 97 $CaCO_3$ mg/l. Therefore, although the acidity could be expected to increase as a result of the water's contact with the tailings, the results obtained do not substantiate such increase. Although the background water does have natural acidity, upon contact with the tailings, no further increase in acidity is observed.

It is likely that the relationship between the Zn concentrations and the flows which has been evident in Tailings Pond 2, result from the retention time of the water in the ponds and the volumes of water passing through the system.

For the close-out scenario, consideration must be given to the fact that the Buchans gangue minerals are reported as 23% barite, 32% silicates, 4% calcite, and 4.1% pyrite (Hart, 1973). Such a mineral composition suggests that tailings and waste rock can be expected to be acid generating. An acid base balance, carried out by ASARCO on the tailings and waste rock material, indicated that all material tested was deficient in neutralization capacity, i.e. could generate acid.

Acid generation is generally believed to be a process which is initially mediated by the weathering of pyrite. The resulting acidic conditions in the waste material facilitate an environment which allows microbial acid generation. As the pH drops further below 3.5, ferric iron acts as a further oxidant in the system. Considering that this sequence of events lead to acid generation, it is essential that measures are taken to ensure that the initial oxidation of the tailings does not occur.

At present, significant oxidation of the tailings does not appear to be taking place, due to the flow conditions in the tailings drainage basins and their extensive water cover. Samples of the vegetation which has started to colonize the sands in Lake 1 were collected for identification as possible indicators of ecosystem trends (Plate 2). The dominant macrophytes are Potamogeton natans (Pond weed), Equisetum hymenale var. clatum (horsetail), and sedges and rushes: Eriophorum viridi - carinatum, Juncus perlocarpus, Scirpus atrovirens, Carex aquatilis, Carex haydenii. These species are typical colonizers of denuded water bodies and are not known to be specific to acidic conditions. They are generally hardy species and can thus be expected to further colonize the water.

PLATE 2: View of vegetation on the sands of Lake 1

The extensive meadow of horsetail, Equisetum, which has essentially covered the channel between Lake 1 and Tailings Pond 1, indicates that natural colonization of the water-covered tailings area is progressing. Furthermore, it was noted that although the -bottom of the tailings pond is extremely hard packed, resembling a smooth, clay-like surface, aquatic moss (unidentified) appears to be colonizing the tailings bottom. Measures to facilitate organic matter accumulation on the bottom of the tailings ponds might merit consideration. Such measures might, together with the flow regime, further ensure prevention of acid generation in any significant form in the long term.

4.2 Oriental Pit and its seepages

In Table 4, all pits are described in terms of their dimensions, flows and elevations. The pits which are of immediate concern are the Oriental East and West pits, since the Oriental East pit has, since 1986, been discharging waters at an average of 160 USgpm to the Buchans River. The important difference between the pits is their difference in pH. The Oriental East pit is acidic, showing an average pH of 5.8. The Oriental West pit and Lucky Strike are also acidic, with pH's of 4.6 and 6.6, respectively. Lucky Strike, as reflected in the pH values, has been limed.

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Table 4. Descriptions of Open Pits

	Lucky Glory	Strike Hole	Oriental West Pit		Oriental East Pit	
	Jul-88	Dec-86	Jul-88	Dec-86	Jul-88	Dec-86
Elevations						
Bottom	729'	--	726'	--	678'	--
At Overflow	928'	--	775'	--	759'	--
Current	814'	--	759.6'	--	759.2'	--
Depth						
Full	199'	199'	49'	49'	81'	78'
Current	85'	81'	34'	30'	81'	78'
Volume (USG)						
Full (X 10 E6)	340	294	17.5	17.5	55	55
Current (X 10 E6)	35	38.5	7	4.5	50	55
Fond area	150,000 sq ft		50,000 sq ft		210,000 sq ft	
Drainage Basin Estimate sqft X10E6			1.8 to 0.4		0.5 to 0.335	
Mean pH.	6.6		4.6		5.8	

The difference in pH between Oriental East and West suggests that the conditions in the pits differ from each other. One of the factors which may account for this difference may be the rate at which the water is moving through the pits.

If different retention times of the water sources resulst in the pH difference, then the water system feeding the pits may be different. Although the catchment area for the Oriental West pit is difficult to estimate, as indicated by the different estimates given in Table 4, the catchment for both pits might be similar in range. The source of the water leaving the Oriental East pit, therefore, is unclear. Based on a summary of the Buchans weather data, the mean annual precipitation is 1200 mm; mean annual lake evaporation is about 465 mm; evapo-transpiration is about 370 mm, and, finally, the annual run-off is about 900 mm.

A rough estimate of the volume of water falling on the Oriental East pit would indicate that it is approximately 23 times less than the volume of the water leaving the pit. Based on 735 mm net precipitation (mean annual precipitation minus lake evaporation) the net volume of precipitation for the Oriental East pit is estimated at 14,000 m^3 per annum. As the volume of water leaving the pit is 318,000 m^3 per annum, this shows a differential factor of 23. This means that water has to enter the pit from some source. The flow out of the Oriental East pit is, on average, about 6.6 l/s between April 1987 and December, 1987. The pit started to overflow in 1987. The elevations measured in 1988 and presented in Table 4, are 759.6 ft. for Oriental West, and 759.2 ft. for the East pit. This suggests that the water flows from the West to the East pit.

Considering retention time in the pits, if it is assumed that the West pit flows into the East, about 217,400 U.S. gallons of water each day goes to the West pit, providing the source of the flow out of the East pit. If this is in fact the case, both pits should have the same water characteristics, which is not the case. Despite the preliminary nature of these considerations, it is suggested that the source of water to the Oriental East pit must be determined.

An investigation of both pits was carried out to determine stratification of the water by pH, electrical conductivity and temperature. If stratification occurs in the pits, it might be useful to pinpoint at least the direction of the water source to the pit. In Table 5a, the data are given for three profiles in the Oriental West pit. This pit appears to be uniform up to 5 to 6 m depths, as no major changes from the top to the bottom are noted in pH and conductivity. Below this depth however, 1.5 to 2 m from the bottom of the pit, the water is somewhat more acid, with an increase in electrical conductivity and a lower temperature. The Oriental West pit is, therefore, nearly completely mixed, with a

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Table 5a. ORIENTAL WEST PIT PROFILES

pH, CONDUCTIVITY (umhos/cm) AND TEMPERATURE (C)

	pH	COND	TEMP	COMMENTS
ORIENTAL WEST PIT				JULY 15/88
MIDDLE PROFILE				
0 M	2.73	800	18.0	
1 M	3.20	800	17.0	
2 M	3.21	800	18.0	
3 M	3.20	800	18.0	
4 M	3.20	800	18.0	
5 M	2.77	800	17.5	
6 M	2.63	900	15.5	
6.5 M	2.93	900	14.5	
WEST SIDE NEAR RAISE				JULY 15/88
AT SULPHIDE SHOWING				
0 M	3.10	800	17.5	
1 M	3.48	880	17.0	
2 M	3.31	780	16.5	
3 M	3.45	780	17.0	
4 M	3.33	780	17.0	
5 M	3.46	790	16.0	
6 M	3.40	960	14.5	
7 M	3.36	950	13.5	
7.5 M	3.33	1010	13.0	
EAST SIDE PROFILE				JULY 16/88
0 M	3.28	750	17.5	
1 M	3.34	800	17.0	
2 M	3.35	800	18.0	
3 M	3.36	800	18.0	
4 M	3.38	800	18.0	
4.5 M	3.37	800	17.0	

very acidic bottom. In fact, it appears from these profiles that acid generation in the bottom of the pit has progressed significantly, and measures should be taken to alter this condition. This is especially important since this pit has an exposed face, with a sulphide showing (Plate 3).

PLATE 3: Oriental West Pit showing the exposed sulphide.

In Table 5b, the data for the Oriental East Pit are presented. Two profiles have been obtained in this deeper pit, which has no exposed sulphide showing. These two profiles are somewhat more complex, in that only subtle changes in pH are noted. The changes in conductivity and temperature with depth are of interest.

In Figures 4a and 4b, the same data are presented for the northeast section, closer to the overflow of the pit, and the other, at the southwest section of the pit. In both profiles, the surface water has the same temperature of about 18 to 19°C to a depth of 3 meters. The temperature drops to about 9°C at a depth of 6 m, below which depth only minor changes occur in temperature . The conductivity decreases rapidly to about 3 meters in the northeast section, and more gradually to a depth of 7 m in the southwest section. From this depth downward, an increase in conductivity is noted, to a final high value of about 2000 umhos/cm at the bottom.

From the conductivity profile, several observations can be made. The input from precipitation into the pit does not, as might be expected if this contribution was a major source of water, produce a decrease in electrical conductivity at the surface. On the other hand, the decreasing electrical conductivity between 3 and 7 m depths, could be due to input from the Oriental West pit. An associated pH depression however, is not evident. It therefore

Table 5b. ORIENTAL EAST PIT PROFILES
pH, CONDUCTIVITY (umhos/cm) AND TEMPERATURE (C)

	pH	COND	TEMP	COMMENTS
ORIENTAL EAST PIT 5				
O M	6.56	1900	18.0	
1 M	6.76	1700	18.5	
2 M	6.98	1600	19.0	
3 M	6.98	1300	16.0	
4 M	6.25	1650	12.5	
5 M	6.19	1650	12.0	
6 M	6.17	1475	9.0	
7 M	5.81	1600	9.5	
8 M	5.97	1600	10.0	
9 M	6.07	1650	10.0	
10 M	6.14	1600	9.3	
11 M	6.05	1700	10.0	
12 M	6.05	1775	10.0	
13 M	6.05	1800	10.0	
14 M	6.03	1950	10.0	
15 M	6.01	2025	11.0	
16 M	6.00	2025	10.5	
17 M	6.31	2075	11.0	
18 M	5.86	2025	11.0	
19 M	5.98	2075	10.0	
ORIENTAL EAST PIT 6				
O M	6.93	1890	19.0	
1 M	7.00	1850	18.9	
2 M	6.89	1900	18.1	
3 M	6.65	1740	14.8	
4 M	6.30	1650	12.3	
5 M	6.10	1580	9.9	
6 M	6.36	1530	9.5	
7 M	5.70	1590	10.5	
8 M	5.92	1580	9.2	
9 M	5.95	1590	9.2	
10 M	5.99	1610	9.2	
11 M	6.05	1680	10.2	
12 M	6.03	1780	10.3	
13 M	6.11	1810	10.7	
14 M	6.05	1980	10.8	
15 M	6.07	2030	11.2	

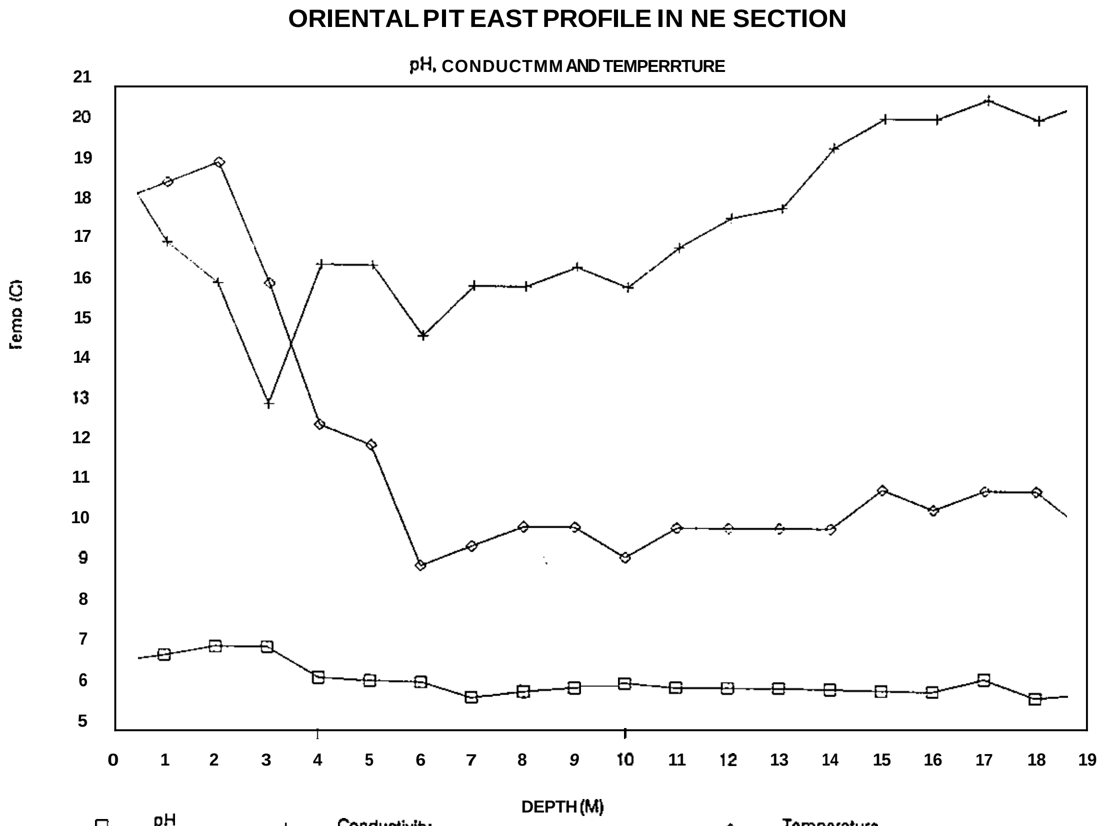

Figure 4a. pH, Conductivity and Temperature along depth profile of Oriental East Pit NorthEast Section

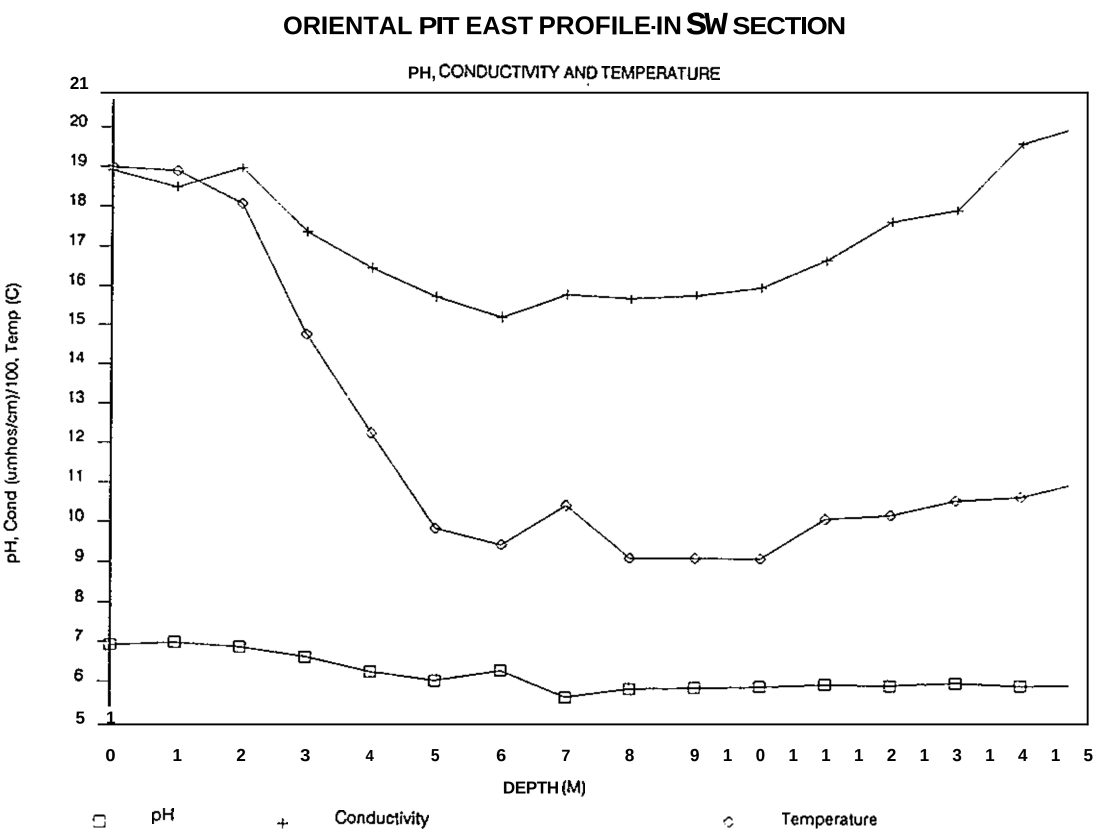

Figure 4b. pH, Conductivity and Temperature along depth profile of Oriental East Pit SouthWest Section

appears, based on the profiles, that water might be entering the pit below 3 m.

An examination of the variations in elemental composition of the waters in the pits at various depths would further assist the determination of the nature of the water or the sources to the pit.

In Table 6, the concentrations of the major elements are presented. The water in the two pits is different for all elements reported, with the exception of Zn and Phosphorus. The higher concentrations of Ca, Mg and Mn in the East pit, compared to the West pit, together with the higher concentrations of S, are indicative of an existing neutralization system. These elements are likely supplied by incoming water. The concentrations of these elements are considerably lower in the acidic West pit, together with a lower pH. The less acidic conditions in the East pit could be explained by a supply of hydroxyl ions derived from Ca, Mg and Mn. It is important to note that the waters of both pits display about the same range of acidities.

Table 6. Water Analysis of ORIENTAL PITS
Samples collected July 16, 1988

	EAST PIT (SLIGHTLY ACID)			WEST PIT (ACID)			
	1.25 M	6 M	19 M	Middle Surface	West Surface	Middle Bottom	West Bottom
Lab:							
pH	5.94	5.36	5.59	3.17	3.22	3.1	3.09
ELEMENTS (mg/L)							
Al	0.3	0.2	0.3	3.9	3.8	4.7	4.9
Ba	0.03	0.03	0.02	0.03	0.03	0.03	0.02
Ca	382	409	509	126	122	155	163
cu	0.04	0.06	0.04	1.8	1.8	2.3	2.3
Fe	0.08	2.4	58	1.4	1.3	2.7	3.6
Mg	41	41	52	13	12	16	17
Mn	9.9	9.8	13.3	2.7	2.6	3.2	3.3
P	1.5	0.3	1.6	1.9	1.7	1.7	0.3
Pb	0.1	0.09	0.1	1.6	0.15	1.8	1.7
S	398	391	508	176	170	220	230
SO4 as S	220	330	390	102	102	114	102
Zn	47	50	61	54	53	70	75
Acidity as CaCO3	128	184	445	120	173	189	220

The comparison of the waters of the East and West pits suggest that a water supply, other than by way of precipitation, is present in the East pit. As expected, acid is being generated in the bottom of both pits, and this is particularly evident in the East pit, where high acidity, high sulphate and high iron concentrations are present.

The determination of concentrations of total sulphur and S, as sulphate, are of interest. If all the sulphur was present as sulphate, then both concentrations should be within the analytical error, i.e. relatively close. However, there is no clear relationship between these concentrations. It appears that approximately half of the sulphur concentrations are present as sulphate, and the remainder in some other form.

The data presented on the pits, together with the observations derived from them, suggest two important factors to be considered for close-out. Firstly, acid generation in the West pit will continue to progress, and secondly, water from an undefined source enters the East pit which has the ability to generate acid. Presently, some supply of hydroxyl ions counteracts further acidification of the water.

4.3 The interaction of the Oriental East overflow and the meadows

The water leaving from the Oriental East pit runs through two meadows which are separated by a relatively narrow strip of treed area (Plate 4). In Map 3, the sampling location indicated as 610, is in this vicinity, indicated by an arrow.

PLATE 4: Oriental East Overflow. View of treed strip in the first meadow.

In this first meadow, extensive mineral precipitation occurs in the creek bed and in the vegetation (Plate 5).

PLATE 5: Oriental East Overflow. View of vegetation in creek bed with precipitation.

As the main surface water flow enters the second meadow (Plate 6), the direction of the contaminated water is altered through tracks of an all-terrain vehicle station 607 (Plate 7). The surface water appears to be channelled southward, flowing through the tracks and the meadow to Station 606, and through a densely forested area into the Buchans River at Station 603. The quantity of precipitate is reduced throughout this path until it is undetectable after Station 605.

PLATE 6: Oriental East Overflow. View of second meadow.

PLATE 7: Oriental East Overflow. View showing vehicle markings affecting drainage flow.

Biological polishing processes which remove metals from the water require the presence of suitably indigenous polishing agents, or plants with the appropriate characteristics. A wetland system, bogs or fens, are ecotypes in which it is possible for this biological removal system to be developed. Species suitable as polishing agents may either already be present and capable of growth enhancement, or may need to be introduced.

The meadow system located below the Oriental East pit was assessed for its capability to support a biological polishing system for Zn removal. It is anticipated that Zn concentrations in the water will decrease as a result of chemical processes which lead to the formation of precipitate, as well as through biological polishing activity.

In Table 7, the water characteristics of the flow path, commencing with the sample at the Buchans river (603), and following the main surface water path to the outflow of the pit (611), are presented. The concentrations of all elements determined through ICP remain the same between the time they leave the pit at Station 611, and arrive at the seepage into the Buchans River at Station 603.

The seepage into the Buchans River at Station 603, is not a point source, as the flow of the water through the meadow is diffuse. To confirm this fact, a sample was collected about 250 m further along the river bed (Station 604). This station represents a similar seepage flow emerging into the Buchans River from a treed

Table 7. Water characteristics of ORIENTAL DRAINAGE
Data collected July 16, 1988

Station No.	603	604	605	606	607	609A	609B	610	611	608A	608B	608C
Field:												
Temp	13.0	12.0	13.0	13.0	15.0				25.0			
pH	4.90	3.50	6.10	5.70	5.90	6.11	5.44	6.48	6.80	5.16	5.44	5.56
Cond	1,300	1,100	1,350	1,350	1,750	1,720	1,120	1.810	1,850	610	55	360
Lab:												
pH	4.74	4.17	5.37	5.42	5.51	5.62	4.46	5.51	5.79	4.68	4.99	4.93
ELEMENTS (mg/L)												
Al	0.3	0.6	0.4	0.2	0.2	0.2	0.3	0.3	0.3	0.2	0.1	0.2
Ba	0.03	0.04	0.03	0.03	0.03	0.03	0.04	0.03	0.02	0.1	0.1	0.1
C	1202	1205	643	976	1093	999	904	593	465	926	970	1179
Ca	292	195	273	266	397	320	250	345	357	101	6.1	56
cu	0.02	0.03	0.05	0.04	0.02	0.03	0.04	0.04	0.04	0.03	0.02	0.04
Fe	(0.01	0.6	0.04	0.01	(0.01	0.01	0.1	<0.01	(0.01	:0.01	0.03	<0.01
Mg	33	22	32	31	39	40	29	41	38	12	1.1	7
M''	8.2	7.6	6.7	6.5	9	9.2	6.1	9.6	9.1	2	0.08	1
P	0.1	0.1	1.7	0.2	1.2	2.1	1.1	1.7	1.5	0.1	0.1	1.7
Pb	0.06	0.1	0.1	0.1	0.08	0.1	0.1	0.1	0.1	0.06	0.06	0.09
S	332	229	306	299	392	392	282	392	370	113	6.9	64
SO4	354	120	360	240	142	118	233		120	50	112	
Zn	25	18	24	24	32	35	26	40.6	43	9.3	1.2	5.4
Acidity as CaCO3	77	50	86	60	86	162	72	97	109	60	24	95

meadow. The elemental composition of both seeps is essentially the same.

Overall, a slight reduction of zinc concentrations, from 43 to 25 mg/l can be noted. However, it is likely that this reduction is due to dilution, since the meadow through which the water runs is saturated with water. The characteristics of the water draining into the meadow were investigated through a series of samples collected around Station 608, which is further east from the tire track diversion of the main flow from the pit, at Station 607. Based on the topography, the streams 608a and 608c were considered to be more contaminated than stream 608b. This stream (608b) originated from the hill and it is unlikely that it received water from the first meadow. The concentrations of all elements considered were indeed lowest in this sample, (e.g. Zn concentration was only **1.2** mg/l, compared to 9.3 and **5.4** mg/l in the other two streams). Given that the water of the pit leaves at a concentration of around **24** to 30 mg/l, dilution is probably the main factor contributing to the decrease in Zn concentration noted in this series of water samples.

To obtain some insight into the potential for biological polishing as a water treatment in the area, samples of periphytic algae (attached algal growth) were collected in three locations (607, 605 and 603) in the second meadow and on branches in the Oriental East Pit. In Table 8 the concentrations of the elements occurring in the solid material in large quantities are presented.

The samples referred to as Ulothrix and OW jelly (Table 8) are samples selected for analysis, which represent a larger group of periphyton which was identified. The identification of the periphyton samples is given in Table 9. The main algal mass is

Table 8. Elemental characteristics of vegetation
Samples collected - July 16, 1988

	Ulothrix			OW
	#607	#605	#603	Jelly
Element (mg/L):				
Ba	832	224	269	2,582
cu	80	27	136	1,091
Pb	168	36	267	1,750
S	0.7	1.2	0.9	0.9
Zn	4,781	1,487	2,352	1,944
(%				
A1203	1.4	0.1	1.6	6.1
Fe203	6.9	0.5	1.4	16.4

composed of Ulothrix or Mougeotia, (long hair-like filaments) that are associated with diatoms (with or without silica), and unicellular green algae, referred to as Bacillariophyceae, Chrysophyceae and Chlorophyceae, respectively.

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Table 9. ALGAL SPECIES PRESENCE/ABSENCE : PERIPHYTON

ALGAL TAXON			Oriental		
			East	West	West
	603	607	Branches	Bottom	Branches
CHLOROPHYCEAE					
& DESMIDS					
Ankistrodesmus spp.	X				
Binuclearia sp.					
Chamydomonas spp.		X			
Microspora sp.					
Mougeotia spp.	X				
Netrium sp.					
Ulothrix spp.	X	X	X	X	X
Unidentified spp.					
EUGLENOPHYCEAE					
Euglena sp.		X			
CHRYSOPHYCEAE					
Ochromonas spp.					
Unidentified spp.					
BACILLARIOPHYCEAE					
Achnanthes spp.			X		
Eunotia spp.	X	X	X		X
Navicula spp.			X		
Pinnularia spp.			X		

The algal mass collected in location ***607*** is depicted in Plate 8 and can be compared to that in Plate 9 which represents the same algal complex at location ***603.*** The difference in appearance of the complex is striking. The whitish mass of station ***607*** was not as healthy as the algal mass at station ***603*** at the end of the seep on the Buchans river. The elemental analysis clearly supports these observations, as the algal mass contained 4780 ug/g of zinc as compared to 2352 ug/g of zinc at station ***603.***

PLATE 8: Algal mats collected at Location 607. High Zn concentration

PLATE 9: Algal mats from location 603. Note healthier appearance than Plate 8

These results indicate, that there is some potential to develop polishing capacity with this algal group in the meadows. However, the metal concentrations present in the system impose an upper limit of Zn concentration, at which the algal mass remains healthy. The periphyton samples from the pits suggest a similar trend, here expressed by decreasing species. In samples from the pits the number of green algae or diatoms which are associated in the algal complexes are considerably lower than in samples from the meadow below the Oriental East seep. However, the uptake in the OE jelly sample, which consists mainly of Ulothrix spp, growing on tree branches suspended in the pit water, is striking for the metals Ba, Cu, Pb, Zn and Fe (Table 8).

In essence the metal concentrations of the pit water are such that an extremely reduced phytoplankton community can be expected, hence the absence of associated species on the periphytic algal mass. However, this does not impair the polishing capacity of the algae but likely the growth condition for the algae.

Phytoplankton community, suspended algal populations, can be used to assess the potential for improvingthe conditions for periphytic algae. Phytoplankton has been identified in pit water, and for comparison, in Lake 1 and Tailings Pond 1 water. In Table 10 the results of a presence/absence evaluation is given for the four

Table 10. ALGAL SPECIES PRESENCE/ABSENCE : PHYTOPLANKTON

ALGAL TAXON	LAKE 1	TAILINGS POND 1	ORIENTAL EAST	ORIENTAL WEST
CYANOPHYCEAE				
Anabaena sp.	X			
Chroococcus sp.	X			
Gloeocapsa sp.	X			
Merismopedia sp.	X			
CHLOROPHYCEAE & DESMIDS				
Ankistrodesmus spp.	X	X		
Binuclearia ap.				
Chamydomonas spp.		X		
Closterium sp.	X			
Cosmarium spp.	X			
Microspora sp.			X	
Mougeotia spp.				
Netrium sp.				
Oedogonium sp.				
Oocystis spp.	X	X		
Pleurotaenium sp.	X			
Quadrigula sp.	X	X		
Scenedesmus sp.	X			
Spondylosium spp.	X			
Tetraedron sp.	X			
Ulothrix spp.				X
Unidentified spp.	X	X		
NGLENOPHYCEAE				
Euglena mutabilis				X
Lepocincles sp.		X		
CHRYSOPHYCEAE				
Chromulina spp.	X	X		
Chroomonas spp.	X			
Chrysochromulina spp.		X		
Dinobryon bavaricum	X	X		
Ochromonas spp.	X	X		
Unidentified spp.	X			
BACILLARIOPHYCEAE				
Achnanthes spp.			X	
Diatoma sp.	X			
Eunotia spp.	X			
Navicula spp.	X		X	
Nitzschia spp.	X			
Pinnularia spp.	X			
Synedra spp.	X			
Tabellaria fenestrata	X			
Tabellaria flocculosa	X	X		
CRYPTOPHYCEAE				
Cryptomonas erosa	X	X		
Rhodomonas lacustris	X	X		
Rhodomonas minutus	X	X		
DINOPHYCEAE				
Peridinium inconopicuum	X			

Mg (Levinson, 1980).

Table 11. Elemental characteristics of sediments
Samples collected - July 16, 1988

	EAST PIT sediment	WEST PIT sediment	Stn 610 Floc	White Floc
(p.p.m.)				
Element (mg/L):				
Ba	1,833	3.996	1,018	921
cu	227	653	665	813
Pb	2.973	10,860	1,005	806
S	0.5	0.6	0.9	1.6
Zn	3,645	3,620	82,800	222,000
(%)				
A1203	10.2	12.3	3.4	3.1
Fe203	3.6	7.1	20.9	6.7

Therefore, one means of improving the water quality in the pit would be through addition of organic matter. A second means to improving the effluent quality may be through utilization of the precipitation process which occurs in the creek bed. Two types of precipitate have been analyzed, a predominantly yellow brown material (Plate 10) and white material (Plate 11). The white material contains 22% Zn and 6% iron/oxide and the brown material 8% Zn and 21% ironoxide. The white material could be smithsonite ($ZnCO_3$) and the brown, some form of iron/hydroxide.

PLATE 10: Yellow/Brown Material

PLATE 11: White Material

These precipitation and co-precipitation processes further remove metals from the water as indicated by the concentrations of Ba, Cu and Pb. It follows that by determining the factors which lead to the formation of the precipitate those could provide potential means to remove metal from the water.

5.0 CONCLUSION AND RECOMMENDATIONS

The results of the field survey, the historical data, the results of the elemental composition of the water, solid material and algal mass have been discussed. An attempt was made to utilize all technical information to support the following conclusions.

1. The tailings system does not appear to provide environmental concern with respect to water quality of the Buchans River. This appears to be the case, as long as the hydrological conditions which prevail at present are maintained in the long term.

2. The water quality in the pits is likely to deteriorate in the long term, as acid generation may progress and the neutralization sources may be depleted. Conventional water treatment, designed for the present water characteristics could improve the effluent quality, given these conditions, but such a treatment could not address water quality deterioration in the long term. It is therefore recommended to focus on prevention of water deterioration followed by water treatment.

From the analysis of the data it can be concluded that a significant fraction of water sources to the Oriental East pit are unknown. Those sources, however, dominate the present chemical conditions in the pit. Therefore prior to any evaluation of water treatment options, the source of the water to the pit should be identified.

3. Water treatment options for the pits should focus on preventing further acid generation. Means by which this could be achieved are the provision of organic adsorption sites in the pit and promoting growth of biological polishing agents. If these methods are utilized on a test basis in the Oriental West pit, they can then be applied in all pits and areas which require curtailment of acid generation.

   One such area is the old mine drainage tunnel, which had been a significant contributor to the heavy metal loading leaving the mine site. This drainage tunnel was plugged in June 1988 and was not covered in this study. Recent sampling has indicated that the tunnel effluent continues to be a source of heavy metals. The tunnel must therefore be included in future planning.

4. It can be concluded that precipitation removes a considerable quantity of Zn, Cu and Pb in the first meadow as the water leaves the Oriental East pit. This process should be qualified and optimized. Through suchmeasures the metal load received in the second meadow can be reduced and would facilitate the potential for some effective biological polishing with the indigenous species identified.

6.0 CLOSE-OUT MEASURES FOR TREATMENT OF AMD AT BUCHANS

1. Tailings and Terrestrial areas

The investigation carried out by Boojum Research Limited in 1988 indicated that the tailings area, if present conditions are maintained, do not present a major environmental concern. Although in future the terrestrial areas will probably require some degree of reclamation, this is unlikely to present a technical problem as the areas requiring treatment are well defined and reclamation techniques for acidified, metal-contaminated soils and tailings currently exist. Boojum can be of assistance in determining those specifications required for reclamation contracts if this should be desired.

Reclamation measures for the dry/exposed areas should however, be determined on the basis of a cost/benefit analysis. The outcome of any activity will be mainly of aesthetic value rather than assisting in the environmental objective of improving water quality. The investigation of tailings ponds 1 and 2 suggested that in pond 2 (Jackson's Pond), the exposed tailings beaches may contribute to some Zn loading of the water. A terrestrial/semi-aquatic moss cover could be established, or conditions created which would promote invasion of such a cover (as evidence is present of moss colonization in tailings pond 1). In view of the annual loading from the tailings from each pond of about 2,000 kg of Zn, measures to reduce these Zn loadings in the long term cannot be considered a priority concern when compared to the annual loading of 16,000 kg Zn from Oriental East pit. Accordingly, Boojum proposes that the primary objective be the development of a program which focuses on improving the quality of water leaving the pits.

2. Ameliorating Quality of the Water Leaving the Pits, and Curtailing AMD

With respect to improving water quality, the investigation of the Buchans site identified three main areas in which work should proceed in order to achieve the ultimate objective of improving water quality employing a low-maintenance or, possibly, maintenance-free treatment system.

It is envisaged that the tasks will be addressed in 1989. The results of the investigations and tests carried out in 1989 will indicate the direction in which scale-up tests should proceed, and confirm the feasibility of implementation of successful measures on a larger scale by the end of 1989.

Once the larger scale implementations have been made, their performance must be monitored over a 2-year period, and the results obtained from these applications will lead to final implementation plans and the formulation of action to be taken in 1992.

2.1 Tasks to be addressed in 1989

The work can be separated into three distinct tasks:

A. Identify the sources of water to the Oriental pits.

B. Determine controlling factors of the precipitation process.

C. Test cost-effective organic amendments for the pits.

The rationale and an outline of these three activities is given briefly below:

A. WATER SOURCES TO THE ORIENTAL EAST PIT

Through identification of the water sources to the pit, it may be possible to consider reduction of water volumes to be treated. The present annual loading of 16 tonnes of zinc (based on 1987 data) from the Oriental East pit, at an average flow of 6.6 l/s into the meadows below the pit, could potentially be contained within the pit and the first meadow if the flow can be reduced and the precipitation process promoted. If it is not cost effective to reduce the flow, containment structures may have to be extended into the second meadow.

Identification of the water sources to the pit may also make it possible to alter the flow conditions in the Oriental East pit. By supplying water with characteristics that facilitate precipitation of metals in the pit, an in-situ treatment process can be developed. Finally, it may be possible to eliminate the water source entirely, and this would result in an entirely different scenario which would probably be similar to that for the Oriental West pit and Lucky Strike.

WORK PLAN

A detailed analysis will be made of all hydrological information supplied to Boojum on the Buchans site, and possibly, some further information respecting the questions raised through the 1988 study. This will lead either to the identification of the sources or of several potential locations to be tested.

After careful assessment of the material supplied by ASARCO and through discussions of the observations made with Mr. Neary, it may be found that all the relevant information is available and that no further detailed hydrological studies are required. Given the meadow nature of the area and its mining history, it is our opinion that field investigations are likely to produce more questions than answers. Accordingly, a thorough assessment of the existing hydrological information will prove cost effective and will facilitate at least the identification of the most likely sources.

B. FACTORS CONTROLLING THE PRECIPITATION PROCESS

It is likely that the precipitation process is controlled by a number of factors which are physical and chemical in nature. As it occurs in different forms after the water leaves the Oriental East Pit, the conditions which drive precipitation have to exist in the first meadow, and it is therefore believed that they can be identified through experimentation.

A determination of the factors controlling the precipitation process will make it possible to promote its occurrence in the pit and within the first meadow. This would lead to reduced concentrations of metals in the second meadow, which will in turn improve conditions for biological polishing in the second meadow.

A two-pronged approach is proposed. Some tests will be carried out in the laboratory to formulate field-testing conditions. Factors such as aeration, surface characteristics and the effects of dilution and temperature on precipitation, can be addressed in a laboratory testing program. Those factors that appear promising can then form the basis for experimental work in the field. The results of the field work would lead to larger-scale application and, finally, to implementation of the required conditions.

WORK PLAN

We are presently studying the precipitation processes in effluents from waste sites at INCO and DEVCO, and thus a considerable amount of the literature work and some experiments have already been carried out. The results from our experiments indicate that the approach being used is a valid one, i.e. we get quantifiable precipitate forming.

Water from both pits will be exposed to aeration, monitoring pH and precipitation will be quantified. One of the experimental set-ups will address circulating the water, while one will be stagnant (creek and pit simulations). Substrates, such as stones and wood surfaces, will be tested in both experimental designs. After the initial results are obtained, dilution and temperature effects will be addressed.

We have retained intact the water samples shipped earlier by Mr. Neary, except for pH measurement. Results indicate that both Oriental East and Oriental West pits solution has retained very similar pH after 4 months' storage (+0.04 and 0.06, respectively). We anticipate that some initial tests could be run with these samples. We will however, require more water for subsequent runs.

PHASE la: Laboratory

Objective: Determination of the fractions of those elements of concern which are both dissolved and suspended as precipitates in solutions collected from Oriental East and West.

<u>Methods</u>: While the dissolved concentrations of elemental constituents have already been reported, the concentrations of elements in a particulate form must yet be determined. These values will be determined with analysis of the filters used to separate out the dissolved portions of elements in the samples collected. These filters have been frozen since collection.

PHASE 1b: Laboratory

<u>Objective</u>: Examination of the shift in the proportion of dissolved and suspended contaminants as precipitate with physical and chemical manipulation of solutions collected from Oriental East and West.

<u>Methods</u>: The proportion of precipitates which can be removed by physical measures will be addressed by gravity settling, centrifugation, and stream bed simulation (i.e., unidirectional sheet flow with organic/inorganic obstacles).

The outcome of the laboratory tests will lead to the field test design, to be implemented in the pits and in the outflow in the first meadow.

C. COST-EFFECTIVE ORGANIC AMENDMENTS FOR THE PITS

Objective: Examination of the shift in the proportion of dissolved, suspended (as precipitate) or immobilized contaminants (as, for example, sulphides) with biochemical changes induced by microbiological processes occurring in Oriental East and West solutions.

Methods: Contaminant form and location upon incubation of solutions with various organic amendments, either in large test chambers or within test cells constructed at the edge of the pits, will be examined in the field.

These tests are intended to commence just prior to run-off and, depending on the results by mid-summer, the on-site test cells can be set up.

Measures to be developed to prevent acidification are based on establishing microbiological reducing conditions which can be brought about through the addition of the proper organic material that is "palatable" to sulphate and iron reducers, as well as to decomposing heterotrophs.

As it is the ultimate aim to produce these conditions in all acidic locations (Oriental West, Lucky Strike, and in the seepage from the waste-rock pile), the organic material required will be needed in relatively large quantities. In order to be cost-effective, these should be available locally.

During the work carried out by us on tailings sites of DENISON and INCO (pH 1.5 to 3.5), where several types of organic amendments were tested, some gave better results than others. The chemical composition of the acidic water at BUCHANS is significantly different from those in which the amendment materials were tested, particularly with respect to iron and sulphate. Our analysis of the BUCHANS water, comparing total S to Sulphate, suggested that other sulphur species are present in the water. Depending on the type of sulphur species, it may be favourable for the microbial process if the sulphur is present as an organic sulphur species, or it may be a disadvantage if it is a source of sulphur for further oxidation.

These results suggest that tests should be carried out with different materials which are available locally but which resemble the amendments previously tested so that the results can be interpreted in a broader framework. The materials envisaged are sawdust, brush-cuttings with lots of leaves from logging, and possibly peat-type meadow material which could be "mined" on site.

Tests should be carried out in an on-site location, possibly constructing a containment structure in the Oriental West pit. Some tests may have to be carried out in stagnant conditions in oil-drum size containers on site.

The results from these investigations should identify the most suitable and cost-effective organic amendment to be used in the pits and at other locations. We envisage that experiments within the waste water path will incorporate those materials which showed the most promising results in the smaller scale (e.g. drum) experiments. The practicality of various structures, such as rafts, netting or ditching, for suspension of these materials in contact with wastewater will be tested over the growth season.

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