Boojum Research Limited

The Abandonment of the South Bay Waste Management Area.

For :

BP Resources

Canada Limited

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SUMMARY

The South Bay copper/zinc concentrator was located in the Red Lake district of Northern Ontario, and was closed in 1981. In an area of 25 hectares, 760,000 tonnes of tailings, which are composed of 41% pyrite and 4.1% pyrrhotite, are contained within low dams. The 75 hectare mine site is surrounded by recreational fishing lakes of the English river drainage system.

Decommissioning procedures for the site have been developed which will, in the long term, ensure that the quality of the water leaving the waste management area is environmentally acceptable. Ecological Engineering methods provide a means to ameliorate the effects of acid mine drainage originating from the wastes on the site. In the long term, the Ecological Engineering systems implemented will be self-sustaining and maintenance free.

The Ecological Engineering methods being developed are based on the results of studies carried out on the natural recovery process which takes place on abandoned tailings sites (Kalin, 1983; Kalin, 1984; Cairns, 1980), the principles of which have been presented in detail by Kalin and van Everdingen (1988) and by Mitch and Jorgensen (1989). The metal and sulphate removal capacity of the system depends on the growth rates of the biological agents causing

removal, the rate of sulphate reduction, the rate of adsorption, co-precipitation, precipitation of metals and the rate at which contaminants are produced in the drainage basins.

The first application of Ecological Engineering measures to an acid-generating base metal mining operation was made at the South Bay Mine into three contaminated areas, namely: the main tailings area, Boomerang Lake and the mill/mine site. In the tailings area, although the solid tailings have been covered with overburden and revegetated, acid surface water generated from the tailings drains into decant pond which was limed during operations. The natural source of biological polishing in this area was recognized as the algal complexes comprised of Navicula and Oscillatoria spp. As the algae is growing on material suspended in the pond, the source of the zinc must be the decant pond water. It has been found that the concentrations of zinc in the algal growth formed on the introduced material is in the order of 3% Zn, compared to 1% Zn in the existing sediments. The growing algal mats which are attached to surfaces suspended in the pond water, relegate metals to the sediments. Through the introduction of inert building materials into the decant pond, additional surface area is provided to act as a growth substrate for the algal mats. The sediments, in turn, are being covered by cattails, some of which have been introduced as hydroponic islands and have survived for two years. The effectiveness of the system is evident from the zinc concentrations in the water at decant pond. Although liming was discontinued in 1986, the concentrations of zinc have dropped drastically in all subsequent years, at the onset of the growing season.

In Boomerang Lake, the periphytic algal growth on suspended branches in the lake is responsible for the removal of zinc, the biological polishing capacity being provided by the algal complexes dominated by Achnanthes and Mougeotia spp. To provide surface area for algal growth, log booms have been installed in the lake and brush has been placed behind these. The concentrations of iron and zinc indicate that these metals are being removed from the water. A submerged aquatic moss has been introduced to maintain a reducing environment over the algal material relegated to the bottom sediments by sloughing. The apical part of the moss provides growth and the basal portion decays, consuming oxygen. The success of the system in Boomerang Lake has been shown by the decrease in zinc values in the lake since the introduction of Ecological Engineering methods to the lake and the connected mill/mine site.

It is evident from the success achieved that the South Bay mine site can now be abandoned with confidence that the Ecological Engineering methods put in place there will continue to control the acid drainage in the long term.

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1.0 Introduction and Background

Boojum Research Limited was retained by BP Selco in 1986 to determine the feasibility of developing an Ecologically Engineered close-out scenario for abandonment of the South Bay mine site. A detailed site assessment, carried out during the summer of 1986, revealed that this mine site, inactive since 1981, was indeed ideally suited for this novel approach. A submission was, therefore, made to the Ministry of Environment for Ontario, requesting their approval in principle, and it was granted.

Approval in principle was given by the Ministry of the Environment in September 1986 on the following understanding:

1. That a hydrological survey of the tailings area would be carried out to determine the groundwater flow and acid loading to the Decant Pond and Boomerang Lake.

2. That an assessment of possible sealing of the dam adjacent to Boomerang Lake would be carried out and the dam grouted.

3. That wetland areas be developed in Mill Pond, Decant Pond and in the tailings spill areas.

4. That contouring of the mill site be carried out.

5. That, depending on the results of the work, a possible final close-out scenario be determined by the fall of 1988.

This report summarizes the measures which have been implemented at the South Bay mine site and gives details of the close-out scenario for the site.

1.1 What is Ecological Engineering?

Fundamentally, the Ecological Engineering methods proposed by Boojum are based on the results of ecological studies carried out on the natural recovery process which takes place on waste sites. The principles of this technology have been presented in detail by Kalin and van Everdingen, 1987.

A few species tolerate the conditions found in or on the waste material from mining operations and are therefore indigenous to the sites. The habitat is usually nutrient poor, with extremes in chemical (acidic or alkaline) and physical (exposure and drought) characteristics. The tolerance mechanisms of these species are such that survival occurs only in isolated pockets of the waste sites. The objective of Ecological Engineering is to create those conditions which allow for continued growth of these indigenous species in larger areas then the isolated pockets on the waste site. This can only be accomplished by a thorough understanding and examination of the factors which control growth, followed by the creation of the conditions which are found to assist the natural recovery pxocess.

Ecological Engineering measures can result in a reduction of acid generated and contaminant release. This will be achieved by the development of appropriate biological covers to reduce infiltration and increase evapotranspiration (Kalin, 1987), and through diversion of surface water inputs to the waste material, or the utilization of mine slimes (Kalin, 1988).

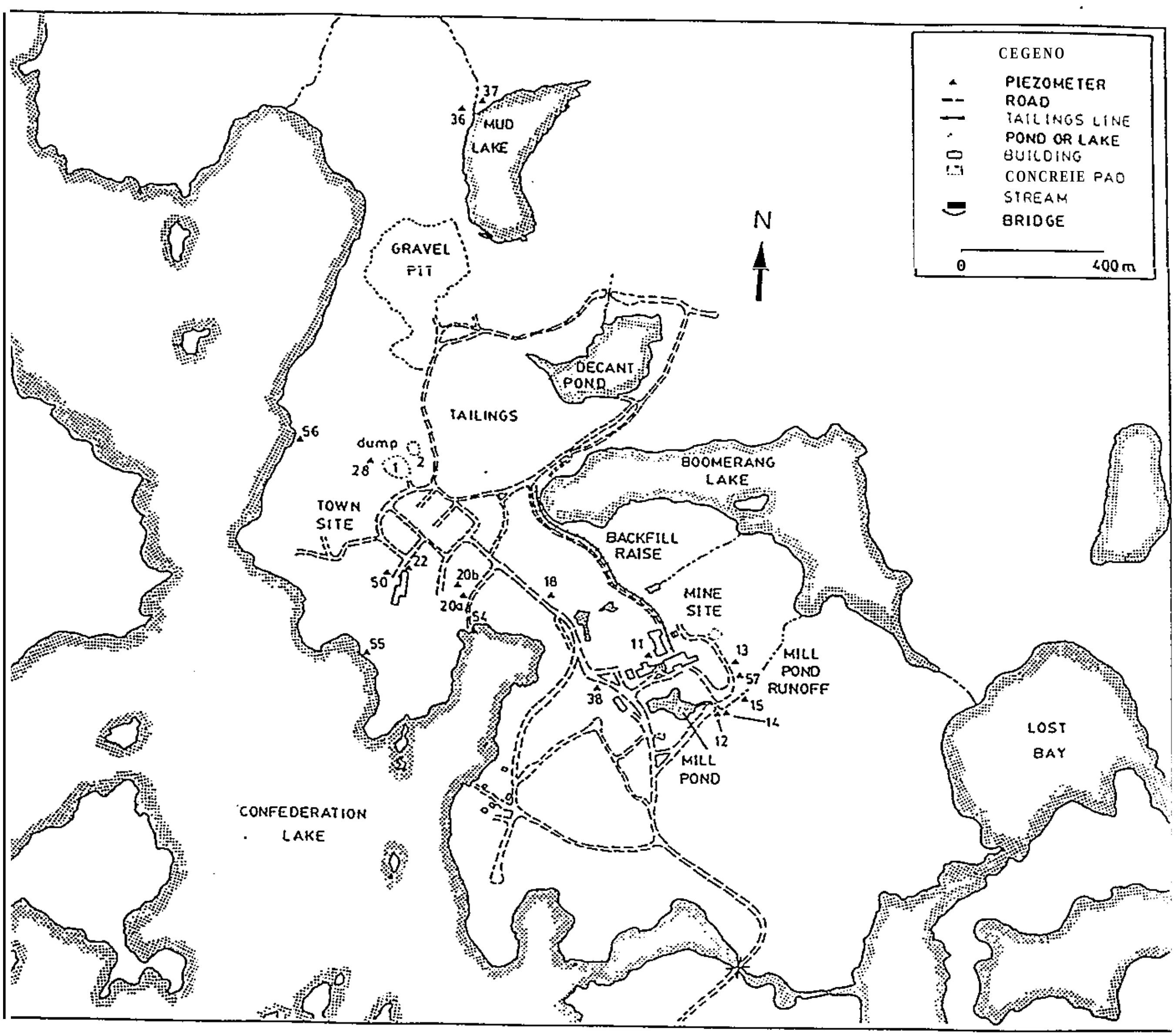
Water quality will be improved through the integration of precipitation processes in interceptor ditches and polishing ponds, followed by biological polishing processes which will facilitate the adsorption of metals onto algal biomass which is relegated to the sediment (Kalin, 1986, Kalin 1987 and Kalin 1988), and through passage of the water through sulphate reducing environments where microbial conversion of sulphate to hydrogen sulphide results in metal precipitation (Kalin, Cairns and Scribalo, 1988).

The Ecological Engineering systems will be self-sustaining in the long term, as well as being maintenance free. It is the goal of this technology that man's assistance be required only during the critical establishment period, and it is to that end that all research to date has been directed. This establishment phase is critical and time consuming, and its eventual success is dependent upon the effectiveness with which the initial work is carried out. Once the system is established, the effectiveness of the recovery process can be measured and further deterioration of the conditions will be halted and an overall improvement noted.

2.0 Site description

The waste management area can be divided into three units - the tailings area with Decant Pond, the Boomerang Lake basin and the Mud Lake basin. Map 1 provides an overview of the site and identifies all major locations where remedial measures have taken place. The South Bay site is surrounded by Confederation Lake, a recreational fishing lake which is part of the English River drainage basin.

Map 1: Overview of the South Bay Waste Management Area



The tailings located close to Boomerang Lake provide the main source of acid generation. They have been covered with 1 - 3 feet of overburden and seeded. Boomerang Lake is acidic and displays increasing concentrations of Zn. A second source of contaminants is the mine/mill site. Concentrate has permeated the area and emerges either in the ground water or in surface run-off. A waste rock pile located on the mill site has been reclaimed and is well covered with vegetation.

In Table 1, the respective area and net precipitation per annum is given for the three basins (Tailings and Decant Ponds, Boomerang and Mud Lakes). Contaminated water originates from the tailings area at a total of 30,000 m^3 per annum. This water leaves the basin in four major directions as outlined on Map 2. The annual flow volume estimates and the flow directions were determined based on the results of a hydrological investigation carried out by Morton Geotech in the fall of 1986. Grouting was carried out in the dam between the tailings and Boomerang Lake during that time.

Hydrological and geochemical investigations were completed and estimates derived of the contaminant loadings from the tailings area to the surrounding environment. These estimates made possible an assessment of the performance needs of the Ecological Engineering measures and the Biological Polishing capacity which

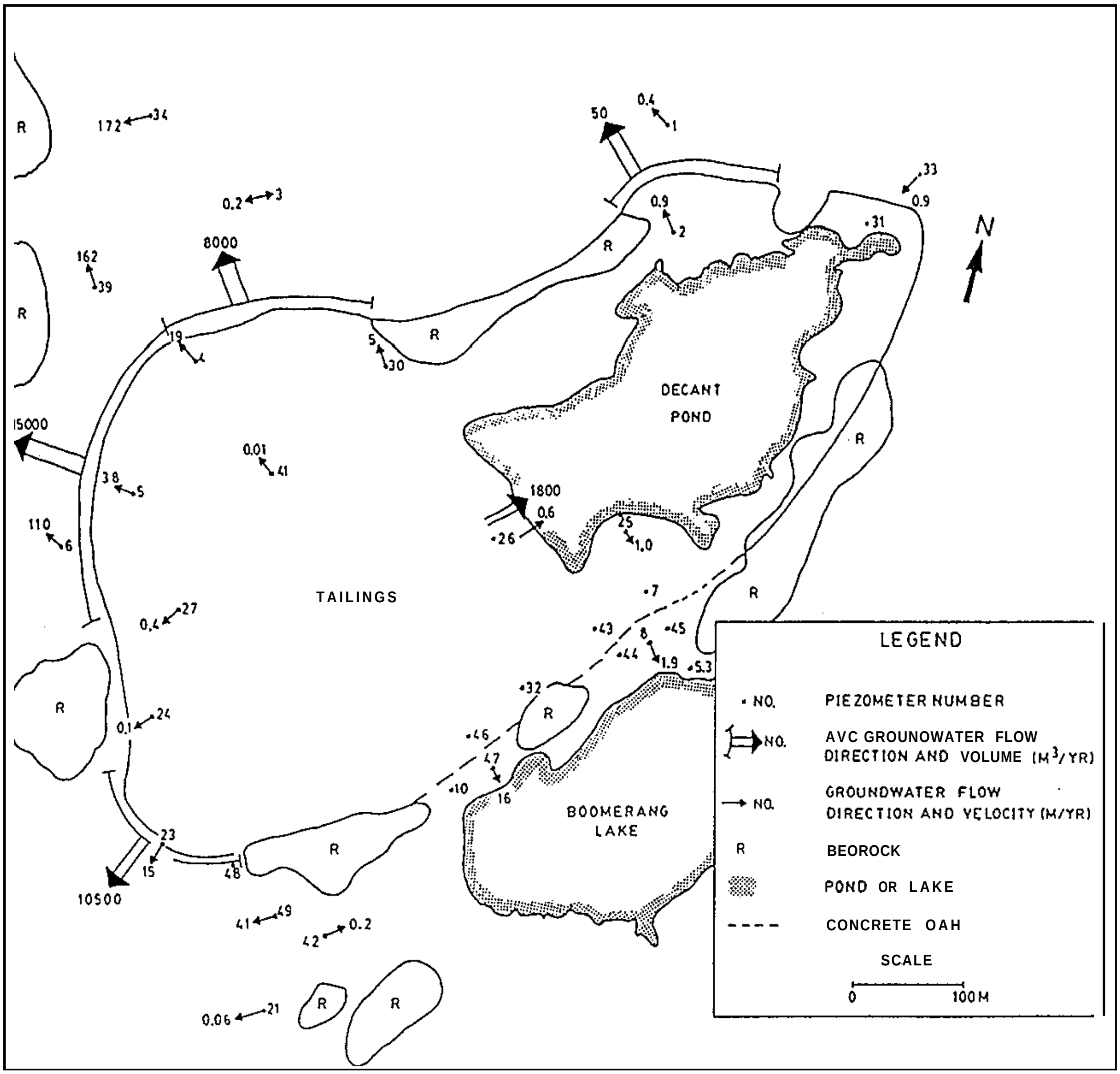
Table 1 Drainage areas for tailings, Boomerang Lake and Mud Lake basin, with precipitation data

Description	Area m^2	Net Precipitation mm/annum		Total Net Precipitation m^3/a
Tailings Basin				
Land area	200,000	250	->(1)	30,000
Decant Pond	50,500	175	(2)->	28,838
Total	250,500			58,838
Boomerang Lake Basin				
"Dirty Runoff" areas	369,395	275		101,584
"Clean Runoff" areas	700,538	275		192,648
Boomerang Lake	235,800	175		41,265
Total	1,305,733			335,497
Mud Lake basin				
Land area	1,765,600	275		485,540
Mud Lake	83,500	175		14,613
North Draw	131,308	175		36,110
Total	1,980,408			536,263

Mean Annual Precipitation 665 mm
Mean Annual Lake Evaporation 490 mm
Net M.A.P. on lakes 175 mm
Mean Annual Evapotranspiration 390 mm
Net M.A.P. on land areas 275 mm

(1) - extra 25 mm evaporation; 100 mm will run off to Decant Pond.
(2) - plus 100 mm runoff from land area.

Map *2:* Hydrology of the tailings area



must be established in order to achieve a self-maintaining walk-away condition.

The Boomerang Lake basin can be divided into contaminated and uncontaminated run-off areas. The contribution of clean water to the annual volume of the Boomerang drainage basin is estimated at two times larger than the portion of the drainage basin which contributes contaminated run-off (Table 1). On an annual basis, a total water volume of 335,400 m^3 can be expected to move through Boomerang Lake basin. The Mud Lake drainage basin receives some 28,800 m^3 per annum of contaminated water from Decant Pond, although the volume of clean water in this basin totals 5,366,000 m^3 per year.

In general, the South Bay waste management areas are well defined and do not exhibit severe environmental degradation. The hydrological conditions of the drainage basins indicated that considerable dilution is available in the drainage basins of concern. These conditions are favourable, and coupled with the Ecological Engineering measures implemented, Confederation Lake can be protected from the potential impact of acid genexation.

2.1 Site specific close-out measures

Biological systems have natural growth limits, and in order to be effective, the contaminant released into the system should not exceed the removal or growth capacity of the biological system. Therefore, for the three drainage basins described in the previous section, an evaluation has to be made of the annual loading from the contaminant sources. Based on these evaluations, it will be possible to make decisions respecting the implementation of Ecological Engineering measures presented in Section 4.

There are three distinct areas of the entire site in which measures to contain or reduce the contaminant loads can be implemented at this site. Only surface water can be addressed with these measures. Polishing ponds and measures which will reduce the metal and acidity loads to Boomerang Lake can be implemented at the mill/mine site in Mill Pond and on the spill areas (Backfill Raise), as well as in Decant Pond where water leaves from the tailings through Mud Lake to Confederation Lake. With respect to the groundwater flows from the tailings to Confederation Lake, it may be possible to divert some sub-surface flow through interception of the ground water. In such an interception ditch, precipitation of iron hydroxide will be followed with neutralization and by polishing before entering Boomerang Lake.

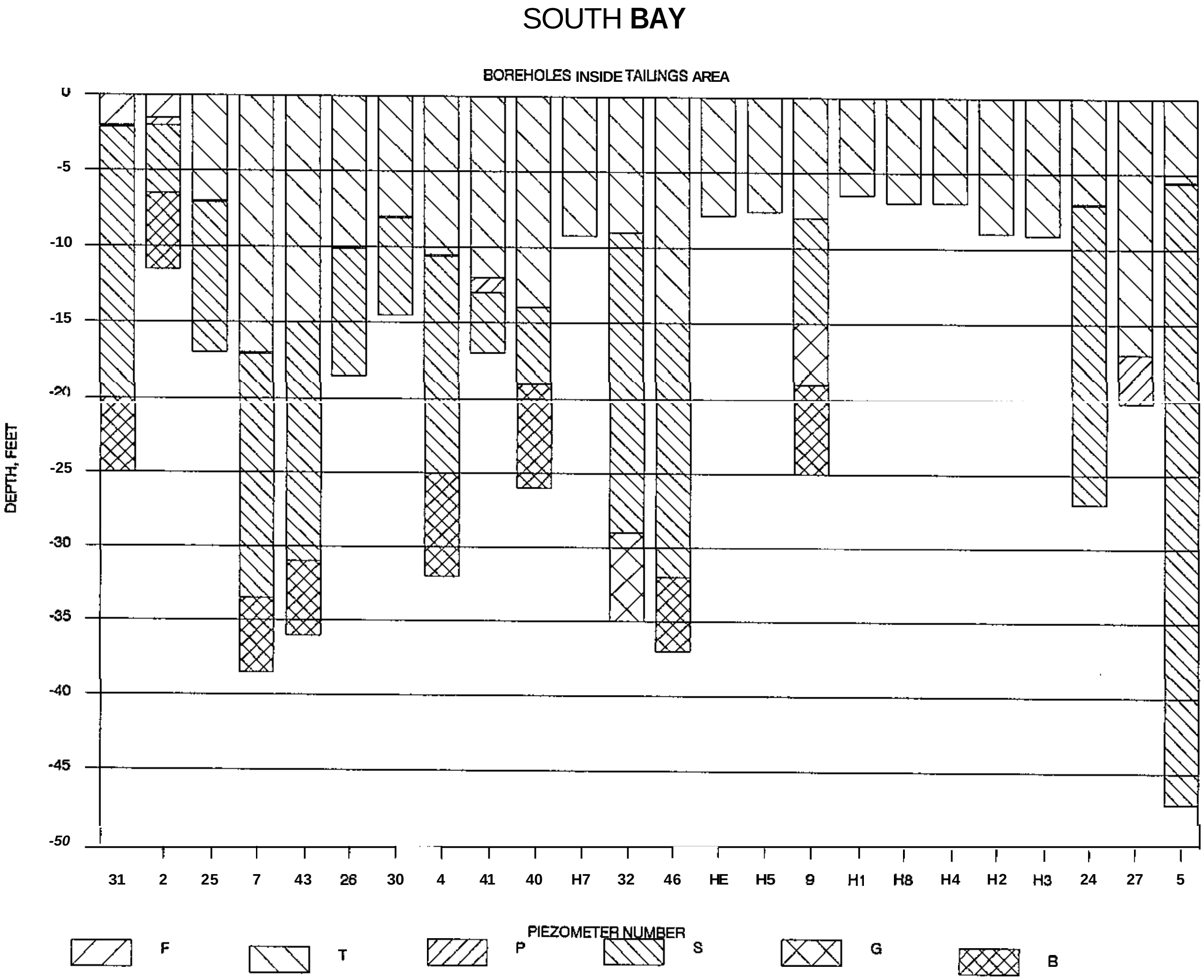
3.0 Description of acid generation and hydrology

During the hydrological study in 1986, carried out by Morton Geotech and reviewed by R.O. van Everdingen, a total of 56 piezometers and/or standpipes were installed. The approximate locations of the installation of these piezometers is provided by number on Map 1 for locations outside the tailings area, and on Map 2 for the tailings area itself. From these piezometer installations, it was possible to determine the location and thickness of the tailings or the overburden, the water table on the site, the flow direction, as well as the chemical characteristics of the water.

3.1 Acid generation in the tailings

Data collected from the bore hole logs are presented in Figure 1A for the tailings, and in Figure 1B for those drill holes outside the tailings area. The tailings are generally 5 to 10 feet thick, overlaying a layer of sand which, in some sections of the tailings area, is laying over bedrock. Outside the tailings area, the material encountered in the boreholes was varied, consisting mainly of fill and/or sand. Based on a particle size analysis of the tailings, an average porosity of 30% was assumed. The nature of the material underlying the tailings indicates that no significant

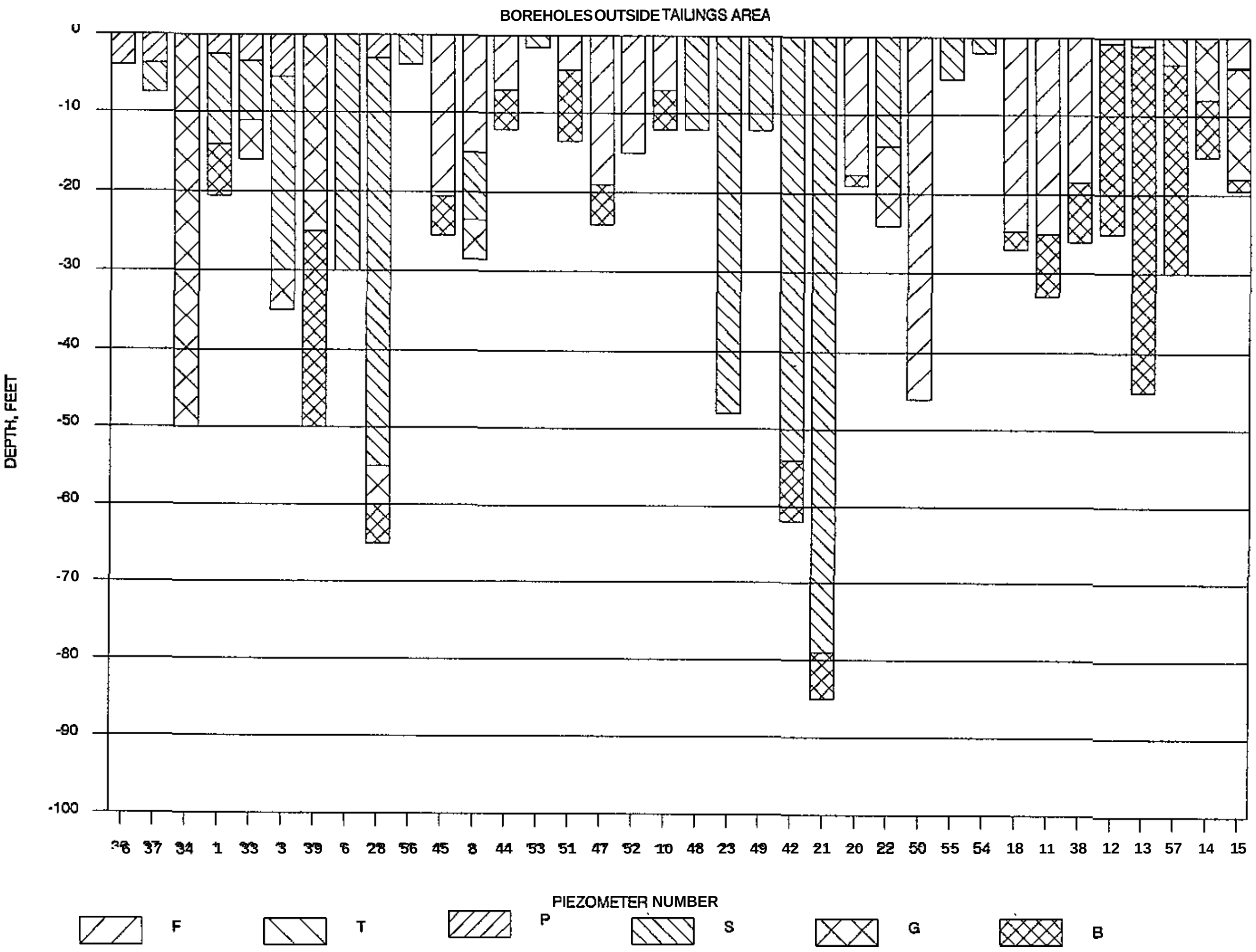
Figure 1A Soil profiles of piezometer boreholes inside the tailings area



** Note : F = Fill, T = Tailings, P = Peat, **S** = Sand, G = Gravel, B = Backfill.**

Figure 1B: **Soil profiles *of* piezometer boreholes outside the tailings area**

SOUTH **BAY**



** Note : F = Fill, T = Tailings, P = Peat, S = Sand, ***G*** = Gravel, B = Backfill.**

natural barriers exist for the retention of contaminated water, other than the bedrock. For example, a layer of clay or peat underneath the tailings would have produced such a barrier. Although on placement it appeared that part of the tailings were placed on boggy material, no extensive peat layer was found during the investigation.

From water level measurements in the piezometers, taken at weekly intervals during 1987 and at monthly intervals during 1988, it was possible to estimate that fraction of the tailings deposit which was saturated, i.e. exposed to water only, and that fraction of the deposit which was exposed to air and water. On average, it was determined that 69 to 100% of the tailings are exposed to air and water, and only 31% of the tailings can be under saturation. Thus, although the tailings are covered with overburden and have been reclaimed, the entire tailings mass is exposed to acid generating conditions.

Water samples were collected from the piezometers for analysis immediately after installation in 1986, and at several intervals throughout 1987 and 1988. An elemental scan (ICP) on filtered (0.45 um) and acidified samples was carried out, and a determination of acidity and sulphate was completed on unpreserved and unfiltered samples by a certified laboratory (Assayers Ontario

Ltd.). The water collected from within the tailings exhibited large concentration ranges. To estimate, therefore, the acid mine drainage production which takes place annually, a range of the concentrations of oxidation products was used (minimum and maximum values) along with an average. Table 2 gives the results of the calculations of the oxidation and precipitation products which can be expected to form in the 760,000 tonnes tailings pile.

The South Bay tailings have an average 43% Fe + Cu + Pb + Zn + S content. The tailings exhibit a relatively high ratio of metals and sulphur (0.6 to 0.75), which no doubt reflects the presence of pyrrhotite, although some Fe may be present in silicate minerals in the tailings. The presence of pyrrhotite is significant with respect to acid production. 2 moles of acidity are produced for each mole of pyrite oxidized during the precipitation of iron hydroxide, but only 1 mole of acidity for each mole of pyrrhotite or chalcopyrite oxidized.

In Table 2, the acid generation potential of the tailings is considered with respect to pyrite and pyrrhotite content. It is estimated that, based on the minimum sulphur concentrations in the water, pyrite depletion from the tailings deposit will take approximately 35,700 years. However, if the rate of depletion is based on the highest sulphur concentrations, it is estimated to

Table 2 Calculations for the estimation of potential acid generation products of the entire tailings mass

PARAMETER	MINIMUM	AVEXAGE	MAXIMUM
Tailings, tonnes	760,000	760,000	760,000
Average density of material, t/m^3	3.65	3.65	3.65
Average bulk porosity, fraction (est.)	0.30	0.30	0.30
Volume, m^3	297.353	297,353	297,353
Surface Area, m^2	200,000	200,000	200,000
Average thickness, m	1.5	1.5	1.5
Initial FeS2 + FeS, mass fraction	0.45	0.45	0.45
Initial pyrite + pyrrhotite, tonnes	342.000	342,000	342,000
Initial pyrite + pyrrhotite, moles	2.94E+09	2.94E+09	2.94E+09
Initial neutr. cap., mass fraction (CaCO3)	0	0	0
Initial neutralizing capacity. tonnes CaCO3	0	0	0
Net mean annual infiltration, m/yr	0.15	0.15	0.15
Average thickness saturated, m	0.94	0.94	0.94
S concentration, mg/L	176	1,669	5.668
SO4 concentration. millimoles/L	5.5	52.1	176.8
Acidity, mg/L	133	9.191	30,120
Fe concentration, mg/L	31	2,328	9.857
Initial SO4 flux, mol/m^2.yr	0.82	7.81	26.52
Pyrite depletion rate. mol/yr	82,346	780,880	2,651,903
Minimum depletion time, yr	35.742	3,769	1,110
Acid production rate. tonnes/yr (CaCO3)	16	156	531
Neutralizing capacity exhaustion period, yr	0	0	0
Acid storage capacity. tonnes (CaCO3)	7.5	516	1,692
Potential discharge delay, yr	0.45	3.30	3.19
PRECIPITATES:			
Maximum Fe(OH)3 quantity, tonnes	314.537	314.537	314,537
Fe(OH)3 production, t/yr (if all from FeS2)	9	83	283
Fe(OH)3 production, t/yr (if all from FeS)	18	167	567
Potential sludge volume at 10% solids, m^3	2,859,424	2,859,424	2,859,424
Annual sludge volume, m^3/yr	80	759	2,576

take 1,100 years. If the entire tailings was oxidized, the acidity which could be expected ranges from 530 tonnes of $CaCO_3$ equivalent per year to 16 tonnes $CaCO_3$ per year. A delay in discharge of this water from the tailings is estimated to range from 0.45 years and 3.2 years. Precipitation of iron hydroxide could produce an estimated volume of sludge annually, ranging from 80 to 2576 m^3/year. The precipitation of the sludge can occur inside the tailings pile or as the water emerges from the pile.

From these estimates of annual contaminant generations, one important point emerges and that is the need for a self-sustaining system, as even given maximum oxidation rates, treatment of the contaminants will be required for at least 1,100 years, i.e. a very long time. Although these estimates appear large, when the entire tailings mass is evaluated, the rates at which these products are produced and the locations at which they appear as contaminants are essential to a determination of their potential in inflicting damage on the receiving environment.

3.2 Hydrology of the tailings pile

The acid generation potential estimated previously for the total pile, has to be distributed with respect to the flow directions in the receiving drainage basins. Total estimated discharge was found to range from a minimum of about 74 m^3/day (27,000 m^3/year) to a maximum of 94 m^3/day (34,000 m^3/year). The average value of 30,000 m^3/year is based on the variations in gradients over the year of observation: it is similar to the value derived from the hydrological calculations presented in Table 1. In Table 3, the average ground water flows which leave the tailings area as contaminated ground water are presented.

The values for the loadings are derived from values of hydraulic conductivity, water level elevations and borehole logs. Minimum and maximum gradients between pairs of piezometers in 1987 were found to have occurred, in most cases, in late February/early May, and in late March/early April (or mid-June), respectively.

Table 3 Sub-surface flow direction from the tailings basin and loadings of iron hydroxide and Zn

Direction	Actual Groundwater Flow Velocity m/a	Average Estimated Annual Fe(OH)3 Discharge t/a *	Average Estimated Annual Zinc Discharge kg/a *
North	0.73 **	0.244	9
Northwest	21 to 75 *	32.9	1272
West	22 to 146 *	63.6	2459
Southwest	15.6 *	36.1	1398

Assuming: * - 30 % porosity; ** - 20 % porosity

Estimated flow velocities in the various flow paths were based on assumed porosities of the overburdens ranging from 20 to 30%. They range from 0.73 to 146 metres per year. The values suggest that subsurface flow may reach Confederation Lake from piezometer site # 39 close to the gravel pit area (Map 2) (with 7.4 mg/1 Zn) in as little as 3.6 years, and from piezometer site # 6 located on the west side of the tailings (Map 2) (with 1.5 mg/1 Zn) in as little as 2.7 years. The latter flow velocity is confirmed by the Zn concentrations found in piezometer # 56 (Map 1) on the shores of Confederation Lake , which ranges in Zn concentrations from 1.5 to 3.0 mg/1.

Estimates for the quantities of Fe (OH), discharged annually from the tailings, given in Table 3, are based on the average values for the groundwater flows. Minimum Fe (OH), discharge (1 t/a) was calculated using the minimum Fe concentrations for water from piezometers in each of the flow paths: maximum (563 t/a) and "average" (133 t/a) values are based on the maximum and average values for Fe concentrations determined in water collected from piezometers. The annual Zn loadings have been calculated using the same approach. In total, from all flows, only 5 t of Zn will reach Confederation Lake.

3.3 Hydrology of the mill/mine site

The contaminant loading from the mill site and the backfill raise area is complicated by the distribution of piezometers in this area. It does not allow the determination of subsurface flow rates with reasonable accuracy, although some approximate flow velocities and transit times can still be determined.

Contaminated subsurface flow from the Backfill Raise and from the Mill site will eventually reach Confederation Lake. Based on hydraulic conductivities and water level data, groundwater flow velocities towards Confederation Lake range from 2.5 to 4.6 m/a for the flow from Backfill Raise through piezometer site # 18, and from 6.5 to 9.0 m/a for the flow from the Mill site through piezometer site # 38(Map 1). These values in turn suggest that Confederation Lake could start receiving water with 7.5 mg/l Zn from # 18 in 21 to 40 years, and water with 77 mg/l Zn from # 38 in 21 to 30 years.

4.0 Ecological Engineering measures

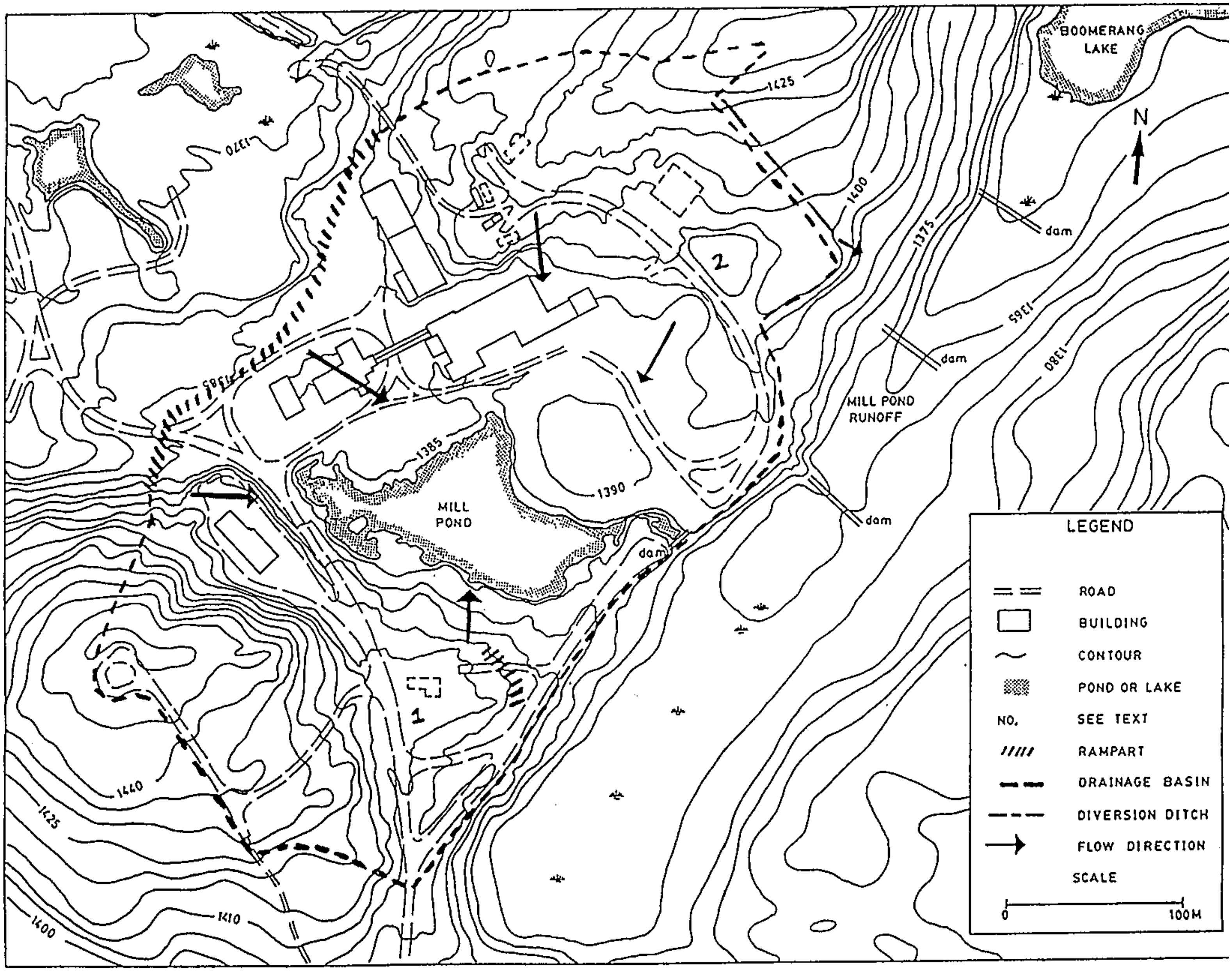
4.1 Mill Site and tailings spills

From the mine/mill site, surface water run-off can reach both Boomerang Lake and Confederation Lake. Following the dismantling of the buildings, the mine site was contoured in such a way that the natural depression (Mill Pond) will receive most of the surface run-off for biological polishing (Map 3). The unconsolidated material, namely reclaimed wasterock, building rubble and foundation has, over the years, been loaded with concentrate. Precipitation falling on the mill site therefore, results in a run-off from the site with high metal concentrations.

In Table 4, the mean concentrations of Cu, Fe, Pb, S and Zn are given for 1986, 1987 and 1988 for two sections of Mill Pond - the main pond and the experimental section close to the overflow. Although high zinc concentrations are present, the large variation in the water quality is a reflection of the type of water entering the pond. For example, sump drainage from the mill buildings during 1986/1987 and the run-off from the site during demolition activities in 1988. However, it is expected that high Zn concentrations will occur for a long time.

Table 4 Concentrations of Cu, Fe, Pb, S and Zn in the waters of Mill Pond

SAMPLING	Mill Pond					EXPERIMENTAL AREA			
	1986		1987		1988	1986		1987	1988
DATE	MEAN	STD	MEAN	STD	23-Aug	MEAN	STD	AVG	AVG
Cu	7.75	6.06	7.83	3.32	11	27.75	34.13	59.75	10.5
Fe	3.53	6.98	20.75	33.08	0.7	37.46	52.71	62.5	82
Pb	0.01	0.01	0.11	0.11	0.1	0.21	0.34	0.85	0.35
S	298.25	54.94	382.75	140.95	538	519.67	98.86	913	996.5
Zn	179.50	39.53	206.25	58.10	290	244.67	115.49	374	480.5



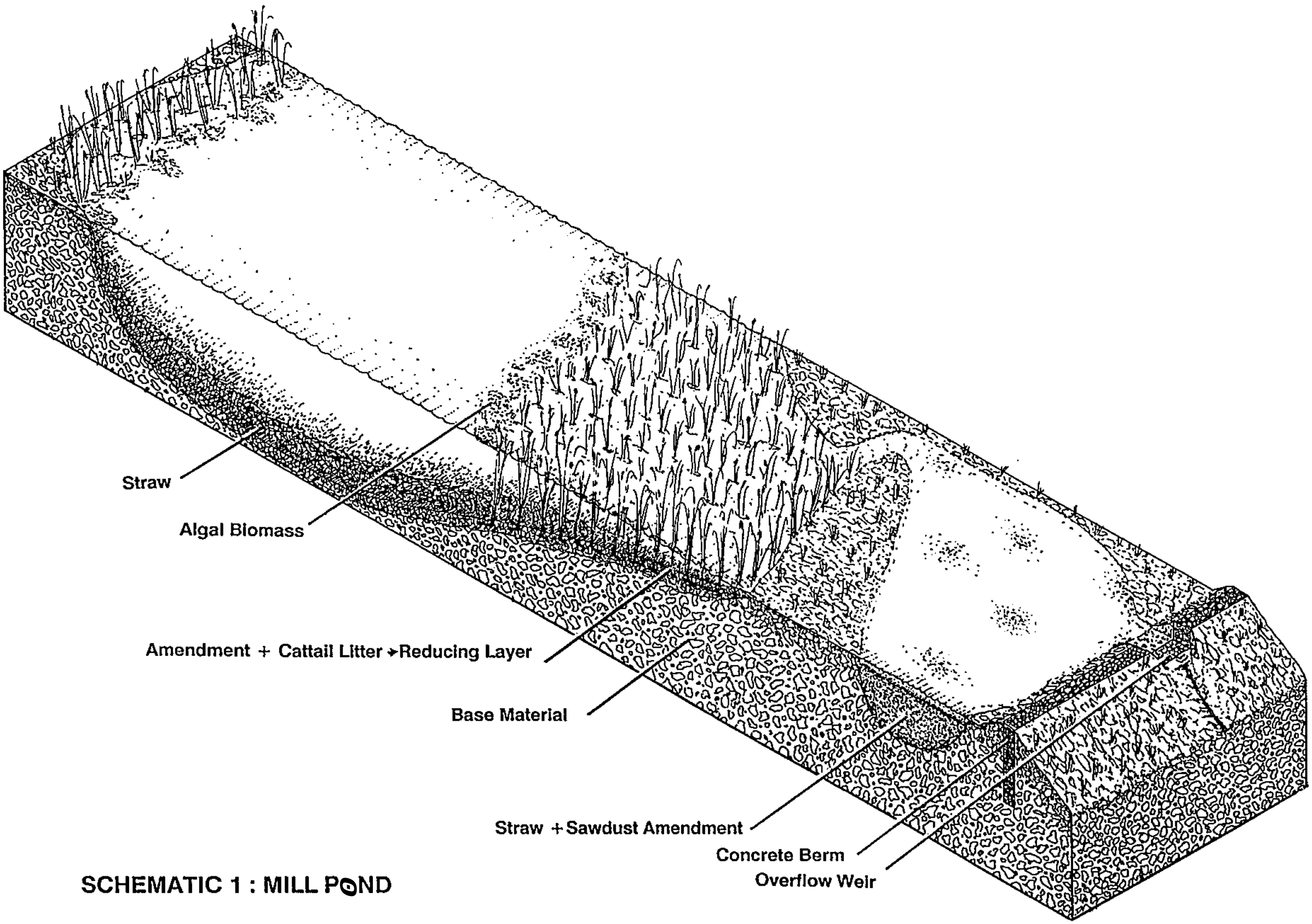
Map 3: Drainage Pattern around the Mill Site

In Schematic 1, the system which is expected to be in place at the mill site in the long term is given. The creation of sulphate reducing conditions in the amended layers, in combination with the fertilization of the pond water and the gradual stabilization of the run-off water characteristics, will result in the development of a polishing capacity providing for cattail growth. The cattails litter produced by a growing stand will provide a continuous supply of organic matter to the sulphate-reducing bacteria and a growth substrate for the algae. In order to implement this system, the following measures have to be taken:

- Placement of adsorbent material (sawdust and straw);
- Transplanting of cattails in various locations in the Pond: and
- Promotion of periphytic algae in the pond.

4.1.1 Placement of absorbent material

It was thought that sawdust could be used as an adsorbent material for metals. However, repeated analysis of the material in 1987 and 1988 indicated that the concentration of Zn and Cu were only slightly increased in the sawdust when compared to the concentrations in the material prior to its placement into the



SCHEMATIC 1 : MILL POND

experimental section of Mill Pond. It was therefore concluded that these measures were ineffective.

It was concluded that in order to establish a biological system in Mill Pond, a considerable amount of organic matter will be required. Two truckloads of sawdust were used to cover the bottom of the pond in 1987 and 70 straw bales were distributed through the pond in 1988. As the water level was extremely low during the 1988 season, only a limited amount of fertilization was carried out (250 lbs. of 6:27:27, N:P:K).

Further straw placement and fertilization of the pond will take place in 1989. It is hoped that the cattail growth will have sufficiently improved by 1989 as a result of the treatment carried out in 1988 described above.

Table 5 Shoot counts from mechanically and hand transplanted cattails along the edge of Mill Pond

Transplant #	Cattail Shoot Count 03-Jun-86	31-May-87	14-Jul-87	05-Oct-87	14-Jun-88	22-Aug-88
I	17	2	0	0	0	0
II	40	20	20	0	2	2
III	21	12	12	0	3	6
IV	31	34	wrecked	--	2	10
V	12	7	8	0	4	5
VI	12	13	16	0	18	25
VII	12	8	1	0	0	0
VIII	12	14	10	0	19	34

1-4 mechanical and 5-8 are by hand

Table 6 Shoot counts of cattail hand transplants in the middle of Mill Pond

Transplant Status	Frequency 31-May-87	14-Jul-87	** 11-Aug-87	05-Oct-87	15-Jun-88	22-Aug-88
No Shoots	32	45	52	75	95	105
1 Shoot	17	12	11	4	18	21
2 Shoots	11	6	13	2	11	3
3 Shoots	9	1	54	40	6	2
4 Shoots	2	1	1	0	1	0

** 50 transplant sites with 3 plants each added on this date

The survival of the cattails is evidenced by the fact that in 3 locations the number of shoots increased. In 3 other locations the numbers decreased, and in 2 locations the cattails could not persist. Although it cannot be said that the cattails are growing, the lack of growth can be attributed to the high zinc concentrations and possibly to the extremely dry weather experienced in 1988. However, they are surviving in these conditions and following an improvement in the water characteristics anticipated in the future because of stabilization of metal input and addition of straw which will reduce acidity, growth should take place.

4.1.2 Promotion of periphytic algae

Small-scale fertilization experiments were carried out in 1986, where fertilizer was added to pools of water at the edge of Mill Pond. Extensive algal growth was noted in the fertilized pools, compared to those pools where no fertilization was carried out. Plate 1 depicts one of the fertilized pools. Fertilizer was added to Mill Pond in July 1987. A survey of the algal mat types along three transects in Mill Pond is provided in Table 7. The type of algal mats on the bottom of the ponds were classified, 1 representing the lowest algal cover, and 4 extensive biomass production. The mat types were reassessed in August 1987, to determine whether the fertilization had resulted in maintenance of the algal mats.

Plate 1 Algal growth in fertilized pool in Mill Pond

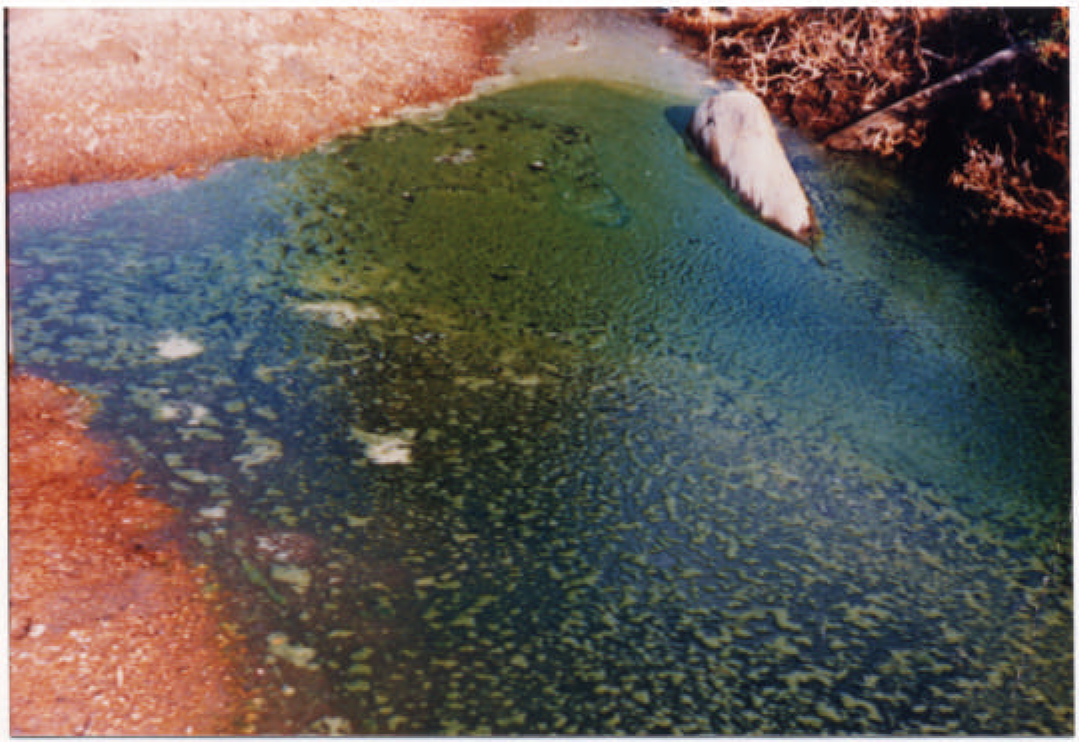


Table 7 Averages of algal mat ratings after fertilization between June and August 1987

	July 17		August 16	
Transect	Total Distance (m)	Avg. Mat Type	Total Distance (m)	Avg. Mat Type
MPII to X	25	2.48	25	2.94
Y to MPVI	34	2.62	33	2.94
MPVII to MPI	52	2.06	50.5	2.48

Mat Types: Euglena present, flat mat, flat mat with some tufts, very tufty mat. Avg. Mat type is weighted average.

The average of the mat types of all transects across Mill Pond suggests that algal mat maintenance was assisted by the fertilization (Table 7) as in August, a similar value to that of July was obtained.

4.1.3 **Mill** Pond run-off and **tailings spill** areas

During spring and fall run-off, Mill Pond can overflow. In anticipation of this event, a polishing system has been established in the ravine below Mill Pond, referred to as Mill Pond Run-Off (Map 3). This ravine will provide some polishing capacity to the contaminated ground water which may emerge from the mill site. Three retention structures have been built to slow the flow of water though not allowing overflow of the structures.

The water characteristics are given in Table 8 for the three retention structures created in the ravine. The first dam, referred to as Dave's Dam, has the highest concentrations of Zn in 1986, while in 1988, the concentrations of Cu, Fe, Pb, S and Zn are considerably lower. Water samples collected from the ponds behind the upper and lower retention structures con tructed in 1988, generally exhibit the same concentration ranges.

Table *8* Concentrations of Cu, Fe, Pb, S and Zn in the waters of Mill Pond run-off

SAMPLING CODE	DAVE'S DAM 8/17/86	10/15/86	4/5/87	4/27/87	7/13/87	(FILT) 8/13/87	(UNFILT) 8/13/87	4/12/88	6/19/88
pH	5.2	4.2	6.89	4.1	5.35	-	-	5.87	4.85
cond:umho	370	110	130	120	88	100	100	30	205
Elem:mg/L									
Cu	0.95	0.75	1.3	0.7	0.5	0.2	0.4	0.07	0.1
Fe	2.3	4.9	14.1	<0.01	223	2.8	2.8	<0.01	1.5
Pb	<0.01	<0.01	<0.01	0.1	0.3	<0.01	<0.01	0.07	<0.01
S	24	14	8.8	29	308	<.01	1.4	4.6	20
Zn	12	4.5	2.9	5.7	35	0.4	0.1	0.5	1.4

SAMPLING CODE	MPR DAM 2 (FILT) 8/13/87	(UNFILT) 8/13/87	(upper) (dam) 4/12/88	6/19/88	MPR DAM 1 (FILT) 8/13/87	(UNFILT) 8/13/87	(lower) (dam) 4/12/88	6/19/88
pH	5.52	5.52	5.37	5.85	5.39	5.39	5.4	5.82
cond:umho	900	900	50	85	950	950	80	80
Elem:mg/L								
Cu	0.7	1.2	0.53	0.4	0.9	1.2	0.1	0.4
Fe	4.3	4.5	0.2	1.5	4.6	5.1	1.7	2
Pb	<0.01	<0.01	0.1	<0.01	<0.01	<0.01	<0.01	<0.01
S	1.7	149	22	5.9	<.01	<.01	11	4.4
Zn	0.8	11	4.1	1.6	0.6	1.6	2	0.8

In areas where tailings spills have occurred, similar retention structures have been implemented, preventing pulses of metals and acidity which would normally be discharged during run-off periods and precipitation events. In the ponds which are building up behind the structures, organic material and brush has been placed to encourage the development of microbial sulfate reduction (Plate 2).

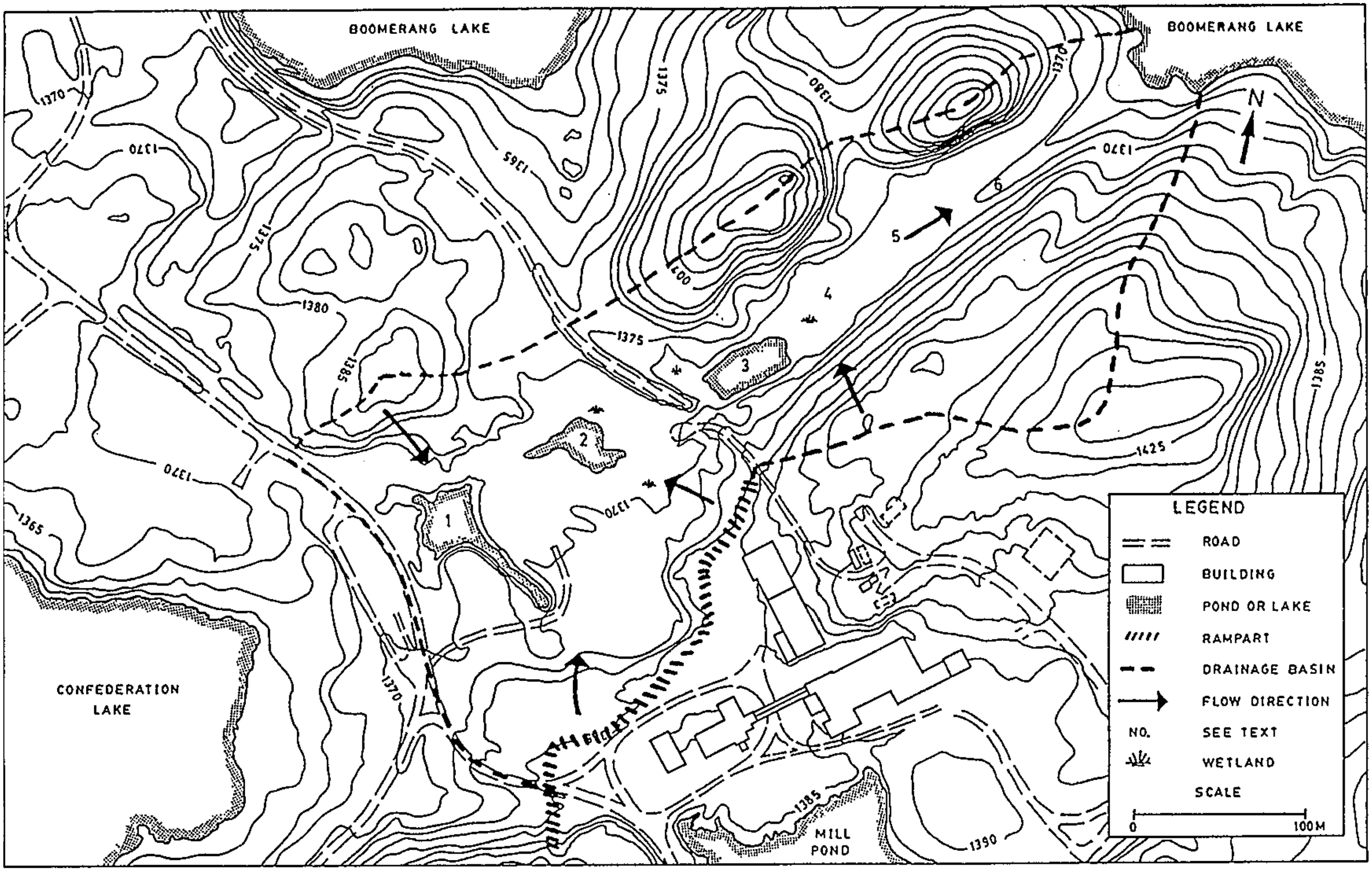
Plate 2 Straw placement in pools behind run-off retention structures in spill areas

In a larger spill area, referred to as Backfill Raise, more extensive work was carried out. In Map 4, an overview of the area is given. Ponds 1 and 2 were covered with a layer of lime, followed by sand and covered with wasterock from the former tailings line embankment. The third pond in the basin receives surface water from a densely vegetated area where cattails and acid-tolerant moss (Drepanocladus fluitans) can be found.

The high point in the drainage system was excavated to divert the flow of fresh water from this basin away from the tailings spill and into Boomerang Lake. In Table 9, the water characteristics are given for the clean water (Stations 5 and 6) and for those sampling points where the same water was contaminated by flowing through the tailings spill (Stations 1 to 4). The flow diversion was effective, as in 1989 the water continued to move towards Boomerang Lake and the tailings spill was dry on the surface.

4.2 Boomerang Lake and Ground Water Interceptor Ditch

The contaminant loadings to Boomerang Lake from the mine site and the tailings area are the sum of contributions of allochthonous sources (run-off from the mine site and spill areas) and autochthonous sources (metal flux from the sediments and ground



Map 4: Drainage pattern in Backfill Raise

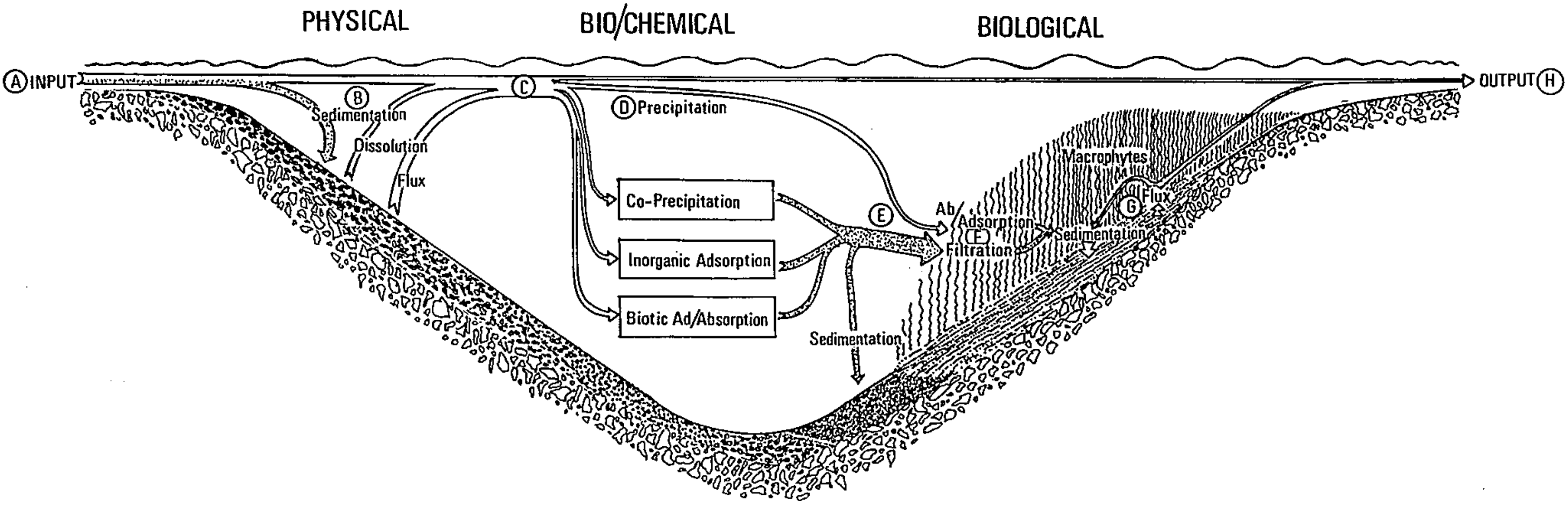
Table 9 Concentrations of Cu, Fe, Pb, S and Zn in Backfill Raise drainage basin

SAMPLING CODE	Station 1							Station 3 PILT.	UNFILT.		
	4/5/86	6/15/86	4/5/87	7/13/07	8/12/07	4/12/08	6/23/88	5/31/87	5/31/07	7/13/87	8/12/07
pH	3.2	-	3.6	3	4.54	2.03		3.13	3.13	-	3.6
cond:umh	400	-	1200	2200	400	250		455	455	-	750
Elem.mg/											
Cu	6.4	1.84	5.5	0.7	0.5	0.06	0.01	0.3	0.3	0.5	0.01
Fe	88.0	55.2	84	83	17	1	0.7	6	4	107	0.6
Pb	0.04	0.2	(0.01	0.4	<0.01	0.06	(0.01	0.9	0.2	0.6	(0.01
S	336	501.2	364	661	149	23	36	81	67	252	66
Zn	122	173.2	97	119	11	4.1	3.6	5	5	14.8	2.5

SAMPLING CODE	Station 4 (RECHARGE)		Station 5	Station 6 FILT.	UNFILT.		
	6/16/86	4/5/87	7/13/87	5/31/87	5/31/87	7/13/87	8/12/87
pH	-	5.33	-	4.6	4.6	-	-
cond:umh	-	380	-	170	170	-	-
Elem.mg/							
Cu	0.03	<0.005	0.2	0.03	0.03	0.5	0.01
Fe	8.1	91	<0.01	0.7	0.6	3.5	0.1
Pb	0.02	<0.01	0.06	<0.01	<0.01	0.2	<0.01
S	24	86	8	25	26	43	29
Zn	1.3	0.35	<0.005	0.9	0.9	<0.005	0.1

water discharge from the tailings). In Schematic 2, these sources are depicted on the left side of the diagram. Processes relevant to the removal of these contaminant sources are sedimentation of particulate matter, the magnitude of contaminant flux from the sediment and dissolution of contaminants.

The suspended solids loading received by Boomerang Lake is small, due to the fact that no direct fresh water input exists to the lake. The processes which will drive Zn removal from the water column are adsorption on and co-precipitation with Mn oxides and amorphous Fe oxides and adsorption on organic matter, depicted in the centre of Schematic 2. The adsorption affinities of Zn however, are affected by pH, Eh, mineralogy and organic acids. Reducing conditions under the biological filtration system will produce organic acids. The removal processes for Zn are therefore expected to vary, depending on local conditions. They are depicted on the right side of Schematic 2.



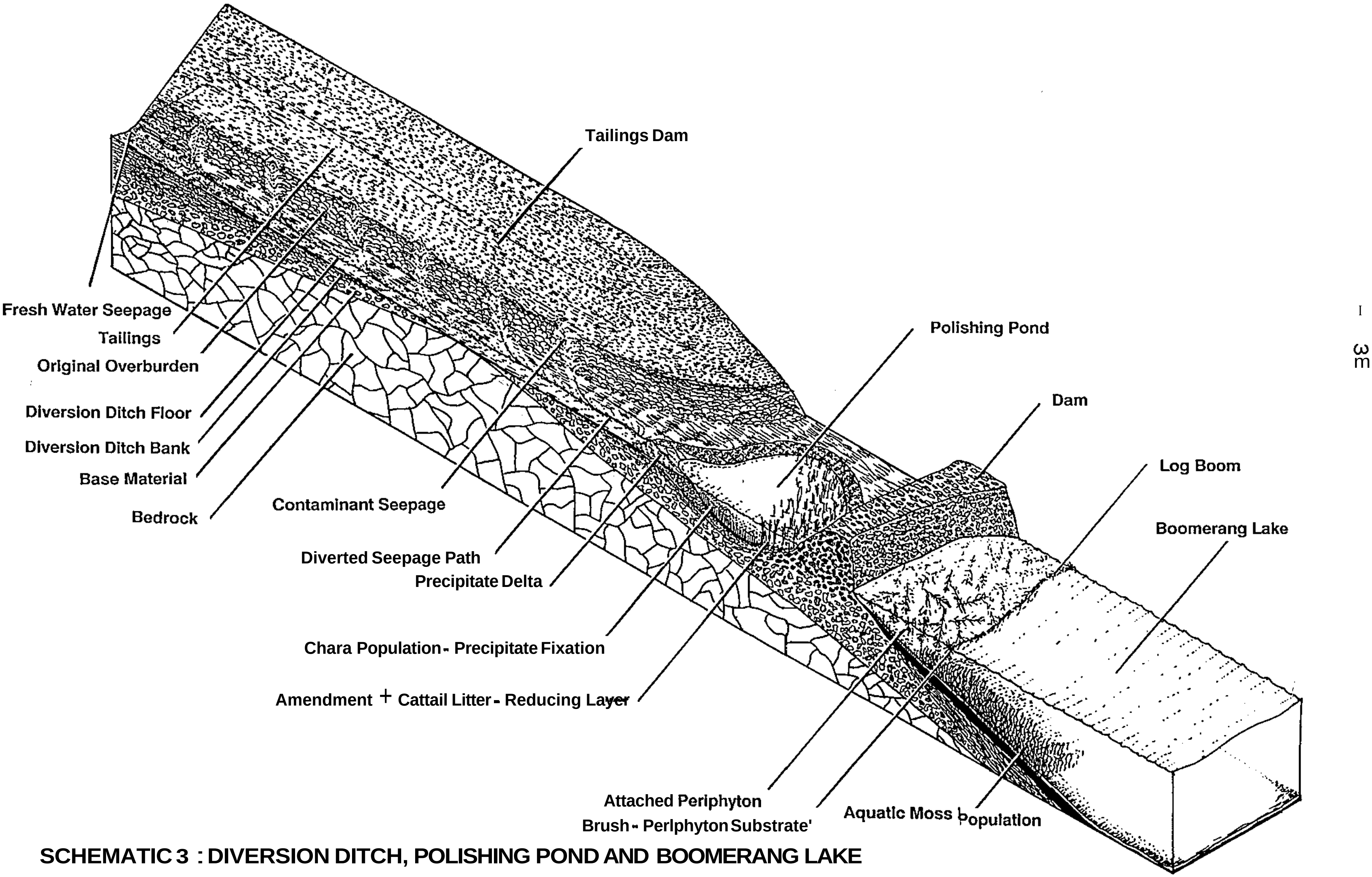
SCHEMATIC 2 : T[illegible] WHICH APPLY TO CONTAMINANT REMOVAL

In order to enhance these natural removal processes, conditions have to be created which promote organic matter production, thereby assisting in the adsorption process of Zn. In Schematic 3, a representation of the combination of the measures employed in Boomerang Lake is given. The biological polishing system in Boomerang Lake is complemented by precipitation/neutralization which is expected to occur in a groundwater-interceptor ditch and a polishing pond which have been constructed. The measures which have to be implemented consist of:

- Provide organic absorption sites
- Provide reducing conditions for the sediment sink
- Provide precipitation/neutralization ponds for subsurface flow: and
- Provide sulphate reducing conditions.

4.2.1 Provide organic adsorption sites

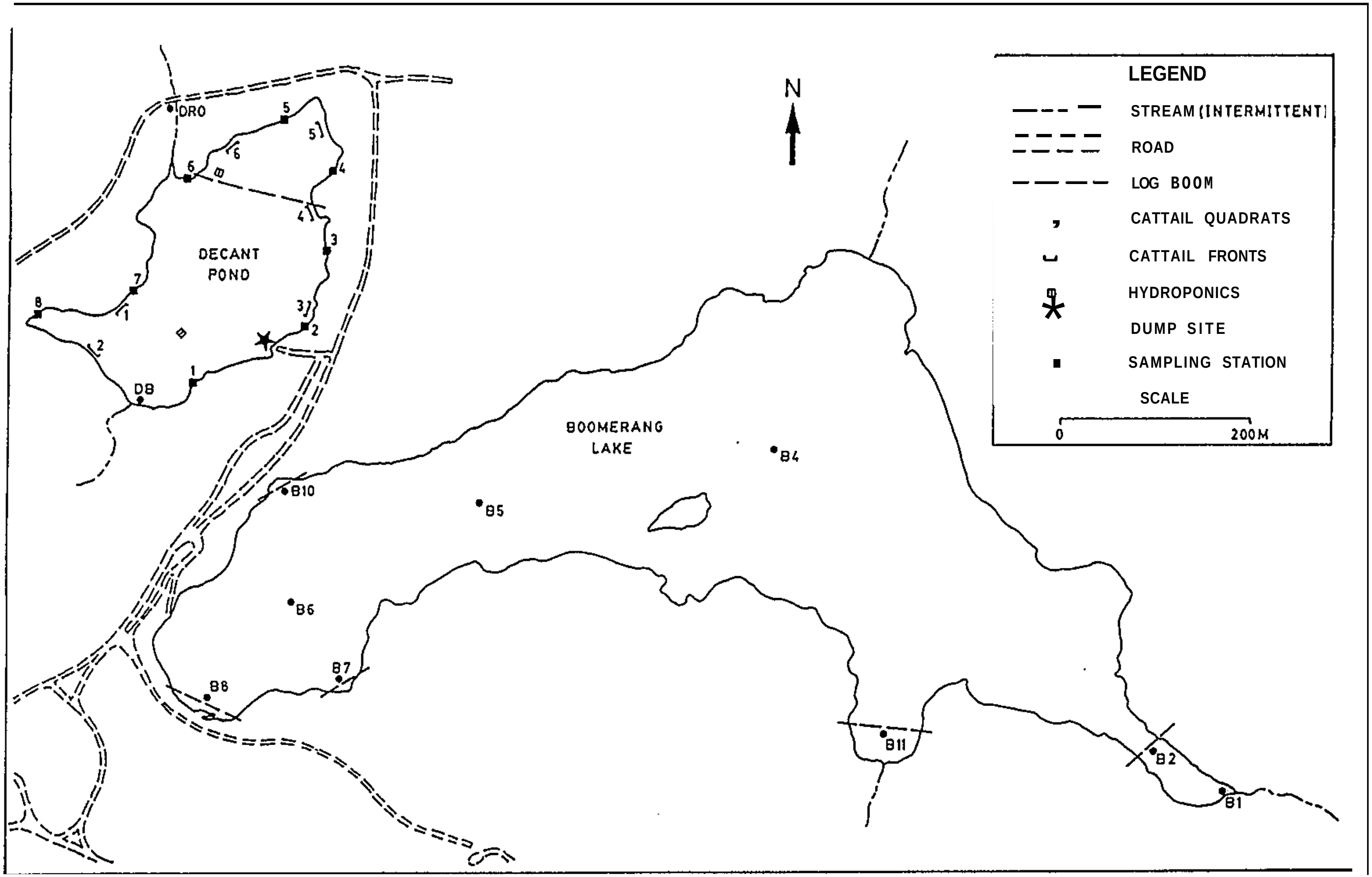
Phytoplankton is one source of suspended organic matter in a lake. Therefore the phytoplankton community in Boomerang Lake was determined. A phytoplankton community, typical for an acidified shield lake, was found (Kalin, Olaveson and McIntyre, 1988). The phytoplankton diversity in Boomerang Lake showed distinct differences between that found in the acidified lake and in the



SCHEMATIC 3 : DIVERSION DITCH, POLISHING POND AND BOOMERANG LAKE receiving waters, namely Confederation Lake. Species, such as Desmids, were markedly absent from Boomerang Lake though present in the discharge areas. Desmids are considered very good indicator species for environmental degradation, and their presence led to the belief that no significant environmental degradation is occurring to Lost Bay, part of Confederation Lake due to the discharge of water from Boomerang Lake.

Although adsorption of zinc will occur by the phytoplankton present in Boomerang Lake, its biomass volume is small and therefore does not play a significant role in the removal of zinc from the water. However, periphytic algal growth on the sediment and suspended branches in the lake shows prolific growth and could therefore contribute significantly to organic matter production, i.e. adsorption sites for Zn.

Therefore, in areas of Boomerang Lake where discharges of water with relatively high zinc concentrations are expected to occur (Polishing Pond, Mill Pond run-off and spill areas), log booms have been installed (Map 5), behind which brush has been placed. The biological polishing capacity represented by the periphytic growth on the brush consists mainly of an algal complex dominated by *Achnanthes* and *Mougeotia* *spp.* The methods used for the collection of algal material are given in the Appendix.



Map 5: Cattail experiment locations in Decant Pond; water sampling stations and log boom locations in Boomerang Lake

The concentrations of Fe, Cu, S and Zn contained in this algal material collected from the branches are given in Table 10A after one growing season of colonization of the brush: after two growing seasons in Table 10B, and Table 10C presents those concentrations for which the accumulation time is unknown.

The differences in metal concentration in the algal material are distinct for iron, in that after the first growing season, a mean iron concentration of 20 g/kg (± 15 g/kg) of branches and needles was determined which had increased to 40 g/kg (± 18 g/kg) of algal mat. This suggests that one of the major processes of zinc removal will be the co-precipitation of metals with iron hydroxides. This removal process was discussed earlier (Schematic 2). Although the increase in iron concentration from one growing season to the second is drastic, the metals in the algal mat do not increase proportionally. The concentration in algal mats collected from those branches where the time of suspension if unknown, was one order of magnitude higher in metal concentration (Table 10C). The iron concentrations were 166 g/kg (± 6 g/kg) and the Zn concentration was 6 g/kg (± 0.7 g/kg), compared to two years' growth where iron concentration was 4^{1}/g/kg ± (18g/kg) and zinc was 0.5 g/kg (± 0.1 g/kg). The material for which the time of growth was unknown consisted of a very thick algal agglomeration on a branch in a protected bay of the lake representing an

Table 10A: Concentrations of Cu Fe, Pb, S and Zn in algal biomass after one growing season (1988)

Element (ppm)	Mean	Std	Min	Max
Cu	129	71	68	206
Fe	20794	15505	3196	32445
Pb	22	9	13	30
S	248	143	91	373
Zn	449	125	328	577

Note: n=5; Days of Growth=113

Table 10B: Concentrations of Cu, Fe, Pb, S and Zn in algal biomass after two growing seasons (1987 and 1988)

Element (ppm)	Mean	Std	Min	Max
Cu	196	68	93	270
Fe	41394	18414	19419	67151
Pb	35	14	16	51
S	335	80	277	462
Zn	541	124	373	699

Note: n=5; Days of Growth=496

Table 10C: Concentrations of Cu, Fe, Pb, S and Zn in algal biomass suspended for more than 2 years (long term)

Element (ppm)	Mean	Std	Min	Max
Cu	1825	126	1700	2000
Fe	166500	6455	158000	172000
Pb	200	0	200	200
S	11050	1552	9200	11000
Zn	6275	690	5800	7300

Note: n=4; Days of Growth=Unknown

accumulation of precipitate formed over several years. Therefore, the concentrations determined after one or two years' growth indicated that the adsorption process is related to time and is continuous. Therefore, the determination of estimates of algal growth based on sampling of branches with algal mat at regular intervals, will be an underestimate of growth and thus of zinc removal.

4.2.2 Provide reducing conditions for the sediment sink

As the algal material on the branches increases in volume, it will be relegated to the bottom sediments by wave action and through sloughing. The sediments in the lake will be enriched with the metals adsorbed by the algal complex. Therefore, to ensure that the sediments act as a permanent sink for the metals, a reducing environment has to be maintained. For this purpose, submerged aquatic moss has been introduced into the areas with log booms. The moss carpet which will develop will serve as a cover to consume oxygen above the sediments through continuous growth of the upper portion of the moss stand and in addition, will provide filtration capacity for suspended matter.

From the investigation of a lake in Northern Saskatchewan (pH 3.5) which received tailings, it was found that this species of moss covered the entire lake bottom and provided an effective barrier to oxygen over the sediment (Kalin, 1985). Its ability as a cation exchange medium was found to be limited in the presence of concentrations of iron greater than 35 mg/l in acidic waters (Buggeln and Kalin, 1986). However, the moss functions as adsorption and precipitation sites, as well as providing filtration capacity for particulates.

A total of 200 moss bags (Plate 3) have been introduced into the lake in all locations where log booms have been placed. The concentrations obtained in the aquatic moss are presented in Table 11, and those of the particulate matter washed from the new grown moss are given in Table 12. The concentrationss of Cu and Zn found in the moss and in the preceipitate trapped by the moss carpet are somewhat lower than those determined for the algal mats.

Plate 3: Moss growth after one complete growing season in Boomerang Lake

Table 11 Concentrations of Cu, Fe, Pb, S and Zn in aquatic moss from Boomerang Lake

Element (ppm)	Mean	Std	Max.	Min.
Cu	142	18	167.2	119.2
Fe	49565	39705	104527.6	27231.6
Pb	174	31	203.8	184.1
S	1070	415	1779.6	729
Zn	164	102	333.5	115.9
L.O.I.	81	9	87.8	69.3

n=4: Days of Growth= 70 - 394

Table 12 Concentrations of Cu, Fe, Pb, S and Zn in precipitate trapped by aquatic moss

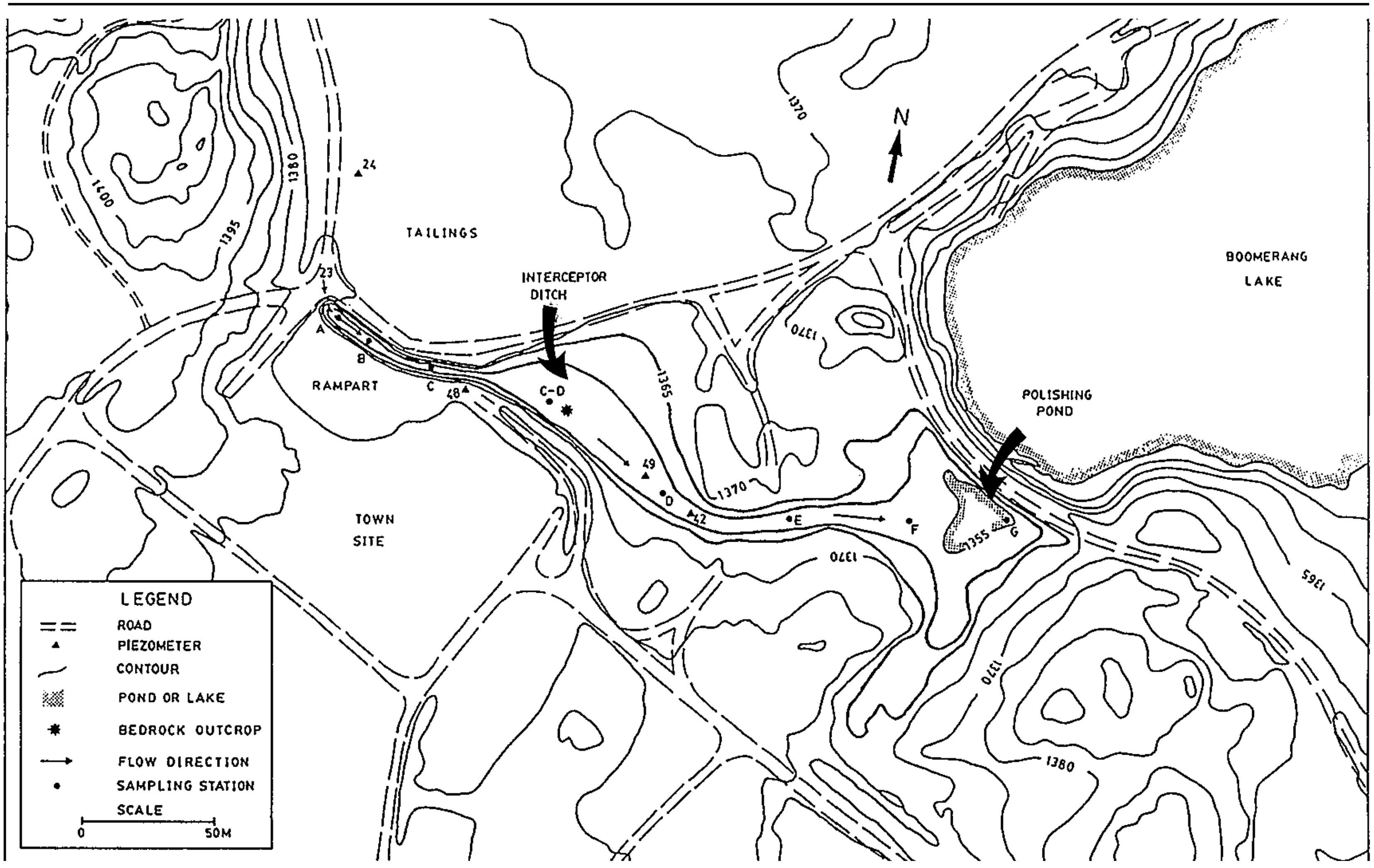
Element (ppm)	Mean	Std	Max.	Min.
Cu	46	16	212.4	27.7
Fe	4793	1592	160022.6	3344.2
Pb	13	2	228.8	11.1
S	213	132	965.4	92.9
Zn	162	92	635.2	97.5
L.O.I.	28	9	40.9	18.6

n=3; Days of growth= 70 - 394

4.2.3 Provide preciptation/neutralization ponds for subsurface flow

Based on the evaluations of the subsurface flow paths and their contaminant loadings, it was decided that an interceptor ditch would be required to protect the bay of Confederation Lake which is expected to receive loadings from the south west tailings flow, from the spill area (Backfill Raise) and from the mill site.

The location of the interceptor ditch is given in Map 6. Its location was dictated by the topography of the tailings and the prevailing groundwater flows.



Map E: Interceptor Ditch and Polishing Pond with locations of water sampling stations (A - G)

Two options were considered for this ditch construction. Option I consisted of a single ditch, starting in the North Borrow Pit (near piezometer No. 34), with a bottom elevation of 1,358 ft, and with a bottom elevation of no more than 1,351 ft at the tailings line embankment near Boomerang Lake. For the approximate length of 3,600 ft. this would have provided a gradient of about 2 ft per thousand feet. The bedrock high centre at Northing (15,300) and Easting (10,700) presented a serious obstacle to the use of this option.

Option II was the construction of two ditches, one discharging north into Mud Lake, the other discharging into the polishing pond near Boomerang Lake (Map 6). The North ditch would have started near the bedrock high (mentioned under Option I), with a bottom elevation of 1,358 ft, to discharge into Mud Lake with a water level elevation of about 1,357 feet. This would have provided a gradient of no more than 1 ft in about 1,600 feet.

The South ditch would have started near the bedrock high with a bottom elevation of about 1,365 ft dropping to an elevation of 1,358 ft near piezometer No. 23 and ending at an elevation of about 1,351 ft in the polishing pond at the tailings line embankment.

In view of the potential problems with the bedrock high (Option I) and the low gradient which could be expected from the North Ditch (Option II), it was decided that only the South Ditch of Option II would be implemented.

These options were developed based on the water level measurements carried out on a weekly basis in **1987** and on a monthly basis in **1988.** Map **7A** presents first approximation water level contours for the **1987** minimum levels (March 15, **1987);** Map **7B** shows the minimum water levels for **1988** (observed in January), and Map **7C** gives the maximum levels for April **1987.** These may not however, be the true minimum and maximum water levels of the site since the measurement intervals were insufficient in the second year. The relative water level differences between the various piezometers remained the same in most cases, which in turn indicates that the flow directions did not change much from those which have been used to assess groundwater flow (Map 2).

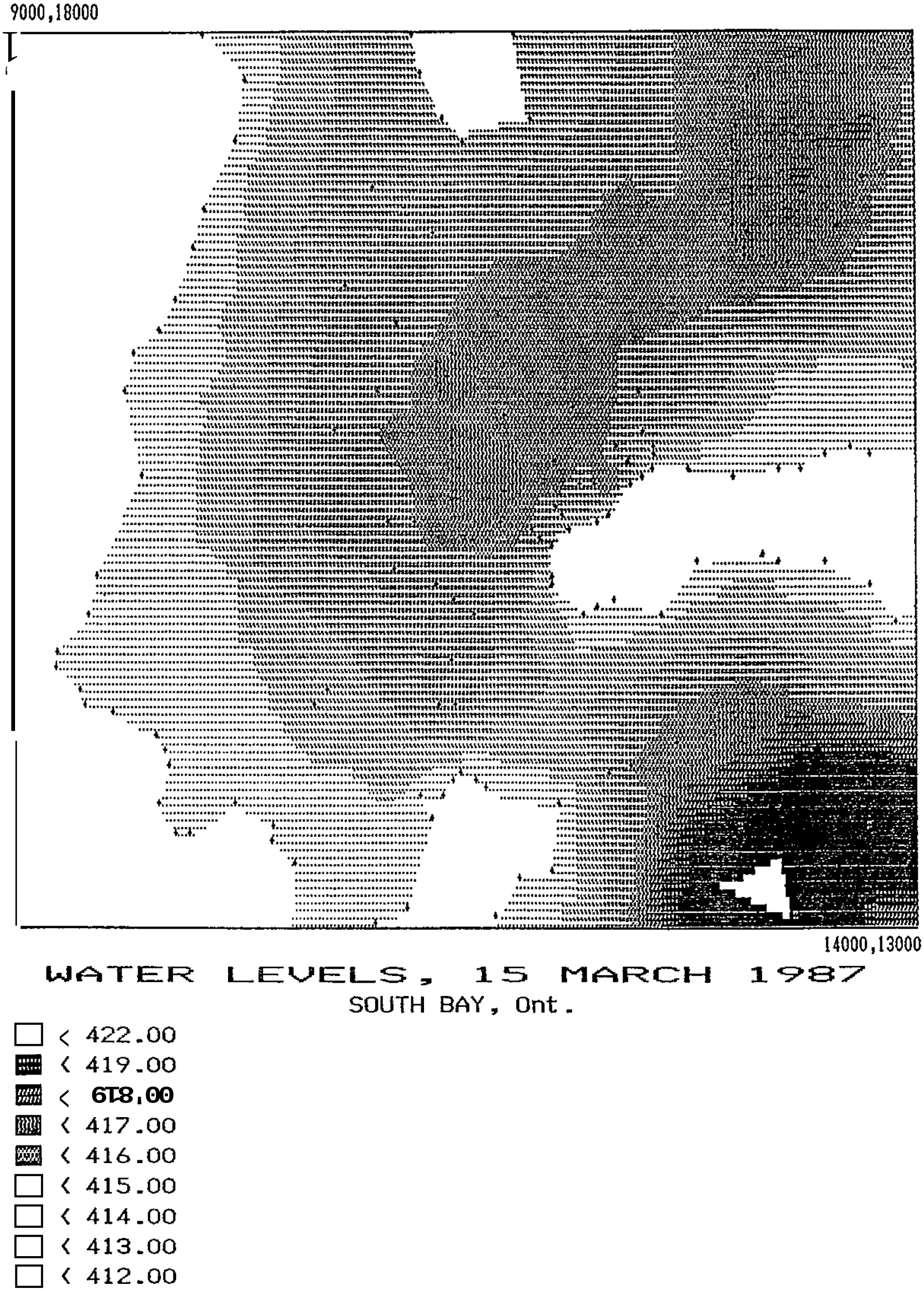
During the period of May 25 - 27, **1987,** a ditch was excavated from the tailings line embankment in a roughly westerly direction through the locations of Piezometer No.s 42, **48** and 49, ending at Piezometer No. 23. Piezometer No. 42 was destroyed in the process (Map 2). The upper portion of the ditch was deepened by a few feet on July **19,** and a large hole was excavated to the water table just beyond piezometer No. 23. On August 12 and August **14,** the ditch was extended by about 150 feet, from piezometer No. 23 to near the edge of the bedrock high, west of piezometer No. **24,** and a bedrock hump near piezometer No. **48** was partly removed. Piezometer No. **48** was destroyed during the later operation.

The min and max water levels given in Maps 7A, 7B and 7C, indicate that the water table in the tailings will fluctuate over the season by about 0.2 to 0.5 m. The implementation of the interceptor ditch to a depth of 1,365 feet, based on the water levels determined in **1987** and **1988,** appears to be effective and was favoured by the fact that **1988** was a year with low precipitation. During the construction of the ditch, the water level was clearly apparent and the elevation of the ditch bottom was at least 1.5 m below the water table at the time of construction (Plate **4).**

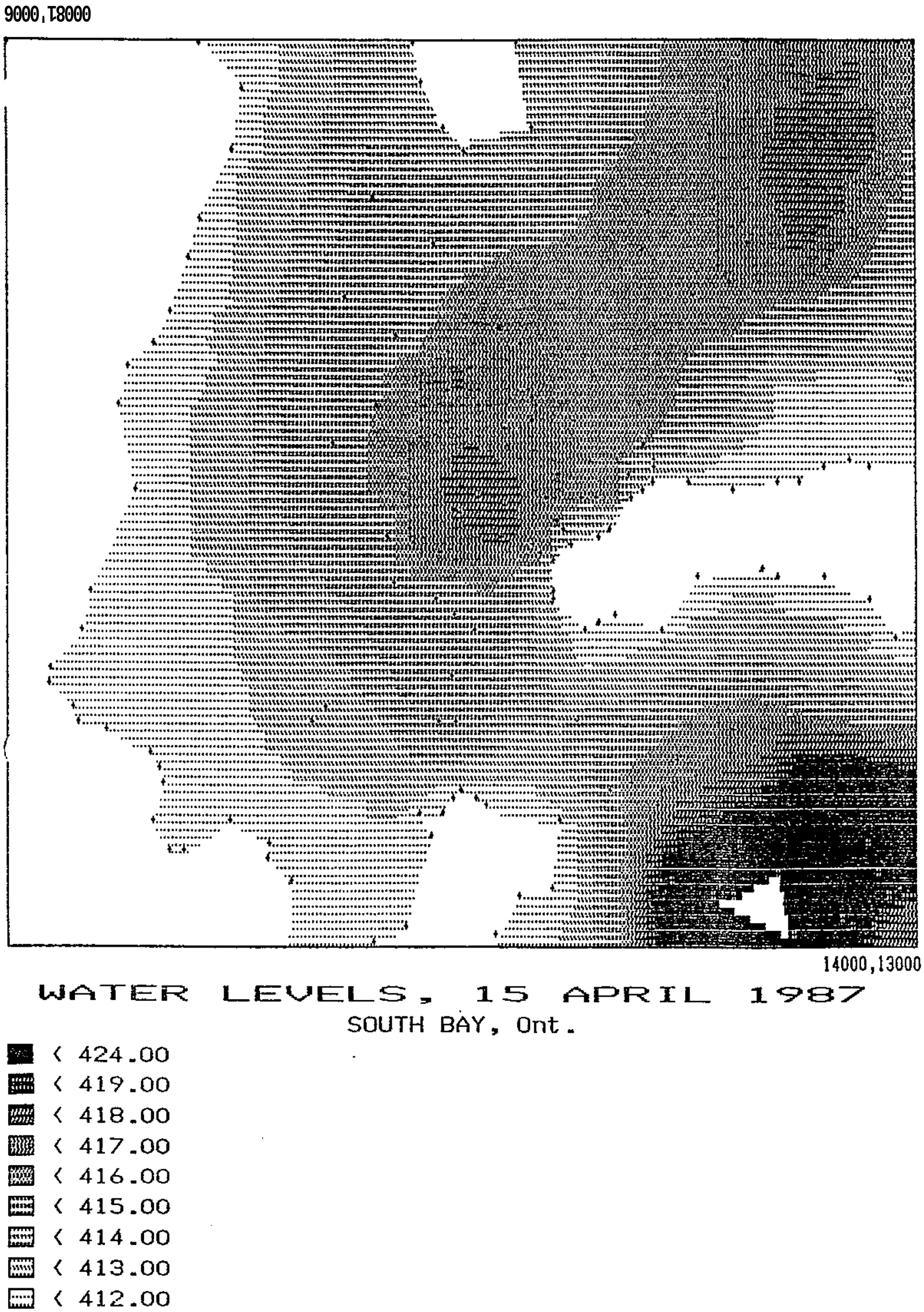
To monitor the effectiveness of the interceptor ditch, the piezometers in close proximity to the ditch were evaluated. Only piezometer No. **49** has shown any immediate effect of the excavation of the ditch, by a drop of 0.22 m in its water level. Effects on the water levels in other nearby piezometers were expected to be both smaller and delayed, due to the relatively low permeability of the aquifer materials: the effects appear to have been largely obscured by the general downward trend of the water levels in the area since the first week of June, 1987.

Plate 4: Aerial view of the upper portion of the interceptor ditch with seepage emerging into the ditch from the tailings

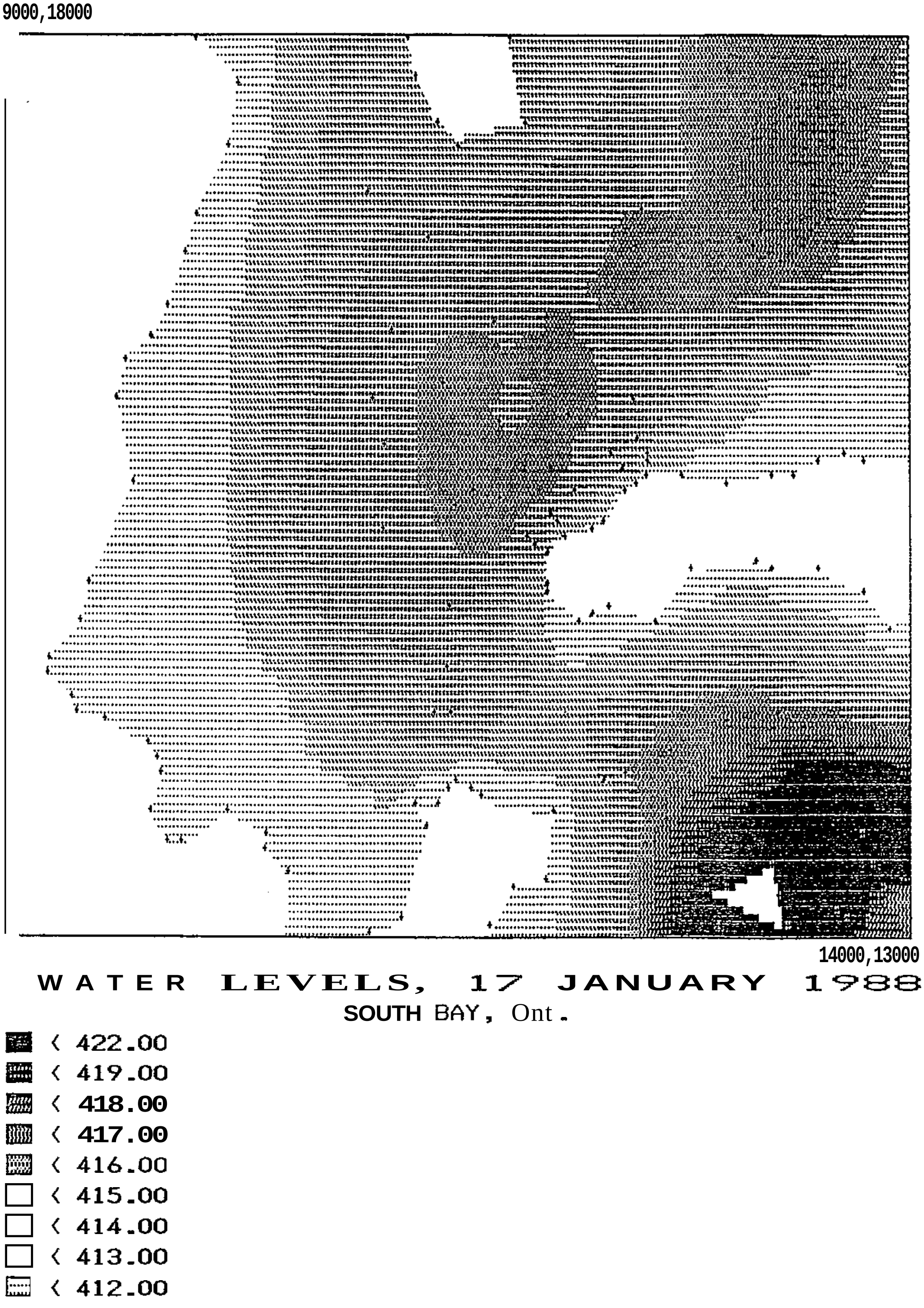
The generally lower groundwater levels observed during the 1987/1988 season, as compared with observations during the 1986/1987 season, could reflect either the influence of the ditch system established in the summer of 1987 or, more likely, lower precipitation amounts.



Map 7A: Water levels recorded from piezometers on March 15, 1987



Map 7B: Water levels recorded from piezometers on April 15, 1987



Map 7C: Water levels recorded from piezometers on January 17, 1988

Precipitation of iron hydroxide does occur as the tailings seepage is exposed to the air. The precipitation process will be further enhanced by the mixing of the seepage water with uncontaminated ground water drawn into the ditch from the other side. Neutralization is expected to occur through the addition of this uncontaminated water.

The settling pond at the lower end of the interceptor ditch will facilitate the completion of the precipitation step, allowing settling of the precipitate. A neutralizing buffer can be established through the introduction of a Chara population. Such a population has colonized a seepage path leaving the tailings in the northern direction. Chara populations accumulate calcium and magnesium carbonate on the outside of their cell walls during growth, and in this way serve as a buffer to the expected acidification.

To date, the transplanting of Chara into the polishing pond has not been successful, as the sedimentation load from the ditch to the polishing pond has been extensive. Erosion control measures (seeding the banks of the interceptor ditch) were carried out in 1988, but due to the dry weather, only the part in which the ground water emerges could be covered with grass. Thus, the sediment loading to the polishing pond remained heavy, covering the transplanted Chara and producing water with a low light transmissivity (murky water). The ditch will be seeded in early spring 1989, and transplanting of Chara will initiate the establishment of a population in 1989. For this measure to be effective, a solid population of Chara has to be established, prior to severe acidification of the polishing pond, as the algae require neutral waters for growth.

The water characteristics of the interceptor ditch and the polishing pond have been monitored since the construction of the ditch. In Table 13, the data are presented for pH, electrical conductivity values, as well as the concentrations of Cu, Fe, Pb, S and Zn.

TEMP.	26.5	28	18	25.8	22.5	25.6	22	23	24
pH.	6.6	3.74	6.9	6.04	7.07	6.58	7.2	6.5	6.74
COND.	470	760	110	424	690	560	800	600	460
Element (mg/L)									
Cu	(0.01	3	<0.01	(0.01	0.03	0.02	(0.01	<0.01	0.02
Zn	0.02	35	0.1	(0.01	0.4	0.6	0.4	0.6	0.5

The sampling locations in the interceptor ditch are given in Map 6. In general, the pH values are between 6.0 and **7.0,** with only one sampling location where the pH was acidic, with **3.7.** This sample had the highest sulphur and metal concentrations, compared to all other water samples collected in the interceptor ditch.

Although the data on the interceptor ditch represents those conditions prior to the effectiveness of the erosion control measures, they indicate that the processes precipitation/ acidification followed by neutralization are occurxing. The formation of iron hydroxide precipitate is depicted in Plate 5.

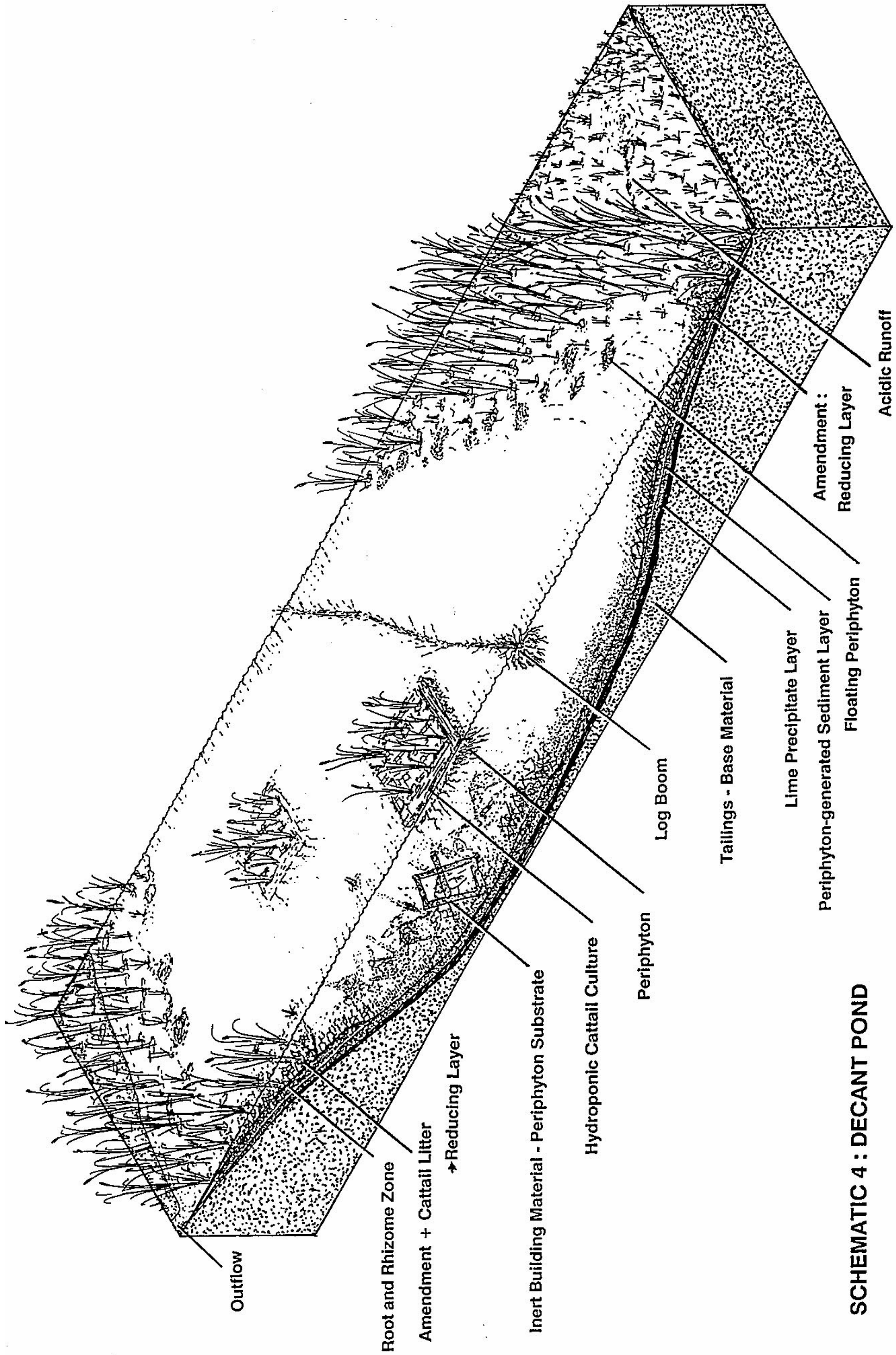
Throughout the summer, attempts were made to quantify the iron hydroxide/jarosite precipitation as this would be an opportunity to confirm the estimates made previously for the southwest groundwater seep. It is expected that this seep will produce **36.1** t of iron hydroxide per annum, along with 1.4 t of Zn. However, a quantification was not possible because of the repeated covering of the precipitation layer by sediment.

Plate 5: Precipitate in the lower part of the interceptor ditch

During the feasibility study in 1986, the introduced vegetation cover of the tailings area was assessed in detail. As were the conditions of the fill and tailings layers below the vegetation. It was determined that the type of vegetation or cover had no significant effect on the acidic tailings layer below, with the possible exception of some areas where an indigenous moss cover dominated.

Although the results of fertilization of the vegetation cover indicated that its above-ground biomass could be increased, such increase was not considered sufficiently beneficial to justify its use as a measure to significantly reduce infiltration of water to the tailings layers below and thereby affecting the acid generation in the tailings. Similar conclusions were derived from a study of other acid generating tailings by Veldhuizen, Blowes and Siwik **(1987).** It follows, therefore, that the existing acid generating conditions from the tailings will remain and acid run-off and seepage will continue to reach Decant Pond, potentially acidifying this water body. During operation and prior to the implementation in **1986** of Ecological Engineering measures, liming of this pond was carried out two or three times per year. As a result, the sediment of Decant Pond consists of extremely fine precipitate formed during the years of liming of the pond.

The pond is shallow (max depth 1.5 m), and its sediment contains about 1 to **3%** Zn. Mobilization of the metals from these fine sediments through acidification from the tailings should therefore be curtailed, despite the fact that the Mud Lake drainage basin naturally provides extensive dilution and polishing capacities. Accordingly, a system has been implemented, as described in Schematic 4.



SCHEMATIC 4 : DECANT POND

This system requires implementation of the following measures:

- Microbial sulphate reduction for the seepage from the tailings to Decant Pond
- Expansion of the cattail cover over the pond: and
- Surface area for biological polishing.

4.3.1 Microbial sulphate reduction for the seepage from the tailings

Reducing conditions are to be created through the placement of straw amendment in the acidic seepage areas along the tailings beach. A microbiological assessment carried out by Dearborn Environmental on samples of straw placed on the beach of Decant Pond in 1988, collected in May, 1989, revealed that sulphate reducing bacteria have colonized this location. The straw addition in both Mill Pond and at the beach stimulated the presence of alkalinity generating micro organisms (sulphate reducers, iron reducers and ammonifiers).

4.3.2 Expansion of the cattail cover over the pond

Cattails were transplanted along the shore of Decant Pond. The results of three years' growth of both the hand and mechanically transplanted cattails are summarized in Table 14. Both methods show increases in the number of shoots for most locations along the tailings beach, with the exception of one location (8), where the number of shoots decreased. This location is close to the dump site for inert material from the dismantling of the building (wood, rubber, insulation, etc.), and was affected by this activity.

Cattails have naturally colonized all other beaches of the Decant Pond, and cattail growth, quantified by the number of shoots per meter square, has been monitored since 1986. In Table 15, the counts for 8 quadrats in the natural stands are given, and in Map 5, approximate locations are indicated. Comparing the transplanted cattail shoot density to that of the natural stands along the beach, it may appear that the transplanted populations are slightly denser than the natural populations. This is expected, as the transplanted cattails along the shore are not subjected to the same water level fluctuations as those on the naturally colonized shore. The water long this beach is generally deeper than along the other shores. It is likely that colonization along the beach was not occurring due to wave action and water depth.

Table 14: Cattail counts /m^2 from mechanical and hand transplants around Decant Pond

QUAD #	# PLANTS 03-Jun-86	14-Aug-87	PERCENT CHANGE FROM START	14-Jun-88	PERCENT CHANGE FROM START
1	42	60	43	101	140
2	17	51	200	48	182
3	65	110	69	95	46
4	31	30	-3	54	74
5	12	22	83	26	117
6	12	36	200	28	133
7	12	26	117	26	117
8	12	12	0	10	-17

**NOTE: 1-4 were mechanical and 5-8 were by hand

Table 15: Cattail counts /m^2 of non-transplanted areas of Decant Pond

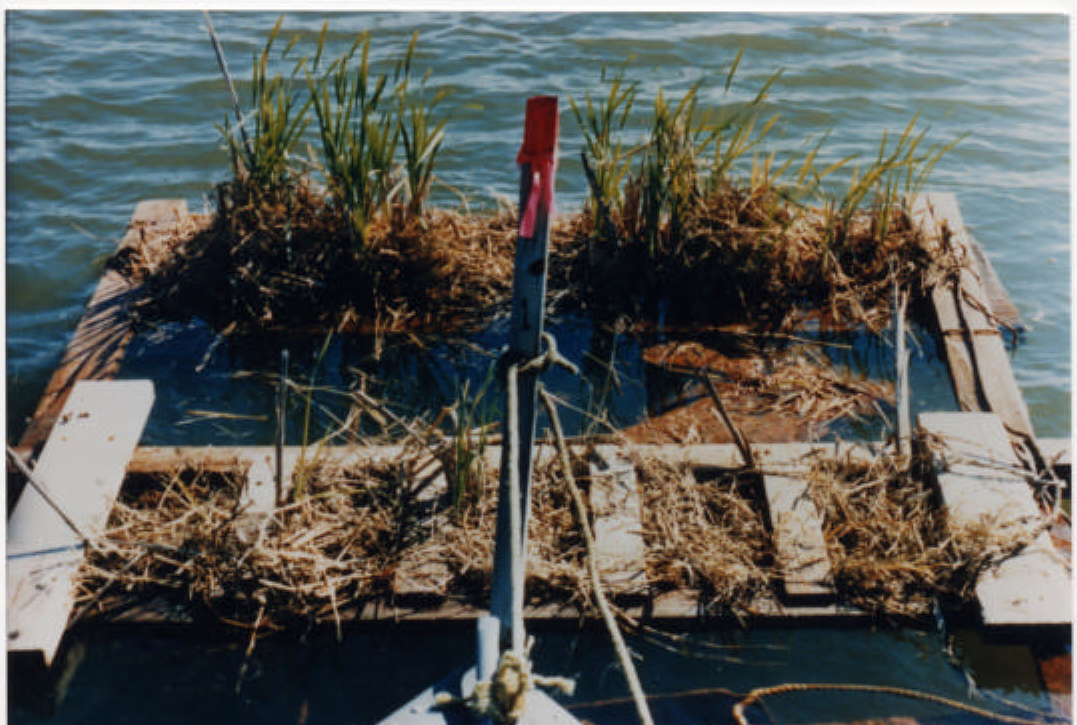
QUAD #	# PLANTS 22-May-86	21-Jul-86	PERCENT CHANGE FROM START	31-May-87	11-Aug-87	05-Oct-87	PERCENT CHANGE FROM START	14-Jun-88	PERCENT CHANGE FROM START
1	27	34	26	26	37	30	11	47	74
2	22	34	55	16	26	25	14	32	45
3	13	22	69	22	22	19	38	23	77
4	26	41	58	20	19	26	0	25	-4
5	16	30	88	16	23	18	13	11	-31
6	9	10	11	3	5	2	-78	(dry) 4	-56
7	13	13	0	17	20	19	38	9	-31
8	18	16	11	24	20	21	17	15	-17

In order to develop an effective vegetation cover over Decant Pond, measures had to be taken to increase the natural colonization rate of the cattails. A log boom was placed across the pond in the spring of 1988 (Plate 6), containing a total of 28 hydroponic cattail rafts, which were placed in the pond. Two hydroponic rafts were placed in 1986, and 26 followed in 1987 (Plate 7), as the overwintering results of those placed in the previous year were evaluated. The survival over the winter and the growth noted in the 1987 season encouraged an increase in the number of rafts in the pond. In June 1988, the number of cattails in both hydroponic populations was counted and an average of 16 cattails are growing in each raft. In five rafts, cattail seedlings had germinated. The results indicate that the creation of cattail islands in the centre of the pond has been achieved. The placement of a log boom is expected to encourage cattail growth in the pond.

Monitoring stations for the advancement of the edges of the natural stands were set up in 1988, and their locations are indicated in Map 5. Although between June and August 1988 an average of only 3 cattails were found outside the marked edge area, the edges are advancing.

Plate 6: Aerial view of log boom across Decant Pond

Plate 7: Hydroponic cattails after 2 years of overwintering



The main factor controlling cattail stand expansion is the water level and water depth (Kalin 1987, Morton J.F. 1975, and others). Therefore, the cattail cover will increase as an accumulation of the periphytic material reduces water depth.

4.3.3 Provide surface area for biological polishing

Decant Pond was used as a depository for all building materials which are expected to be inert and therefore non-contributory to the metal loading of the pond. This material, particularly insulation and wood, was found during the feasibility study, to provide excellent growth substrate for periphytic algae (Plate 8). Quantification of these polishing agents, consisting mainly of an algal complex dominated by Oscillatoria and Navicula spp. has been made.

In Table 16, the concentrations of metals (Cu, Fe, Pb, S and Zn) in the algal mats collected from different growth substrates are summarized, along with the concentrations in 4 sediment samples. Some estimates were made of the biomass produced per square meter or per kg of growth substrate. A comparison of the Zn concentrations found in the algal material with that found in the sediment clearly shows that the algal material contains higher concentrations of Zn, ranging from 2 to 4%, compared to 0.8 to 1%

Zn in the sediment. The same holds true for Fe and Cu, where the concentrations in the algal material are generally higher by the same order of magnitude. As expected however, the sulphate concentrations are higher in the sediment than in the algal material as they represent precipitates of calcium sulphate produced by liming.

Plate 8: Algal mats growth on insulation material in Decant pond.

	Substrate												Substrate				Sediment			
	Rope			Top of Hydroponic				Side of Hydroponic					Trees				East of Beach >1cm	Inside Boom 0-1cm	West of Beach 0cm	West of Beach >1cm
Days of Growth	90	801	801	65	801	801	65	65	801	801	801	801	?	?	104	104				
Jelly Biomass (g/m2)	79	85	194	89	185	67	30	44	54	44	52	64	169	130	27	73				
(g/kg)													606	138	190	481				
Element (%) (ppm)																				
Cu	0.93	0.76	0.91	0.98	0.79	0.98	1.09	0.91	0.71	0.73	0.02	0.55	0.55	0.83	0.56	0.55	0.1	0.59	0.18	2973
Fe	11.04	8.73	10.87	12.08	10.84	11.56	12.65	10.73	8.85	7.29	7.43	6.43	10.75	10.22	7.17	7.22	3.6	6.53	15.18	9.08
Pb	0.027	0.026	0.026	0.03	0.035	0.025	0.029	0.023	0.02	0.016	0.004	0.019	0.087	0.019	0.014	0.01	0.051	0.227	0.058	0.141
S	0.092	0.184	0.182	0.268	0.176	0.178	0.182	0.183	0.09	0.091	0.064	0.092	0.092	0.184	0.084	0.091	3.561	3.34	0.092	0.297
Zn	3.95	5.05	4.55	3.58	3.17	3.55	4.09	3.47	3.05	3.26	0.08	2.68	2.39	3.4	3.51	2.47	1.09	1.96	0.92	0.89
L.O.I. %	33	48	40	12	38	35	36	38	41	52	48	53	30	36	52	55	21	17	27	17
Moisture %	8	8	9	11	12	11	9	9	10	9	9	8	8	8	7	9	1	2	8	1
Wet Volume	60	32	37	74	160	160	28	38	51	68	54	58			230	250				

Table 16: Concentrations of Cu, Fe, Pb, S and Zn in algal mats growing in Decant Pond and in sediments

5.0 The effectiveness of the implemented measures

The previous sections described the Ecological Engineering measures implemented in the three drainage basins which contribute to the contaminant loadings leaving the site. The data discussed describe the natural processes which will remove the contaminants from the water and confirm that they are present and functioning. The biological polishing agents - attached algal groups, submerged moss carpets and cattail covers - together with the creation of conditions which promote microbial sulphate reduction (under investigation in other Ecological Engineering projects), will reduce the sulphate and metal loads leaving the site to Confederation Lake.

At this early stage, after implementation of the measures, the system is only just beginning to function. The data collected during this phase and presented in this section, indicate the expected trends of the system and attest to its effectiveness in the long term.

The metal and sulphate removal capacity of the system will depend on the rates at which the processes employed occur. Those are the growth rates of the biological agents, the rate of sulphate reduction, the rates of adsorption, co-precipitation and precipitation of metals, and the rate at which the contaminants are produced in the three drainage basins. To enable a determination of some of these rates, data have been collected. Quantification of biomass of the polishing agents has been carried out for the algal material growing on the brush cuttings from Boomerang Lake. The results are presented in Figure 2, expressed as algal biomass weight per kg of growth substrate, versus the number of days the material was suspended.

As discussed earlier, absolute growth rates and the resulting total accumulation of biomass cannot be obtained, as abrasive wave action continuously strips biomass which settles to the sediments. If the accumulation process is dependent on growth, then after the winter months a comparable quantities of biomass should be attached to the branches in the spring. The assumption is made that the amount of biomass relegated to the sediment is, on average, the same throughout the year. However, the quantities of biomass determined per kg of substrate suspended (both air dried in an oven at 60°C) indicate that an incremental increase in biomass is noted after about 180 days of suspension (Figure 2).

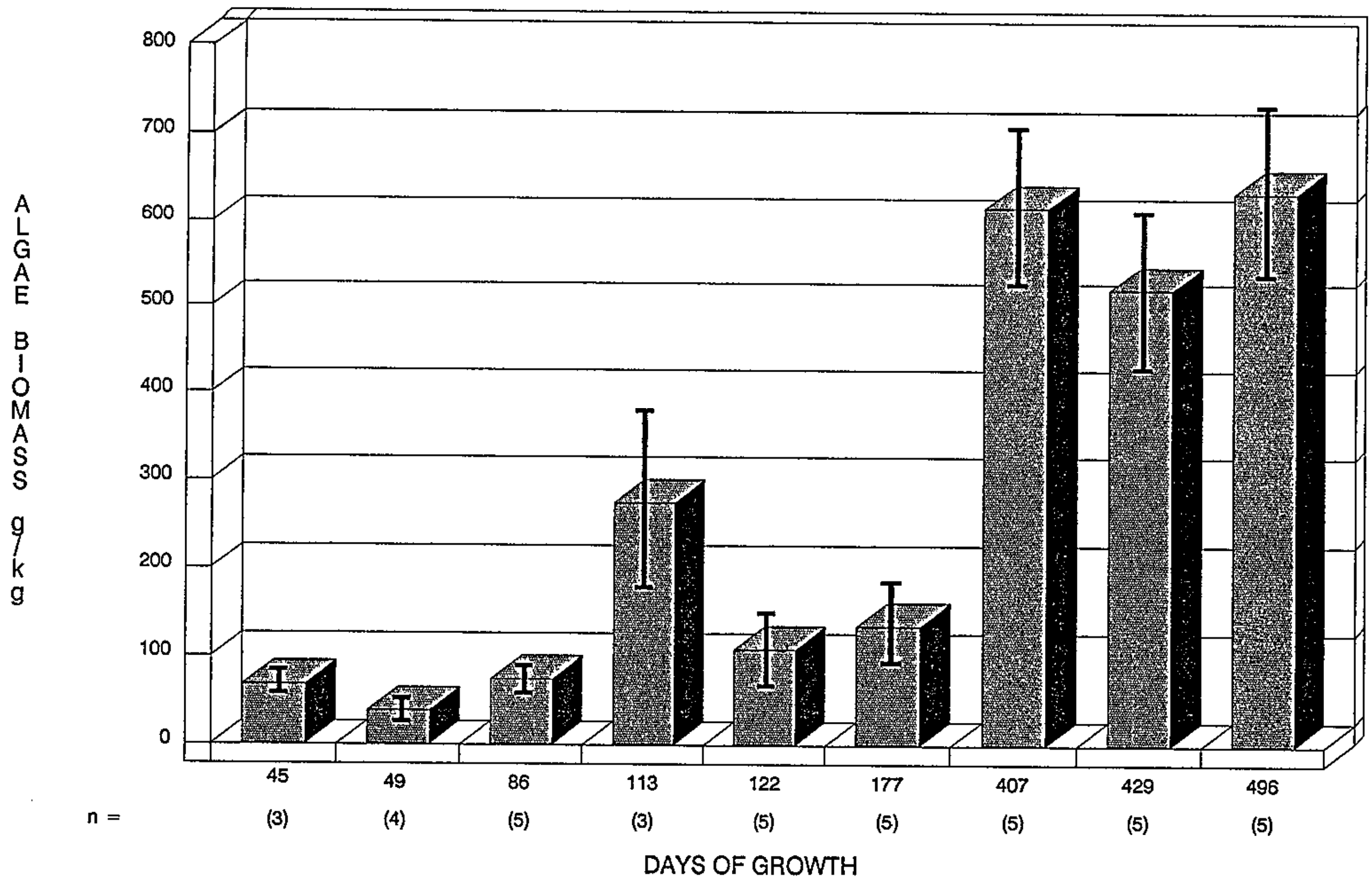


Figure 2 Algal biomass growth estimated on tree branches for various times of suspension.

This suggests that the removal process is not only dependent on growth alone, but involves adsorption processes which are likely related to a continuous process of accumulation of iron hydroxide. Therefore, the material on the branches has accumulated as a result of two processes - growth during the growing season, and adsorption. The biomass accumulation on the branches is clearly higher after the second growing season, as it has increased from less than 200 g/kg to around 500 g/kg in the second year.

An estimate was made with respect to the total growth substrate which might be provided by a spruce tree of similar dimensions to those used as part of the brush suspended in Boomerang Lake. About 200 branches were counted on a tree of about 10 m tall, and one branch produced about 200 gr of growth substrate (branch and needles) dry weight. One tree, therefore, can be expected to produce about 40 kg of growth substrate without the trunk. In the long term it can be expected that the needles will fall off the branches. For the estimates therefore, the tree trunks will subsitute for the loss on needle surface area. One tree can accordingly be estimated to provide substrate for about 8 kg of biomass in the first year after placement, which will increase to 20 kg in the second year. It would be reasonable to assume that 500g/kg growth substrate is a realistic estimate for the long term, as more biomass on a branch would probably be removed by wave action.

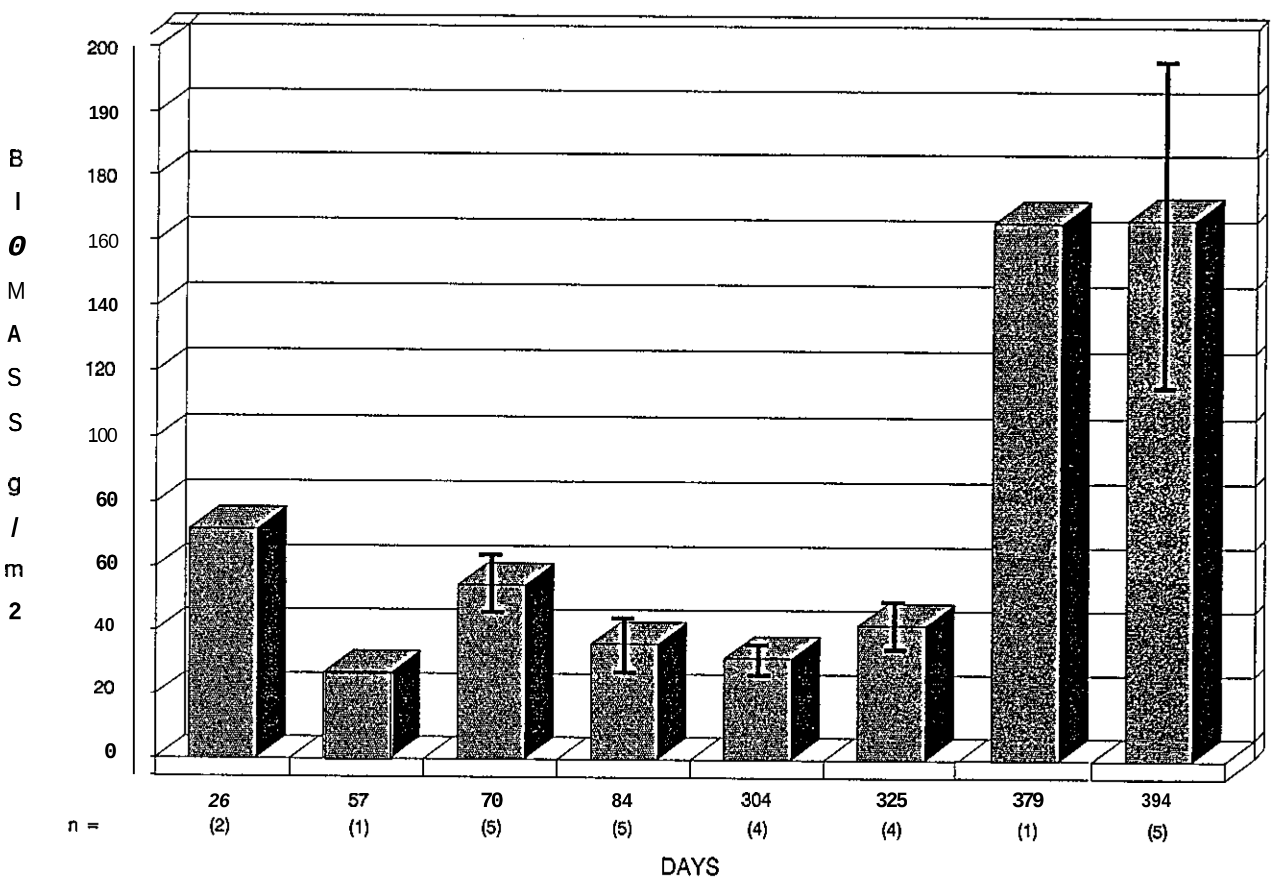
These 8 kg or 20 kg of biomass contain about, on average, 4.2% iron, 0.02% Cu, 0.003% Pb and about 0.05% Zn after one and two years of growth, which concentrations increases in the long term to 16 % iron, 0.1 % Cu, 0.02 % Pb and 0.6 % Zn (Table 10 a, b and c.). This would mean that about 4 to 10 grams of Zn can be removed by the branches of one tree in the beginning of the functioning of the polishing system, and in the long term, an increase of Zn removal can be expected to be in the order of 120 g/tree suspendend in the lake.

If the polishing capacity is evaluated purely on the basis of trees suspended, it is apparent that for the removal of the annual loading of zinc to Boomerang Lake, ranging from 1.4 to 2.5 tonnes per year, about 10 to 15,000 trees would be required. However, there is no doubt that these calcualtions based on tree units represent and underestimate of the growth substrate provided by the brush behind the log booms. The number of trees susbended in Boomerang lake behind all the log booms has not been estimated and is considered at the present time sufficient. The perfomace of the system will be measured by the water quality achieved in the long term.

The quantification of the growth rates of the aquatic moss is not as complicated as that of the algal biomass on brush. The emergent biomass is harvested attached to a moss bag and can therefore be measured per unit area. The ability to filter particulate matter will increases as the moss strands increase in height. This hight can be expected to exceed 1 m, based on measurements made in the lake studied in Northern Saskatewan. Only the tip of the moss strand continues to grow and the older parts of the strand remain in the reducing zone over the sediment. In Figure 3, the biomass quantities of moss which has been growing for different lengths of time are presented. The biomass quantity determined after two growing seasons is significantly higher than that obtained within one growing season. This increase may in part be due to the adhered material on the non-growing parts of the moss strands, but on the other hand it is expected to increase, reflecting continued growth in the second year. After the establishment of the moss carpet, the growth rates per unit area should however, be relatively constant during the growing season.

The rate of growth the first year following introduction of the moss was about 0.4 to 0.8 $g/m^2/day$ and in the second growing season about 1.5 $g/m^2/day$. Moss bags which were harvested in spring after overwintering displayed no growth during the winter as expected, with a negative growth rate of 0.02 $g/m^2/day$.

Figure 3: Moss biomass per m^2 growing for various periods of time



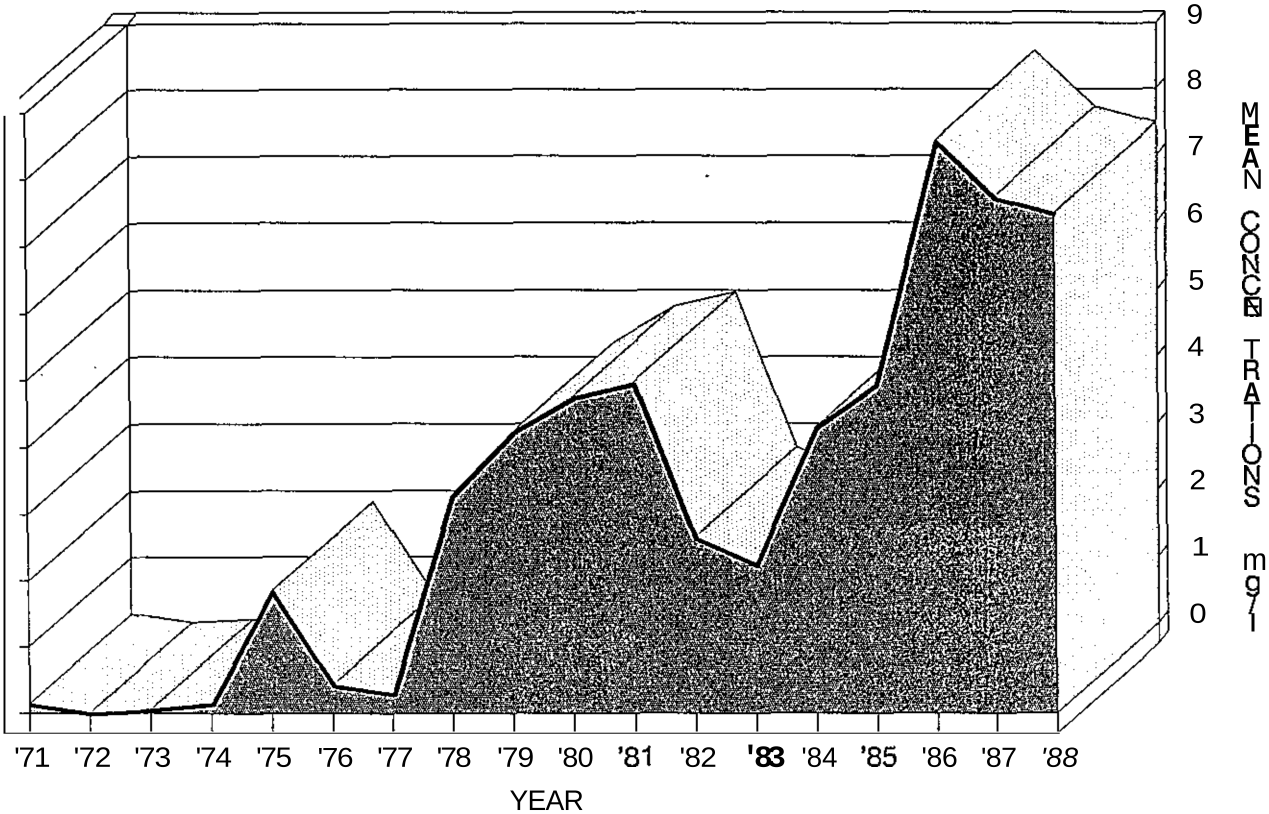
Although the moss carpet is not expected to provide a significant polishing capacity, a brief evaluation of the uptake is carried out. It is reasonable to assume that the moss carpet growth rate would be around 1.5 $g/m^2/day$. Thus, each year, within a 5 month growing season, about 225 g/m^2 of new moss can be expected. This value is somewhat lower than growth rates determined for the same moss species in laboratory studies. Those ranged from 20 to 170 g/m^2/month or 100 to **850** g/m^2 for **5** months (Kalin & Buggeln, **1986).**

Assuming that the lower growth rate applies to Boomerang Lake, each year, in 1 m^2, the new moss biomass of about **150** g will remove about 7.5 g of iron, and 0.02 g of Zn, based on the concentrations determined in the moss (Table 11). From these concentrations it can be seen, that the moss carpet does not contribute significantly to the polishing capacity of the system. However its role of providing reducing conditions over the sediments in the lake is essential for the performance of the system.

These estimates of the polishing capacity of the system have been obtained from the average values determined during the establishment phase of the system at a time when functioning at full capacity could not be expected. Once growth is progressing the moss carpet has increased in height and the algal biomass has attained those concentrations expected in the long term, the system will be fully operational. Finally, and possibly most importantly to the system, is the ecological process of recovery which has been initiated with the measures implemented. This overall recovery will be exhibited by an overall improvement of the conditions in the lake. This will be assisted further by the expected reduction of contaminant loading at Mill Pond and through the functioning of the interceptor ditch and colonization by other biota will increase.

The ultimate proof of the effectiveness of the measures implemented can be obtained directly by a determination of the concentrations of zinc in Boomerang Lake. In Figure 4, the zinc concentrations in the lake, since 1971, are given.

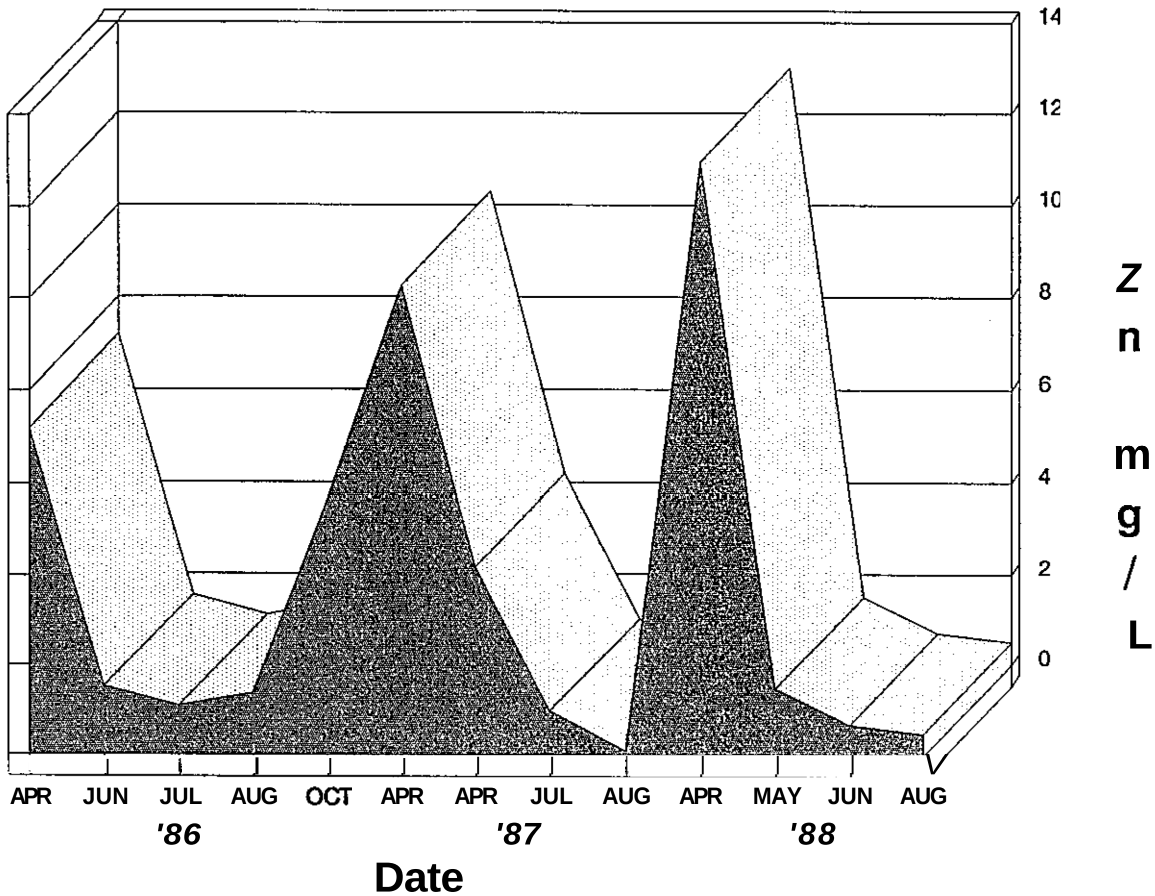
Figure 4: Zinc concentrations in Boomerang Lake between 1971 and 1988



A steady increase in Zinc concentration can be noted up to **1981**, and a decrease by an average of **2** mg/l in **1982**. This decrease is suspected to be the result of liming. The remnants of this liming activity are still noticeable on the lake bottom close to the tailings dam. As expected, the effects of liming are short-lived, and within the same year the concentration of Zn in the lake continued to increase. The **1986** year marked the beginning of the implementation of the Ecological Engineering measures and along with this, a steady decline in the Zn concentrations is evident to date. These immediate effects are likely due to the grouting of the dam between the tailings and Boomerang Lake, as the biological system will only take effect in subsequent years.

An examination of the Zn concentrations in Decant Pond (Figure 5), shows the effectiveness of the biological polishing capacity. In this pond, liming was discontinued in **1986**. High concentrations of metals found in the algal mats which were growing in the pond suggested that these mats could function as polishing agents. This system, having already been established, only needed improvement of capacity by increasing the surface area on which algal mats could grow.

Figure 5: Zinc concentrations in Decant Pond after liming had ceased in 1986



This is different from the conditions present in Boomerang Lake were . The natural polishing system was effectively in place and functioning. The zinc concentrations in Decant Pond water dropped drastically in all three years at the onset of the growing season. During 1987 and 1988, building material was added to the pond. This measure increased the surface area on which algal mats could grow and provide polishing capacity for water quality improvement during the summer.

In Table 16, concentrations of metals are given for the algal material collected from different growth substrates. Clearly, with concentrations of about 3% Zn higher than those of the sediment (1% Zn), these polishing agents are effective. The quantification of growth rates is again complicated, due to sloughing of biomass. Despite this, some quantification has been attempted based on collection of mats on trees placed into the pond for this purpose, and on accumulation of biomass from cleared areas on the hydroponic rafts at different time intervals.

Table 17 presents the growth rates per day, ranging from 0.2 g/m^2 of tree branch/day (surface areas were determined based on measurements of needles and branches, see Appendix), to 1.2g/m^2/day for the top side of the wood forming the hydroponic raft. In a growing season, therefore, the biomass of this algal mat is expected to produce 30 to 180 g/m^2.

Table 17: Growth rates per day of algal mats in Decant Pond on different substrates

New Growth Trees (g/m2/day)			New Growth Side of Hydroponic (g/m2/day)			New Growth Top of Hydroponic (g/m2/day)		
Mean	Std	N	Mean	Std	N	Avg.	Std	N
0.45	0.215	4	0.6	0.097	3	1.28	--	2

If we assume that growth will occur only over the sediment surface area of Decant Pond (50,000 m^2,), a biomass production of 1.5 tonnes to 9.0 tonnes can be expected. As this biomass contains about 3% Zn (Table 18), a polishing capacity of 45 kg to 270 kg is present. However, given that algal mats are attaching to suspended material, the actual surface area present in Decant Pond, providing substrate for growth of the polishing agent, is higher.

The ultimate test of the biological systems will be the water quality, and the decrease of the metal concentrations from the higher concentrations in spring to low concentrations during the growing season, is clear evidence of a system working to sufficient capacity.

6.0 CONCLUSION

This is the first implementation of Ecological Engineering measures to achieve a successful abandonment from an acid-generating tailings area. Without such an on-site demonstration, it would not be possible to determine the actual effectiveness of these measures. The estimates of the contaminant loadings to Confederation Lake indicate that all measures have been taken to protect this water body. The contaminated ground-water plumes leaving the tailings area without being intercepted by a ditch are small and they are not expected to affect Confederation Lake.

It is evident from the success achieved over the past two years that the South Bay mine site can now be abandoned with confidence that the Ecological Systems put in place will continue to control the acid drainage in the long term.

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8.0 APPENDIX

METHODS

1. Organic amendment addition

In the summer of 1986, 1 truck load of saw dust was added to the outflow area of Mill Pond. A front end loader was used to bring the material to the site and the material was then manually distributed. In 1987 three further truck loads were added to the pond. In 1988, straw bales were distributed on the site. Approximately 60 bales to Mill Pond, 120 to Decant Pond beach and 6 bales in each of the cells of Harold's Dam. The bales were broken and distributed by hand.

In 1987, brush was pushed into Harold's Dam retention structures. In both 1987 and 1988, trees were felled in the early spring and placed behind log booms on the ice on areas in Boomerang Lake.

2. Cattail techniques

Racks constructed of wood and fishnetting were floated in Decant Pond. Individual cattail roots/rhizomes were then suspended in the fishnetting. Half of the racks constructed contained sphagnum moss as a substrate to protect the cattail roots. In June 1988, straw was used as a replacement for the sphagnum that had washed out. Large hydroponic racks were anchored in place, while smaller ones were allowed to draft freely to the shore of existing cattail stands.

3. Periphytic algae techniques

Algae covered branches were collected from both Boomerang Lake and Decant Pond. Branches were cut and then floated or lifted into a plastic bag. All samples were maintained at a low temperature prior to processing. Processing of the jelly entailed washing the periphytic algae from the branch with a hand-pumped water spray bottle and physical manipulation. Branch bark and needles were separated from the algae by sieving the sample through a fine mesh screen.

Algae samples were then settled for at least 12 hours in graduated cylinders. The volume of algae was recorded before decanting the liquid. As a control against the loss of metals in the supernatant, several samples were collected for analysis. Dry weights of algae, as well as branches and needles were determined after oven drying at 60°. Selected samples were analyzed by ICP for metal content.

The surface area of the branches was determined by dividing the branchlets into various diameter groupings and the length of each branchlet was measured. Measurement of the lengths and diameters of these groups allowed the calculation of the surface area which could be covered by periphytic algae.

The surface area of needles was also calculated by measuring the length and diameter of individual needles. Twenty (20) needles of each spruce and pine were measured for surface area. A conversion factor of 1.0054 cm^2/needle was determined for jack pine and the surface area for spruce was 0.22868 cm^2/needle. The weight of three sub-samples of needles was determined (700, 500 spruce needles, and 1,115 pine needles) and a conversion factor of 0.001 gr/needle was determined for an old spruce. For new spruce needles, the conversion was 0.002 g/needle. New pine needles were found to be heavier than old ones, with *a* conversion of 0.01 g/needle.