ECOLOGICAL ENGINEERING
TESTS OF CONCEPTS AND ASSUMPTIONS ON LEVACK
YEAR 2: CONFIRMATION OF CONCEPTS

BY

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SUMMARY

The experiments for the development of Ecological Engineering methods on the Levack site in 1986 addressed three main aspects:

(1) the covering of pyrrhotite with waste water as well as the promotion of growth and establishment of indigenous species:

(2) the chemical and biological mechanisms at work in the seepages from the tailings: and

(3) improving the surface water in contact with the pyrrhotite.

The results for each of these three aspects are summarized below.

(1) The experiments were based on the results obtained from the investigations carried out in the previous year (Kalin, 1986). The utilization of waste water, indigenous plants and amendments to improve the water quality on the surface of the waste management area and that leaving acid generating waste management areas, are major tenets of Ecological Engineering.

The distribution of waste water was found suitable for amelioration of the pyrrhotite surface, however intermediate size dams were too difficult to construct due to the unstable ground. Seeding of the mine slimes with semi-aquatic indigenous species requires some testing of the methods used to keep the seeds in place. However, the transplanting of cattails proves to be a cost effective method. Cattails transplanted in clumps doubled within the first three months, and those transplanted in 1985 increased by 200% by the end of the growing season.

Observation of moss cover growth over 2 years suggested that two main growth phases exist, early spring and late summer. Fertilization may be effective in promoting growth during these phases. Colonization patterns of vascular plants indicated that straw mulch does not assist in cattail seedling survival but appears to promote the establishment of other vascular plants.

The Chara populations introduced from Timmins indicated growth in the mine water retention pond. The new shoots survived a significant pH depression which occurred during heavy rainstorms. Based on the results obtained from these investigations, a close-out scenario accommodating waste rock, mine water and possible improvements in effluent quality was developed.

(2) The removal of iron at the foot of a seepage, concurrent with a pH decrease described in detail in 1985, was confirmed. The iron accumulation in the grass pool appears to be a process which has taken place over a considerable period of time, given that the wetland is accumulating organic matter. In areas of medium to dense grass growth of the pool, 35 to 40 kg of iron precipitate (dry weight) have accumulated, along with 3 to 4 kg of organic matter per square meter in the grass pool. The biomass provides a surface for iron precipitation and it is therefore essential to determine the growth behaviour of the grass, particularly in those areas where the grass is sparse.

Experimental cells have been built at the foot of the seepage creek to initiate tests for removal of metals from the acidic water resulting from iron removal. Some indigenous species have been introduced and appear to have grown. The chemical data collected in the cells serve as background for future work.

(3) The sulphate concentrations in the pre-bog acid creek cells which had received various organic amendments to assist in improving the chemical conditions of this extremely acidic water, consistently increased from June to September in all cells, regardless of the type of amendment made to the cells. Metal concentrations did not show any consistent trends due to amendments, however treatment with fodder produced a striking colour change. The clear coloured water is presently explained by the reduction of ferric iron to ferrous iron. It is postulated that the reduction is mediated by microbial action, with the possible involvement of a synergistic population of bacteria consisting of two distinct populations. One group of bacteria which might provide a nutrient source for the reducing population was identified.

In summary, it can be concluded that the results of the cattail transplant experiments and the work on the promotion of indigenous species, in conjunction with the use of waste water, warrant application of the methods developed. The results from the work on Biological Polishing of seepages and extremely acidic water strongly indicate that the objectives for improving water quality by the use of self-sustaining Ecologically Engineered treatment systems have progressed beyond the conceptual stage.

ACKNOWLEDGEMENTS

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1. INTRODUCTION

The Levack tailings area has been the focus of research activities since 1984. The site consists basically of a pryyhotite surface with mine slimes forming a fan and meandering in channels of mine water and sandplant water, leaving to the mine water pond. A detailed description of the site and the work carried out to date has been given in a report entitled 'Ecological Engineering Tests of Concepts and Assumptions on Levack; Year 1 Ecology' (Kalin, 1986).

Various experiments have been implemented which aim to develop Ecological Engineering procedures. The approach is to utilize and promote indigenous plants to improve water quality on the tailings and water leaving the tailings. The procedures will be particularly applicable for close-out and abandonment of tailings areas when waste water treatment facilities are to be withdrawn.

Some results of the work carried out during 1985 are relevant to an understanding of the objectives defined for the 1986 work, and have been summarized below.

1) Boomerang Dams: Sealing of pyrrhotite surface with waste water and the promotion of organic matter development

In several areas on the Levack site, different introduction and expansion methods for indigenous species to acidic and alkaline conditions were tested. The growth of the transplanted cattails, as well as the response of mosses and cattail seedlings to various amendments, were encouraging.

Different distribution systems for waste water were tested. A stream system, consisting of half-moon shaped ridges, referred to as Boomerang dams, were found suitable for the distribution of mine slimes over the pyrrhotite surface.

The objectives of the **1986** program were therefore:
a) to test the scale-up of the Boomerang dam concept: b) evaluate the changes in waste water characteristics due to sealing of the pyrrhotite surface with mine slimes and sandplant suspended matter: and c) further address the promotion of organic matter production in extreme alkaline water-saturated conditions. With respect to the promotion of organic matter, the investigations focused on factors which might affect the transplanting of cattails and the distribution, as well as the perishing, of the mosses and cattail seedlings. Finally, since considerable growth of introduced Chara had occurred in **1985** which was followed by a sudden, unexplained kill of the shoots, further tests with Chara were warranted in the mine water pond.

2. Seepages from tailings: If self-sustaining treatment systems for seepage water resulting from tailings dams could be developed, they would assist water quality control in many situations

were continuous recycling is presently required or where treatment of the water is not feasible from an economic standpoint. In an area referred to as Seepage Creek, the possible role of filamentous green algae as biological polishing agents was investigated in 1985. The algae were found to provide a large surface area for precipitation of iron. Significant removal of iron was noted to occur consistently over three sampling periods in 1985.

The objectives in 1986 were therefore to confirm the chemical behaviour of the Seepage Creek and investigate further parameters of the iron removal process. Experimental cells containing the acidified water with reduced iron concentrations were built at the end of the seepage to initiate development of a biological polishing system to reduce sulfates and metals in the water.

3) Pre-bog acid creek: Pyrrhotite surface water improvement tests: During 1985, test cells were created by damming water in a pyrrhotite erosion channel with dams to produce a constant supply of surface water quality representative of that of creeks and or puddles in contact with pyrrhotite. These extremely acidic conditions (pH 2.5) with iron concentrations of 1000 to 2000 mg/l, sulphate concentrations of 4000 to 6400 mg/l and acidities which can be as high as 15,400 mg/l, certainly qualify as the worst type of surface water associated with pyritic inactive tailings. Nevertheless the water is colonized by attached algae, namely Euglena mutabilis, which suggests that this water is not

an entirely abiotic condition.

Measures which could lead to improvement of these water characteristics would clearly lead to reducing the contaminant load originating in those conditions where contact of the surface with pyritic material cannot be avoided.

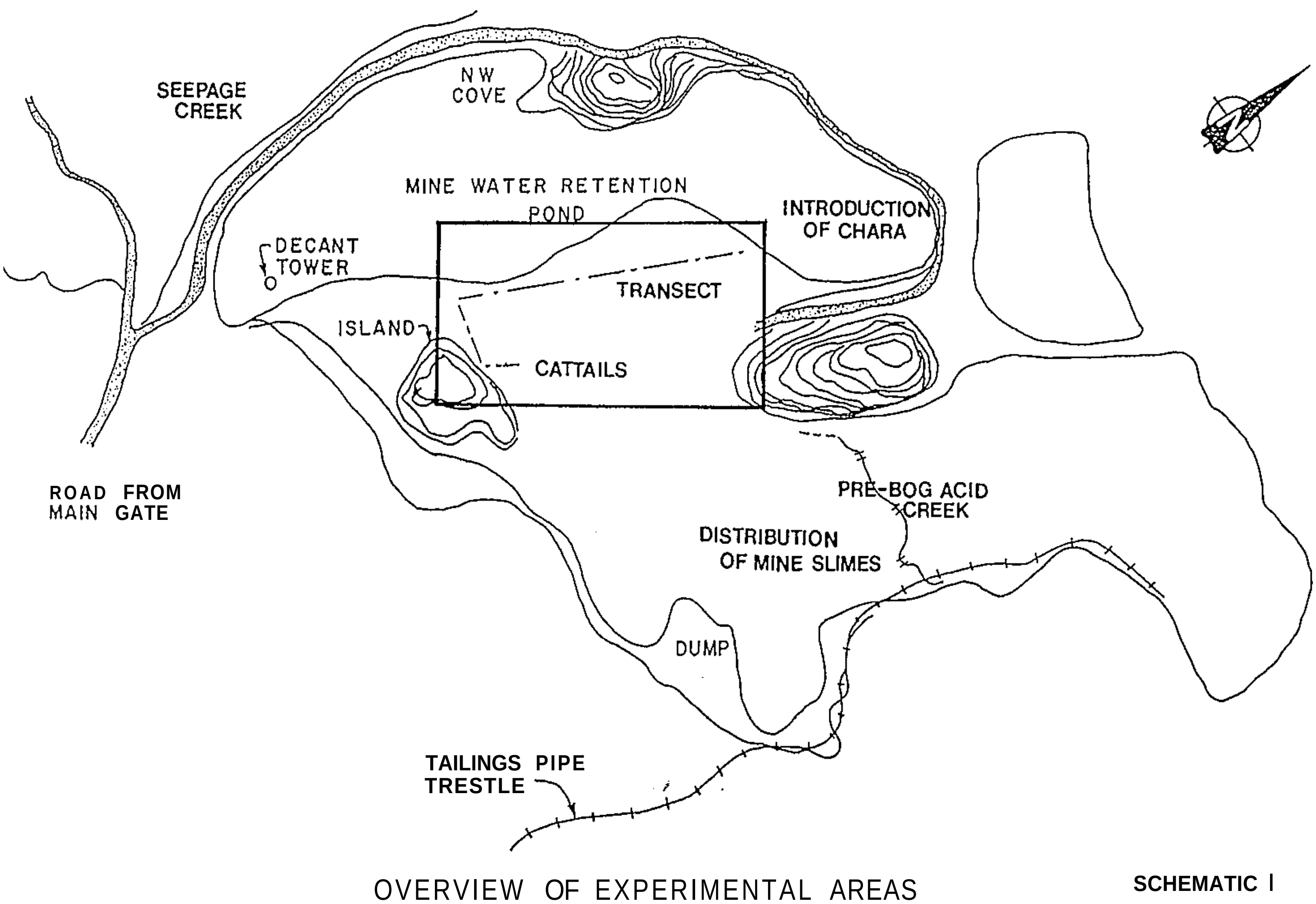
In this area, referred to as pre-bog acid creek, the objective of 1986 was the testing of different organic amendments and an evaluation of their potential as materials to assist in the altering of the conditions so as to facilitate the introduction of acid tolerant wetland species.

2. METHODS

The locations of the 6 experimental areas on the Levack site are given in Schematic 1. Details of the methods have been given in the previous report and only a brief description is given below of the main aspects of the work.

2.1 Distribution of mine slimes over pyrrhotite

The half-moon shaped boomerang dams were to be constructed out of broken pyrrhotite by a tractor with a rear mounted blade. Seeding was carried out by seeds contained within cheesecloth bags which were fastened with stones to the mine slimes. Clumps of cattails



Schematic 1 Overview of experimental areas

and sedges, consisting of rootstocks and the upper green portion of the plant were placed into the mine slimes in a manner that ensured that the green portion was upright.

2.2 Chara introduction tests

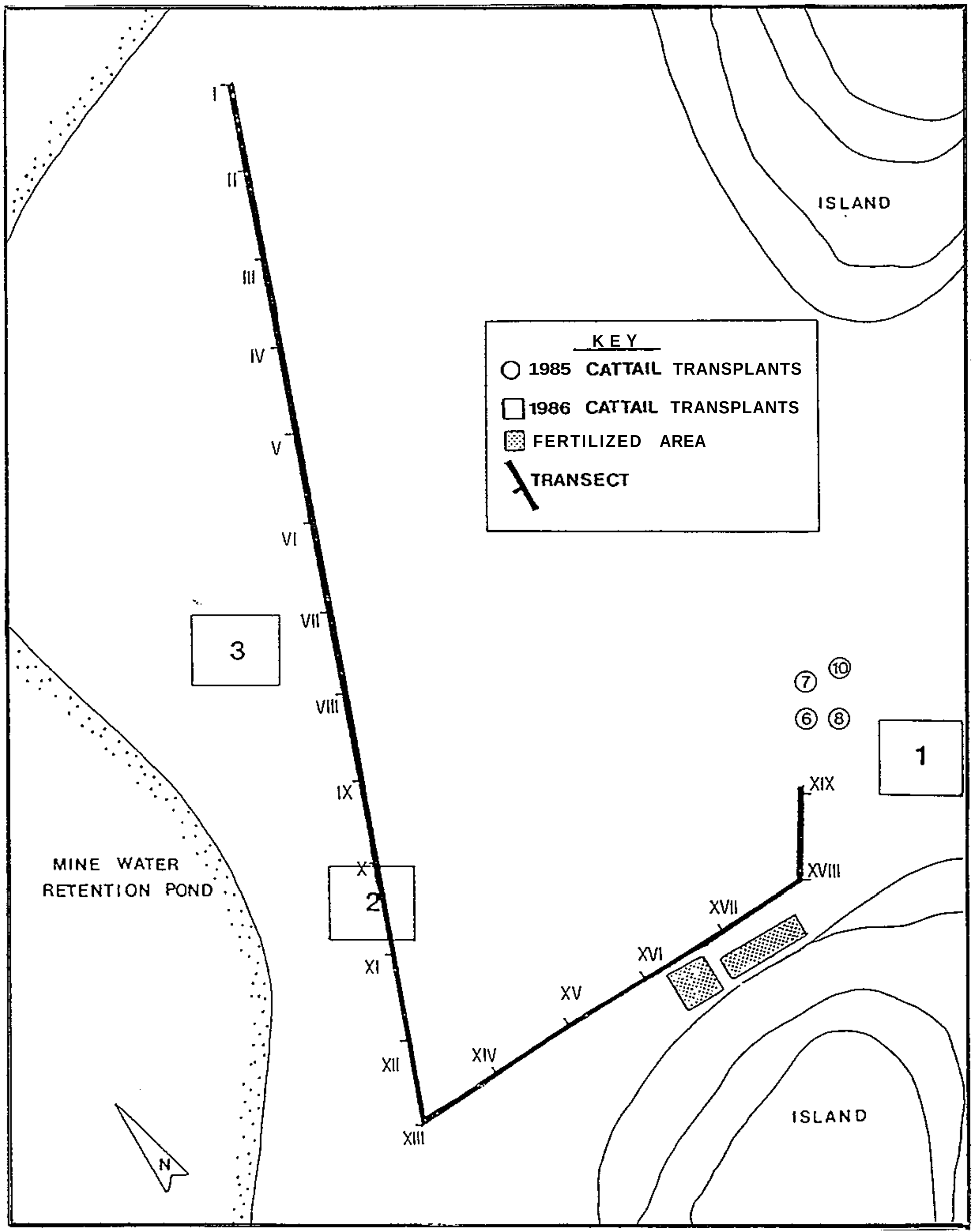
Wire racks covered with onion netting of 0.5 m^2 were filled with Chara plants from two different locations in the Timmins area (Langmuir and Schumacher). The rack is filled with plant material to about 2 cm thickness. These racks are then placed on the mine slimes which form the sediments of the mine water pond. The Chara racks are marked with a styrofoam float. Observations on growth were made on one rack of each introduced type by recovering the rack. On the remaining 10 racks, visual observations were made but the racks were not disturbed throughout the growing season.

Within a 2 x 2 m frame, consisting of 2 x 4 wooden planks fixed into the sediments of the mine water retention pond, 2 coolers full of Chara (not contained in racks) from a third location in Timmins (Hollinger) were introduced by trampling the plants into the mine slimes.

2.3 Cattail growth and transplanting

Cattail growth was assessed by counting overwintered plants, new plants and measuring their heights. Transplanting was carried out by excavating rhizomes with the green portion of the plant. Clumps of cattails, containing on the average 2 to 5 plants, were transported in buckets and immediately transplanted in three experimental areas (Schematic 2). The three areas differed in the degree of water saturation, exposure to drought and presence or absence of volunteer cattail colonization.

The transplanting depth was kept as shallow as possible, not exceeding 25 cm. The cattail clumps were secured into the mine slimes with footsteps in those areas which were not too water-logged. Each clump of the transplanted populations was mapped with reference to the transect line along the mine water retention beach (Schematic 2).



Schematic 2 Locations of fertilization and cattail transplant pots

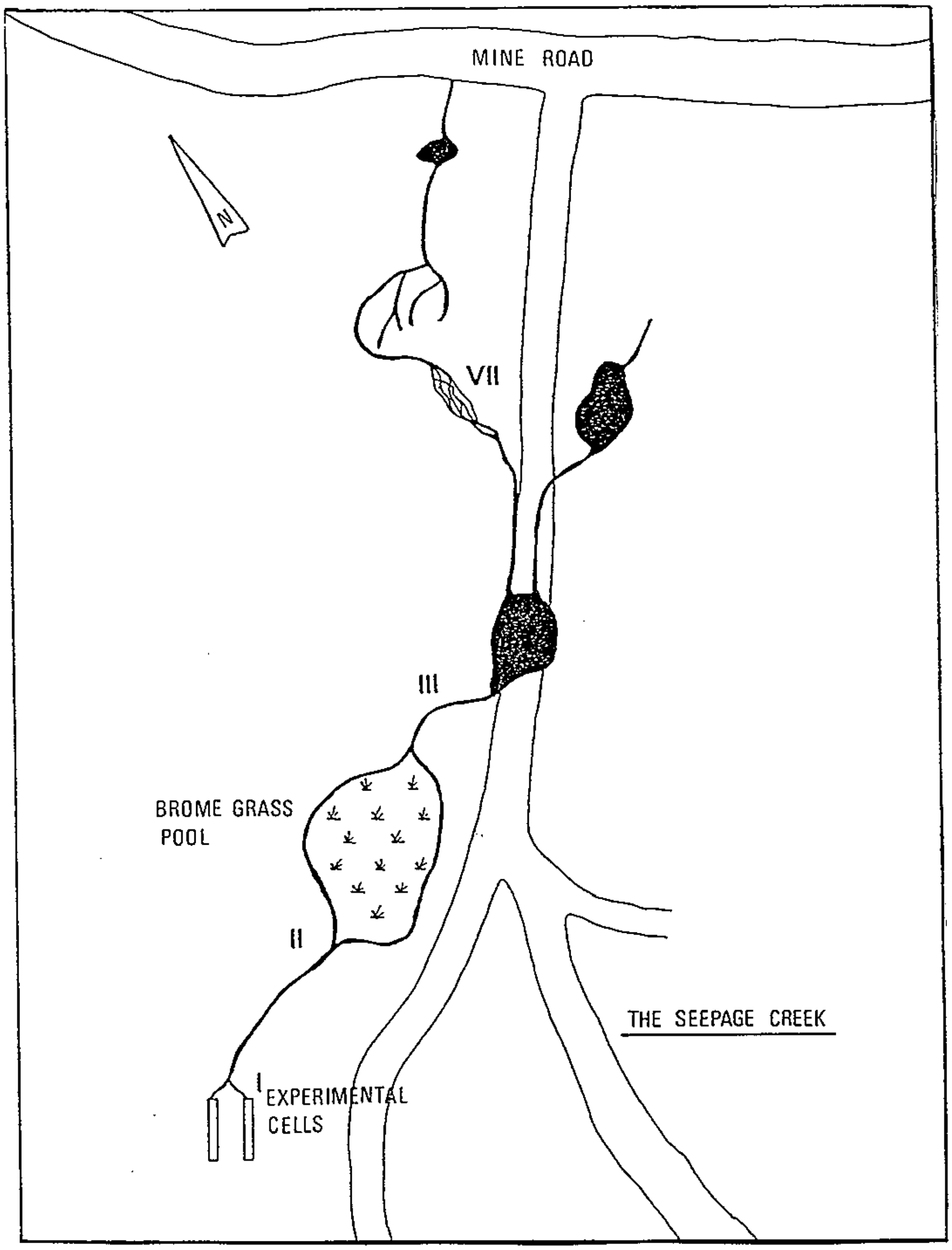
2.4 Indigenous species distribution and survival

The percentage cover along the transect was estimated for bare tailings, moss cover, cattail seedlings and sorrel in July and September. Areas of 300 m^2 were fertilized with a hand operated fertilizer spreader along the transect, with light application of fertilizer (6-24-24) (app. 40gr/m^2). Further fertilizer applications were carried out along the section of the transect running along the island (Schematic 2) which differs in the degree of shading compared to the other transect section. Seven areas of approximately 10x10 m were selected with different degrees of shading and different degrees of indigenous vegetation cover. Two types of fertilizer applications were made: heavy, consisting of 20 kg/ 100 m^2; and light, 12.5 kg/100 m^2.

Fertilizer was also applied on approximately 55 m^2 (300gr/m^2) of the moss amendment experiment which is located in close vicinity to the mine water and sandplant discharges (Schematic 1).

2.5 Seepage behavior and experimental cells

The seepage creek characteristics of all stations were described and water sampled in May to determine if changes had occurred during the winter month. In subsequent month, water was sampled only from stations I, II , III and VII at monthly intervals The locations of the sampling points, the precipitation pool and the experimental cells are given in Schematic 3.



Schematic 3 Locations of the seepage creek sampling stations and experimental cells

The iron precipitation section (brome grass pool) was assessed in relation to areas with dense, medium and sparse alive grass cover. Estimates of the required sampling size for below-ground matter and precipitate were derived by inserting a tailings pipe cylinder of 30 cm diameter to the bottom of the precipitate layer. The entire sample was separated by washing the precipitate through a mesh, thereby separating precipitate and dead organic matter. Based on the dry weight estimates from this first sample, sediment cores of 5 cm diameter were found adequate for assessing various areas within the pool, with different above-ground densities of live grass. Several cores for each surface type were collected.

The precipitate was separated by washing with tap water through a Taylor mesh, collecting the washings in a bucket. Water was evaporated slowly to obtain a air dried precipitate. Dead organic matter was also air dried. Dry weights were measured to the nearest 5 grams.

Above-ground live grass cover was collected in the beginning of the growing season in May and in July. Grass was cut in approx. 0.25 m^2 areas, air dried, and weighed to the nearest 5 grams.

2.6 Pre-bog acid creek amendments

The pre-bog acid creek was equipped with curtains of cotton blankets, manufactured by Verdiol, normally used for adsorption of oil spills, to contain the amendments . The location of the experimental cells is given in the overview (Schematic 1). The amendments were entered at once into the cells after some testing of settling behavior indicated that most materials were floating for at least 24h. The amendments were distributed in the cells in an attempt to establish a sequence of denser application to lighter application. The water depth, length and width of experimental cells and the type of material used are summarized in Table 1.

Table 1: Description of pre-bog acid creek cells

Cell code	Cell Dimensions length m	width m	Water depth cm	Colour	Amendment added
AO	5	2.0	20-50	red	none
A3	5	2.5	40-50	red	peat
B1	17	1.5	30-40	red	fodder
B2	3	2.0	20-40	red	fodder
B4	71	2.0	50-70	red	none
C1	45	1.0	10-30	red	woodwaste
c4	43	3.0	20-25	red	overburden

Water was sampled prior to application of amendments, followed by monthly sampling intervals. During each sampling period, the temperature, pH and conductivity were determined in the field, using a Y.S.I conductivity meter (Model 33) and a Corning Ph meter (Model 103) equipped with a Canlab combination gel-electrode. The pH meter was buffered at pH **4** after every third measurement.

2.7 Analytical methods

All samples were acidified with nitric acid to pH 1 or lower without filtration. Samples for acidity and sulphate determination were neither filtered nor acidified and were analyzed within ***24*** hours of collection. Sulphate and acidity were determined by Assayers Ontario, as well as the elemental concentrations in waters associated with the experimental cell in the seepage creek, by Inductively Coupled Plasma Spectrometry . All other analyses were carried out by Inco Limited Process Technology Laboratory. Those samples collected over the period of June to August were stored at ***4*** $^{\circ}$C until the end of summer shut-down.

3. RESULTS AND DISCUSSION

3.1 Distribution of mine slimes over pyrrhotite

The characteristics of the waste water from the mine and sand-plant which discharges into the mine-water retention pond are summarized in Table 2. The differences noted in concentrations of Ni, Cu, Co, Fe, Mg in water collected in June 1985 and September

1986 are those most likely due to shut-down. The lower concentrations in the mine water are expected during shut-down and the higher concentrations are expected during operation of the mine. Liming requirements differ during these periods, but more importantly these different waste water characteristics result in precipitates with largely different metal concentrations. The water characteristics found in the mine water pond, are however relatively consistent, compared to the differences in elemental composition of the water which runs into the mine water pond (Table 2). This is likely due to the contact with the lime and precipitate in the pond.

The pH and electrical conductivity of the water in the mine water pond was monitored during a period of extensive precipitation in 1986 (Table 3). In June, the pH of the pond was very alkaline, with ranges in pH values of 11.0 to 8.7. These dropped with several severe thunderstorms by the end of July down to pH 3.3. The electrical conductivity does not increase as the water is acidified. This might be due to a reaction of the sulfates with the alkaline precipitate in the mine water retention pond. A hard encrustment was noted, covering the pond precipitates. However, the metal concentrations in the mine water retention pond are subject to fluctuations during precipitation events due to pulses of acidic run-off from the pyrrhotite surface (Table 3).

Table 2 **Alkaline waste water characteristics**

	DISCHARGES				MINE WATER POND			
	MINE WATER		SAND PLANT		SITE I	SITE II	SITE III	SITE IV
mg/L	6/26/85	9/05/86	6/26/85	9/05/86	9/05/86	9/12/85	7/10/86	9/05/86
Al	23.6	65.7	12.8	2.5	2.1	1.1	0.4	1.6
Ca	347.0	402.0	285.0	835.0	333.0	393.0	293.0	334.0
Co	.0	1.5	0.3	<0.006	<0.006	0.02	0.1	0.01
Cu	0.1	18.4	1.0	0.05	0.01	0.02	0.05	0.3
Fe	22.1	171.0	27.5	0.4	0.7	0.8	2.9	0.5
Mg	14.6	100.0	69.5	0.2	9.1	30.3	21.0	11.4
Mn	0.6	3.0	0.8	0.006	0.03	0.1	0.3	0.04
Na	131.0	131.0	129.0	111.0	108.0	145.3	108.0	96.2
Ni	0.4	85.4	23.9	0.03	0.2	0.02	4.7	0.2
P	0.5	1.2	0.5	0.03	0.04	b.d.	<0.01	0.03
Zn	0.2	2.2	0.5	0.3	0.1	0.03	0.007	0.1

LIST OF ELEMENTS BELOW DETECTION LIMITS:

Ag As B* Be* Cd Cr*
Pb* Pt* Sb* Se* Te

Table 3 Seasonal changes in pH and conductivity in waste water

TABLE 3.

(pH IN UNITS, CONDUCTIVITY IN umhos/cm, TEMPERATURE IN C)

LOCATION	DATES 6/20/86	7/10/86	7/18/86	7/29/86	9/05/86
at beach	10.25/-/-	-/-/-	-/-/-	-/-/-	-/-/-
at cattails	9.5/-/-	-/-/-	-/-/-	-/-/-	-/-/-
3rd trans. square	9.5/-/-	-/-/-	-/-/-	-/-/-	-/-/-
cattail trans.	11.0/-/-	-/-/-	-/-/-	-/-/-	-/-/-
site I	11.0/-/-	9.78/2000/23	9.5/1975/21	7.4/1500/20.5	7.2/1500/15
site IV	9.0/-/-	6.97/2100/22	8.5/2100/21.5	3.3/1550/20	6.0/1700/16
200m along road	8.7/-/-	5.00/2100/21	6.7/2100/21	3.3/1600/19.5	6.1/1800/16
corner of dam	8.7/-/-	5.00/2200/23	6.7/2050/20.5	3.1/1750/20	6.3/1700/14
beach at dam	8.7/-/-	5.00/2200/-	-/-/-	-/-/-	-/-/-
decant discharge (on lime)	-	4.7/1700/- 9.1/1850/-	9.0/1900/21	4.1/1400/20	-/-/-
decant tower	10.1/-/-	8.8/2100/24	9.0/1975/21	3.8/1350/21	-/-/-

The water in the pond does not mix well. Run-off forms specific flow patterns leading to point discharges of acid water to the pond. This suggests that after a rainfall a lag time is to be expected during which the water characteristics in the pond will change slowly.

Measurements of the pH and conductivity in the flow channels of the mine water between the discharge from the pipe and the mine water pond were carried out on three occasions (Table 4). The pH fluctuations in these flow channels were drastic, ranging from 10.7 to 3.2 or lower, and similarly large fluctuations in electrical conductivity, ranging from 1000 to 5000 ummohs/cm were measured.

The waste water flows in channels in which a lining of lime precipitate and or mine slimes is formed. However, the reactivity of the water itself and contact with pyrrhotite clearly affects the discharged water immediately upon release from the pipe. The measurements in July were taken during a period of severe thunderstorms, suggesting that general acidification of the water occurs rapidly.

It would appear therefore, that a reduction in the fluctuations of the water characteristics in the mine water pond would not necessarily result from changes in liming activities. Suspended solids which are plentiful in the mine and sandplant water

Table 4 Characteristics of the creeks from discharge to mine water pond

TABLE 4.

(pH IN UNITS. CONDUCTIVITY IN umhos/cm. TEMPERATURE IN C)

MINE H2O	6/20/86	7/18/86	7/29/86	9/05/86
	pH / conductivity / temperature			
discharge	5.23/-/-	5.2/-/-	4.7/1700/15	6.9/2600/15
100m intervals		5.0/-/-		11.6/2200/17
"		8.0/-/-	4.4/1800/15	8.2/2400/17
"		10.7/-/-	4.8/1800/17	10.2/2000/16
"		10.2/-/-	4.8/1600/16	8.5/-/-
green pool		10.0/-/-	4.8/1600/16	9.0/-/-
+ 100m		2.9/1000/-		9.1/-/-
eroded channel	3.73/-/-		4.35/2300/20	
limed pool			11.8/9000/25	
+ 100m		3.2/2200/-		
above trench		2.5/4400/-		
at trench		3.2/5000/19	4.7/2550/23	
10m below trench		3.8/4300/19	5.4/2550/23	
at junction	4.00/-/-	3.4/4250/19	10.4/2450/21	
first branch	5.04/-/-	4.8/2300/18	11.9/3700/21	
at cattails		4.2/2300/18		
+100m		4.1/2500/18		
begin. of trans.		4.0/2300/18.5		
flagged stake		4.3/2300/18	4.3/2400/21.5	
stake 12		4.8/1900/18/5	4.4/2100/21	
stake 8		3.5/-/-	4.1/2450/21.5	
at junction	4.2/-/-	4.5/-/-	4.3/2400/19.5	
second branch	6.3/-/-	5.6/-/-	4.75/1700/19.5	
stand 5		4.1/-/-	4.2/2300/20	
end of cattails		4.5/-/-	4.4/1850/18	
at beach		4.1/-/-	4.4/2100/22.5	

(2.5 to 3.8 g/l) are distributed as a covering over the pyrrhotite surface and would provide some means of obtaining a more consistent water chemistry of the site.

The half-moon shaped Boomerang Dams, tested in 1985, indicated promise in retaining this material to cover the pyrrhotite, however, their construction on a larger scale, using machinery proved extremely difficult. The unstable ground resulted in repeated sinking of the machinery making its use impossible. Dams created in this manner were minimally effective in accumulating mine slimes. However, one diversion into an eroded channel, indicated that within a period of one month large quantities of suspended solids could be accumulated (Plate 1).

Given the difficulties encountered, a scale-up from the small experimental concept to a larger intermediate stage was not possible. However, it is expected that more substantial structures, constructed by a push and fill method, would be effective.

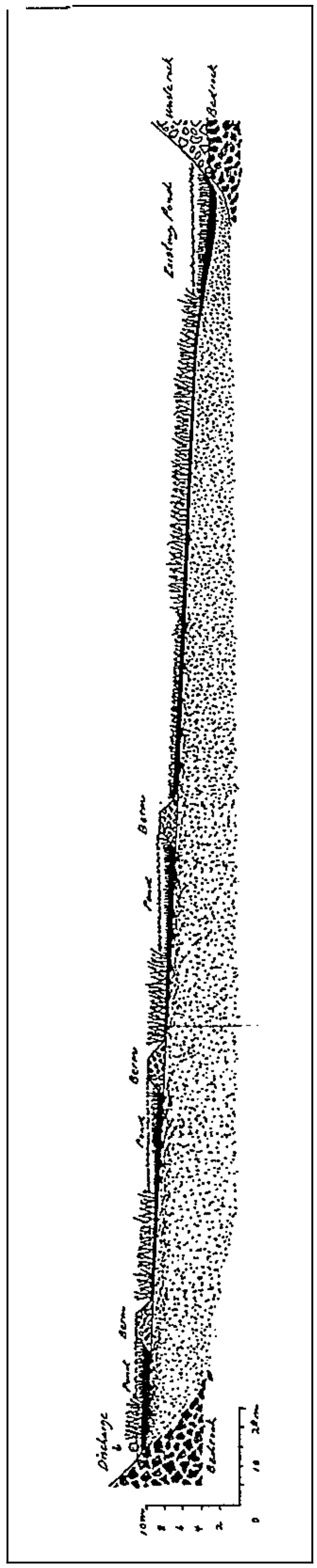
On the mine slimes accumulated behind the dams, transplanting tests of cattails and sedges indicated growth and some overwintering success. Attempts to seed the mine slimes failed since the flow is too strong and the cheesecloth and the seeds get washed away. Those seeds which were retained did not indicate signs of germination.

Plate 1: Suspended solids filling a pyrrhotite erosion channel

The waste water characteristics described in Table 2 to 4, and the indication that the suspended mater settles out over the pyrrhotite and does not alter the water characteristics in the retention pond suggest that an overall stabilization scenario, as outlined in Schematic 4, is likely to be effective in achieving the overall desired effect.

Over a period of several years of continued mine operations, Boomerang Dams, built by push and fill on a larger scale with waste rock, would result in a moist cover of suspended solids over the pyrrhotite. During operation, the neutralized sandplant water and the mine water would provide sufficient moisture so that wetland vegetation, mainly cattails, can be introduced. The cattails, once established, would further assist in retention of mine slimes behind the dams.

In the summer, during shut-down, parts of the site will dry up as the amount of water discharged to the site is reduced. From the existing cattail stands, it appears that a period of drought can be sustained by these plants. The mine slimes appear to have a high moisture retention, or at least sufficient for cattails to survive the dry summer months. The suspended solids in the waste water might ultimately result in sealing the waste rock dams as operation of the mine continues. Some water might therefore be retained behind the dam and would overflow, at which time it should be contained in the second Boomerang Dam. As the waste waters are relatively high in dissolved sulphate (700 to 1600 mg/l), it is reasonable to expect some acidification. The introduction of a layer of organic material onto the settled solids



Schematic 4 Overview of Boomerang Dams and close-out scenarios

to provide isolation, and possibly some amelioration, by preventing resolution of the metals from the slimes, is therefore indicated. This organic layer would be in the form of a wetland/semi-terrestrial vegetation cover. In the long term, such a layer would contribute to the establishment of anaerobic conditions.

In Schematic 4, some features envisaged for a final close-out of the waste management area, are included. Depending on the behavior of the waste water, the Chara process for biological polishing and buffering of the incipient water might be applicable. As the water discharge will cease at the end of the mine operation, the layer of organic matter created from the wetland vegetation would provide a good ground substrate for natural or assisted colonization of terrestrial species.

Implementing this Boomerang Dam concept appears to be an economic approach leading to improved water characteristics leaving the site. It may reduce neutralization costs and save in expenditures required for the final shut-down of the site.

3.2 Chara introduction tests

The Chara introduction tests carried out in 1985, failed to result in persistent growth. The location of the racks was considered to be one of the problems, as well as some unusual fluctuation in pH in the mine water pond during 1985.

On the 28th of June, 1986, Chara from populations growing on abandoned tailings ponds in the Timmins area (Langmuir and Schumacher) were introduced to the north-west section of the mine water pond, adjacent to the gravel pit. New shoots emerged from the racks within the first month after introduction. The amount of growth differed between the populations. More new shoots emerged from the Schumacher populations than from the Langmuir population.

It was expected that these new shoots were unlikely to withstand the drop in the water to pH 3.0, which occurred at the end of July. However by the 14th of October, shoots with, on the average, 1 to 2 internodes long, were healthy.

A detailed microscopic examination of the plants collected at the end of the growing season indicated that indeed the Schumacher plants are healthier than the Langmuir plants. This was expressed by an intact cortex (outer cell layer) on the internodes. The plants were calcified and had developed rhizoids which extended 15 to 20 mm into the sediment. The new shoots from Langmuir, on the other hand, had developed on the average only one internode where the cortex was not intact and no calcification of the plants was noted. The plants introduced by trampling into the sediment in August from a third location (Hollinger), were also alive and healthy in October.

These growth results indicate that the mine water is suitable for further development of the Chara Process and that indeed the plants have the ability to sustain acidification and recalcify. This is certainly an indication that a large Chara population could provide some buffering capacity for waste water.

3.3 Cattail growth and transplanting

In abandoned coal mine areas, establishment of wetlands is achieved through similar techniques used for establishing terrestrial vegetation, accompanied with amendments and fertilization (p.c. Kleinmann, 1987). Based on studies of cattail stands on uranium mill tailings, (Kalin, 1984) it is suggested that establishment of cattail colonies should be possible without amendment and fertilization. Wetlands established without amendments would not only be more cost effective, but would likely provide more secure conditions for perpetual self-maintenance, since the plants are "adjusted" to the waste site conditions.

Hand transplanting was carried out in 1985 along with studies addressing factors controlling stand development and expansion.

The overwintering and growth results are summarized in Table 5. The number of plants which survived indicates that over one growing season growth continued and generally a doubling of the number of plants in each stand had occurred.

Table 5: Hand-transplanted cattail survival and growth 1985/86

Stand #	Number transp.	Number overwintered	Total plants June/Sept.	% Increase over 1 season
6	10	8	18 / 27	238
7	10	9	21 / 27	200
8	10	8	14 / 21	162
10	10	7	16 / 21	200

In a study of habitat partitioning and competitive displacement of cattails by Grace and Wetzel (1981), transplanted rhizomes did not survive in natural stands. These results are in contrast to those obtained from the tailings. The authors interpreted the failure of growth of the transplanted rhizomes due to active competition occurring within the stand. Since the transplanting of rhizomes and upper green parts of the cattails was in areas having no other cattails, the growth of the transplants clearly supports their interpretation.

It is believed that cattails form lateral rhizomes in late fall. In spring the rapid growth is based on the stored resources in these below ground shoots (Grace and Wetzel, 1981). This would suggest that growth in the first year of transplanting, during the early part of the growing season is less likely to result in good growth. In the second year, an increase in shoots should be pronounced, in the absence of competition in a mature stand. The results obtained indicate that indeed growth continues at a reasonable rate and therefore hand transplanting is indicated as an effective method of increasing cattail cover.

Ecological studies in natural cattail stands, i.e. not on waste sites, suggest that the responses to water depth by the two species of Typha latifolia and T. angustifolia differ. In experiments were the water depth was controlled ranging from 15 cm below ground, 15 cm above ground as well as 50 cm, 80 cm and 100 cm determined that T. latifolia was only growing to a depth of 50 cm, whereas T. angustifolia grew in water 100 cm deep. On the shore (-15 to 15cm), T. latifolia was growing and T. angustifolia failed to grow. The water depth at which both species produced biomass was 50 cm (Grace and Wetzel, 1981).

Given these results, it is not unreasonable to expect potential differences in growth of transplanted cattails. The species on the Levack site is likely T. latifolia or the hybrid between T. latifolia and T. angustifolia, namely T. glauca. Whether the mine slime areas differ in degree of water saturation and water availability is not known.

A summary of the cattail transplanting carried out in three different areas is given in Table 6. A total of 206 cattails were transplanted in three different areas of the site. The locations of the transplanted areas 1, 2 and 3 are indicated in Schematic 2.

Table 6: **Summary** of **cattail transplants 1986**

, **TABLE 6.**

TRANSPLANT AREA#	1	2	3
# TRANSPLANTED	39	88	79
TOTAL #S AFTER 2 MONTHS			
HEALTHY PLANTS	74	158	151
NEW SHOOTS	49	82	88
DEAD PLANTS	0	12	16
% INCREASE	190%	180%	191%
AVERAGE CLUMP SIZE	3	2.9	2.7

After two months, in all three areas, the number of plants had doubled, representing a significant increase. The number of new shoots was calculated by subtracting the dead plants from the original numbers transplanted. The fraction of plants which did not survive was highest in area 1, were 14 plants died from the original 39 plants transplanted. Area 1 is an extremely "soupy" section where the cattails were planted as close as possible to the waste water creek. Thus this area is also exposed to fluctuation in pH and conductivity described earlier in Table 4.

An evaluation of the transplants with respect to wetter and drier sections of the other two experimental areas was carried out.

In Table 7, the percentage increase in area 1 is the lowest with 109 %, based on the sum of healthy plants counted in September divided by the sum of the original transplanted plants.

Table 7: Analysis of cattail transplanting locations

TABLE 7.

AREA #	1	2		3	
SOURCE DESCRIPTION	WET	WET	DRY	DRY	
TRANSPLANT LOCATION DESCRIPTION	WET	WET	DRY	WET	DRY
% INCREASE	109	185	171	193	189
% NEW SHOOTS	126	96	88	122	104
% DEAD PLANTS	36	11	18	28	15

However, the percentage of new shoots in this area is necessarily higher, as more plants died in this area than in the other two areas. The same trend is reflected in evaluating area 3, where the percentage of new shoots, being 122%, is very close to that of area 1 (126%), and the percentage of dead plants is also higher with 28 % dead compared to 15 to 18 % dead plants in the drier areas.

The distinctions between wet and dry in areas 2 and 3 are subjective. The degree of water saturation changes over the season, most distinctively noted in the ease of walking/sinking when counting the plants. The differences between wet and dry are very expressed and clear for areas 1 and **3**, but less distinct in area 2, which is indicated by the absence of differences in the percentages calculated for the wet and dry section in area 2. Nevertheless, the results from this evaluation indicate that in the wetter area the percentage of non-surviving transplanted cattails is likely higher than in drier areas. This suggests that more cattails should be transplanted into more saturated areas of the site to achieve higher survival rates.

3.4 Indigenous species cover responses

Germination and growth tests indicated that cattail seeds can be germinated and transplanted to mine sites (Snyder & Aharrah, **1984).** Tests of wetland seed germination, including cattail seeds by Kalin and Bugeln (1985), indicated that alkaline conditions are required and not all types of wetland seeds and cattails will germinate in waste water with the same vigour.

The drastic differences in conditions for establishment of wetland can be appreciated from a brief review of the ecological processes which take place under natural conditions, controlling the growth and development of wetlands.

Germination responses for shoreline species were found to be related to the adult species composition and to the water-depth at which the species occur (Moore and Keddy 1985). Species in undisturbed habitats were found to be competitively superior to those found on more stressful and disturbed shores (Wilson and Keddy, 1985). Wetland seed densities are highest in those areas which are frequently covered and uncovered by water. Expected seed density is in the order of 10^4 seeds /m^2. Water level fluctuations are essential for maintenance and regeneration of wet meadow and marsh shoreline vegetation (Reznicek and Keddy, 1985).

Seed banks for wetland establishment have been evaluated in detail and are categorized into three regenerative groups. Typha belongs to the regenerative group with wind dispersed seeds and is generally considered a very aggressive weed.

However, on the waste sites, the aggressiveness of cattails is reduced to the beginning of the growing season. A dense cover of cattail seeds germinate and establish. Most of the seedlings perish during the dry summer month. Straw mulching applied in spring 1985 prolonged survival of the cattail seedlings. In 1986 the only effects of the mulching was an increased moss cover but no increase in cattail seedling survival.

Given the intensive response of moss growth to fertilization in 1985, fertilization of the moss cover was carried out to promote development to a stage which would be more resistant to survival during the dry summer period. Although the effects of the fertilizer were pronounced until the beginning of July, with a distinctly greener moss cover, the desired initiation of sporophytes from the protonemata stage was not obtained. In Plates 2 and 3 the effects from 1985 fertilization are depicted for the moss cattail seedling cover and can be compared to the effects still noted one year later. Although the effect of the fertilization in 1985 is evident, the promotion of growth is not effective enough to classify it as a satisfactory result.

That a growth response, as drastic as that observed in 1985 was not noted, must be due to solid ecological reasons, probably connected to growth cycles. An analysis of percentage moss cover data along the baseline transect in 1985 and 1986 does yield some definite indications that the time of the fertilization application might be of key importance. In Tables 8(a) to 8(d), the cover estimates are given for the months of July and September for both years, comparing the bare tailings estimates to those of the moss cover. The data for each post station consists of 6 m^2 plots, for a total of 16 posts, i.e. a transect 96 m length (Schematic 1). An increase in moss cover which decreases the bare tailings coverage can be consistently observed in both years for 7 posts (Posts III, IV, V, XII, XIII, XIV and XV) and for 3

Plate 2 Fertilization of moss cattail seedling cover, 1985

Plate 3 Effects of fertilization one year later, 1986

Table 8(a) **Baseline transect data posts II to V**

LEVACK BASELINE TRANSECT DATA - MOSS COVER AND BARE TAILINGS
Represented in percent cover within 1 square metre

STATION POST: II

Cover		Quadrat No. 1 July	1 Sept	2 July	2 Sept	3 July	3 Sept	4 July	4 Sept	5 July	5 Sept	6 July	6 Sept
Bare Tailings	1985	45	60	98	98	95	100	98	83	99	100	100	100
	1986	24	17	35	15	88	90	90	70	60	40	90	95
Moss	1985	0	0	0	0	0	0	0	0	0	0	0	0
	1986	0	0	0	0	10	0	0	0	0	0	5	2

STATION POST: III

Cover		Quadrat No. 1 July	1 Sept	2 July	2 Sept	3 July	3 Sept	4 July	4 Sept	5 July	5 Sept	6 July	6 Sept
Bare Tailings	1985	98	98	40	45	70	70	30	40	50	65	85	80
	1986	87	50	60	35	49	15	60	25	23	33	39	35
Moss	1985	0	0	1	50	0	30	0	25	0	25	0	0
	1986	0	25	10	25	45	75	40	75	30	35	5	25

STATION POST: IV

Cover		Quadrat No. 1 July	1 Sept	2 July	2 Sept	3 July	3 Sept	4 July	4 Sept	5 July	5 Sept	6 July	6 Sept
Bare Tailings	1985	95	99	100	100	100	100	85	52	70	65	100	93
	1986	80	75	95	93	99	90	50	19	64	75	99	89
Moss	1985	0	1	0	0	0	<1	0	35	10	30	<1	5
	1986	19	25	5	5	<1	5	25	50	25	25	0	5

STATION POST: V

Cover		Quadrat No. 1 July	1 Sept	2 July	2 Sept	3 July	3 Sept	4 July	4 Sept	5 July	5 Sept	6 July	6 Sept
Bare Tailings	1985	100	50	100	75	99	93	99	28	100	78	100	98
	1986	97	95	70	40	80	50	75	55	55	60	60	25
Moss	1985	0	50	0	20	0	5	0	70	0	20	0	0
	1986	2	5	15	30	5	25	15	10	20	10	20	30

Table 8(b) **Baseline transect data posts VI to IX**

LEVACK BASELINE TRANSECT DATA - MOSS COVER AND BARE TAILINGS
Represented in percent cover within 1 square metre

STATION POST: VI

Cover		Quadrat No. 1 July	1 Sept	2 July	2 Sept	3 July	3 Sept	4 July	4 Sept	5 July	5 Sept	6 July	6 Sept
Bare Tailings	1985	95	100	65	95	25	95	20	58	95	95	100	100
	1986	98	17	92	15	100	90	99	70	94	40	100	95
Moss	1985	<1	0	10	0	<1	0	40	0	0	0	0	0
	1986	1	3	5	10	0	<1	0	15	5	30	0	10

STATION POST: VII

Cover		Quadrat No. 1 July	1 Sept	2 July	2 Sept	3 July	3 Sept	4 July	4 Sept	5 July	5 Sept	6 July	6 Sept
Bare Tailings	1985	75	85	50	100	80	70	100	100	100	100	100	100
	1986	82	70	90	63	98	57	100	85	99	88	97	70
Moss	1985	<1	0	<1	0	<1	0	0	0	0	0	0	0
	1986	15	25	5	30	<1	40	0	10	0	5	2	25

STATION POST: VIII

Cover		Quadrat No. 1 July	1 Sept	2 July	2 Sept	3 July	3 Sept	4 July	4 Sept	5 July	5 Sept	6 July	6 Sept
Bare Tailings	1985	90	100	75	100	25	100	100	95	100	80	100	90
	1986	100	95	100	98	55	34	98	92	100	97	85	55
Moss	1985	<1	0	10	0	5	0	0	0	0	0	0	0
	1986	0	5	0	2	20	30	<1	5	0	2	10	30

STATION POST: IX

Cover		Quadrat No. 1 July	1 Sept	2 July	2 Sept	3 July	3 Sept	4 July	4 Sept	5 July	5 Sept	6 July	6 Sept
Bare Tailings	1985	70	100	5	100	90	100	92	100	99	100	100	100
	1986	69	40	78	63	90	57	85	55	98	80	99	92
Moss	1985	<2	0	90	0	10	0	5	0	1	0	0	0
	1986	20	30	5	25	5	30	5	35	<1	15	<1	3

Table 8(c) Baseline transect data posts X to XIII

LEVACK BASELINE TRANSECT DATA - MOSS COVER AND BARE TAILINGS
Represented in percent cover within 1 square metre

STATION POST: X

Cover		Quadrat No. 1		2		3		4		5		6	
		July	Sept	July	Sept	July	Sept	July	Sept	July	Sept	July	Sept
Bare Tailings	1985	100	100	100	100	99	100	100	100	75	100	20	100
	1986	100	100	95	80	100	100	100	100	80	50	88	55
Moss	1985	0	0	0	0	1	0	0	0	<1	0	60	0
	1986	0	0	5	20	0	0	0	0	0	0	0	0

STATION POST: XI

Cover		Quadrat No. 1		2		3		4		5		6	
		July	Sept	July	Sept	July	Sept	July	Sept	July	Sept	July	Sept
Bare Tailings	1985	100	100	100	100	100	100	100	100	100	100	100	100
	1986	100	100	100	90	100	100	100	99	100	100	100	100
Moss	1985	0	0	0	0	0	0	0	0	0	0	0	0
	1986	0	0	0	10	0	<1	0	1	0	<1	0	<1

STATION POST: XII

Cover		Quadrat No. 1		2		3		4		5		6	
		July	Sept	July	Sept	July	Sept	July	Sept	July	Sept	July	Sept
Bare Tailings	1985	95	95	100	95	100	95	100	100	100	100	100	90
	1986	10	95	99	80	99	70	99	60	90	55	90	55
Moss	1985	0	0	<1	5	0	5	0	0	0	0	<1	10
	1986	0	5	<1	20	<1	30	<1	40	10	45	10	45

STATION POST: XIII

Cover		Quadrat No. 1		2		3		4		5		6	
		July	Sept	July	Sept	July	Sept	July	Sept	July	Sept	July	Sept
Bare Tailings	1985	100	90	80	23	87	46	90	40	75	65	75	10
	1986	100	80	92	53	74	55	60	55	10	35	66	60
Moss	1985	0	10	15	70	<1	40	<1	50	0	20	<1	80
	1986	0	20	5	30	0	10	<1	30	0	25	0	20

Table 8(d) **Baseline transect data posts IV to XVIII**

LEVACK BASELINE TRANSECT DATA - MOSS COVER AND BARE TAILINGS
Represented in percent cover within 1 square metre

STATION POST: XIV

		Quadrat No.											
		1		2		3		4		5		6	
Cover		July	Sept	July	Sept	July	Sept	July	Sept	July	Sept	July	Sept
Bare Tailings	1985	20	20	100	90	100	99	100	85	85	60	100	75
	1986	48	35	80	75	100	90	100	90	99	89	100	100
Moss	1985	5	40	0	10	0	<1	0	15	0	40	0	25
	1986	2	30	10	15	0	10	0	10	<1	7	0	<1

STATION POST: XV

		Quadrat No.											
		1		2		3		4		5		6	
Cover		July	Sept	July	Sept	July	Sept	July	Sept	July	Sept	July	Sept
Bare Tailings	1985	55	45	70	20	5	25	25	10	50	40	25	40
	1986	96	72	83	75	74	20	87	43	65	43	85	45
Moss	1985	0	50	0	75	0	70	10	80	0	60	0	60
	1986	2	20	<1	10	13	40	5	30	6	30	10	30

STATION POST: XVI

		Quadrat No.											
		1		2		3		4		5		6	
Cover		July	Sept	July	Sept	July	Sept	July	Sept	July	Sept	July	Sept
Bare Tailings	1985	10	20	80	99	65	82	83	50	55	40	45	55
	1986	59	35	44	41	25	23	80	60	57	40	76	58
Moss	1985	0	5	0	0	0	5	0	40	0	60	0	0
	1986	10	40	50	50	70	60	10	30	41	40	20	30

STATION POST: XVIII

		Quadrat No.											
		1		2		3		4		5		6	
Cover		July	Sept	July	Sept	July	Sept	July	Sept	July	Sept	July	Sept
Bare Tailings	1985	60	75	55	65	10	43	7	12	7	50	85	47
	1986	28	48	50	35	68	15	83	56	95	50	95	80
Moss	1985	0	0	0	10	0	20	<1	50	0	5	5	40
	1986	50	40	40	25	1	30	5	10	3	20	5	20

posts the increase in percentage moss cover is only noted in 1986 (Posts VII, VIII and IX). For 3 posts, the moss cover does not change significantly between July and September observations, and the surface between 3 posts remained bare. In 60 m of the transect, or about two-thirds, the seasonal increase in moss cover was persistent for two years.

These observations suggest that the time for fertilizer application is either early spring or later in the summer which is concurrent with the lower light intensity and higher frequency of rain which are factors known to affect moss growth. These observation do serve to explain the absence of a fertilizer effect in 1986. The effect obtained in 1985 was likely due to the late summer application of fertilizer. The fertilization in 1985 was carried out at the beginning of August.

In Plates 4 and 5, the growth noted in the straw mulched moss plot confirms the observations by D. Bolton (p.c. Inco, Agriculture). When straw mulch is used for dust control, the growth of grass seeds is considerably better when the same area is seeded at a later stage. The layout of the experimental plots set up in 1985, depicted in Plate 4, can be compared to Plate 5. The photograph was taken in September 1986, and clearly at that time vascular plants had survived the summer. It is important to note, that the experiment in 1985 did not indicate any positive effects of the straw mulch on moss cover, emphasizing the obvious i.e.

Plate 4 Experimental plots with straw mulch in 1985

Plate 5 Indigenous vegetation on plot in September, 1986

growth takes time. The effect of the straw amendment and fertilization in 1986 is possibly due to increased moisture retention and the uneven surface characteristics. The effect is very distinct, expressed by the absence of any growth in the other three experimental plots.

3.5 Seepage behavior and experimental cells

The seepage creek water sampling stations and the location of the iron precipitation pool are outlined in Schematic 3.

The elemental composition and the physical characteristics of all stations in the seepage creek are given in Table 9, comparing the November 1985 data with those obtained in May 1986.

Differences in the parameters would indicate changes which have occurred during the winter months and spring run-off. The pH at station I is the same in the spring of 1986 as that of November 1985. The water in the iron precipitation pond in November 1985 is less acidic, which is possibly reflected in slightly lower concentrations of sulphate and low acidities. The low temperatures measured in November at station I and II would support these noted depressions, accompanied by lower electrical conductivity. The elemental composition of the water at all stations

Table 9: Comparison of the seepage creek characteristics in November, 1985 and May 1986

TABLE 9. (1985 values listed directly below 1986 values.)

STATION #	I	II	III	IV	V	VI	VII	VIII
temp-C	12	12	13	12	-	12	11	9
	1.5	1.5	4	6.5	6	7.5	8	9
pH	4.15	4.1	6.14	6.12	-	6.15	6.1	5.67
	4.1	5.5	5.6	6.2	6.4	5.8	6.5	5.6
cond-umhos/cm	1800	1800	2100	2100	-	2100	2100	2100
	1050	1050	1250	1320	1370	1400	1450	1450
SO4-mg/L	1251	1194	1251	1348	1251	1078	1348	1271
	1290	1001	1059	1155	1117	1155	1078	1117
acidity	10	<2	10	10	10	10	20	20
mg/L CaCO3	<2	<2	<2	6	10	6	26	24
elements-mg/L								
1986 value								
1985 value								
Al	1.60	1.60	1.51	1.52	1.63	1.99	1.64	1.96
	1.33	1.25	1.07	1.12	1.05	1.18	0.93	1.15
B	0.02	0.03	0.03	0.07	0.06	0.03	0.05	0.03
	0.03	0.02	0.07	0.03	0.09	0.04	0.05	0.03
Ba	0.06	0.05	0.05	0.05	0.06	0.03	0.07	0.06
	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06
Ca	286.00	291.00	341.00	321.00	341.00	273.00	373.00	336.00
	303.00	303.00	323.00	327.00	345.00	356.00	332.00	343.00
Cu	0.02	0.01	0.01	0.01	0.03	0.01	0.07	0.02
	0.03	0.01	0.02	b.d.	0.01	0.03	0.004	0.01
Fe	0.17	0.32	7.35	12.30	19.50	4.19	22.00	24.80
	1.13	1.77	8.74	14.20	22.60	28.80	23.50	25.10
Mg	13.70	13.90	15.90	15.10	16.10	14.10	15.90	15.90
	16.70	16.80	17.20	17.30	17.40	18.00	17.20	17.10
Mn	0.84	60.83	0.95	0.91	0.93	0.95	0.92	0.92
	1.00	1.00	1.03	1.03	0.97	1.02	0.95	0.99
Na	121.00	123.00	144.00	138.00	143.00	119.00	145.00	141.00
	108.00	110.00	117.00	118.00	122.00	126.00	122.00	123.00
Ni	0.07	0.06	0.03	0.02	0.14	0.06	0.04	0.03
	0.11	0.11	0.03	0.03	0.03	0.03	b.d.	0.02
Zn	0.01	0.01	0.01	<0.0047	0.04	<0.0047	0.02	<0.0047
	0.05	0.01	0.05	0.02	0.02	0.03	0.02	0.02

was not affected. The iron is removed to the same degree and the concentrations of nickel increase slightly as observed during the summer months at Stations I and II. These observations indicate, that the only change in characteristics in the seepage creek system is related to the lower temperatures.

Sampling in 1986 to confirm the general behavior of the seepage creek described in 1985, was therefore limited to Station I, 10 m downstream from the iron precipitation pool, Station II, at the end of the pool, Station III, at the entrance of the pool and Station VII, at the beginning of the seepage (Schematic 3).

In Table 10, the concentrations of major elements in the water are summarized for 1986 for comparison to those determined in 1985 (the value is reported for the same months in the same column below the 1986 value). A notable change in seepage characteristic was the slightly higher pH in Stations I and II, and somewhat higher acidity values. One extremely high value of 1340 mg/l $CaCO_3$ for station III in July is likely to be erroneous, since it does not follow any trend on the same sampling date in the downstream stations. In 1985, the water temperatures were slightly lower which may be related to the slightly lower sulphate concentrations determined for 1986.

Table 10: Annual and seasonal changes in selected parameters in Stations I, II, III and VII

TTBLE 11.

ANNUAL AND SEASONAL CHANGES IN pH, CONDUCTIVITY, ACIDITY, SULPHATES, AND ELEMENTS IN THE SEEPAGE CREEK
(pH IN UNITS, CONDUCTIVITY IN umhos/cm, ACIDITY IN mg/L CaCO3)

PARAMETRE	STATION I				STATION II				STATION III				STATION VII			
date	5/07/86	6/09/86	7/10/86	9/05/86	5/07/86	6/09/86	7/10/86	9/05/86	5/07/86	6/09/86	7/10/86	9/05/86	5/07/86	6/09/86	7/10/86	9/05/86
			7/--/85	9/--/85			7/--/85	9/--/85			7/--/85	9/--/85			7/--/85	9/--/85
temp-C	12	-	12	11	12	-	14	15	13	-	14	19	11	-	12	11
			18.5	9			22	11			20	9			18.5	9
pH	4.15	4.2	4.7	4.6	4.1	4.35	4.3	4.5	6.14	65.7	5.4	5.2	6.1	5.9	5.6	5.5
			3.6	3.9			3.6	3.9			5.5	5.9			5.9	5.9
cond-umhos/cm	1800	-	1450	1300	1800	-	1500	1500	2100	-	1450	1500	2100	-	1450	1400
			1400	1400			1550	1450			1500	1400			1500	1250
SO4-mg/L	1251	726	763	100	1194	705	742	108	1251	765	803	92	1348	789	784	104
			-	1117			-	1059			-	1059			-	1117
acidity	-	15.3	23	10	-	10.2	37	10	-	15.2	1340	100	-	66.1	168	<2
mg/L CaCO3			-	<2			-	<2			-	10			-	28
elements-mg/L																
1986 value																
1985 value																
Al	1.60	1.53	2.05	1.87	1.60	1.36	1.50	1.69	1.51	1.58	1.40	1.62	1.64	1.72	1.30	1.50
			4.25	1.08			1.61	1.24			1.53	1.02			1.16	1.41
Ca	286.00	297.00	312.00	264.00	291.00	292.00	301.00	250.00	341.00	324.00	332.00	303.00	373.00	334.00	374.00	298.00
			286.00	283.40			278.00	284.50			296.00	302.70			317.00	306.30
Fe	0.17	18.00	18.90	0.13	0.32	14.90	1.14	0.02	7.35	31.80	15.30	1.54	22.00	105.00	32.10	17.30
			229.00	0.23			6.37	0.75			8.07	13.20			23.50	21.45
Mg	13.70	15.30	16.10	13.50	13.90	13.60	14.10	12.80	15.90	14.60	14.66	14.60	15.90	14.80	15.90	13.90
			17.80	16.24			15.90	16.89			16.20	16.38			16.70	16.01
Mn	0.84	0.97	1.04	1.02	0.83	0.86	0.90	0.97	0.95	0.93	0.93	1.03	0.92	0.88	0.98	0.90
			1.14	1.06			0.98	1.18			1.02	1.00			0.92	0.90
Na	121	99.50	97.20	97.20	123.00	95.90	95.90	93.50	144.00	104.00	104.00	110.00	145.00	106.00	115.00	109.00
			97.80	104.50			93.90	106.00			104.00	111.00			105.00	112.60
P	0.04	0.03	0.05	<0.0259	0.04	0.05	0.04	<0.0259	0.05	0.05	0.04	<0.0259	0.10	0.17	0.05	0.03
			0.32	b.d.			0.06	b.d.			0.03	0.03			b.d.	b.d.

The concentrations of the elements Al, Ca, Mg, Mn, Na and P do not change over the season and have not changed since 1985. Total iron concentrations are generally erratic in all stations for the months of May, June and July 1986. Severe rainstorms during those months likely caused the iron distribution throughout the system, significantly increasing the flow rate through the pool. The retention time in this area is probably connected to the iron precipitation process.

However, when one looks at the samples collected in September 1986, it is seen that the iron removal trend noted in 1985, which constituted a significant decrease in iron between Stations VII and I, remains evident. The decrease from Station VII with 17.3 mg/l to Station I with 0.1 mg/l, is in the same order of magnitude as that observed in 1985.

In Table 11, the metal concentrations of Cd, Cu, Ni and Zn are summarized, repeating the physical characteristics of the stations' seepage. Evaluating these metals, a slight increase in the generally very low concentrations is noted for Stations I and II, when compared to Stations III and VII. The increase is concomitant with the lower pH at these stations, evidencing the same phenomenon as was noted in 1985.

Table 11: Annual and seasonal changes in metals in seepage creek

TABLE 10.

ANNUAL AND SEASONAL CHANGES IN pH, CONDUCTIVITY, ACCDITY, SULPHATES, AND METALS IN THE SEEPAGE CREEK

(pH IN UNITS, CONDUCTIVITY IN umhos/cm, ACIDITY IN mg/L CaCO3)

PARAMETRE	STATION I				STATION II				STATION III				STATION VII			
date	5/07/86	6/09/86	7/10/86	9/05/86	5/07/86	6/09/86	7/10/86	9/05/86	5/07/86	6/09/86	7/10/86	9/05/86	5/07/86	6/09/86	7/10/86	9/05/86
			7/--/85	9/--/85			7/--/85	9/--/85			7/--/85	9/--/85			7/--/85	9/--/85
temp-C	12	-	12	11	12	-	14	15	13	-	14	19	11	-	12	11
			18.5	9			22	11			20	9			18.5	9
pH	4.15	4.2	4.7	4.6	4.1	4.35	4.3	4.5	6.14	65.7	5.4	5.2	6.1	5.9	5.6	5.5
			3.6	3.9			3.6	3.9			5.5	5.9			5.9	5.9
cond-umhos/cm	1800	-	1450	1300	1800	-	1500	1500	2100	-	1450	1500	2100	-	1450	1400
			1400	1400			1550	1450			1500	1400			1500	1250
SO4-mg/L	1251	726	763	100	1194	705	742	108	1251	765	803	92	1348	789	784	104
			-	1117			-	1059			-	1059			-	1117
acidity mg/L CaCO3	-	15.3	23	10	-	10.2	37	10	-	15.2	1340	100	-	66.1	168	<2
			-	<2			-	<2			-	10			-	28
elements-mg/L 1986 value 1985 value																
Cd	<0.0026	0.79	0.41	<0.0026	<0.0026	0.20	0.13	<0.0026	<0.0026	0.19	0.06	<0.0026	0.02	0.02	1.60	<0.0026
			0.12	b.d.			0.04	b.d.			0.004	b.d.			0.07	b.d.
Cu	0.02	0.03	0.06	0.02	0.01	0.03	0.03	<0.0028	0.01	0.02	0.02	<0.0028	0.07	0.03	0.04	<0.0028
			0.13	b.d.			0.04	0.02			0.07	0.01			b.d.	b.d.
Ni	0.07	0.32	0.4	0.09	0.06	0.06	0.10	0.08	0.03	0.08	0.04	0.03	0.04	0.04	0.04	<0.0180
			0.4	0.12			0.20	0.22			0.08	0.06			<0.018	0.03
Zn	0.01	0.08	0.11	0.08	0.01	<0.0024	0.05	0.06	0.01	0.03	0.02	0.06	0.02	0.02	0.21	0.05
			0.15	0.04			0.08	0.02			0.05	0.03			0.08	b.d.

These observations and chemical concentrations clearly indicate that the iron removal process is a consistent phenomena. Changes in the seepage creek system could only be due to physical removal of the grass pool and its organic matter.

Wieder and Lang (1984), report on a bog which receives acid mine drainage from a 21 ha abandoned, unreclaimed coal surface mine. The water quality entering the bog has the following drainage characteristics; pH 2.2 and concentrations of Ca, Mg Sulphate and Fe of 20 ,7 276 , 73 mg/l respectively. The seepage creek investigated here has considerably higher concentrations of Ca, Mg and sulphate, but lower concentrations of iron, certainly due to the iron removal process.

Gerber, Burris and Stone (1985) propose a two-step process for the removal of iron by aquatic moss _Spagnum spp._ 1) physical adsorption of the cation followed by 2) oxidation of metal cation, resulting in regeneration of adsorption sites and the subsequent utilization of cations by bacteria. They suggest that the iron removal is mainly mediated by bacteria.

One factor which seems to emerge repeatedly in the literature is that long residence times and low iron concentrations are required for a reduction of Ca, Mg and SO_4. However, to reduce the hydrogen ions and Fe^{+2}, long residence times are reported to be less important (Wieder and Lang, 1984).

The seepage creek chemistry does not seem to concur with these observations. The retention time in the grass pool with the organic matter is greater than at any other station in the seepage creek, and most of the iron removal occurs over the grass pool expanse. Concomitant to the reduction in iron is an increase in hydrogen ions, i.e. lower pH is observed, which is also contrary to the suggestions by Wieder and Lang (1984).

Since iron removal appears to occur effectively in the grass pool, its characteristics were studied in more detail. Based on a set of core samples, the material composition below the living grass cover was quantified. The areas of grass (identified as <u>Calamagrostis canadensis</u>, Blue joint) were differentiated with respect to density of growth. The summary of the values in dry weight/m^2 are presented in Table 12.

Table 12: **The characteristics of the iron precipitate pool**

Sample Type	number	Dead organic density g/m^2	Fe precipitate density g/m^2	Fe precipitate per gr dead org. g/g	Living density g/m^2
Dense	6	4880	35,275	7	1560
Medium	6	3790	35,360	9	544
Sparse	6	1940	41,080	21	54

Some estimate of annual organic matter production in these areas was derived from harvests of the living grass. In the beginning of the growth season in May, 1.5 kg/m^2 was harvested and there was no increase by the end of the season in September, as the average living biomass remained the same for the medium grass cover area.

To ascertain whether the grass pool is an accumulating or decomposing wetland system, assuming an exponential decay process, decomposition coefficients can be used to assess the time frame necessary to accumulate the dead organic matter. For the quantities of organic matter accumulated, a low decomposition coefficient of about 0.2 k/year has to be assumed, given the productivity of the living grass matter. Such low coefficients are considered representative of wetlands on tailings and northern peatlands (Kalin, 1984 and Brinson et. al, 1981). Hence decomposition is low, and the system is either in a steady state or accumulating some organic matter in the medium and dense areas. The amount of organic matter represents at least 10 to 15 years of material. In any event, the quantities of dead organic matter accumulated below the living grass cover in the grass pool suggest that the system has been working for a considerable period of time.

The critical question emerging from the observations of different living grass densities in the precipitation pool area is that of its continuation. The chemical analysis and experiments carried out in 1985 indicated that it is the surface provided by the organic matter and algae which serve as the main agent for iron removal. Therefore, continued growth of the grass would be essential for perpetual functioning of the system.

The data in Table 12 suggest that the below-ground dead organic matter in the areas with sparse grass growth and the quantities of iron precipitate could be interrelated. The lower quantity of dead organic matter is associated with nearly 2 to 3 times as much iron precipitate (21 g/g) as compared to that in the medium and dense grass growth areas. On the one hand, only a given quantity of organic matter is necessary to initiate iron precipitate and subsequently further accumulation of precipitation continues. On the other hand, it suggests that the sparse grass growth could be due to the density of iron precipitate. With less or no annual addition of organic matter, the stability of the iron precipitation "cake" could ultimately be reduced and result in displacement and disturbance of the system. Clearly the cause and effect question relating to the organic matter, grass growth and iron removal cannot be determined with any degree of certainty from the existing data.

Although detailed studies of the effects on wetlands water quality improvement are scarce in the literature, it is generally believed that wetlands, due to their reducing conditions and biological polishing capacity, may ameliorate acid mine drainage. At the foot of the seepage creek, after iron removal has occurred, sulphate and metal concentrations are not reduced.

To alter these water characteristics, reducing conditions are required. Two experimental cells have been constructed during this season (Plate 6) out of gravel, lined with plastic to control water percolation into the gravel bed. The water characteristics and the concentrations of major elements and metals are given for each cell (experimental and blank), for the incoming water leaving the iron precipitation pond (Station I) and that water leaving the cells in Table 13.

Due to the severe rainstorms, the cells had to be reinforced in July. In the experimental cells, moss and algae were introduced from an extremely acidic site (pH 2.5) in the Timmins area, and sedges from an acidic Falconbridge bog. In the first year, only the establishment of species could be expected and no major growth. The introduced plants (sedges, moss and algae), started taking root throughout the growing season.

To ascertain whether the plants overwinter in the shallow gravel will have to await the spring of 1987. In the next stage of the experiment, factors controlling the biological polishing capacity of suited wetland species under field conditions will be

Plate 6 **Experimental cells at the foot of the seepage**

addressed. One of the key features of the experimental cells will be some ability to control the flow of water in the system.

Water quality improvements are not anticipated until a thick layer of organic matter has been established. These experimental cells (Table 13) will serve to identify the parameters required to obtain reducing conditions which are anticipated to improve water quality associated with acidic mine seepages. The elemental concentrations for the cells represent background conditions for future work.

Table 13: **Water characteristics of the experimental cells**

JUNE - SEPTEMBER 1986 (acidity in mg/L CaCO3)

PARAMETRE	STATION I	BEFORE CONSTRUCT	RECONSTRCTN	BEFORE DAM	CELL 1 EXPMNTAL	CELL 2 BLANK		AFTER DAM
date	6/09/86	6/29/86	7/10/86	9/05/86	7/10/86	7/10/86	9/05/86	9/05/86
temp-C	-	-	12	-	11	12	12	-
pH	4.2	-	4.7	4.5	4.2	4.2	4.5	4.6
cond-umhos/cm	-	-	1450	-	1400-1500	1400-1500	1300	-
SO4-mg/L	726	-	783	100	789	792	96	100
acidity	15.3	17	18	10	14	19	10	40
elements-mg/L								
Al	1.53	0.50	0.68	1.98	0.49	0.80	2.11	2.98
Ca	297.00	263.00	225.00	260.00	220.00	242.00	267.00	289.00
Cd	0.79	<0.005	0.01	<0.0026	<0.005	0.01	<0.0026	<0.0026
Cu	0.03	0.03	0.06	0.07	0.03	0.07	0.03	0.05
Fe	18.00	0.02	<0.01	0.48	<0.01	0.11	0.23	1.92
Mg	15.30	14.30	13.00	13.50	13.00	14.00	13.60	15.00
Mn	0.97	1.02	1.00	1.02	0.84	0.93	1.02	1.11
Na	99.50	126.00	127.00	97.30	99.00	112.00	97.10	106.00
Ni	0.32	0.07	0.09	0.12	0.06	0.10	0.09	0.21
P	0.03	<0.005	<0.01	0.04	<0.01	0.04	<0.0259	0.06
Zn	0.08	<0.005	0.16	0.12	<0.005	0.01	0.09	0.12

3.6 Pre-bog acid creek amendments

In Table 14, the values of acidity and sulphate are given for each cell with the amendments in sequence of the water flow from the blank cell A0 to C4 at the end of the pre-bog acid creek. Concentration trends of values which would either increase or decrease consistently with the amendments added or with the extremely slow flow through the cells, from the origin to the end, are not noticeable.

One trend is somewhat persistent, and that is a seasonal increase in sulphate concentration between the beginning of June and September (Figure 1). This trend is not surprising as thermodynamic and microbial activity are related to the temperature in the tailings which likely assists acid generation. However, the increase in concentration could also be due to increased evaporation during the summer months.

The highest sulphate and acidity values are reported for the month of July only at sampling points B1 and B2. In Table 15(a) and 15(b), the concentrations of Al, Ca, Cd, Co, Cu, Fe, Mg, Mn, Na, Ni, P and Zn are given. Distinct trends of concentration changes related to either season, amendment added, or location in the pre-bog acid system, from origin to end, are not obvious. Subtle relationships might be evident if the data is analyzed in

Table 14 Conductivity, sulfates and acidity in pre-bog acid creek

TABLE 14.

(pH IN UNITS, CONDUCTIVITY IN umhos/cm, ACIDITY IN mg/L CaCO3)

DATES	CELL	A0	A3	B1	B2	B4	C1	C4
JUNE 9/86	SO4	-	4095	-	4107	-	4272	-
	ACIDITY	-	4112	-	3919	-	3787	-
JUNE 21/86	SO4	4323	4308	4518	4740	5088	5082	5100
	ACIDITY	3826	3865	4252	4183	4688	4619	4430
JULY 10/86	SO4	5001	4659	5415	4921	5397	5298	5199
	ACIDITY	5570	7620	4890	13730	2500	21680	4890
JULY 29/86	SO4	1726	1857	7568	7890	4386	5541	3183
	ACIDITY	5788	4071	14624	15434	12933	8158	14696
SEPT. 5/86	SO4	6545	5775	6468	6160	5775	6160	5544
	ACIDITY	3700	3100	3400	4700	3800	4000	3500
pH RANGE		2.0-2.9	2.4-3.0	2.6-3.2	2.6-3.2	2.5-2.8	2.5-2.7	2.2-2.7
COND. RANGE		2300-5600	2500-6000	3600-8000	4300-8000	4500-4900	4800-6500	3750-7500

Figure 1 **Sulphate concentration in pre-bog acid creek**

Legend: The codes A0 to C4 represent the cells with the various amendments and the four bars for each cell represent the different sampling dates in 1986.

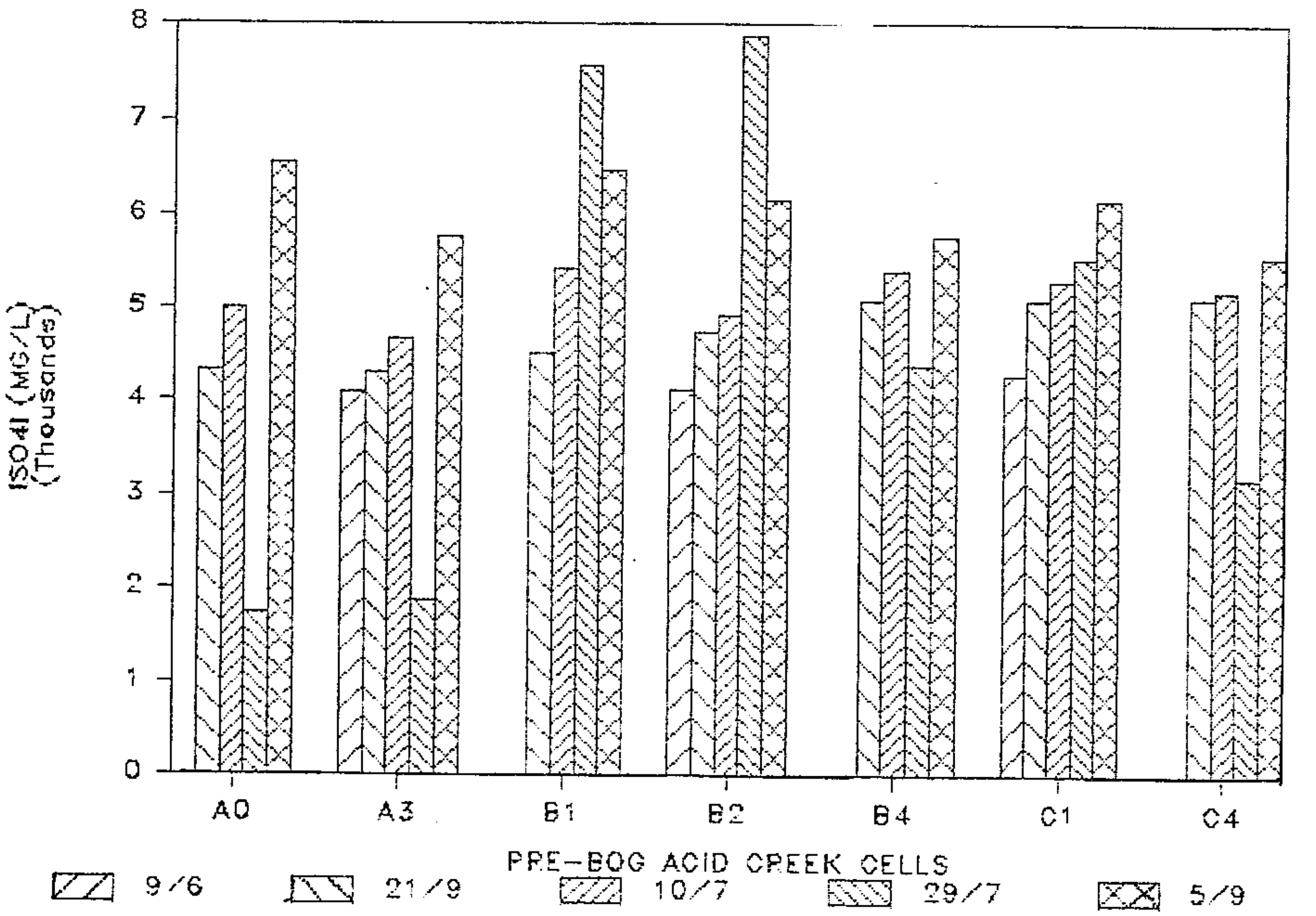


Table 15 (a) **Elemental concentrations in water in pre-bog acid creek**

ELEMENTAL CONCENTRATIONS IN WATER OF PRE-BOG ACID CREEK AMENDMENT CELLS

CELL	A0				A3				B1				B2			
mg/L	6/22	7/10	7/29	9/05	6/22	7/10	7/29	9/05	6/22	7/10	7/29	9/05	6/22	7/10	7/29	9/05
Al	9.62	8.47	18.40	9.11	10.30	15.40	26.00	15.90	18.50	16.80	118.0	16.10	18.70	16.90	118.00	17.70
Ca	408.00	426.00	142.00	366.00	341.00	496.00	158.00	302.00	503.0	552.00	443.0	466.00	523.0	560.00	463.00	443.00
Cd	0.17	0.12	0.30	0.11	0.10	0.43	0.05	0.12	0.07	1.53	0.05	0.12	0.10	0.35	<0.026	0.13
Co	0.14	0.11	0.24	0.49	0.15	0.22	0.32	0.38	0.20	0.15	0.88	0.21	0.20	0.16	0.94	0.25
Cu	0.53	0.60	2.33	1.27	0.51	0.71	3.22	1.84	0.43	0.27	8.21	0.45	0.41	0.48	8.76	0.72
Fe	1511	1801	915.00	1980	1194	1690	1040	1500	1628	2018	2763	2210	1797	1893	2820	2150
Mg	152.00	182.00	47.30	195.00	108.00	162.00	51.40	122.00	103.0	130.00	206.0	111.00	125.0	137.00	219.00	139.00
Mn	8.08	9.16	2.53	10.30	6.14	9.04	2.77	7.21	6.17	7.78	11.10	7.45	7.43	8.05	12.00	8.63
Na	8.63	6.69	4.37	6.65	28.30	10.50	3.94	6.18	46.70	51.20	27.90	45.20	47.20	49.00	26.50	36.00
Ni	23.30	18.40	13.50	41.50	19.10	24.00	17.50	27.40	13.90	14.50	53.10	14.10	16.70	13.90	56.60	16.80
P	<0.259	<0.496	0.36	0.30	<0.259	<0.496	0.49	0.21	0.30	<0.496	2.80	0.28	0.68	<0.496	2.67	0.30
Zn	0.94	0.62	1.06	1.90	0.61	0.89	0.27	1.07	0.20	0.40	1.35	0.55	0.25	0.28	1.60	0.70

Table 15 (b) Elemental concentrations in water in pre-bog acid creek

CELL	B4			C1				C4					
mg/L	7/10	7/29	9/05	6/22	7/10	7/29	9/05	6/22	7/10	7/18	7/29	9/05	9/05
Al	11.80	0.29	12.70	13.20	11.20	23.80	15.50	24.40	36.40	47.80	20.60	17.10	16.90
Ca	647.00	356.00	434.00	541.00	609.00	467.00	500.00	606.00	500.00	450.00	303.00	433.00	416.00
Cd	0.24	<0.026	0.12	1.97	0.54	<0.026	0.39	0.17	<0.026	0.35	<0.026	0.07	0.07
Co	0.11	0.33	0.20	0.11	0.08	0.35	0.23	0.22	0.19	0.16	0.32	0.20	0.19
Cu	0.17	2.32	0.42	0.32	0.13	1.97	0.45	0.60	0.49	0.52	1.94	0.55	0.52
Fe	2148	1677	1910	1555	1972	2180	2220	1387	1197	1189	1126	1500	1450
Mg	145.00	101.00	118.00	130.00	136.00	139.00	141.00	151.00	126.00	112.00	79.60	113.00	110.00
Mn	9.80	6.13	7.83	8.35	9.16	8.67	9.17	9.51	8.39	7.62	5.13	7.60	7.40
Na	131.00	27.00	47.50	80.00	123.00	52.30	66.20	75.20	68.20	64.70	25.40	50.90	49.50
Ni	13.60	28.60	14.70	18.60	13.20	37.70	18.70	27.70	20.00	15.10	27.40	16.20	15.70
P	<0.496	0.37	0.25	<0.259	<0.496	0.42	0.30	<0.259	<0.496	0.45	<0.259	0.25	0.25
Zn	0.08	0.33	0.55	1.88	0.13	0.55	0.79	0.49	0.25	0.37	0.27	0.61	0.64

more detail. Since the objective is to improve water quality with the amendments, a detailed analysis is inappropriate, particularly because of the many variations in the field conditions.

In fact it appears that the concentrations of the elements remain consistently in the same range throughout the season and throughout the pre-bog acid system, with erratic fluctuations mainly associated with the sampling at the end of July. However, there is nothing consistent about the fluctuation, with the exception of Cu, which increases throughout the system on the 29th of July.

It was not expected that the elemental composition of this extremely acidic water would be altered by the amendments, but rather it was hoped that processes which produce more amenable conditions for acid tolerant biota would be obtained.

One rather striking result has been obtained in that the cells of Amendment B produced water nearly clear in colour, as opposed to the adjacent cells with dark red colored water (Plate 7).

Plate 1: Suspended solids filling a pyrrhotite erosion channel

This color change took place within two weeks of placement and persisted throughout the season. Such change lasted despite extensive rainstorms, persisted throughout the winter and was evident directly at the curtain separating the cells.

The material was extensively colonized by Euglena mutabilis and small flagellates Clamydomonas spp.

This striking colour change can only be explained to date by a change in the form of iron, i.e. from ferric to ferrous form, due to the presence of a reducing agent such as H_2S, since the amount of total iron in the water was not altered. The pH ranges reported throughout the season for the cells in Table 14, differing by about 0.4 of a pH unit, indicate that the largest range was reported with Amendment B.

It is extremely tempting to conclude, given that the objective of these amendments is to produce reducing conditions, that this is in fact occurring. Such temptation was resisted by conducting a microbiological assessment of the material which indicated that a common soil bacteria, morphologically similar to Bacillus subtilis, gram positive, subterminal spore, completely monocultural, is present. This member of the genus Bacillus has not been reported in connection with sulphur bacteria, i.e. those bacteria which are known to be vectors of the sulfur cycle (Fjerdingstad, 1979). However Sjamekal, Krause and Cook (1964) report a synergistic relationship between Bacilli and sulphate reducers, such as Desulfovibrio in sulphur hot springs in Alberta. Bacilli are generally facultative heterotrophs, in that they require organic carbon and can live with or without oxygen.

<u>Bacilli</u> do not active produce reducing conditions, but they form rather copious amounts of polysaccarides. Those polysaccarides may be of significance in relation to the synergistic relationship reported to the sulphate reducing bacteria.

Based on the information to date, a hypothesis can be formulated which would involve a second microbe requiring the sugar supplied by <u>Bacillus</u> spp. and would in turn produce the desired reducing conditions by producing H_2S.

Support for such a hypothesis can be derived from studies of sulphur accumulation in lake sediments and generally from an understanding of microbial processes involved in mineral formation. "The combined reduction of sulfate and iron consumes H^+ and produces FeS and FeS_2 as follows: FeS formation - $2H^+$ consumed per mole of SO_4^{-2} reduced:

$9\ CH_2O + 4\ FeOOH + 4\ SO_4^{-2} + 8H^+ \text{ --- } 9CO_2 + 4FeS + 15H_2O.$

FeS_2 formation $-2H^+$ consumed per mole of SO_4^{-2} reduced:

$8CH_2O + 4SO_4^{-2} + 8H^+ \text{ --- } 8\ CO_2 + 4H_2S + 8\ H_2$

$Fe_2O_3 + 4H_2S \text{ --- } 2FeS_2 + 3\ H_2O + H_2$

Formerly it was assumed that the consumption of sulfuric acid in acidified lakes by sulfate reduction resulted only in the formation of iron sulfide as expressed in the above equations". (Rudd et. al, 1986). Work is underway to test the hypothesis formulated above.

CONCLUSIONS AND RECOMMENDATIONS

A restatement of the concluding paragraph of the 1985 report is an appropriate beginning for the conclusions in 1986, as it highlights the importance of perseverance in ecological research: "Results from the overwintering experiments are still wanting at present and therefore conclusions are not warranted on many aspects of the work at Levack" (Kalin, 1986). It is gratifying that the results obtained after one additional growing season and further experiments now warrant some conclusions. They are summarized below, relating to each of the objectives which was set.

1) Boomerang dams ; Sealing of pyrrhotite surface with waste water and the promotion of organic matter development.

The use of waste water, with high suspended solids content as a cover over the pyrrhotite surface, is a practicable approach, but as indicated by attempts to build intermediate sized structures, the concept should be implemented with larger scale boomerang dams. Most appropriately, waste rock might be used for the dam construction. Since waste rock can also generate environmentally undesirable conditions, its placement within the waste management area is highly appropriate.

Once sufficient suspended solids have accumulated, cattails should be transplanted and seeding of semi-aquatic grasses should be attempted to establish an organic matter layer. Given the results of the transplanting experiments, it is unlikely that the establishment of cattails will present a problem. Methods of seed material transfer could be developed to assist biomass production.

Sufficient background work exists, based on the on-site work and germination tests carried out last year, to formulate an effective short test program. Some practical means to contain seeds in place has to be found, since the cheesecloth approach was not effective. Seeds from wetlands can be collected at the appropriate time of the season and transferred to appropriate areas of the accumulated slimes, i.e. areas with reduced flow. Sediments from wetlands can be used as seed sources, as it is possible that the soil material would inhibit downstream transport by the waste water.

As the work on the Chara process has progressed and the field tests indicate that Chara is tolerant to the mine water pond conditions, the next phase for the development of Chara populations could e initiated. However, as an experimental program will be implemented to determine the most effective means to establish Chara populations in waste water systems, further work on the

Levack site should await the results of this program. This would facilitate cost effective implementation of this process at a later stage.

The fertilization and amendment tests to promote indigenous moss and cattail seedling development clearly indicate that the fertilization was carried out at the wrong time of the season. The observations made on the distribution of the moss cover along the baseline transect, the effects of the straw mulch on the mine slimes, and the lasting effect on the plot fertilized in late summer 1985, strongly indicate that some assistance to these processes will result in the desired objective. Fertilization should be carried out in the early spring and late summer, and this should conclude the experimental phase of the tests to assist the development of indigenous species cover.

The conclusions from the cattail investigations and transplanting experiments are clear cut. Cattail stands on the site have developed only in limited areas where suitable conditions exist for seed germination and seedling growth. This can be concluded based on marked pockets of cattail yearlings in 1985 which continued to grow in 1986. Further development and expansion is inhibited by burial of the rhizomes to a depth at which new shoots from lateral rhizomes have difficulty emerging. This was determined based on the experimental plots set up at the edges of the mapped cattail stands and within the stands. The problems encountered with the markings of the stands prevented the collection of data and hence these conclusions are based only on observations. Quantification can be carried out in 1987. Hand-transplanting cattails at shallow depths in clumps rather than as individuals, appears to be a very effective means of establishing cattail stands. Implementing the Boomerang Dams will reduce the amount of suspended solids reaching the beach area. As the transplants from 1985 over-wintered and continued to grow in 1986, expansion of the 1986 transplanted stands can be expected.

2) Seepages from tailings: The iron removal process was confirmed as it persisted throughout the entire second year. Significant quantities of dead organic matter (4 to 5 kg/m^2) are accumulated and those are associated with 35 to 40 kg/m^2 of iron precipitate in the grass pool system. Using decomposition coefficients, assuming an exponential decay for organic matter, the wetland systems have either a very low decomposition rate or could be accumulating. It can be concluded that the system has been in effect for at least one decade. Continued growth of the blue joint grass in dense areas produces about 1.5 kg of organic matter per year, however the origin of the sparse areas, producing only 54 g of organic matter, is unclear. Since the objective is to develop a self-maintaining system for seepages, it is essential that the growth of the grass continue in order to provide organic matter for stability, retention and a precipitation surface. Since the iron removal is effective, it is concluded

that factors controlling the growth of the grass should be addressed.

The test cells have been established, and introduced acid tolerant species appeared to take root. Overwintering of both plants and the structures should be evaluated, leading to the next phase of the work.

3) Pre-bog acid creek: Pyrrhotite surface water improvement tests: One of the most challenging aspects to be achieved, based on the general concepts of Ecological Engineering, was the search for amendments which would ameliorate extremely acidic water in such a way that reducing conditions are initiated. The observations on the effect of the fodder addition, and the hypothesis formulated based on the existence of the Bacilli spp. population, lead to the conclusion that there is indeed a strong possibility that the objectives for improving these extremely contaminated waters by establishing self-supporting treatment systems can be achieved.

Reducing conditions are initiated and they persist throughout the winter. The processes involved have to be elucidated; the relationship of amendment to the quantity of the water; the surface water; and growth conditions for the microbes; have to be further addressed, and experiments must begin in these areas to complement the progress made to date.

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