THE DEVELOPMENT
OF
ECOLOGICAL ENGINEERING
TOWARDS CLOSE-OUT

1990 FINAL REPORT

For

ASARCO INCORPORATED

Buchans Unit

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SUMMARY

The collective data from the investigations in 1988 and experimentation in 1989, supported the conclusion that zinc removal from the effluent of the Oriental East gloryhole could likely be achieved through implementation of an Ecologically Engineered system in both gloryholes, and in the Meadows presently receiving the effluent.

Through the implementation of the ARUM process (Acid Reduction Using Microbiology) in the Oriental West gloryhole, and near the outflow of the Oriental East gloryhole, it is anticipated that zinc concentrations will be reduced. A long-term supply of organic matter demanded by the ARUM system is to be provided by populations of floating cattails, established over sections of both gloryholes. The final stages of zinc removal will be achieved using biological polishing systems located within the first meadow.

Since their installation in 1989, the experimental enclosures (limnocorrals) in the East and West gloryholes have initiated and maintained conditions for zinc removal; zinc concentrations have been decreasing from the initial concentrations (approximately 40 ppm) over 1990, to concentrations no more than 10 ppm, and as little as 1 ppm. Simple processes, such as adsorption onto the organic matter added, and dilution of the enclosure water, cannot account for these reductions in zinc concentrations. Meanwhile, both the microbiological and geochemical data support the conclusion that the observed metal removal is due to the ARUM process.

Scale-up of the system was performed on an experimental basis by adding large quantities of alfalfa and sawdust in areas defined by burlap curtains representing, by volume, 0.40 % of the Oriental East gloryhole and 1.34 % of the Oriental West gloryhole. The ratio of the two types of organic amendments was chosen based on information gained from lab experiments. Although, during 1990, large scale microbial alkalinity generation was not observed in the area within the curtains, all members of the microbial community have colonized the organic amendment layers, and the onset of microbial activity has been observed.

Techniques have been developed whereby floating cattail populations can be cost-effectively established over the gloryholes. Presently, ten floats supporting seedling and mature cattail populations have been installed on both the East and West Oriental gloryholes. During these investigations, the importance of nutrient availability following transplant has been clearly established.

An essential component, at this stage of the ARUM process's development, is the availability of biodegradable organic carbon to the alkalinity-generating microbial communities. Lab experiments suggested that with the onset of decomposition, alfalfa is a source of easily degradable organic carbon. The results of decomposition experiments performed in the gloryholes concur with observations recorded during the lab experiments. Furthermore, the decomposition experiments still in progress should elucidate the long-term rates of carbon release to the microbial community. These rates will permit accurate determination of the longevity of the organic matter added as a carbon source to the gloryholes.

Investigations of the First and Second Meadows indicate that particulates generated by the chemical reactions in the Oriental East gloryhole and First Meadow are transported to the Second Meadow. Polishing ponds were constructed in 1989 in order to utilize this phenomenon. Zinc removal rates of 66 mg of zinc per cubic meter of polishing pond per hour were calculated, derived from water quality measurements as water passed through the first three experimental ponds in the First Meadow.

These results are encouraging, as there is sufficient area in the First meadow, using this rate, to remove most of the zinc loading. In addition, quantification of algal biomass indicated that the mass of algae has increased in 1990, compared to 1989. However, differentiation of the physical/ chemical processes involved during the biological polishing is difficult, due to the simultaneous accumulation of suspended solids with adsorption of zinc by the algal biomass. Construction of a retention area in the First Meadow

is recommended, but only after leachability studies, examining remobilization of metals upon flooding of the First Meadow, have been completed.

The geochemical conditions which lead to the formation of precipitate in the Oriental East gloryhole and the First Meadow are still under investigation. Using the weights of precipitates captured in Sedimentation traps installed in the Oriental East gloryhole, it appears that 61 to 89 % of zinc, precipitated in the gloryhole, sediments to the gloryhole floor, and is not exported with the outflow. However, only 1.2 to 4.1 % of the zinc leaving the gloryhole is in a solid form, while most of the zinc is in the dissolved form. With continued examination of these precipitation processes, it may be then feasible to optimize the precipitation process, thereby significantly increasing the proportion of zinc settling to the gloryhole floor in the solid form.

In summary, the results of 1990 indicate that Ecological Engineering still remains the viable long-term solution towards the reduction of zinc concentrations, facilitating the close-out of the gloryholes.

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SECTION 1: INTRODUCTION

The application of Ecological Engineering to the Buchans waste management area was evaluated in 1988. In 1989, the hydrological and geochemical environment was described. Experiments were carried out in the same year to determine the suitability of the biological processes for the Oriental East and West gloryholes and the First and Second Meadows. At the end of the 1989 growing season, it was concluded that Ecological Engineering and Biological Polishing were indeed specifically applicable to the site and a close-out scenario was developed for the entire Buchans waste management site.

In 1990, work was carried out in the Oriental gloryholes to obtain conditions which would resemble those in the limnocorrals (~43 m^3 experimental enclosures). Microbial alkalinity was generated in the enclosures which had been amended with organic matter. The microbial activity was accompanied by reductions in zinc concentrations in both the acidic waters of the Oriental West and the circumneutral water of the Oriental East gloryholes. Experiments were initiated in 1990 to determine the decomposition rates of the organic amendments which form the basis of the microbial alkalinity generation.

Six experimental pools were constructed in 1989 in the First Meadow to test the ability of biological agents to enhance the precipitate formation and to remove the precipitate from the water. The preliminary results in 1989 suggested that natural precipitation formation, together with biological surface area for attachment, may provide a means of removing dissolved zinc from the Oriental East effluent.

This zinc removal process can be mediated through indigenous periphytic algal populations growing on brush placed into the pools (to provide surface area and organic carbon), or through the introduction of the algae *Chara* (a biological polishing agent), to the ponds. These biological processes were tested and quantified in 1990. In preparation for the scale- up of a biological polishing system in the First and possibly in the Second Meadow, these areas were assessed with respect to surface water hydrology and metal loadings in the soil.

SECTION 2: ECOLOGICAL ENGINEERING MEASURES FOR METAL REDUCTION IN THE ORIENTAL GLORYHOLES

2.1 Overall System Description

The overall objective is to achieve, within both gloryholes, conditions which would facilitate the ARUM process (Acid Reduction Using Microbiology) in reducing Zn and Cu concentrations. By reducing the metal concentrations in the West gloryhole, the metal loadings to the East gloryhole will be reduced, as water from the West gloryhole represents a source of metal to the East gloryhole. If, in addition, a system can be established in the outflow region of the East gloryhole, further reduction of metal concentrations could be achieved prior to discharge to the First Meadow.

The metal concentration reductions are to be obtained by microbially increasing the pH. Metals are precipitated with hydrogen sulphide produced by sulphate reduction, thereby promoting remineralization of both copper and zinc in the gloryholes. The microbial processes require a combination of aerobic and anaerobic conditions and organic matter. In order to provide organic matter on a continuous basis to maintain the ARUM process, a floating cattail population is to be established on the gloryhole.

Schematic 1 shows the overall system for both the Oriental West and East gloryholes. The organic matter (16 tons of sawdust and 1.1 tons of alfalfa) was added to the 390 m^3 volume of water behind a burlap curtain in the Oriental West gloryhole. Twenty-one (21) tons of sawdust and 1.5 tons of alfalfa were placed between two curtains in the outflow channel of the Oriental East gloryhole, representing a volume of 750 m^3. Ten cattail floats have been installed in each of the gloryholes.

2.2 Zinc and Copper Concentrations in the Orientals

In 1989, it was evident that the zinc concentrations in the Oriental gloryholes were on a general downward trend. In Figure 1b, the downward trend in concentrations of zinc in the Oriental East has continued during 1990, and the trend is consistent with that seen last year. In Figure 2b, zinc loadings are presented for the years 1987 to 1990 for the Oriental East gloryhole. A consistent slight decline in the zinc loading continues in 1990, but the copper loadings have essentially remained the same since 1988 (Figure 2a).

Table 1 gives the concentrations of zinc and copper in waters collected behind the curtains where amendment was placed along with the concentrations in the water which was collected at the same time from the gloryhole at large.

Schematic 1: Ecological Engineering Set-up for 1990

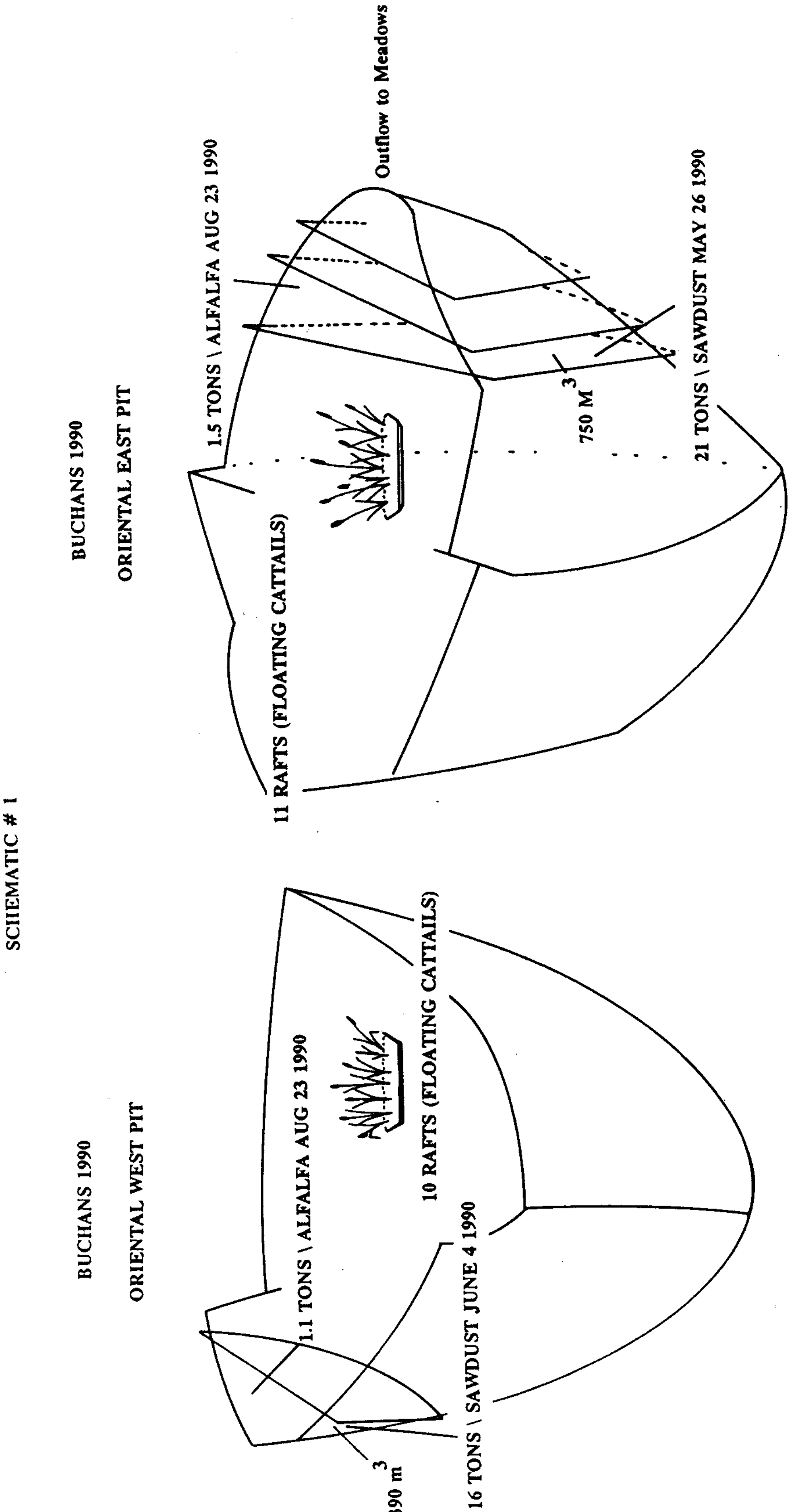


Fig. 1a OE and OW Pit 1989/90
Copper Concentration

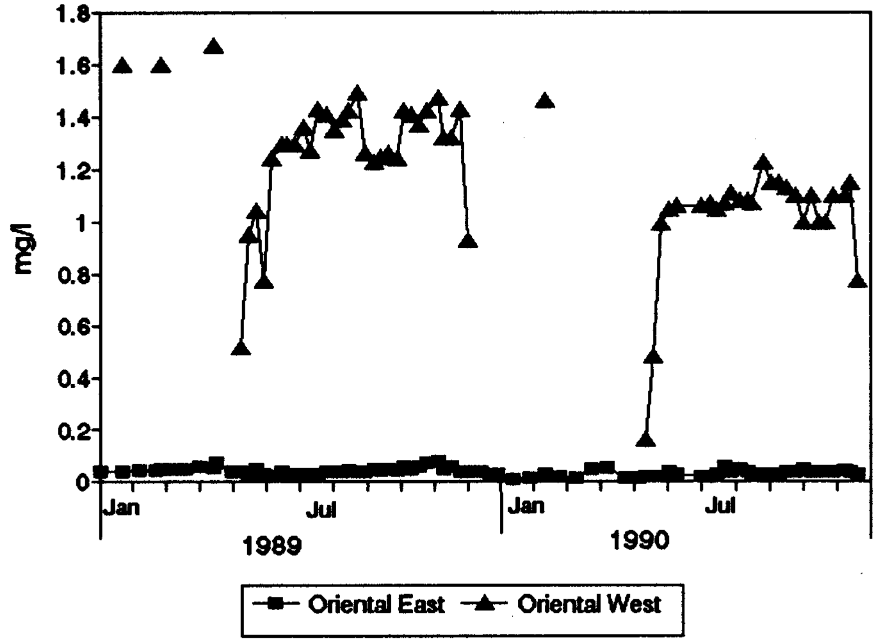


Fig. 1b OE and OW Pit 1989/90
Zinc Concentration

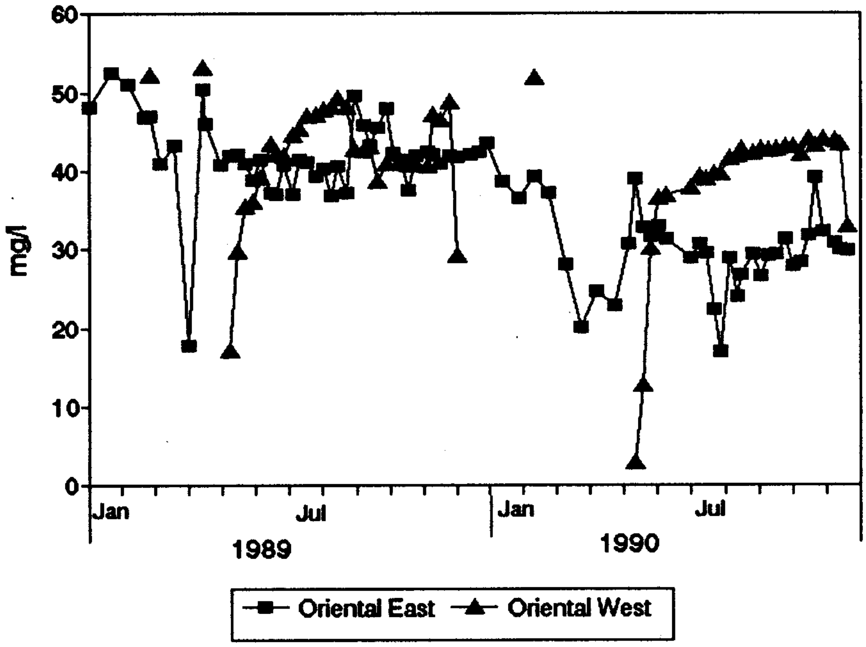


Fig. 2a OE PIT, Copper Loading
Average 1987/88/89/90

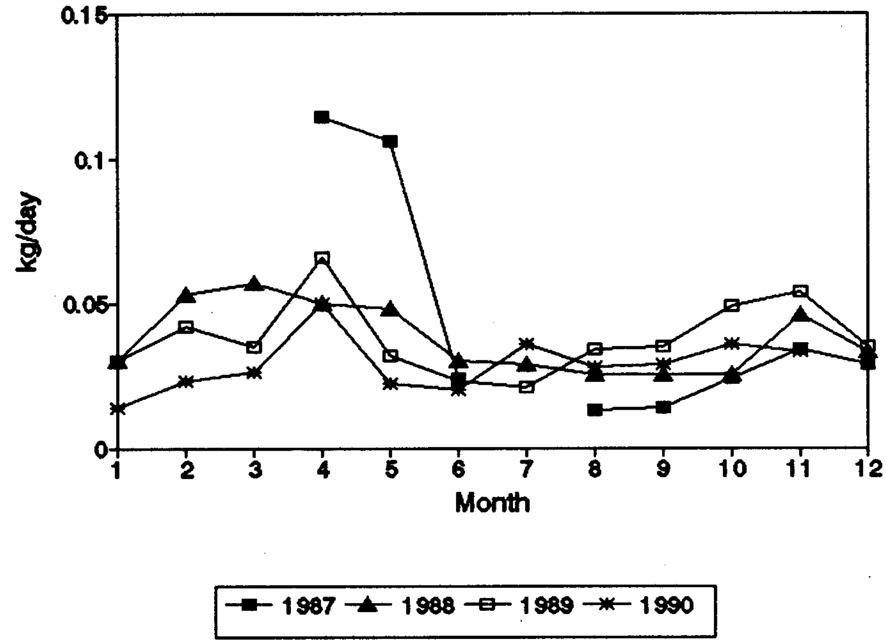


Fig. 2b OE PIT, Zinc Loading
Average 1987/88/89/90

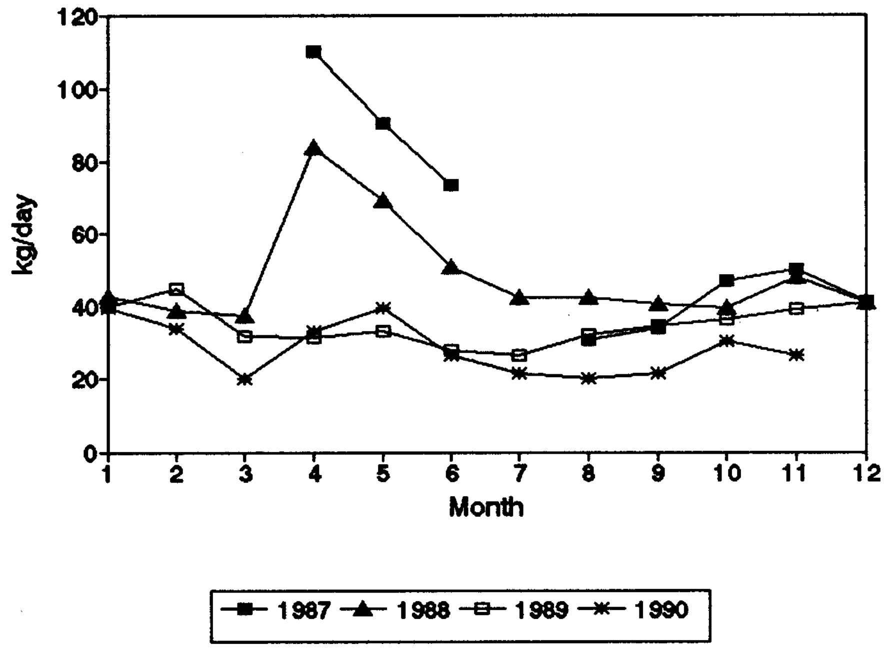


Table 1:

Table 1: Comparison of pH, Cu and Zn in Booms and Pit's

EAST PIT						
	pH		Cu [ug/l]		Zn [ug/l]	
1990	Boom	Pit	Boom	Pit	Boom	Pit
Aug 25	7.0	7.0	50	30	29450	29350
Sep 18	7.3	7.0	40	40	22050	29255
Oct 08	7.0	7.0	45	40	28850	28350
Oct 18	6.9	6.9	50	35	28200	39150
Nov 09	6.8	6.9	45	35	30050	30050
Nov 19	6.9	6.9	40	30	20750	29750

WEST PIT						
	pH		Cu [ug/l]		Zn [ug/l]	
1990	Boom	Pit	Boom	Pit	Boom	Pit
Aug 25	3.8	3.7	1160	1230	41300	42200
Sep 18	3.6	3.6	1120	1135	37650	42800
Oct 08	3.6	3.6	1100	1090	43600	42100
Oct 18	3.6	3.5	1105	1005	43150	43255
Nov 09	3.5	3.5	1095	1155	43450	43450
Nov 19	3.5	3.5	980	770	38955	32850

Although it appears as though the concentrations of both metals are slightly lower in November 1990, it is less likely due to the initiation of the ARUM process than to freeze-out, as ice was already forming on the gloryholes at that time.

The additions of organic matter to the enclosures did not produce any results for the first three months. At that time, based on laboratory tests, it appeared as though the addition

Fig. 3a Limno 123 Copper
Sawdust, Peat, Control

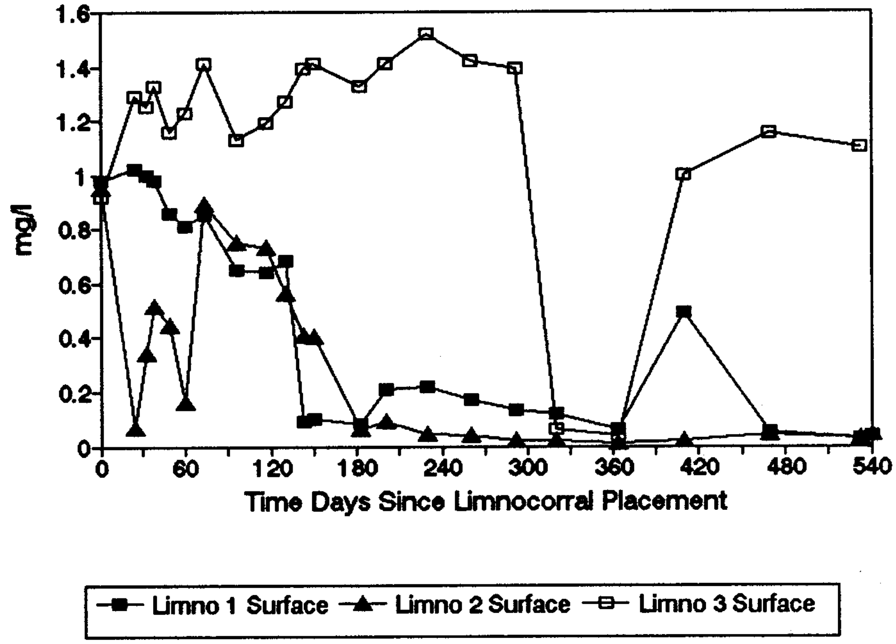


Fig. 3b Limno 123 Copper
Sawdust, Peat, Control

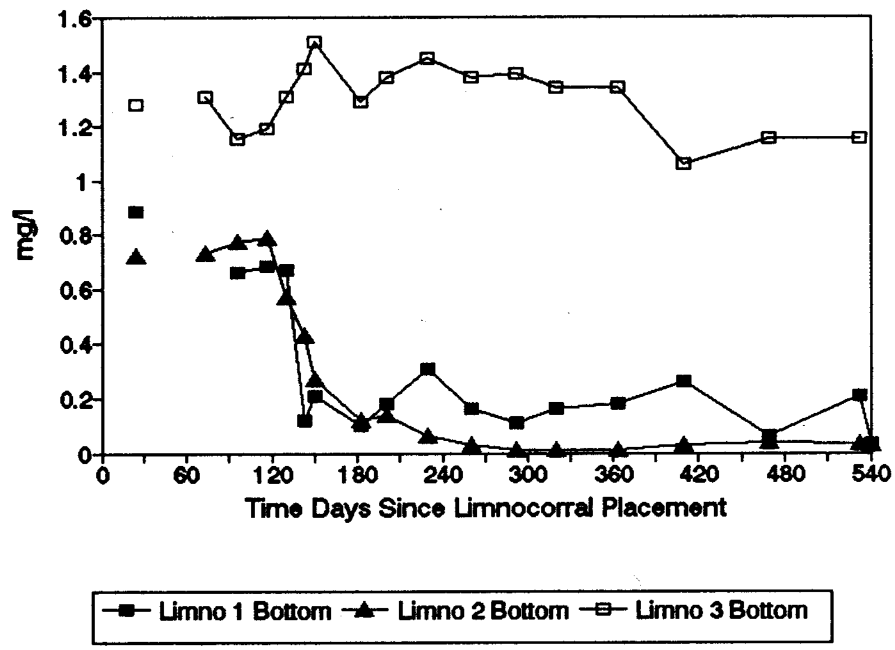


Fig. 4a Limno 123 Zinc
Sawdust, Peat, Control

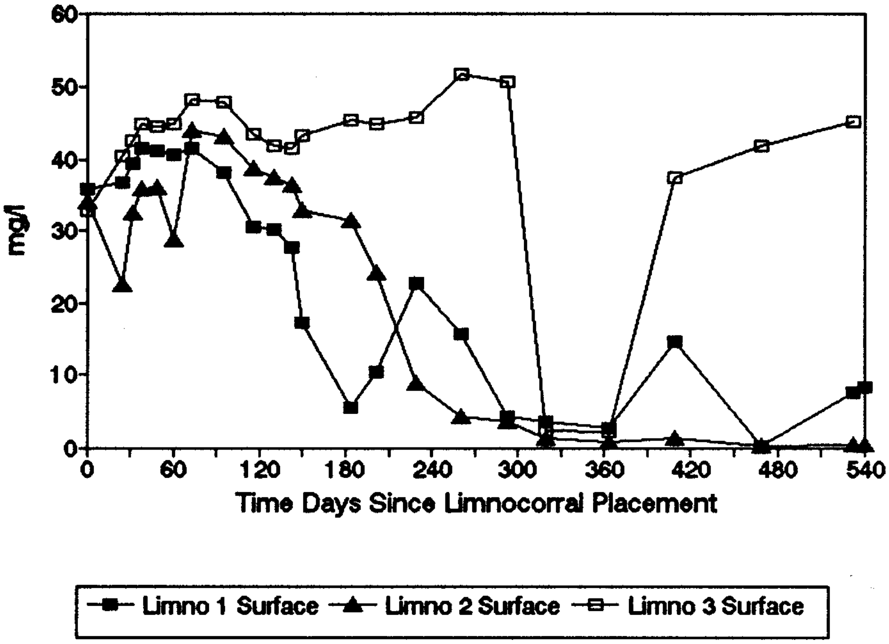
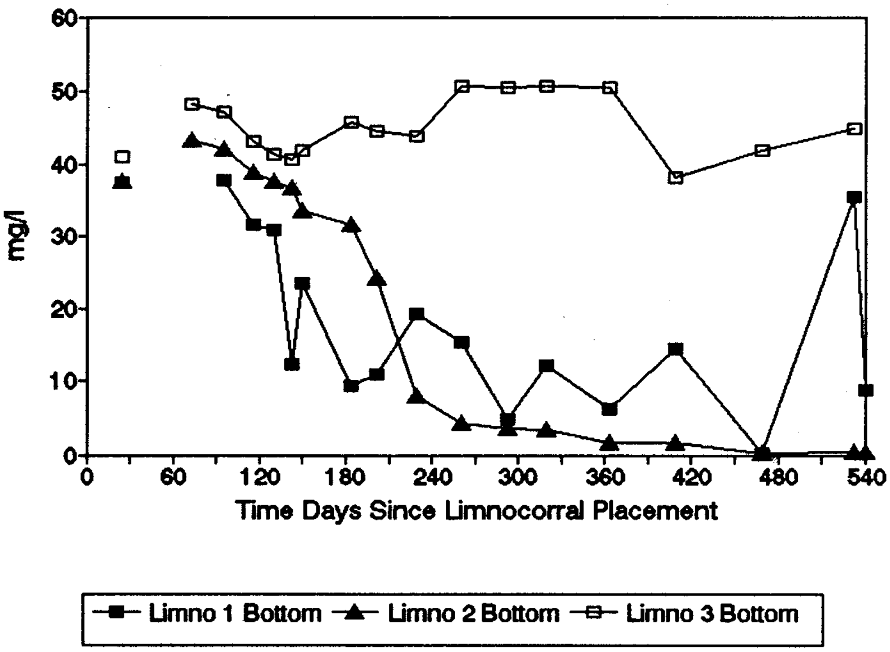


Fig. 4b Limno 123 Zinc
Sawdust, Peat, Control



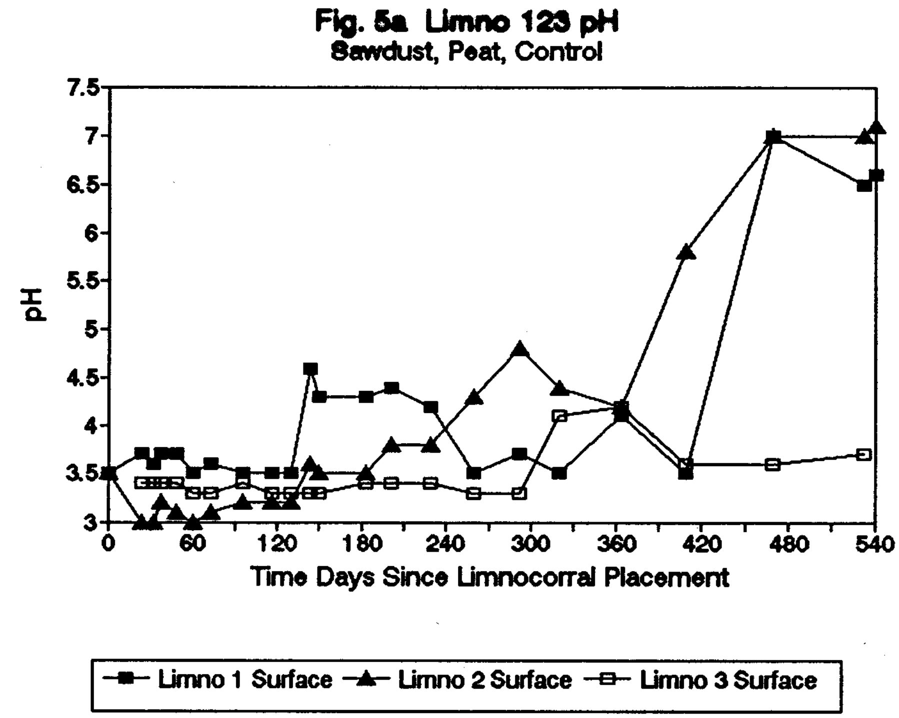


Fig. 5a Limno 123 pH
Sawdust, Peat, Control
pH
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
0
60
120
180
240
300
360
420
480
540
Time Days Since Limnocorral Placement
Limno 1 Surface
Limno 2 Surface
Limno 3 Surface

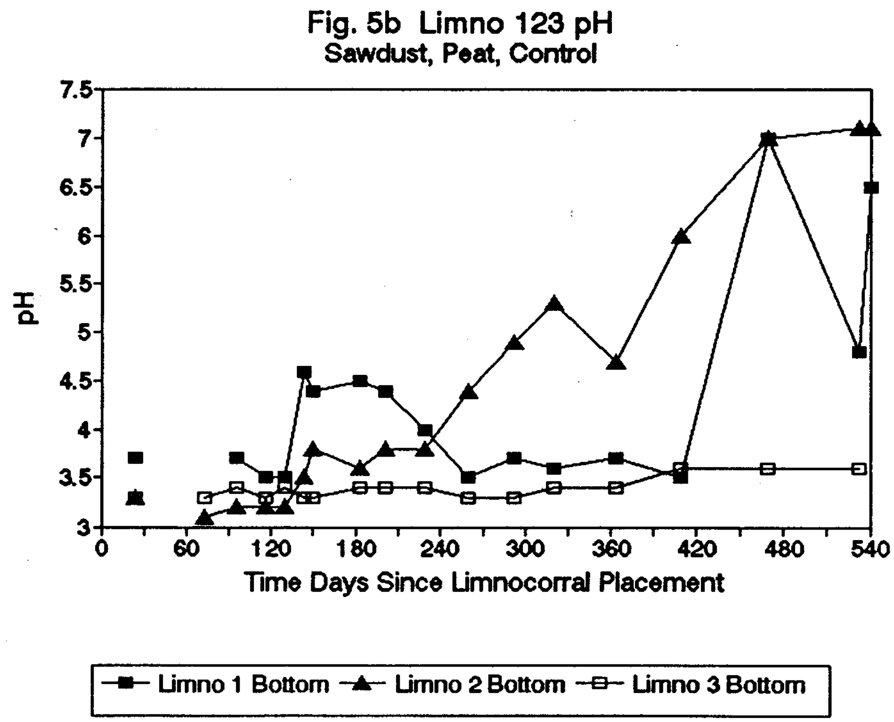


Fig. 5b Limno 123 pH
Sawdust, Peat, Control
pH
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
0
60
120
180
240
300
360
420
480
540
Time Days Since Limnocorral Placement
Limno 1 Bottom
Limno 2 Bottom
Limno 3 Bottom

Fig. 6a Limno 123 Conductivity
Sawdust, Peat, Control

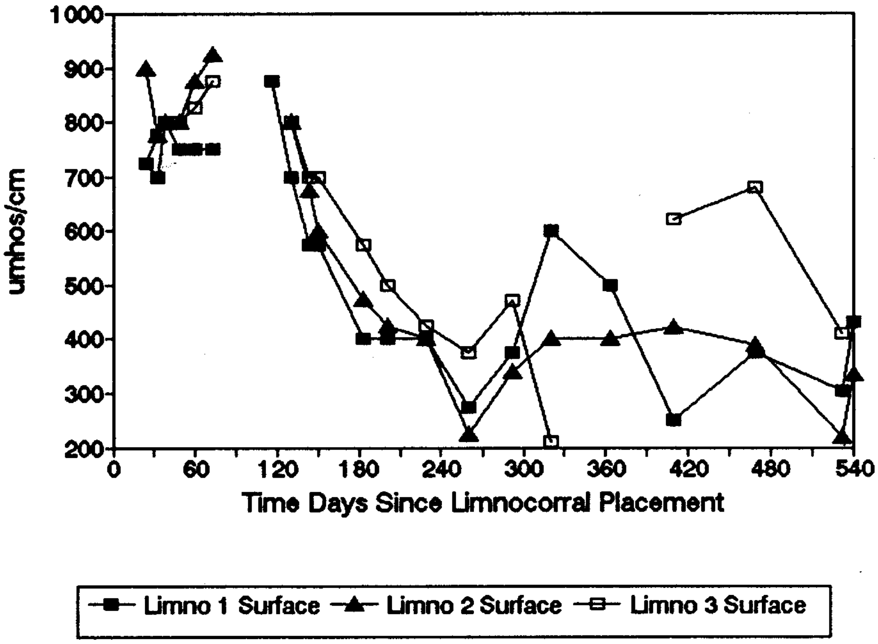


Fig. 6b Limno 123 Conductivity
Sawdust, Peat, Control

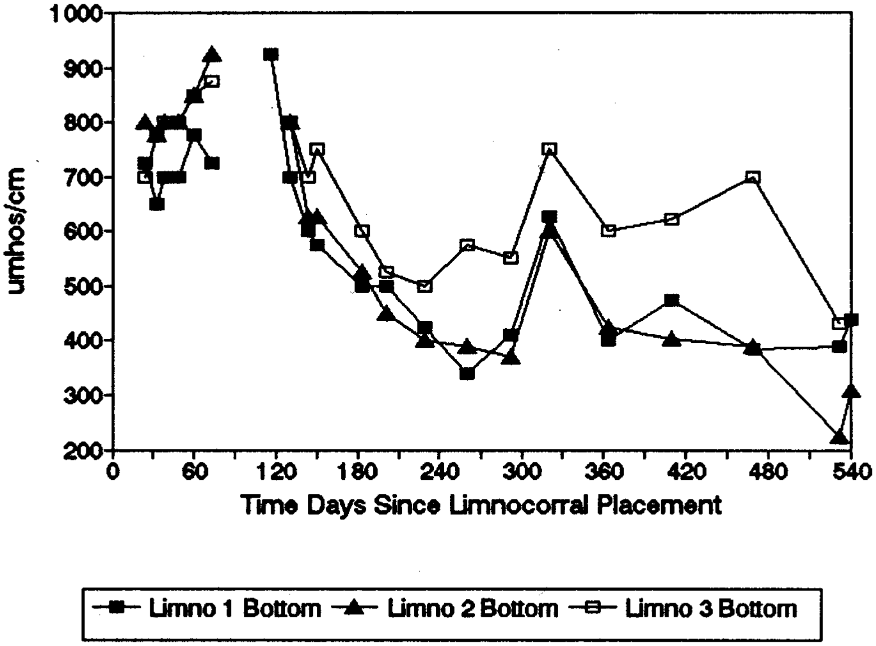


Fig. 7a Limno 123 Temperature
Sawdust, Peat, Control

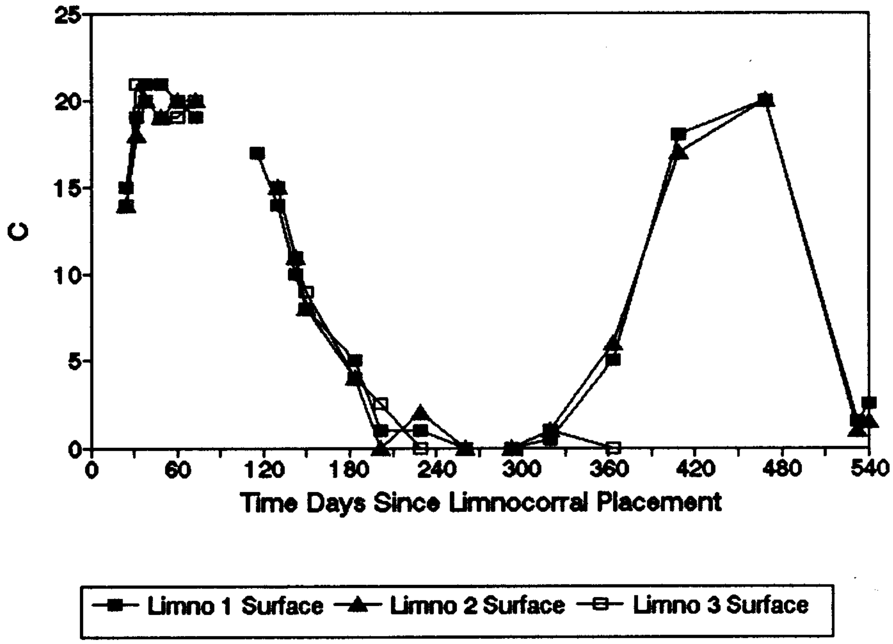


Fig. 7b Limno 123 Temperature
Sawdust, Peat, Control

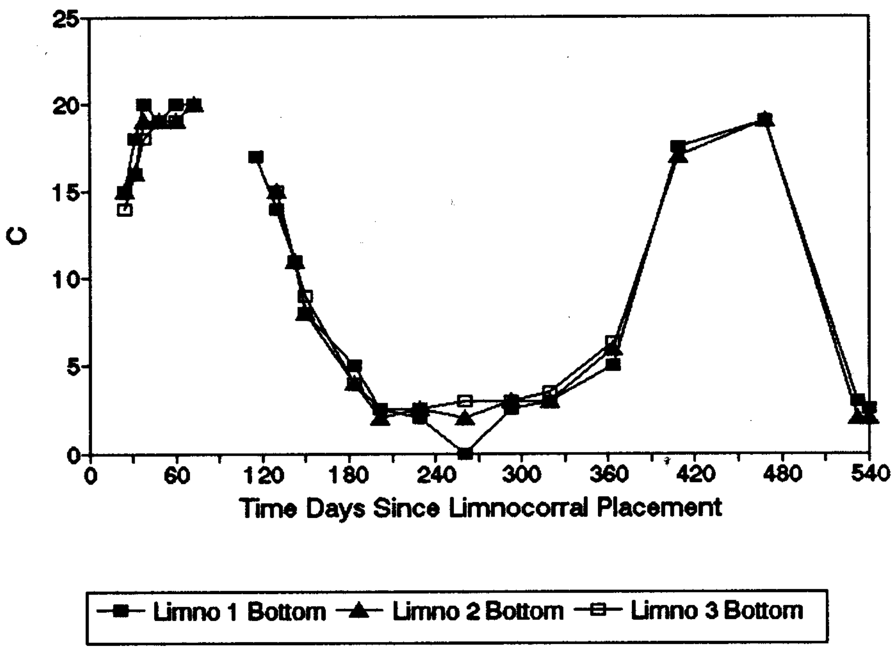


Fig. 8a Limno 456 Copper
Sawdust, Peat, Control

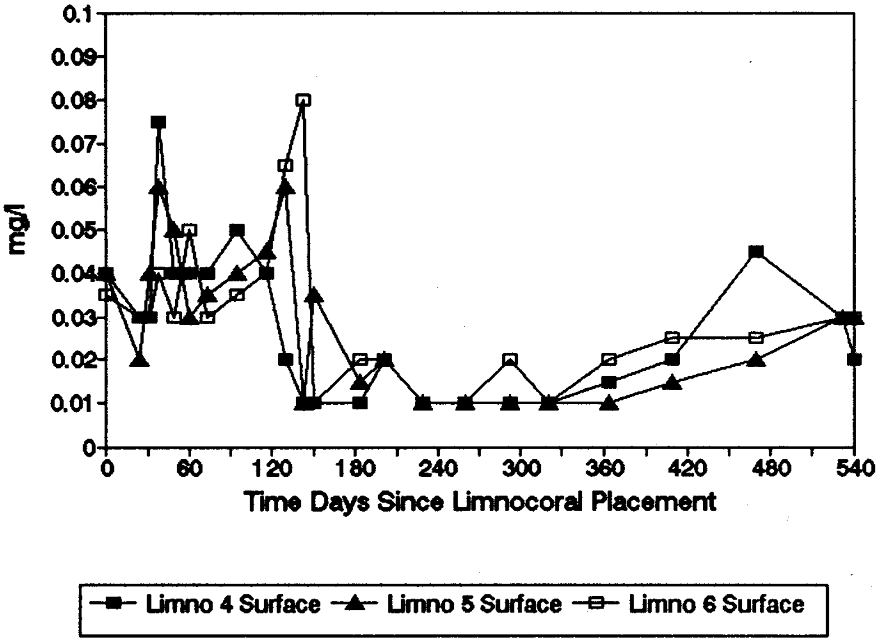


Fig. 8b Limno 456 Copper
Sawdust, Peat, Control

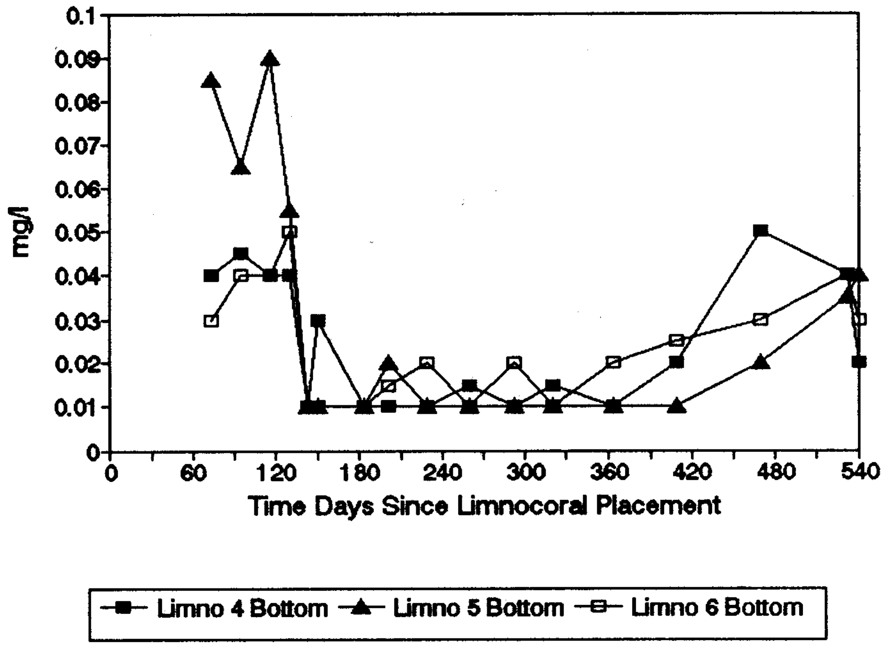


Fig. 9a Limno 456 Zinc
Sawdust, Peat, Control

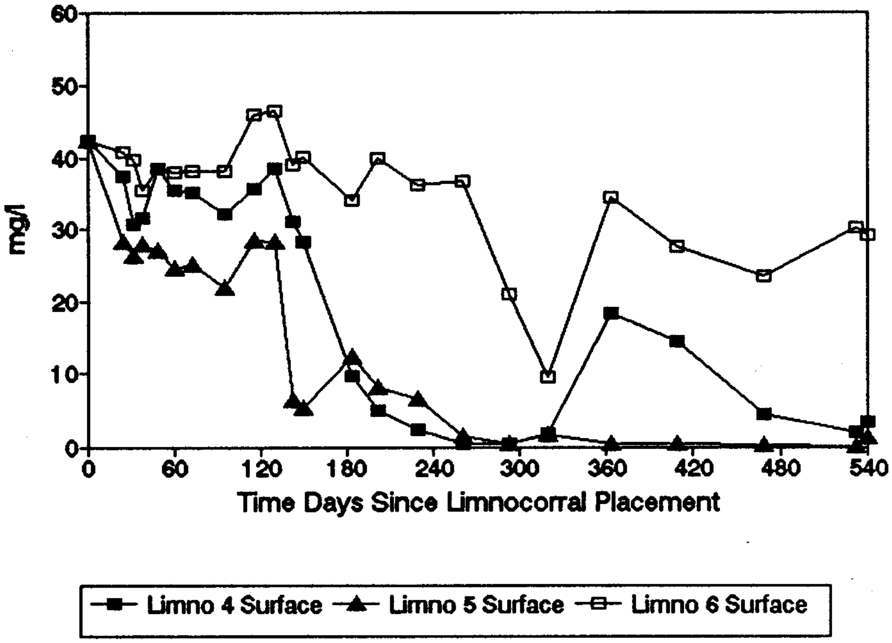


Fig. 9b Limno 456 Zinc
Sawdust, Peat, Control

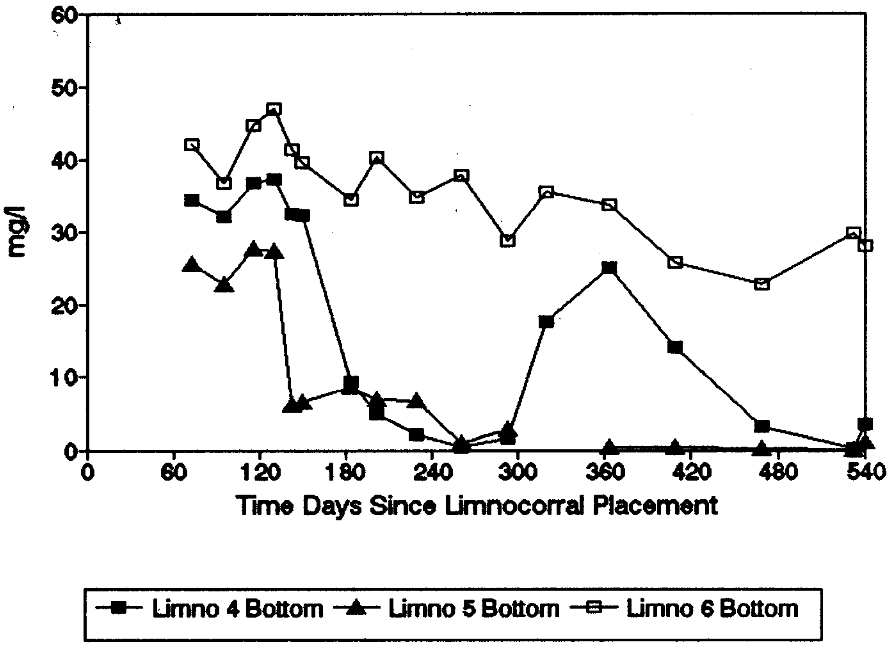


Fig. 10a Limno 456 pH
Sawdust, Peat, Control

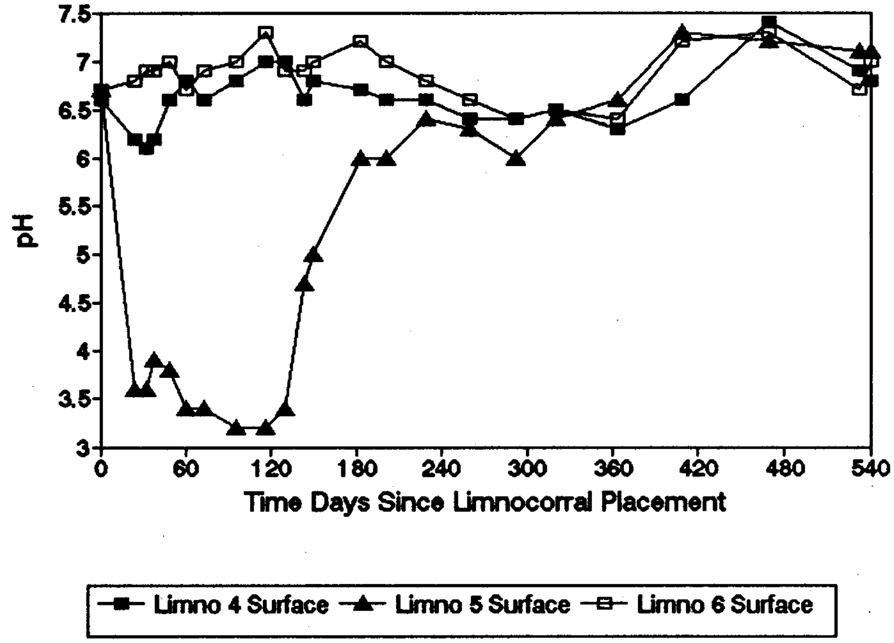


Fig. 10b Limno 456 pH
Sawdust, Peat, Control

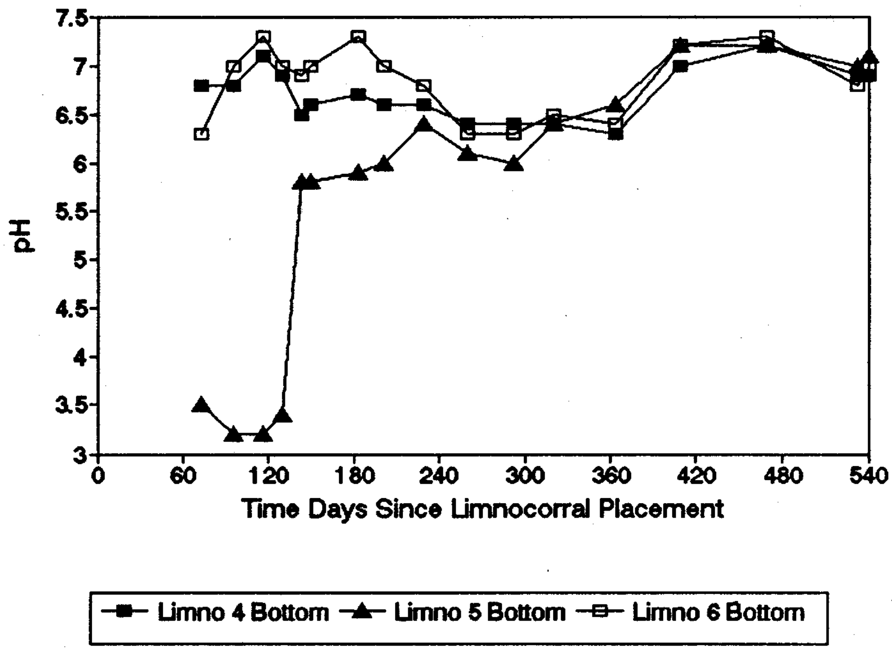


Fig. 11a Limno 456 Conductivity
Sawdust, Peat, Control

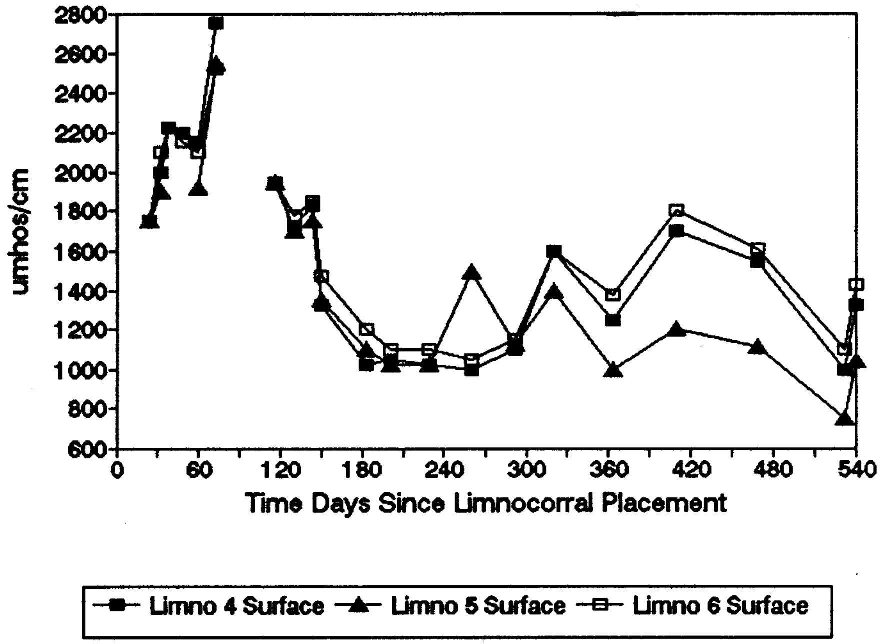


Fig. 11b Limno 456 Conductivity
Sawdust, Peat, Control

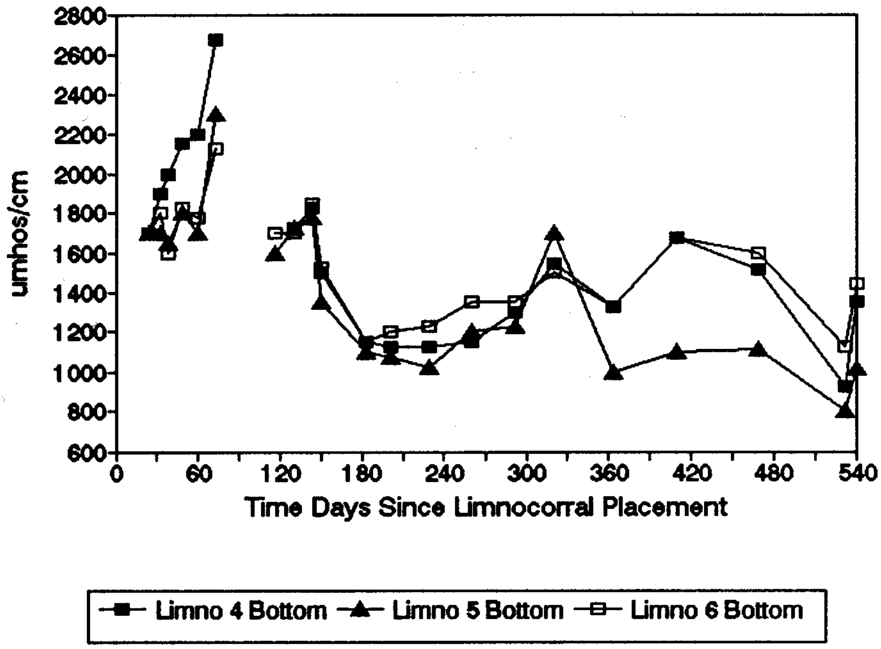


Fig. 12a Limno 456 Temperature
Sawdust, Peat, Control

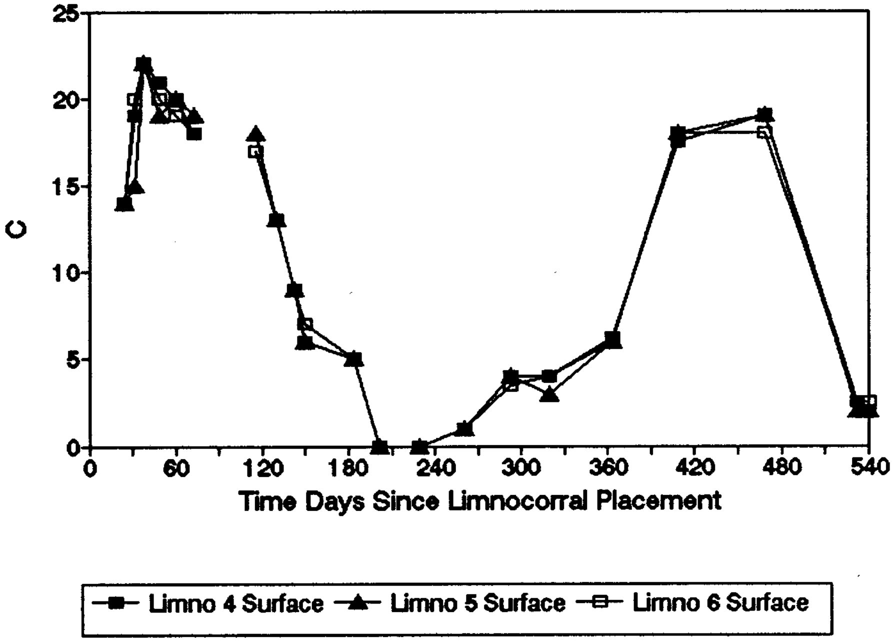
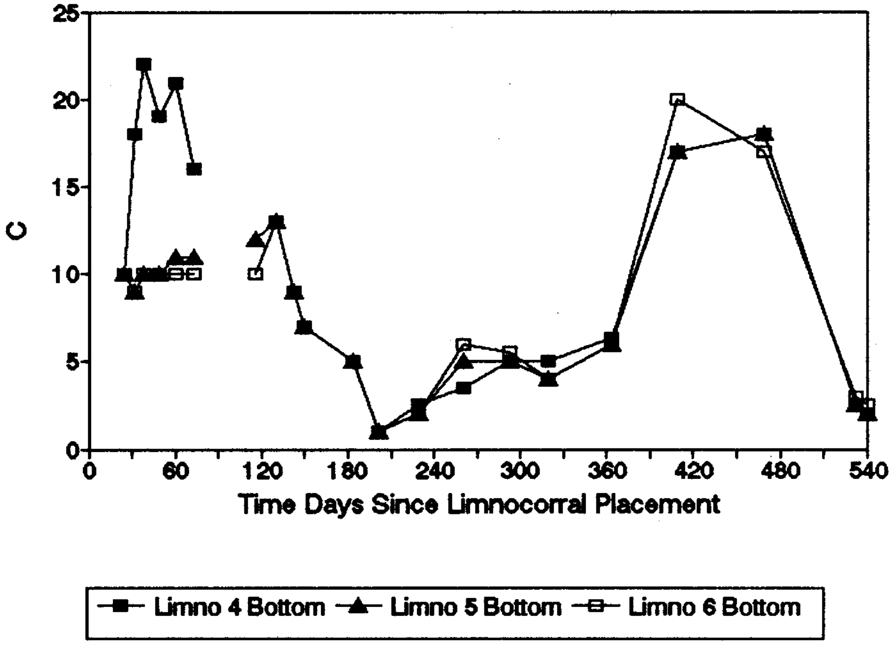


Fig. 12b Limno 456 Temperature
Sawdust, Peat, Control



observed for the first 90 days. After 131 days, a mixture of alfalfa, sawdust and biolyte was added to the amended limnocorrals, and within 10 days of this addition a decrease in metal concentrations was noted in all limnocorrals in both gloryholes. If metal removal was due to adsorption onto the organic surface area then a rapid drop in concentrations can be expected with no further decreases in metal concentrations. However, a continued decrease in metal concentrations is evident for both metals in the limnocorrals in both gloryholes. This suggests that other processes are occurring, such as microbial alkalinity generation, which contributes to metal removal. Clearly, this is reflected in the increasing pH values in the limnocorrals.

Organic matter was added to the limnocorrals in the form of the decomposition experiment. This addition was made after Day 409. In Figures 4a and 4b and 9a and 9b, it is evident that for those limnocorrals (1 and 4) where the concentrations of zinc were still above 10 mg/L, a rapid reduction occurred after the addition.

Table 2 presents the concentrations of metals adsorbed by the organic matter added to the limnocorrals. Although there is a lot of variation in the data, the fact that adsorption occurs has to be recognized and taken into account when evaluating the limnocorral data. Material from the decomposition experiment was analyzed for metal content prior to submergence into the limnocorrals and then again after 31 to 34 days of submergence.

These data have been used to derive some estimates on adsorption of metal to material.

Table 2: Concentrations of Zn and Copper in Organic Material

Table 2: Copper and zinc concentration (ug/g) of amendment at the time of addition, and after 31 days (OEP) and 34 days (OWP)

COPPER					
		Oriental West Pit		Oriental East Pit	
Amendment	Initial	Limnocorral 1	Limnocorral 2	Limnocorral 4	Limnocorral 5
Alfalfa	<10	131	60	<10	12
Cattail	58	108	39	56	55
Peat	40	51	10	17	<10
Sawdust	40	48	14	<10	<10
Straw	40	108	61	<10	14
ZINC					
		Oriental West Pit		Oriental East Pit	
Amendment	Initial	Limnocorral 1	Limnocorral 2	Limnocorral 4	Limnocorral 5
Alfalfa	27	2617	2551	4038	760
Cattail	875	1372	1017	1266	823
Peat	25	815	413	4183	196
Sawdust	32	1594	370	988	221
Straw	10	1272	2993	3920	568

These data suggest a wide range of concentrations. Adsorption of these metals does not appear to vary directly with the surface area. For instance, alfalfa appears to be the material with relatively high concentrations of both Cu and Zn, while peat and sawdust have the highest surface areas per unit volume.

To estimate whether the decreased metal concentrations noted in the limnocorrals could be attributed to the addition of organic matter to the decomposition experiment, the dry weights obtained for each material were used to determine the total quantity of Zn and Cu adsorbed onto the solids. An approximation of the metal balance is derived by subtracting the content of the material before its submergence in the limnocorrals from the metal content after 31 to 34 days, and calculating the total copper and zinc content in the limnocorrals for the time of exposure.

The contents and the changes in total metal content are presented in Table 3. The water content was calculated based on a volume of 42.1 m^3 and a dry weight content calculated based on the dry weight for the organic matter placed into the limnocorrals (7.9 kg alfalfa, 5.4 kg cattail, 4.3 kg peat, 6.9 kg sawdust and 8.0 kg of straw). In limnocorral 1, for example, all components of the decomposition experiments together after 28 days, adsorbed 2.48 g of Cu and 47.1 g of zinc. Of that total, 0.97 g of Cu and 20.7 g of Zn were absorbed by alfalfa alone. Over that time period, the reduction in the water of the limnocorral is equivalent to 8.2 g of Cu and 614 g of Zn. It is evident that, in some cases, adsorption can account for a significant portion of the metals removed from the limnocorrals.

Table 3:

Table 3: Changes in metal content of amendment and water in limnocorrals

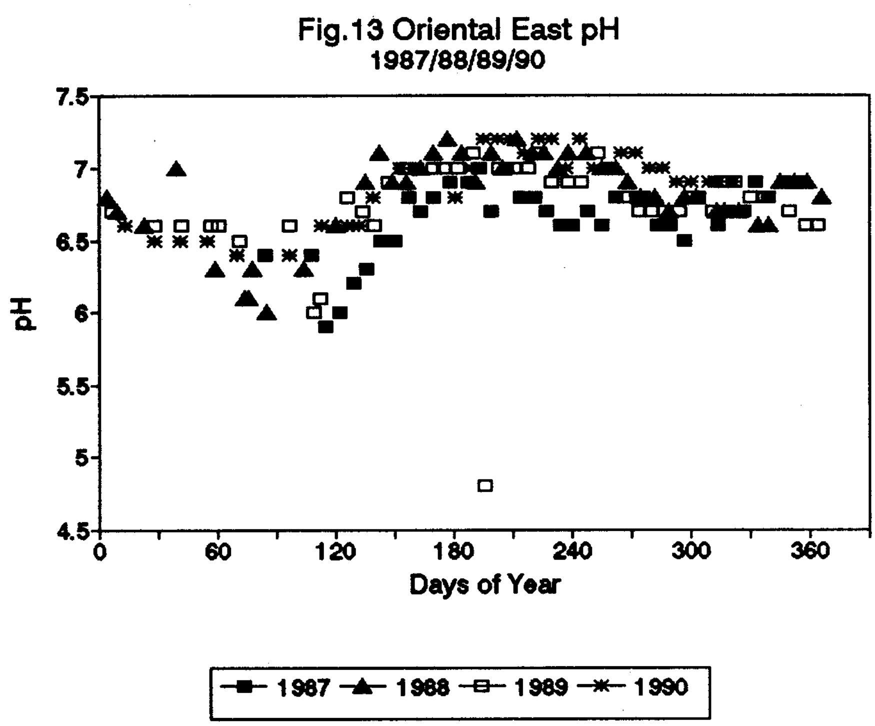
Total metal content (g) in limnocorrals (vol. = 42.1 m^3)

COPPER						
	Limnocoral 1	Limnocoral 2	Limnocoral 3	Limnocoral 4	Limnocoral 5	Limnocoral 6
Total Amendment	+2.48	+0.74	-	+0.015	+0.040	-
Alfalfa	+0.97	+0.40	-	0	+0.016	-
Water	-8.21	+1.05	+4.63	+1.05	+0.21	-0.21
ZINC			ZINC			
	Limnocoral 1	Limnocoral 2	Limnocoral 3	Limnocoral 4	Limnocoral 5	Limnocoral 6
Total Amendment	+47.1	+49.1	-	+90.1	+12.5	-
Alfalfa	+20.7	+20.2	-	+32.0	+5.9	-
Water	-614.8	-56.6	+173.7	-439.1	-7.03	-147.4

The changes in the control limnocorrals, which either increase or decrease in total zinc or copper content, suggest that in the absence of organic material, the metal mass balances are only valid if the enclosures are not leaking. It is apparent that such leakage is occurring, based on the concentrations observed in the control limnocorral.

In summary, although adsorption and dilution may contribute to the metal reductions in the limnocorrals, microbial activity is involved. This is evidenced by a severe rotten egg smell, due to hydrogen sulphide production. Furthermore, the increases in pH in the limnocorrals also suggest an active process. In Figure 13, the pH values for the Oriental East gloryhole are plotted for the last 4 years, to serve as a reference for the normal background pH fluctuations. It is suggested that those are not larger than 1 pH unit.

Figure 13



2.4 Floating Cattail Islands for the Orientals

The integration of floating *Typha* mats as a component of the ARUM process is required to provide organic matter as a source of nutrients for the microbial alkalinity generation. It was essential to be able to produce plants from seed for the establishment of floating cattail mats on a large scale.

The objective of the 1990 work was, therefore, to determine the conditions under which cattail seeds would germinate and establish themselves in the laboratory. The results of these experiments were then used to produce a larger quantity of seedlings in the greenhouse. These were then transplanted to floats in both the Oriental East and West gloryholes.

Several practical techniques for germinating *Typha* seeds, promoting *Typha* seedling development and transplanting juvenile or mature plants to floating rafts have emerged from this work. Maintenance of constant substrate moisture, selection of substrates with circumneutral pH's and provision of nutrients during seedling establishment and transplant have been identified as key measures.

2.4.1 Methods

The experiment in the laboratory was designed to provide conditions of germination and seedling establishment to enable cattail growth in a greenhouse. If cattails could be grown successfully in the greenhouse, a large supply of plant material could be produced for scale-up. Based on the literature, the parameters likely to affect germination are: humidity, fungal attack, fertilizer and water depth. These parameters were tested and the details of these experiments are given in Appendix 3.

Using the information gained from laboratory experiments, the conditions for the greenhouse were defined as follows: eight boxes with floating support were constructed, each box containing 16 plastic germination trays. The trays were lined with burlap cloth and hot-glued to the tray lip perimeter in order to contain the substrate.

Two types of substrate were placed in each tray. A base layer, 4 cm thick and composed of a sandy till, formed the bottom of each tray. A second 4 cm thick layer of local peat, sifted through 0.5 cm minus mesh, formed the germination bed.

Water levels were maintained by the addition of tap water, while ambient sunlight through the translucent plastic sheeting was the only illumination provided. The tray seedbeds were adjusted by weights to maintain moist, but not wet, germination bed surfaces in the trays. Further details on the germination conditions and the seeding methods are given in the Appendix 4. The greenhouse was designed for a minimum temperature of 16° C. In Plate 1, the layout of the greenhouse is shown.

Plate 1: The greenhouse for cattail growth with boxes

Plate 1. The greenhouse for cattail growth with boxes

fixed over the netting floor to ensure containment of sphagnum moss, the substrate used to support newly transplanted seedlings or mature plants. Styrofoam strips were attached to the frame edges in order to maintain the correct level of buoyancy and saturation of the mats.

Twenty rafts were constructed, ten for each gloryhole. On 25 July 1990, the plastic trays enclosing the seedling growth substrate were removed. Blocks of seedlings, consolidated by the seedlings' root networks, were cut into thirds, each representing a clump ready for transplant on 26 July 1990. During the week of July 26, mature plants were excavated from a cattail population below the tailings dam for transplanting to the rafts. In Plate 2, the rafts in the Oriental East are depicted after transplanting was completed.

Rafts were designated as either seedling or mature transplant rafts. Slow-release fertilizer and bone meal were added, alone or together, for comparison of establishment and growth with control (no amendment) conditions. Details of the fertilization applications are given in Appendix 4.

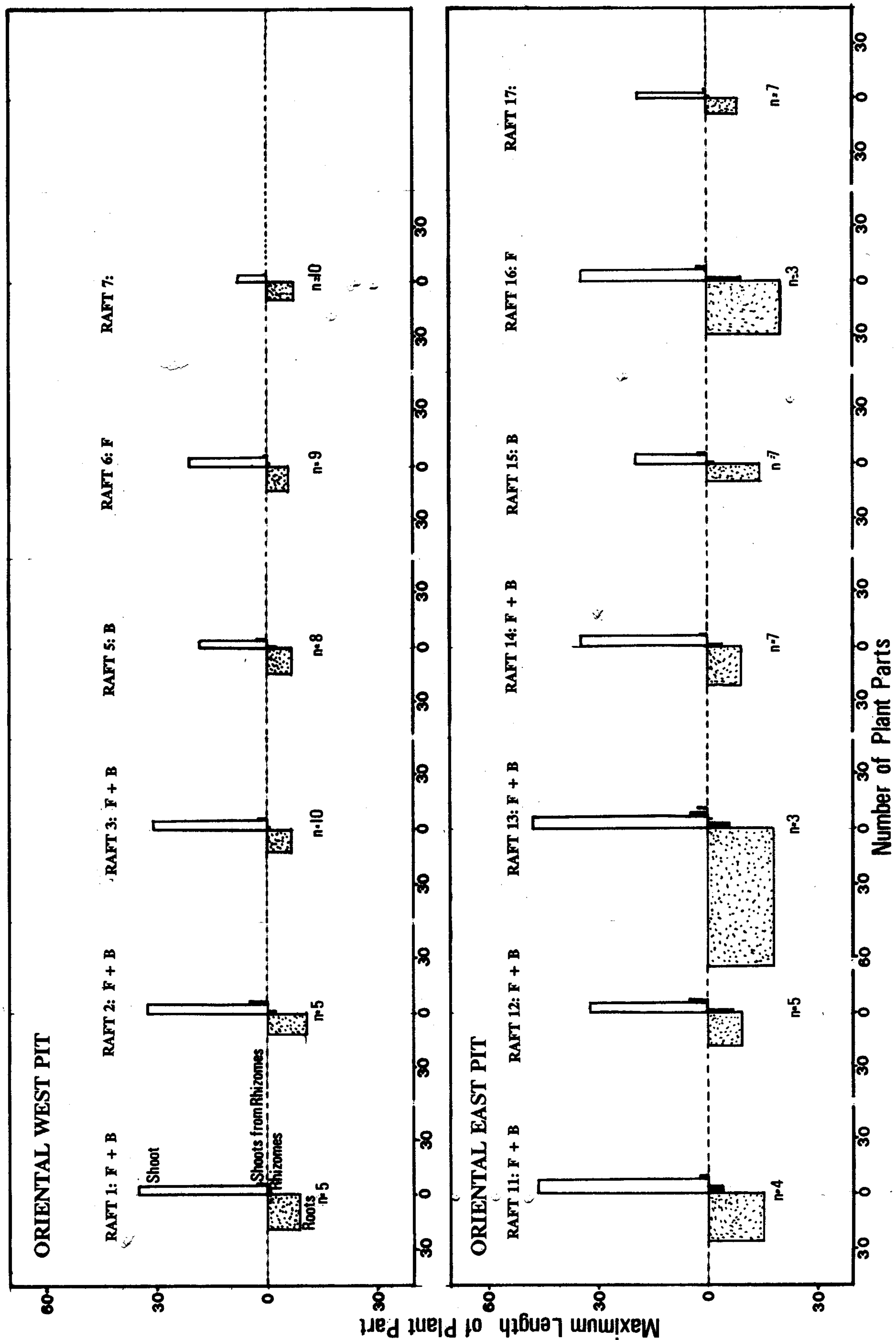
Page 31 and 32 are the same. There is an error in the page numbering.

Plate 2: Floating cattail rafts with cattail transplants.

The best conditions for growth after transplanting were provided by the rafts located in the circumneutral Oriental East Gloryhole, where rafts were amended with fertilizer and bone meal. Neither the rafts amended were fertilizer or bone meal alone provided conditions for the excellent plant development observed when the amendments were combined. Meanwhile, very poor growth of seedlings was observed on the unamended raft. When bone meal or fertilizer was applied alone, the growth was better than in the control.

In Schematic 2, the results of root development on the cattail are depicted, based on a subsample of plants collected at t he end of the growing season from each raft. It is evident

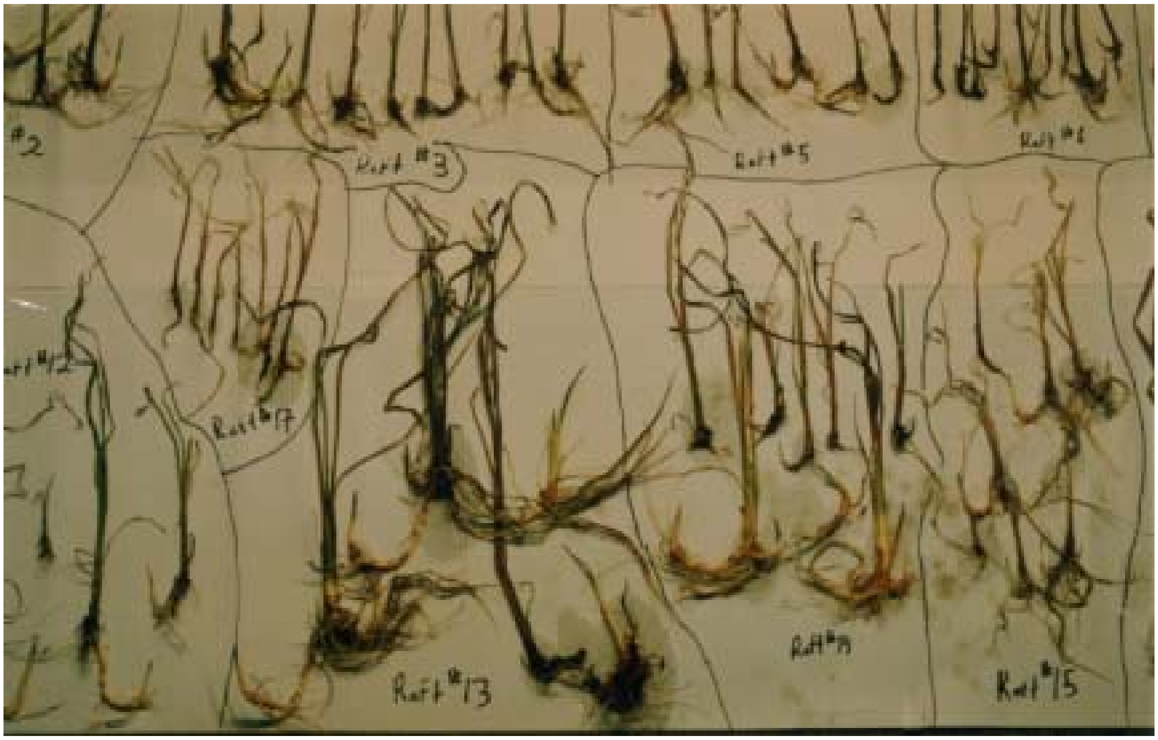
Schematic 2: Root development of Cattail seedlings



that the treatment of slow release fertilizer and bone meal produced the best root development in the first growing season in the cattail populations originating from seeds. In Plates 3 and 4, the root development in the cattail seedlings from all rafts are depicted, illustrating the results given in Schematic 2. In 1991, after over-wintering, the design of the floats and the ability of the plants to withstand the freezing in the gloryhole can be evaluated.

Plate 3: Root development of cattail seedlings: Overview

Plate 4: Root development of cattail seedlings detail



SECTION 3: THE POLISHING PONDS IN THE FIRST MEADOW

In June 1989, 6 ponds were constructed in the First Meadow. A portion of the flow through the main creek draining Oriental East gloryhole was diverted to flow through the 6 ponds in series. In August and September 1989, cut Alder trees (110 trees/pond) were placed in the ponds to serve as precipitation/collection surfaces and as a growth substrate for biological polishing agents.

The series of six experimental pools were constructed with an average volume of 40.5 m^3. A flow of 8.05 m^3/h was diverted through the ponds in July 1989. In November, the flow was reduced to a flow of 0.7 m^3/h.

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Fig. 14a Buchans
Pond 1 - 6 Dissolved Zinc

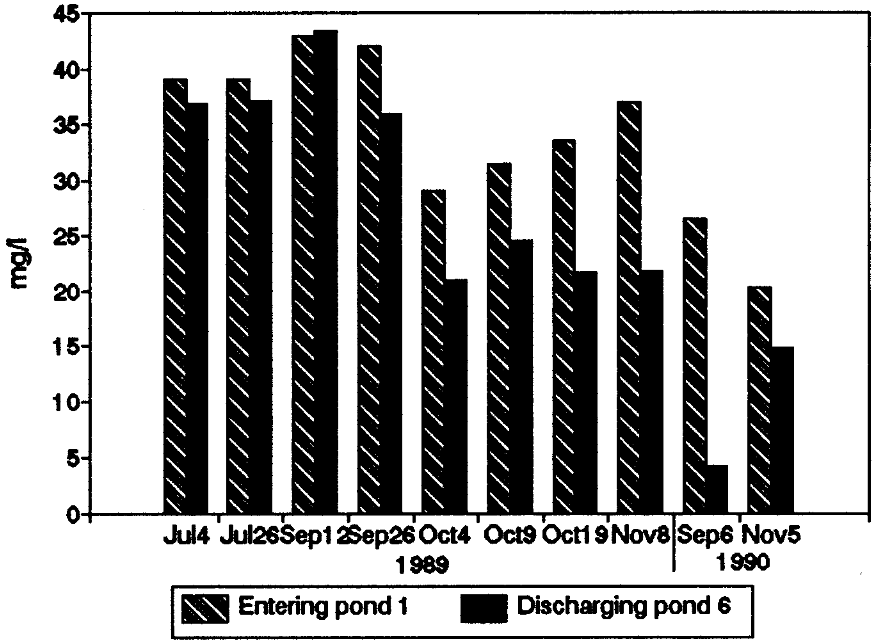
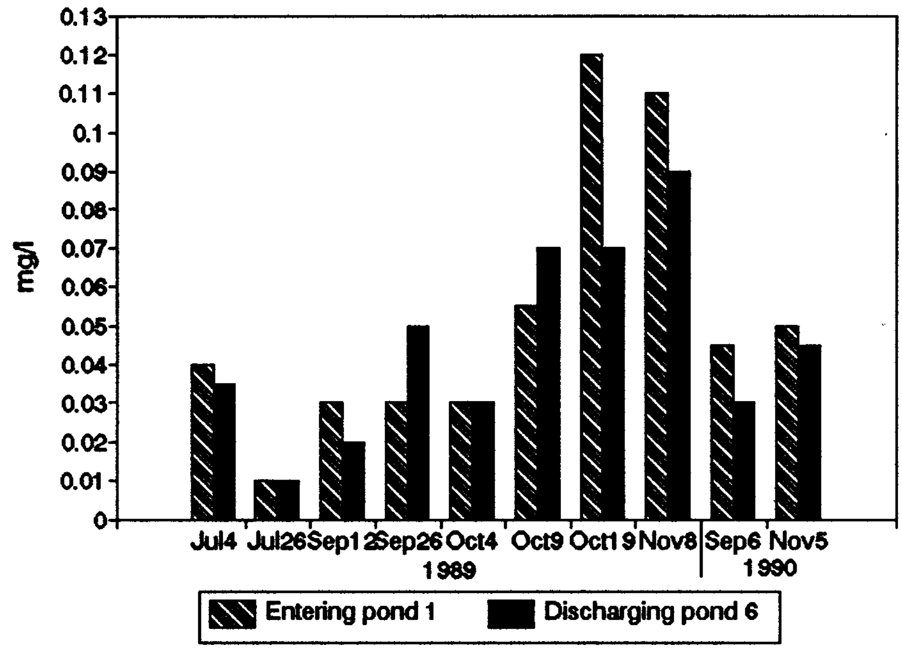
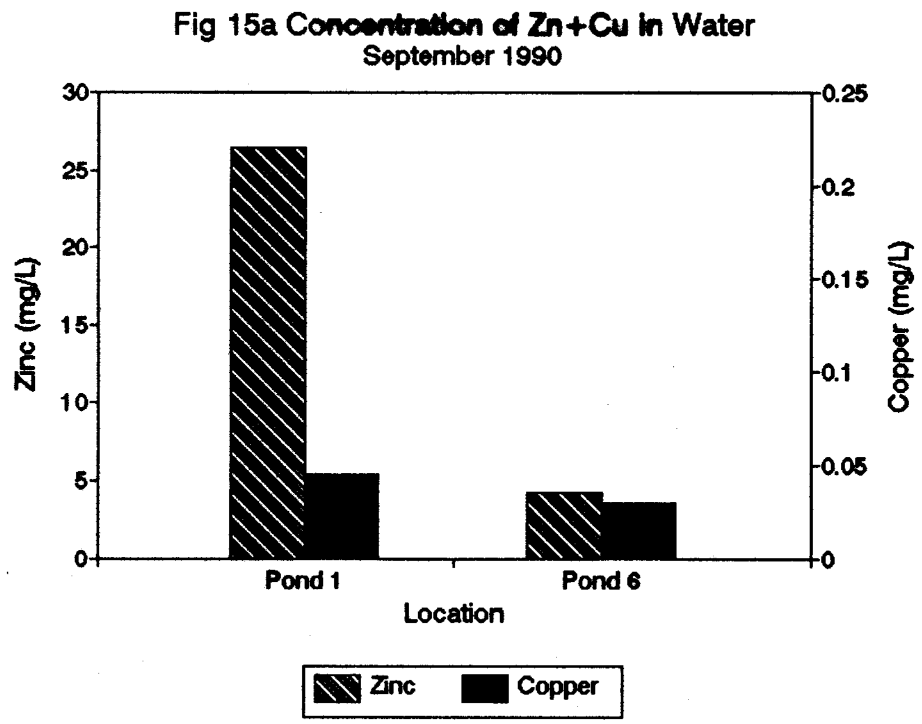


Fig. 14b Buchans
Pond 1 - 6 Dissolved Copper



The results in Figure 15a indicate that, in September, zinc levels dropped by 84% between the inflow of Pond 1 and the outflow of Pond 6, while copper levels dropped by 33% over this same area. In October, zinc levels were dropping by 55% (Figure 15b), while copper concentrations were below the detection limit (<0.01) after passing through the series of ponds. In November, zinc levels dropped 27%, while copper dropped only 10% as the water passes through the ponds. The concentrations of copper in the ponds were at, or near, the detection limits of the ICP methods and, therefore, estimates on removal of copper become unreliable (Figure 15c).

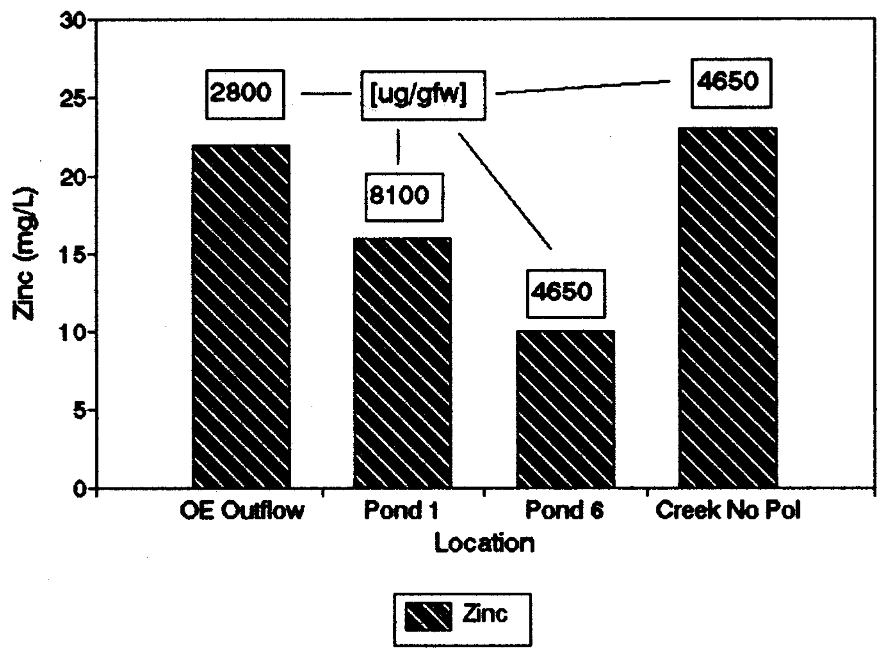
Figure 15a:



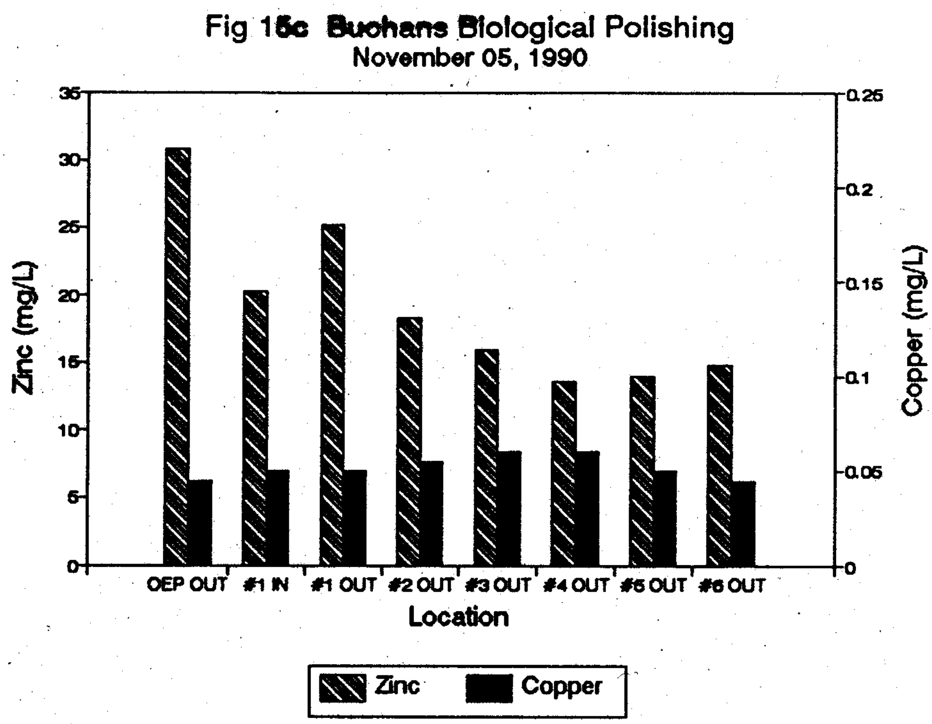
The data suggest that, indeed, the removal of zinc directly varies with season, or more specifically, biological removal appears to be related to the amount of sunlight. As growth of periphyton is tightly coupled with solar radiation, one would expect a drop in uptake with a drop in solar radiation if the growth is relevant to the biological polishing process.

Biomass samples were collected at the same time as water samples, in October. A dense mat, covering the creek bed which runs parallel to Ponds 1 to 6, was identified as a community dominated by diatoms (*Achnanthes*), which is held together by *Microspora*, a filamentous green algae related to *Ulothrix*. *Ulothrix* is the dominant attached algae found in the gloryhole and in the meadow. The results of elemental analysis are given in Figure 15b. The boxes above the bars indicate the μg/g of zinc per gram fresh weight (gfw) in the algae. These concentrations are so high that it is likely that a large fraction of the metals present are particles of precipitate, producing these concentration factors, ranging from 128 to 740, between water and wet algal biomass.

Fig 15b Buchans Biological Polishing
October 26, 1990



In Figure 15c, the concentrations of zinc and copper are given for all the Ponds from 1 to 6. Although changes in the copper concentrations were too subtle and close to the detection limit, precipitation of zinc is virtually complete by Pond 3, whereupon further polishing does not occur in Ponds 4, 5 and 6. This, of course, poses the important question - what factors are inhibiting further polishing in these lower ponds?



If we assume that the polishing is directly related to growth conditions, then the results in Figure 15c may suggest that the growth of algal biomass is reduced in the lower ponds. The biomass (with precipitate) on the branches in each of the ponds was quantified as g/100 g

Fig. 16 Biomass g/100 g of branch (dw)

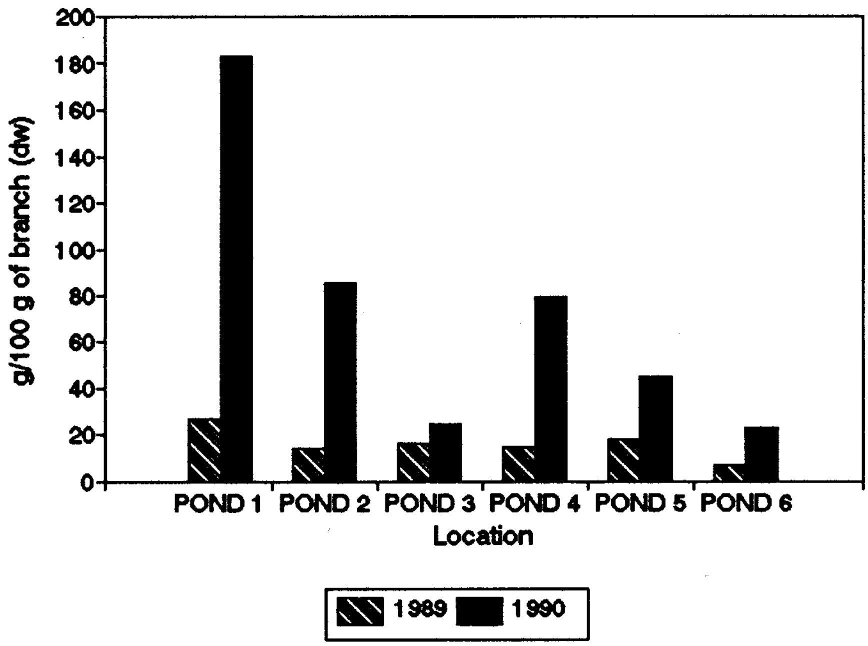


Plate 5: Algal Biomass in Oriental East Outflow

Plate 6: Algal biomass in pond 1

Table 4: **Elemental Concentrations in Algae**

SAMPLE DATE	July 90	July 90	July 90	July 90
SAMPLE VOLUM				
ASSAYERS CODE	1933	1934	1935	1936
SAMPLING LOCA	Buchans Cell 7 Inflow Algae	Buchans Cell 9 Outflow Algae	Buchans 2nd Meadow Algae	Buchans Stn 4 Narrows Algae
Processing Code	SS	SS	SS	SS
ELEMENTS Ag	0.1	0.1	0.1	0.1
(ug/gdw) Al	20140	2650	16430	1060
As	10	< 10	19	13
Ba	5083	6503	2992	2331
Ca	2840	2840	10650	12070
Co	< 10	< 10	20	70
Cr	20	25	33	36
Cu	259	192	56	62
Fe	36400	21700	10500	52500
K	9960	9960	4980	1660
Mg	600	1200	1200	600
Mn	77	77	1540	5390
Na	1480	740	1480	592
Ni	13	22	18	26
P	440	440	880	440
Pb	348	240	379	122
S	5000	6000	4000	3000
Sr	83	75	102	120
Te	< 10	< 10	16	21
Ti	258	86	344	86
U	20	17	18	39
V	14	< 10	17	< 10
W	< 10	< 10	43	51
Zn	1340	1461	14529	18800
Zr	17	10	17	< 10
L.O.I.	84.57	89.61	82.88	80.3

Table 5: Elemental Composition of Algae as Polishing Agents

SAMPLE DATE	26 10 90	26 10 90	26 10 90	26 10 90
SAMPLE VOLUM				
ASSAYERS CODE	2338	2345	2346	2347
SAMPLING LOCA	Buchans 1st Meadow White Precip	Buchans OE Pit Outflow Algae	Buchans OE Pit Creek Algae	Buchans Pol Pond 1 Algae
Processing code	SS	SS	SS	SS
ELEMENTS Ag	62	6	5	4
Al	55042	3176	25933	26992
As	268	< 10	< 10	49
B		400	200	100
Ba	466	685	3939	2287
Ca	17153	13579	12865	12865
Cd	10	69	30	40
Cr	45	33	37	39
Cu	1139	392	391	210
Fe	17486	269281	137088	68544
K	166	2490	12452	7471
Mg	1206	603	3016	2412
Mn	310	774	774	2323
Na	3709	742	13353	11128
Ni	18	62	48	50
P	436	1309	1746	873
Pb	359	399	1070	638
S	16000	5000	3000	5000
Sn	95	79	82	110
Sr	75	203	166	125
Ti	60	60	600	600
Zn^	6799	28100	51800	97000
		28200	46500	81000
L.O.I.	56.83	44.21	29.64	38.52

^ Zn confirmation

Table 6: Fractions of suspended solids in ponds

SAMPLE DATE	08-03-90	08-03-90		08-03-90	08-03-90	
SAMPLE VOLUME	250 ml	250 ml		250 ml	250 ml	
ASSAYERS CODE	1604	1612		1605	1613	
SAMPL. LOCATION	Pond 1	Pond 1		Pond 6	Pond 6	
PROCESS. CODE	FA	FP		FA	FP	
Temp. (C)	0	-	Percentage	0	-	Percentage
pH	6.7	-	solids	6.3	-	solids
Cond. (umhos/cm)	950	-		330	-	
ELEMENTS Al	0.2	12.90	98.5	0.1	1.65	94.3
(mg/L) B	1.8	0.10	5.3	1.5	0.10	6.3
Ba	0.04	0.39	90.7	0.04	0.13	75.9
Ca	599	3.00	0.5	363	1.06	0.3
Cu	0.06	0.10	63.4	0.04	0.02	36.9
Fe	0.01	49.75	100.0	0.01	3.03	99.7
K	15	5.70	27.5	14	0.64	4.3
Mg	47	1.51	3.1	32	0.27	0.8
Mn	14	0.20	1.4	8.6	0.03	0.4
Na	76	7.41	8.9	55	2.16	3.8
Pb	6.1	0.41	6.3	5.5	0.07	1.3
S	433	2.34	0.5	293	1.70	0.6
Si	10	0.00	0.0	10	0.00	0.0
Zn	33	5.05	13.3	25	0.42	1.6

Fig. 17a Composition of biomass
Pond 1 1989/90

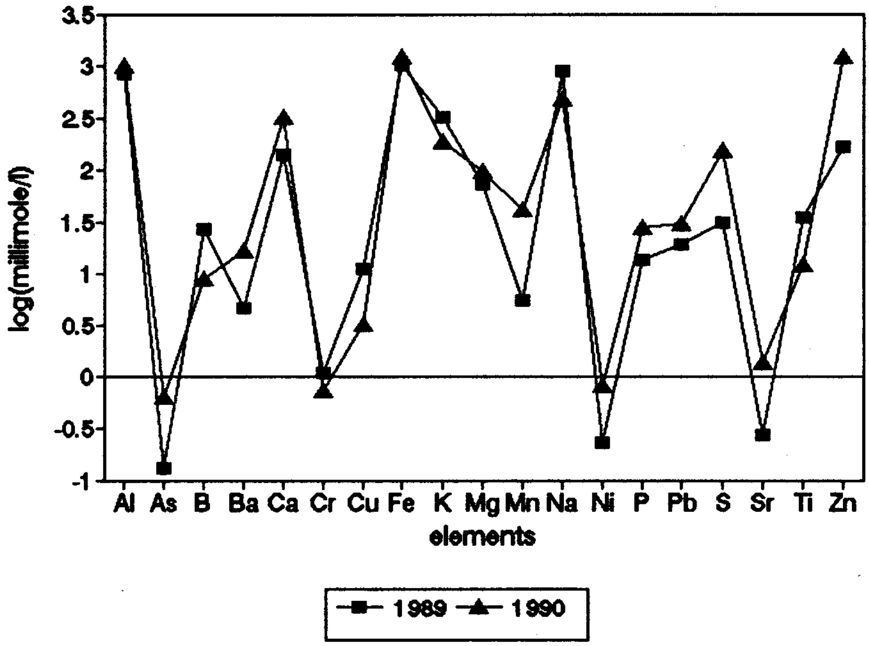
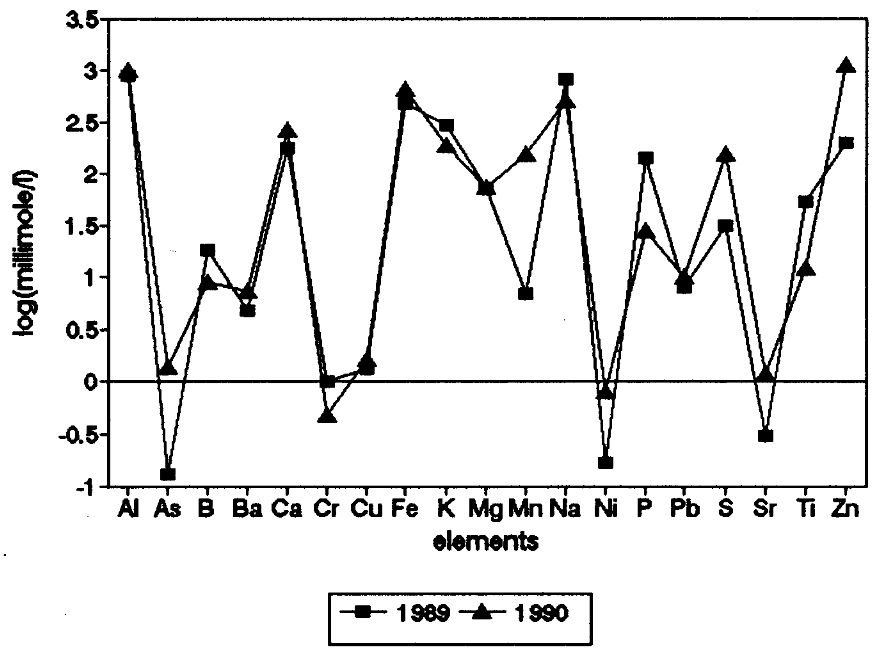


Fig. 17b Composition of biomass
Pond 6 1989/90



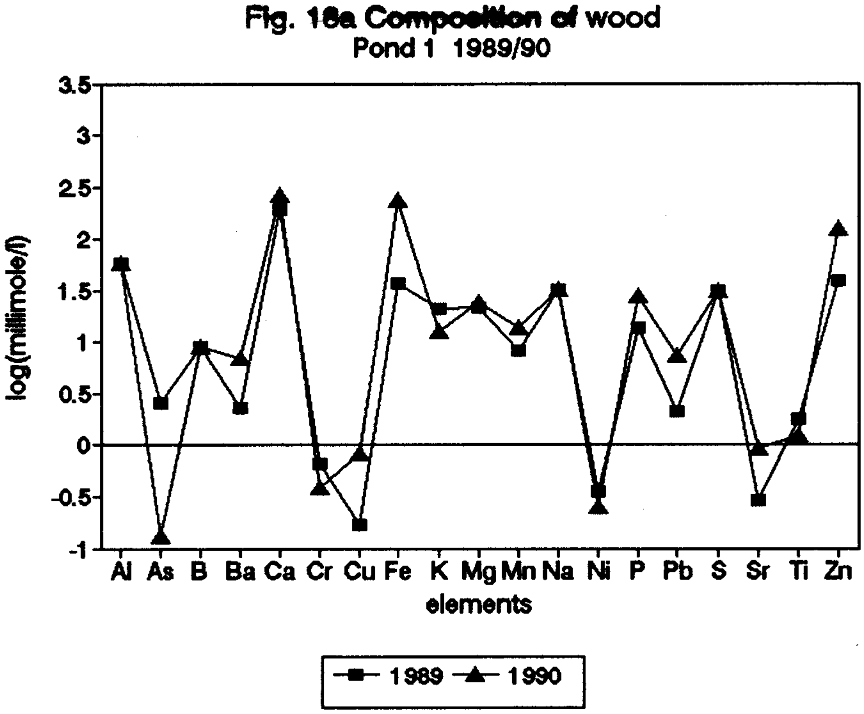


Fig. 18a Composition of wood
Pond 1 1989/90
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
log(millimole/l)
Al As B Ba Ca Cr Cu Fe K Mg Mn Na Ni P Pb S Sr Ti Zn
elements
1989
1990

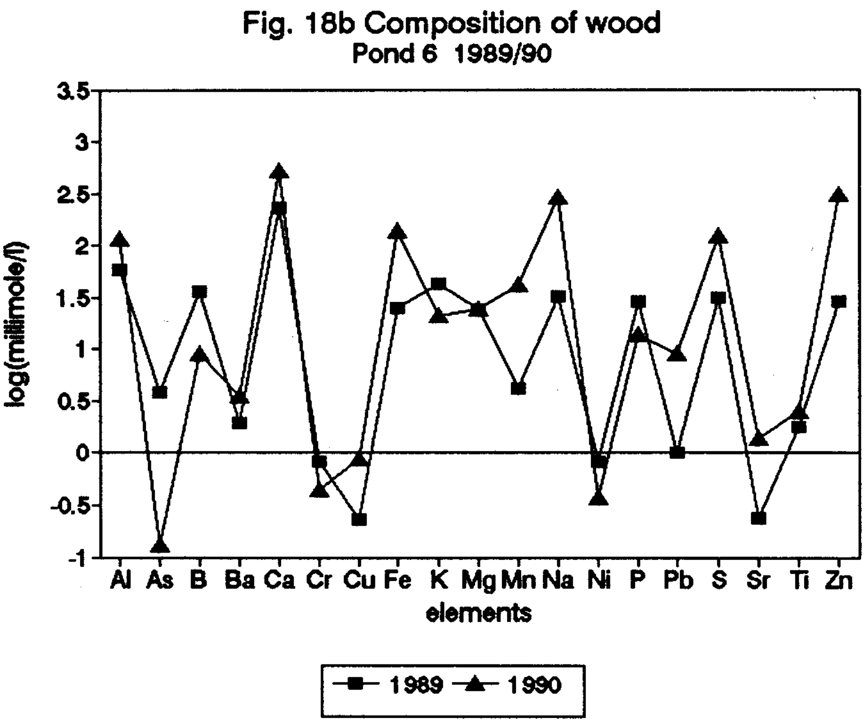


Fig. 18b Composition of wood
Pond 6 1989/90
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
log(millimole/l)
Al As B Ba Ca Cr Cu Fe K Mg Mn Na Ni P Pb S Sr Ti Zn
elements
1989
1990

Fig. 19a Composition of precipitate
Pond 1, 1989/90

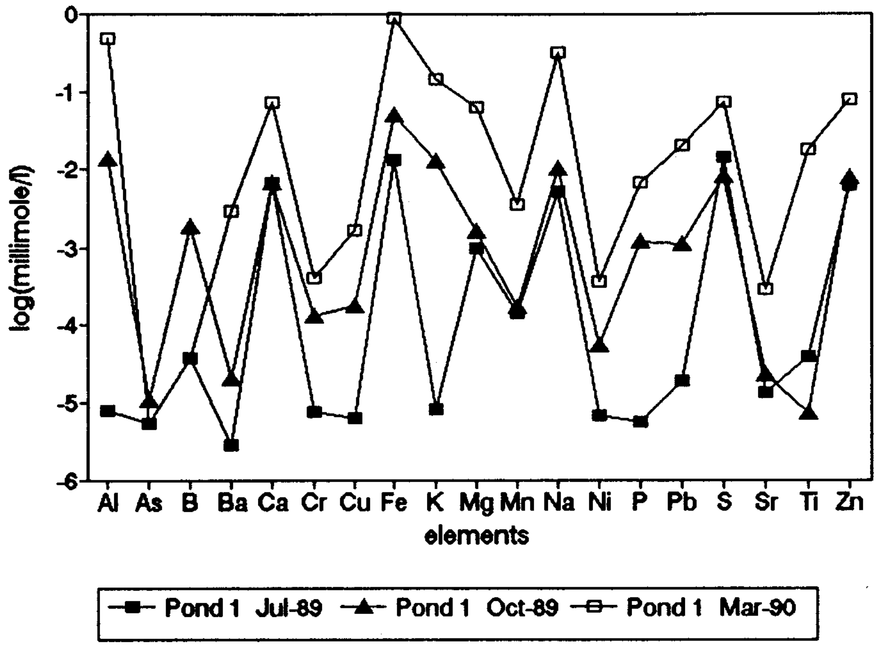
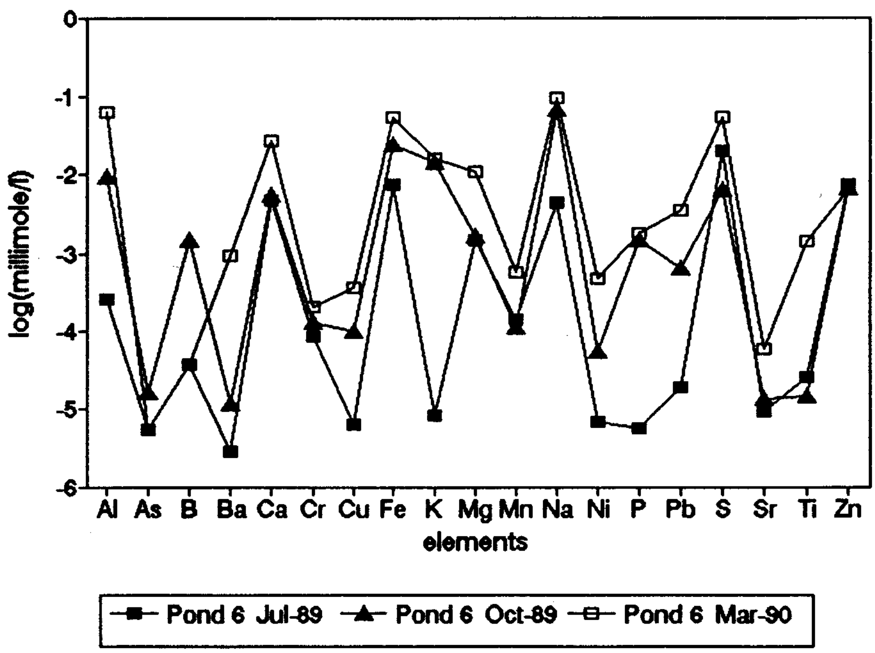
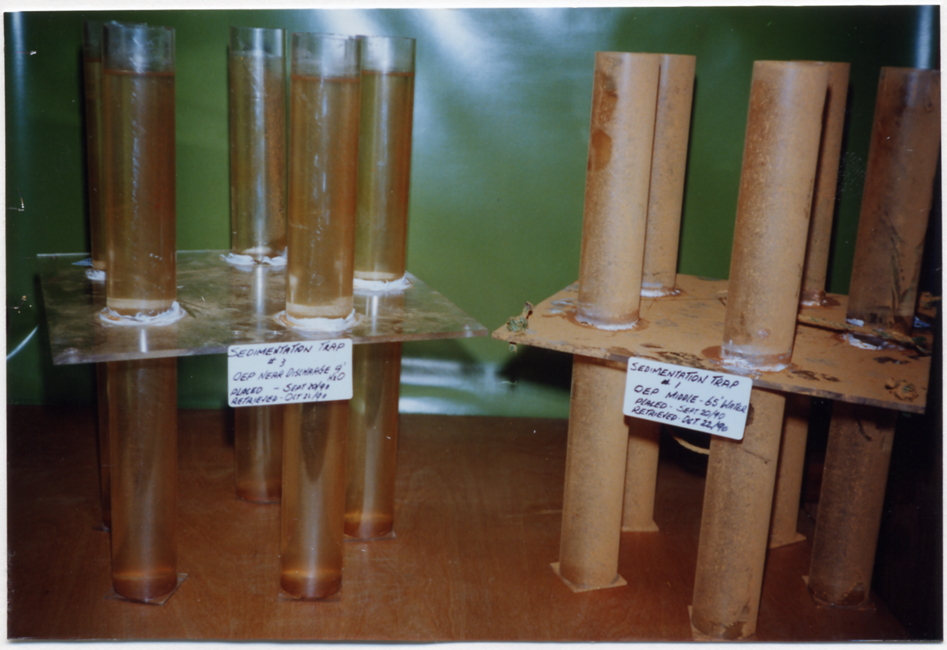


Fig. 19b Composition of precipitate
Pond 6, 1989/90



the outflow, where precipitate formed on the outside of the traps, while at the bottom of the gloryhole, no precipitate formation was occurring, indicated by the clean external surfaces of the trap.

Plate 7: Sedimentation traps retrieved 32 days after placement.



On the right is trap 3 which was positioned in the centre of the gloryhole at a depth of 20 m. On the left is trap number one, positioned in 2.7m near the outflow of the Oriental East gloryhole (contrary to labels in photo).

Plate 8: *Chara buckellii* **shoots 21 days after culture in Oriental East solution**

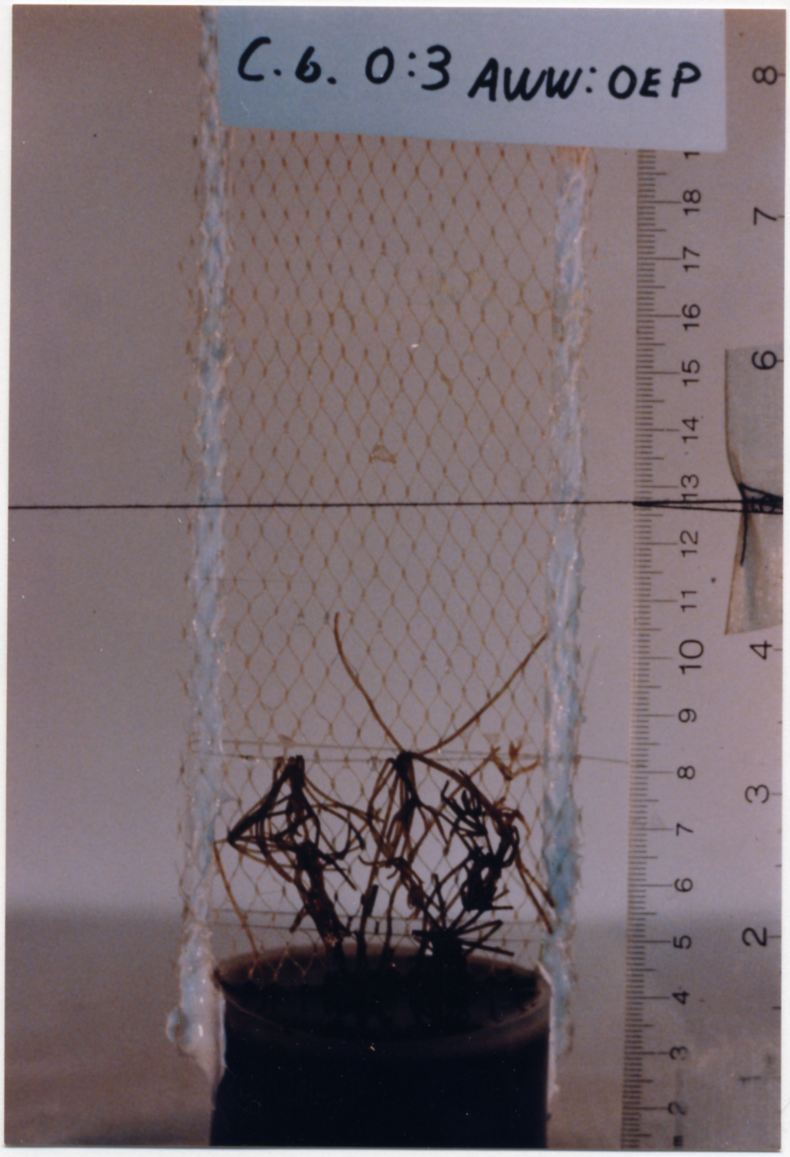


Plate 9: ***Chara vulgaris*** **shoots after 6 days in culture using full strength Oriental East gloryhole solution**

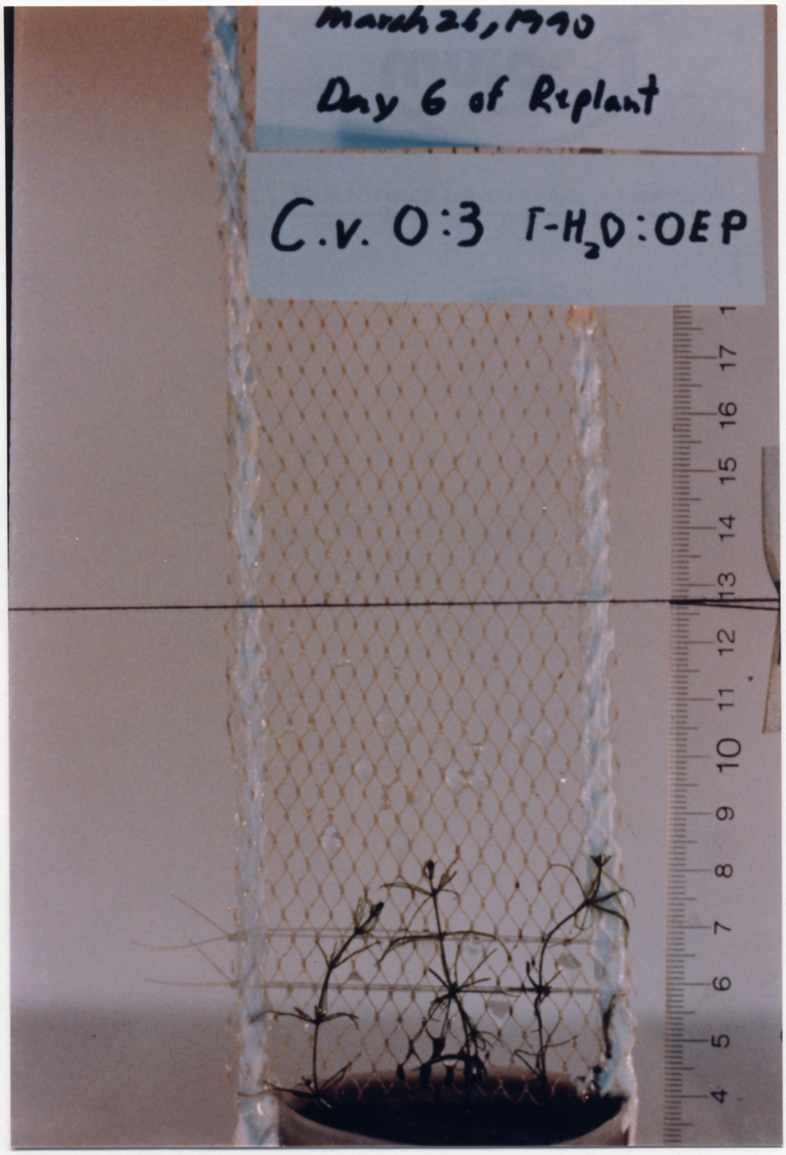
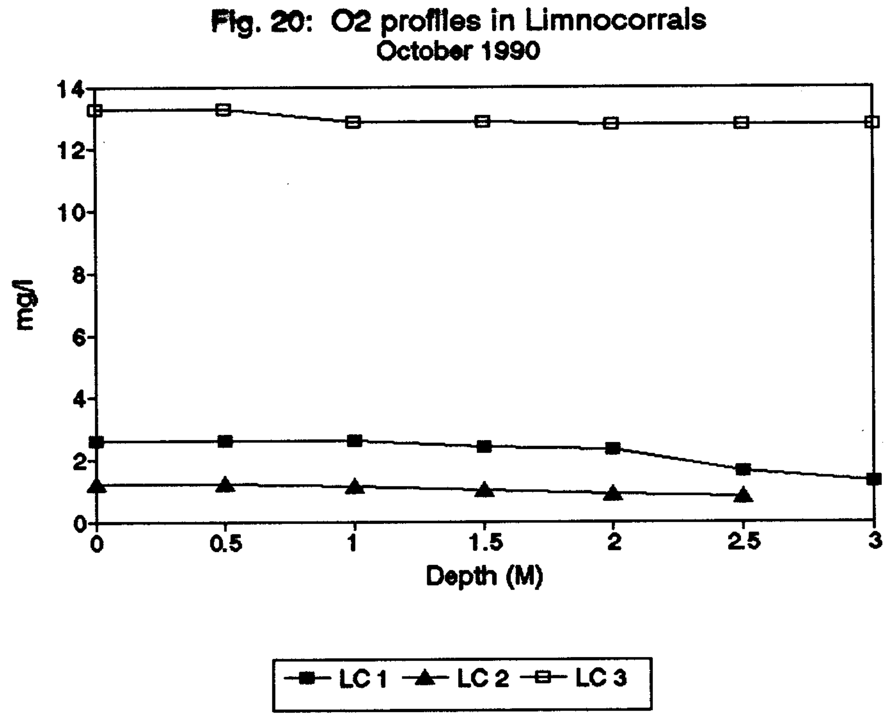


Figure 20



reducing conditions. In limnocorral 3, the control, both surface and bottom water has a positive Eh of 280 and 220, respectively.

A thermocline exists in the Oriental East gloryhole, which has been maintained at a depth of about 5 to 6m throughout the summer of every year, as depicted in Figure 21. This thermocline is associated with reductions in oxygen concentrations, as indicated in Figure 22.

Fig. 21 July temperature 1988/89/90

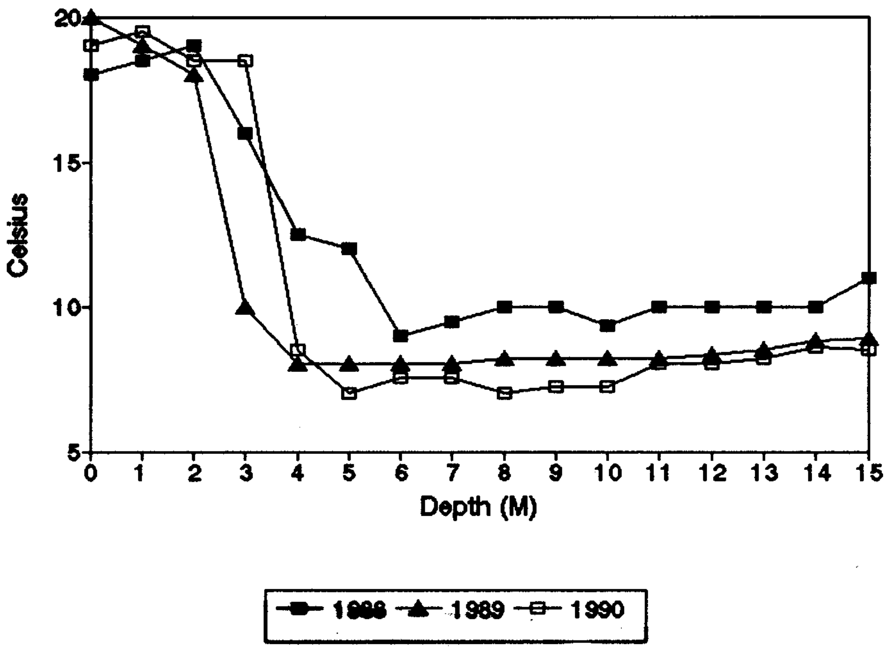
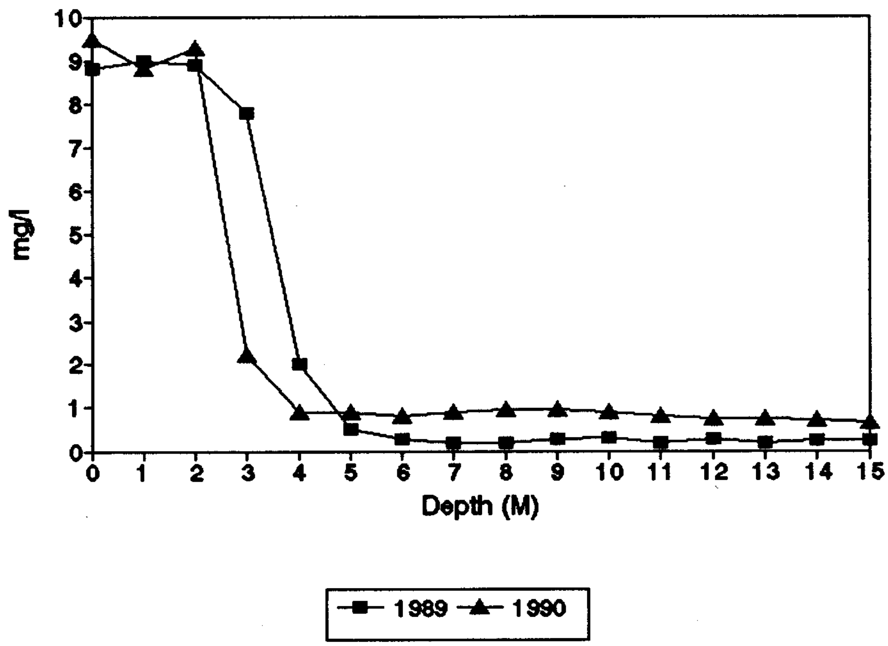
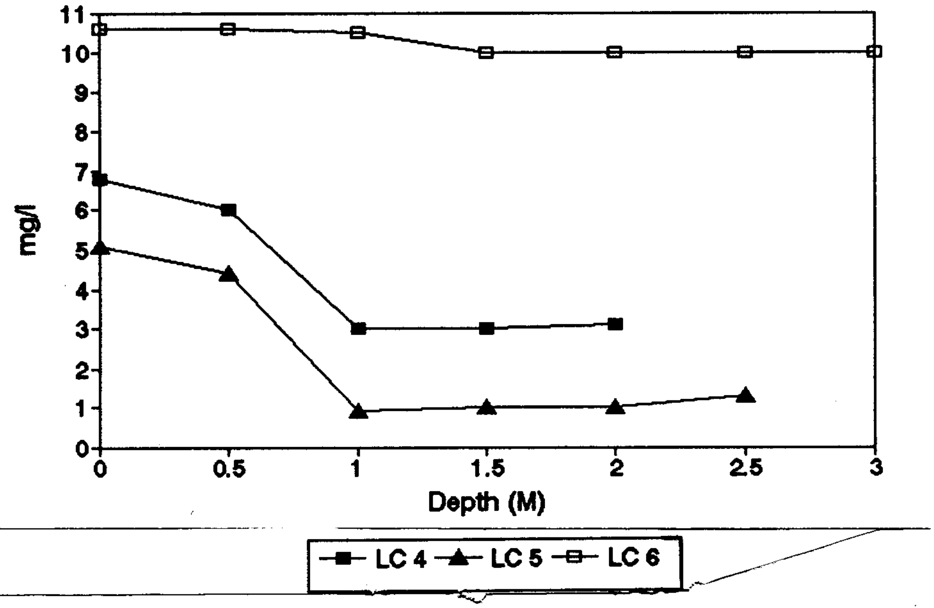


Fig. 22 July oxygen 1989/90



Figure

Fig. 23: O2 profiles in Limnocorrals
October 1990



Amendment material was collected from the limnocorrals in both Oriental East and West gloryholes, as well as samples of sawdust placed behind the curtains in both gloryholes. In Table 8 and 9, the microbial populations which have been identified as the key players in alkalinity generation have been enumerated. ATP (Adenosine triphosphate) is an indicator of live material; SRB stands for sulphate reducing bacteria grown in two different media (Postgate B and F); and IRB or Iron Reducing Bacteria are required for the ARUM process, along with Ammonifiers.

Although the population enumerations cannot be compared quantitatively, those groups found in low numbers are likely candidates when problems in the ARUM process are incurred. The only low numbers of all groups are reported for IRB's in the Oriental East gloryhole, and in limnocorrals 5 and 1. As both these limnocorrals are producing

Table 7: Characteristics of filtered water in alfalfa mat behind the Oriental East curtain

SAMPLE DATE	26 10 90	26 10 90
SAMPLE VOLUME	100	100
ASSAYERS CODE	2332	2334
SAMPL.LOCATION	Buchans OE Pit Curtain No Amendment	Buchans OE Curtain Floating Amendment
PROCESS. CODE	FA	FA
** FIELD **		
Temp. (C)	3.9	3.9
pH	7.0	6.9
Cond. (umhos/cm)	1170	1170
Eh	69	-241
Acidity (mg/l)	N.R.	N.R.
Alkalinity (mg/l)	N.R.	N.R.
** LAB **		
Temp. (C)	15	14
pH	6.16	6.04
Cond. (umhos/cm)	1300	1200
Eh	5.91	8.77
Acidity (mg/l)		
Alkalinity (mg/l)	50	20
ELEMENTS (mg/L) Ca	277	251
Fe	0.09	0.7
Mg	24	21
Mn	6.6	5.8
Na	81	69
S	304	254
Si	3.4	3.2
Sr	3.2	2.7
Zn	22	3.1

Table 8: Microbial Population in Amendments in Oriental East

	Peat Limno 5 Jun-90	Peat Limno 5 Oct-90	Sawdust Curtain Jun-90	Sawdust Curtain Oct-90	Sawdust Limno 4 Jun-90
pH	6.3	6.5	6.6	6.2	6.4
ATP (ng/ml)	81	25	16	97	61
SRB Postgate	>100,000	10,000	1,000	>100,000	>100,000
SRB Postgate	>100,000	1,000	1,000	100,000	>100,000
IRB (/ml)	<1	>100,000	>100,000	>100,000	<1
Ammonifiers	>100,000	>100,000	>100,000	>100,000	>100,000

Table 9: Microbial Population in Amendments in Oriental West

	Sawdust Limno 1 Jun-90	Sawdust Limno 1 Oct-90	Peat Limno 2 Jun-90	Peat Limno 2 Oct-90	Sawdust Curtain Oct-90
pH	4.5	4.7	3.5	6.4	3.5
ATP (ng/ml)	130	11	30	25	52
SRB Postgate	1,000	10,000	1,000	10,000	10,000
SRB Postgate	>100,000	1,000	1,000	100	10,000
IRB (/ml)	1	>100,000	>100,000	>100,000	>100,000
Ammonifiers	>100,000	>100,000	>100,000	>100,000	>100,000

Legend:
ATP - Adenosine-Tri-Phosphate
SRB - Sulphate Reducers
IRB - Iron Reducers
Ammonifiers - Reduce Amino Acids

in the respective pouches. These quantities are based on the detritus decomposition rates of Moran and Hodson (1989).

Five types of amendments were placed in the pouches: sawdust, peat, straw, alfalfa, and cattail litter. Samples of the original amendments were collected for determination of dry weights (Table 10), for analysis of elemental composition (ICP), and analysis for the various forms of carbon present.

The procedure for analysis of the carbon composition, carried out at Dearborn, is a simplified version of forage file analysis (Goering and Van Soest, 1970). The methods are summarised in Schematic 3.

Table 10: Dry matter content of amendments
Moisture content (%) in brackets

Amendment	Dry weight of 1 kg pouch
Alfalfa	888 (11)
Cattail	601 (40)
Peat	478 (52)
Sawdust	775 (22)
Straw	892 (11)

4.2.2 Placement Procedure

Placement of pouches in the Oriental East gloryhole took place on July 10, 1990 at three depths: the surface, the thermocline, and below the thermocline, corresponding to the temperature profiles that exist in this gloryhole. The pouches have been designed to expose the largest (feasible) surface area possible for microbial action to take place, while minimizing amendment compaction. Pouches containing each of the five amendments have also been placed in the respective limnocorrals in the East gloryhole. The assembly of the pouches is depicted in Plate 11.

Plate 11 Assembly of decomposition pouches

Table 11: % weight losses after 31 days (OEP) and 34 days (OWP) in the limnocorrals

		Amendment				
		Alfalfa	Cattail	Peat	Sawdus	Straw
Oriental West Pit	Limnocorral 1	35	8	56	21	12
	Limnocorral 2	54	31	62	13	35
Oriental East Pit	Limnocorral 4	51	9	49	15	14
	Limnocorral 5	54	6	61	26	27

Table 12: Sequential analyses of various amendments before exposure to amd

	Total % loss from Acetone Ext	Total % loss after 4% HCl	Total % loss after 72% H2SO4	% Remaining after 72% H2SO4
Sawdust 1	1.5	29	66	34
Sawdust 2	7.2	29	76	24
Peat	9.0	40	55	45
Straw	6.0	33	76	24
Cattail	5.0	42	69	31
Alfalfa 3	5.1	45	83	17
	Lipids (resins)	soluble sugars,starch amino acids hemicellulose	plus lignin, silica, cellulose	very slow to non - bio degradable

Total degradable (as 100% Bio-available)

1 Feb 23/90 sample
2 July /90 sample
3 July /90 sample

Schematic #4

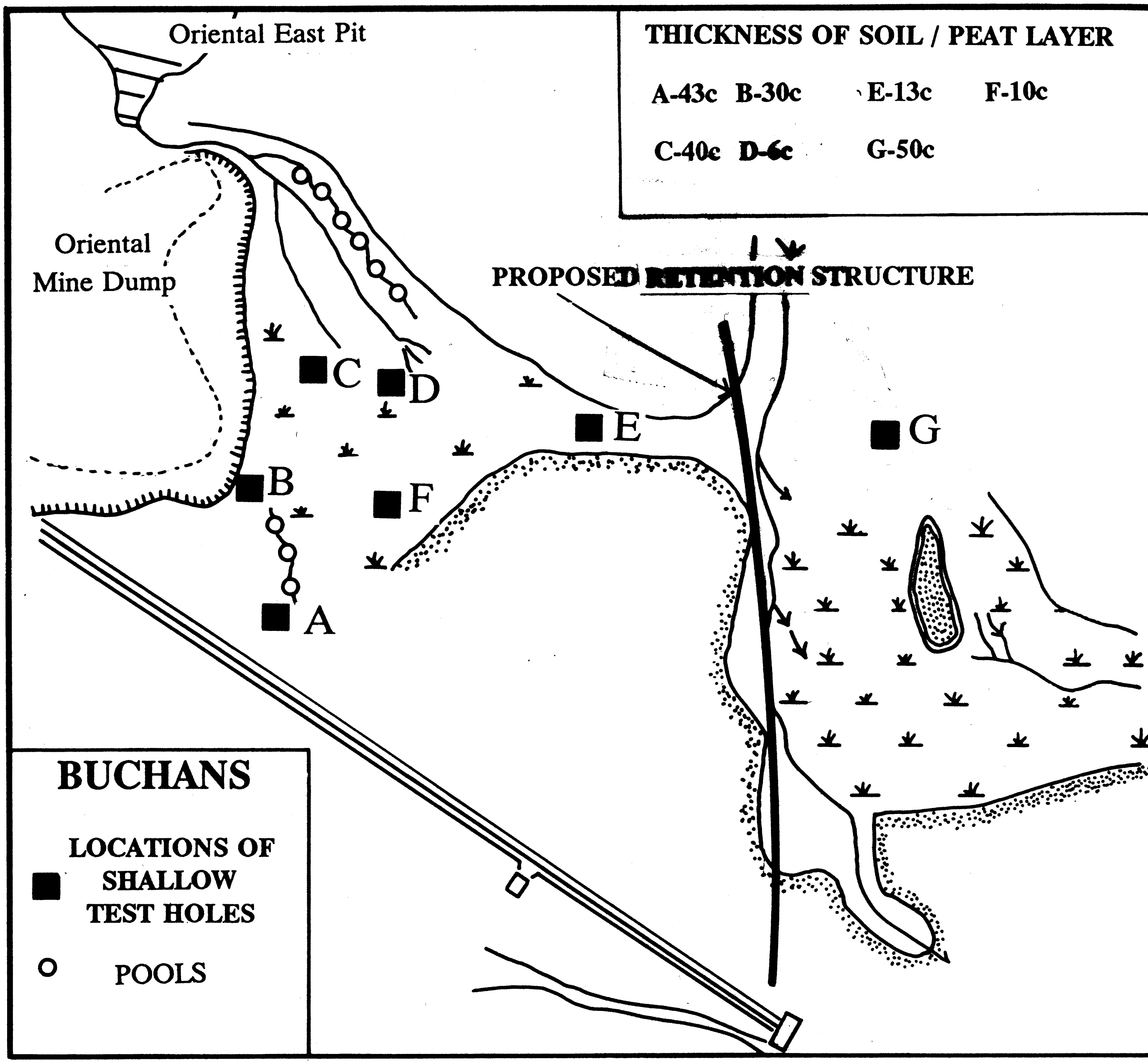

Oriental East Pit
THICKNESS OF SOIL / PEAT LAYER
A-43c B-30c E-13c F-10c
C-40c D-6c G-50c
Oriental
Mine Dump
PROPOSED RETENTION STRUCTURE
C
D
E
G
B
F
A
BUCHANS
LOCATIONS OF
SHALLOW
TEST HOLES
POOLS

TABLE 13: ANALYTICAL RESULTS SOIL SAMPL ES, BUCHANS 1st & 2nd MEADOW: JULY 25, 1990

AS.CODE DEPTH (cm)	2052 At(op) 0-7	2053 Ab(tm) 43-50	2056 Bt 0-3	2057 Bb 30-35	2062 Ct 0-5	2063 Cb 40-45	2058 Dt 0-6	2059 Db 30-50	2060 Et 0-13	2061 Eb 25-50	2054 Ft 0-5	2055 Fb 25-40	2064 Gt 0-10	2065 Gb 30-50
Al	13250	63600	29150	64660	23320	51410	22260	58300	23850	68900	14310	53000	10070	14310
As	<10	13	<10	35	<10	19	47	86	<10	10	<10	68	<10	<10
B	200	100	100	100	100	100	100	100	200	100	200	100	100	100
Ba	13129	1480	26440	1625	18071	1568	6744	1181	14682	1123	15324	1224	4554	385
Ca	5680	7810	4970	6390	14910	6390	3550	5680	14910	6390	18460	4260	3550	4970
Cd	39	<10	<10	<10	15	<10	<10	<10	53	<10	41	<10	<10	<10
Co	10	19	12	16	17	15	<10	11	21	13	36	12	<10	<10
Cr	31	43	33	40	36	50	58	42	22	49	32	28	40	50
Cu	1572	19	547	72	325	17	414	19	177	16	360	16	74	18
Fe	49700	16800	38500	15400	47600	15400	15400	13300	80500	17500	98000	12600	38500	14700
K	3320	20750	9130	23240	5810	17430	5810	19090	5810	18260	3320	19920	830	830
Mg	1800	5400	3000	4800	2400	3600	1200	3000	1800	3600	1800	1800	600	600
Mn	154	308	154	308	770	308	154	231	770	308	1540	308	77	77
Mo	<10	31	10	33	13	21	<10	28	25	36	37	24	<10	<10
Na	8140	33300	15540	35520	11840	28120	10360	30340	9620	27380	20720	25900	1480	1480
Ni	38	15	22	12	30	10	14	10	40	11	46		11	<10
P	880	396	440	440	440	396	440	440	880	440	440	352	880	880
Pb	348	120	623	104	1051	94	6071	104	551	127	632	99	279	55
S	11000	700	6000	700	6000	1000	4000	500	7000	1000	14000	800	4000	5000
Se	11	22	<10	11	<10	<10	<10	12	<10	11	15	18	<10	<10
Sr	2	123	185	118	223	118	89	85	205	91	269	78	51	33
Ti	688	4300	1720	4300	860	5160	2580	3440	1720	4300	774	5160	344	860
Zn	2702	385	1142	240	15829	290	465	118	21631	278	44590	518	1106	221
Zr	58	270	115	365	84	225	147	255	137	290	56	360	20	29
L.O.I.	70.56	6.61	48.86	3.84	52.69	11.83	52.59	9.32	49.85	16.71	53.87	9.38	83.01	80.94

FIGURE 24: Sample A sediment analysis. Difference between surface and bottom horizons are shown.

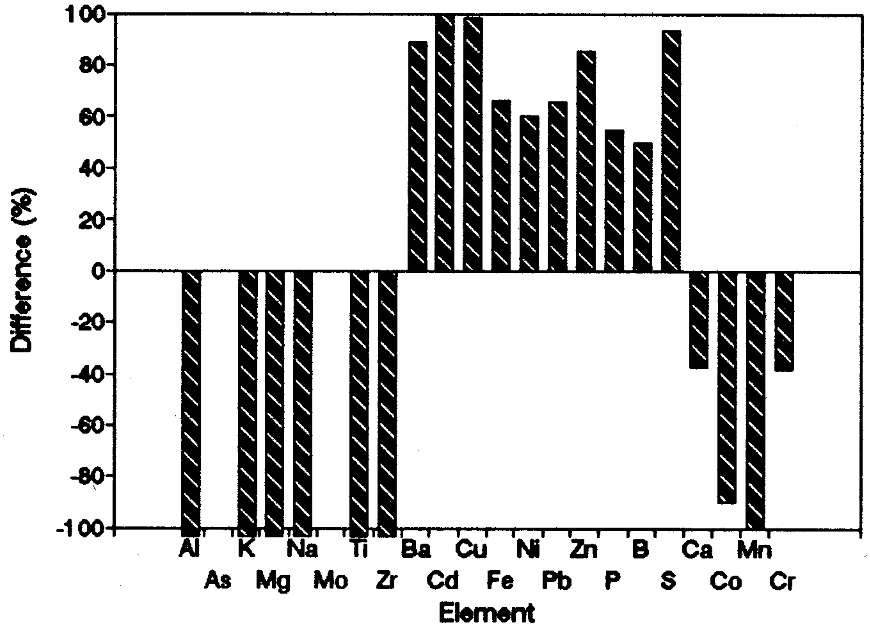


FIGURE 25: Sample B sediment analysis. Difference between surface and bottom horizons are shown.

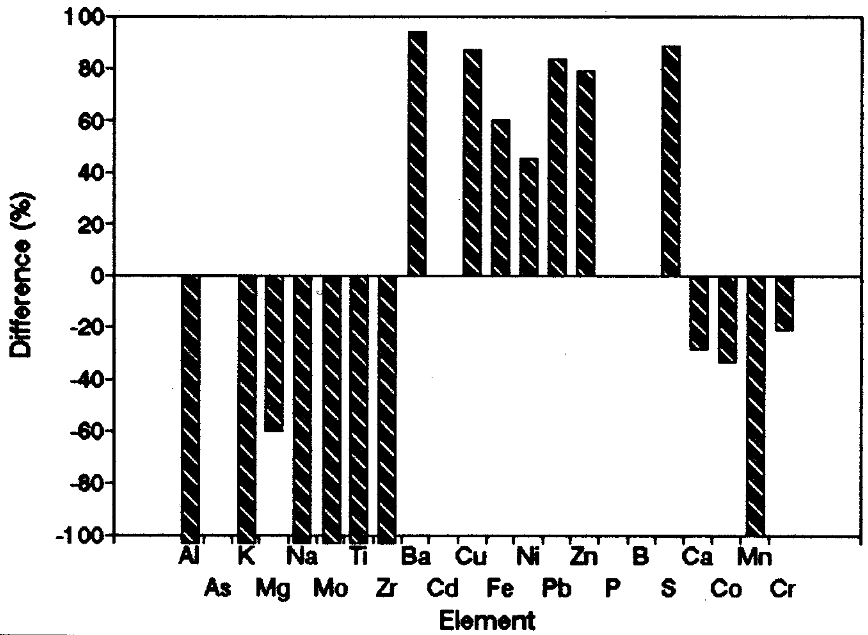


FIGURE 26: Sample C sediment analysis. Difference between surface and bottom horizons are shown.

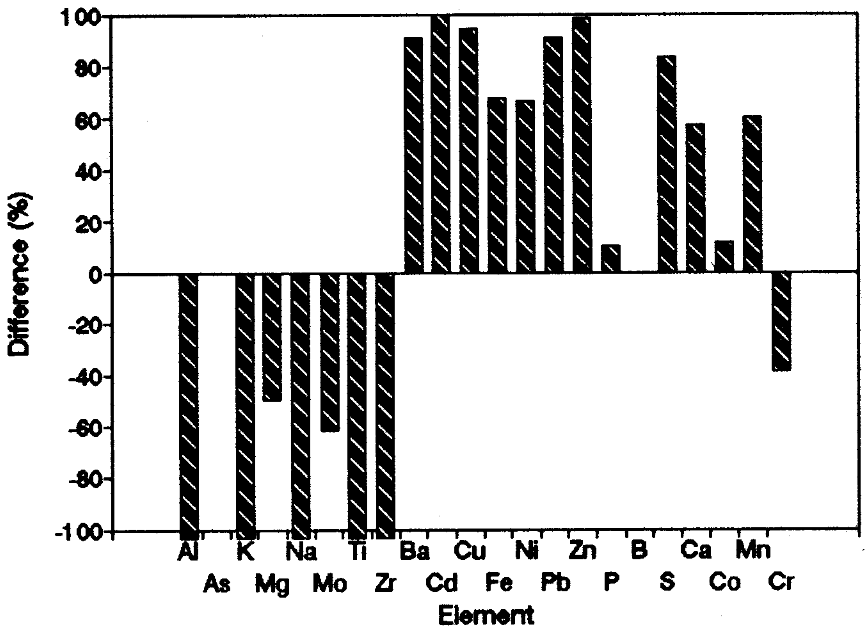


FIGURE 27: Sample D sediment analysis. Difference between surface and bottom horizons are shown.

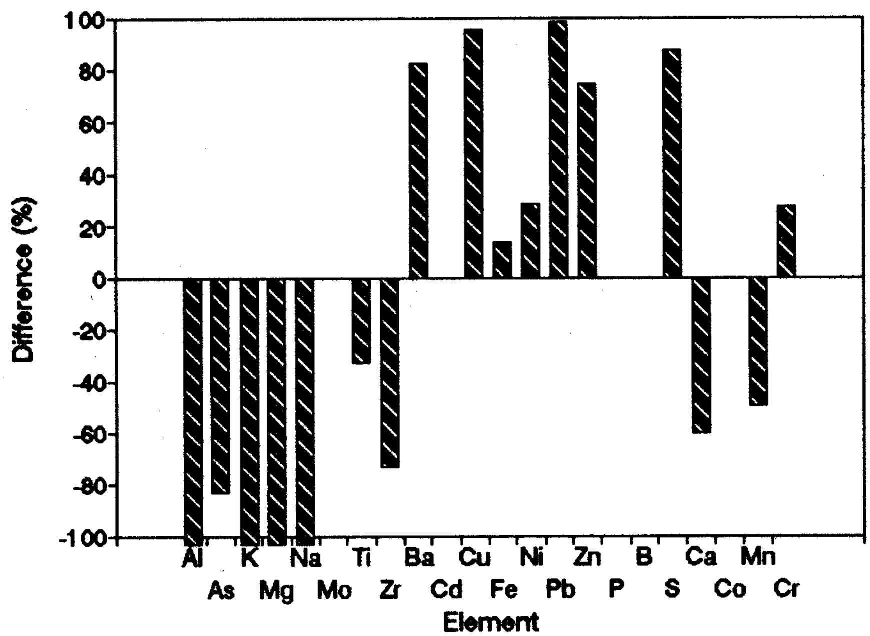


FIGURE 28: Sample E sediment analysis. Difference between surface and bottom horizons are shown.

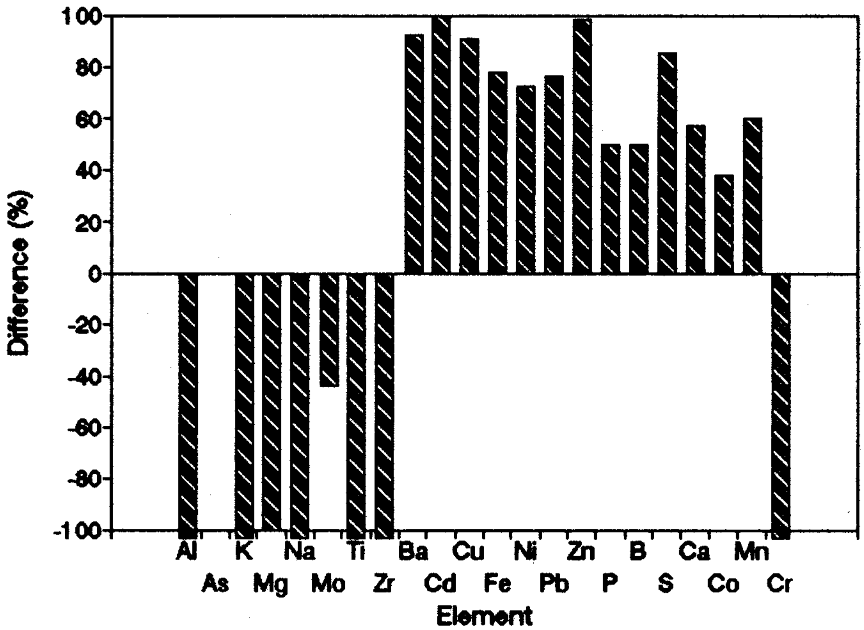


FIGURE 29: Sample F sediment analysis. Difference between surface and bottom horizons are shown.

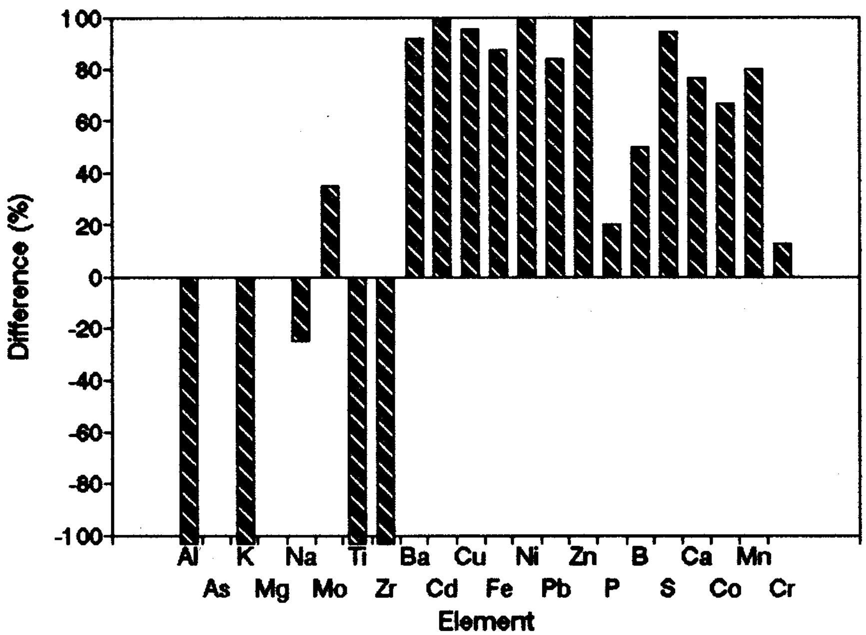
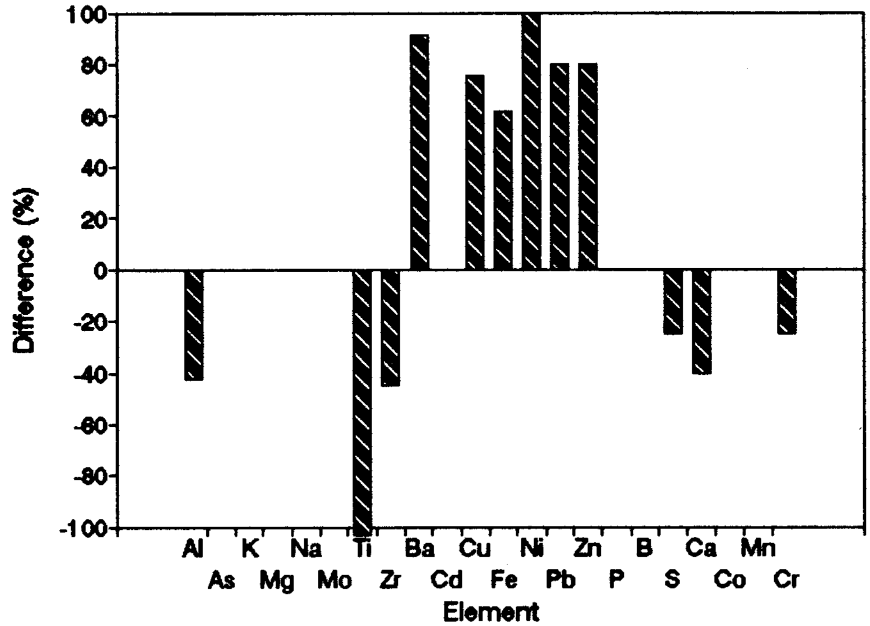


FIGURE 30: Sample G sediment analysis. Difference between surface and bottom horizons are shown.



It is obvious from the foregoing that the highest concentration of elements, which pose a potential threat to the environment, occurs in the top portion of the soil/peat profile. This is also the portion which will be in direct contact with ponded water and may contribute to the metal loading of the water. Further discussion of the analytical results will therefore be restricted to the top samples only.

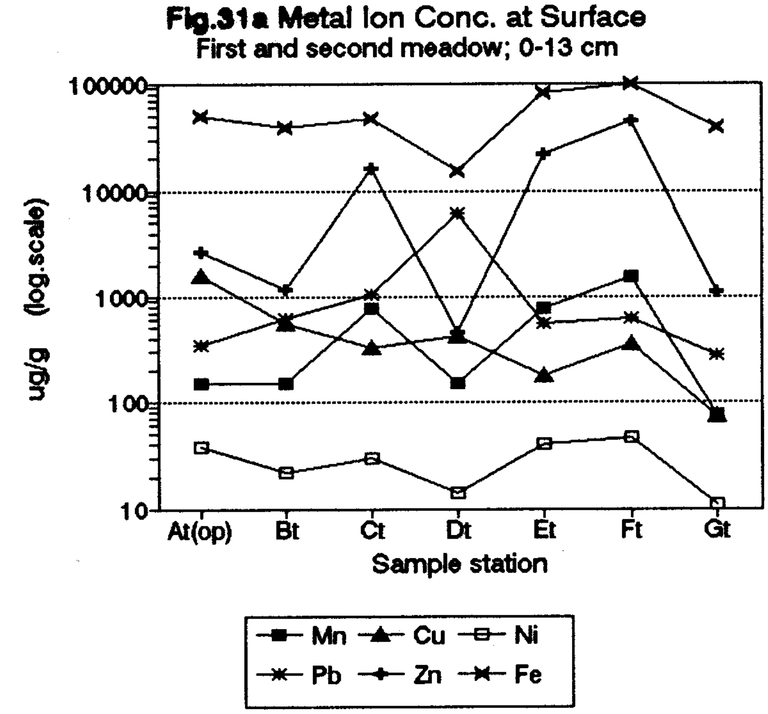


Fig.31a Metal Ion Conc. at Surface
First and second meadow; 0-13 cm
100000
10000
1000
100
10
ug/g (log.scale)
At(op)
Bt
Ct
Dt
Et
Ft
Gt
Sample station
Mn
Cu
Ni
Pb
Zn
Fe

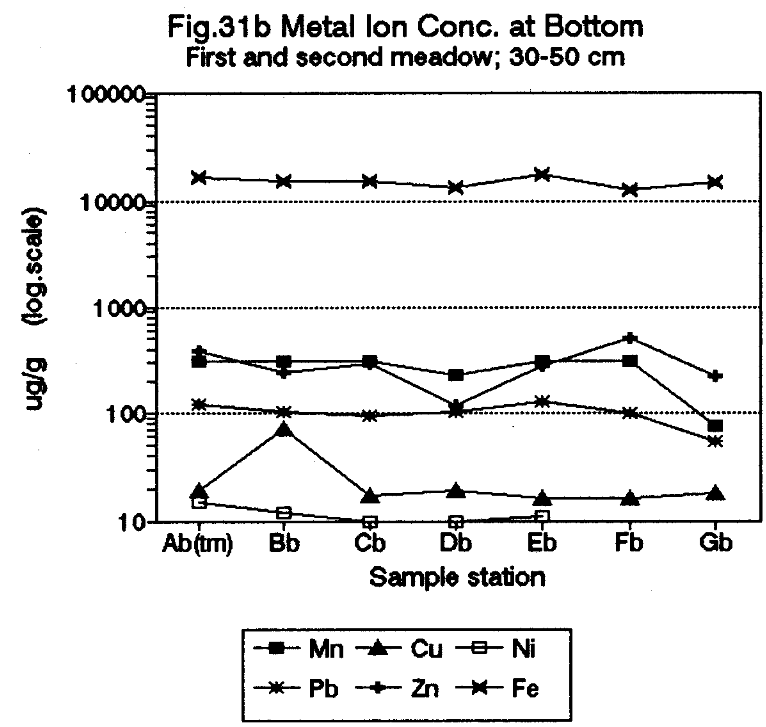
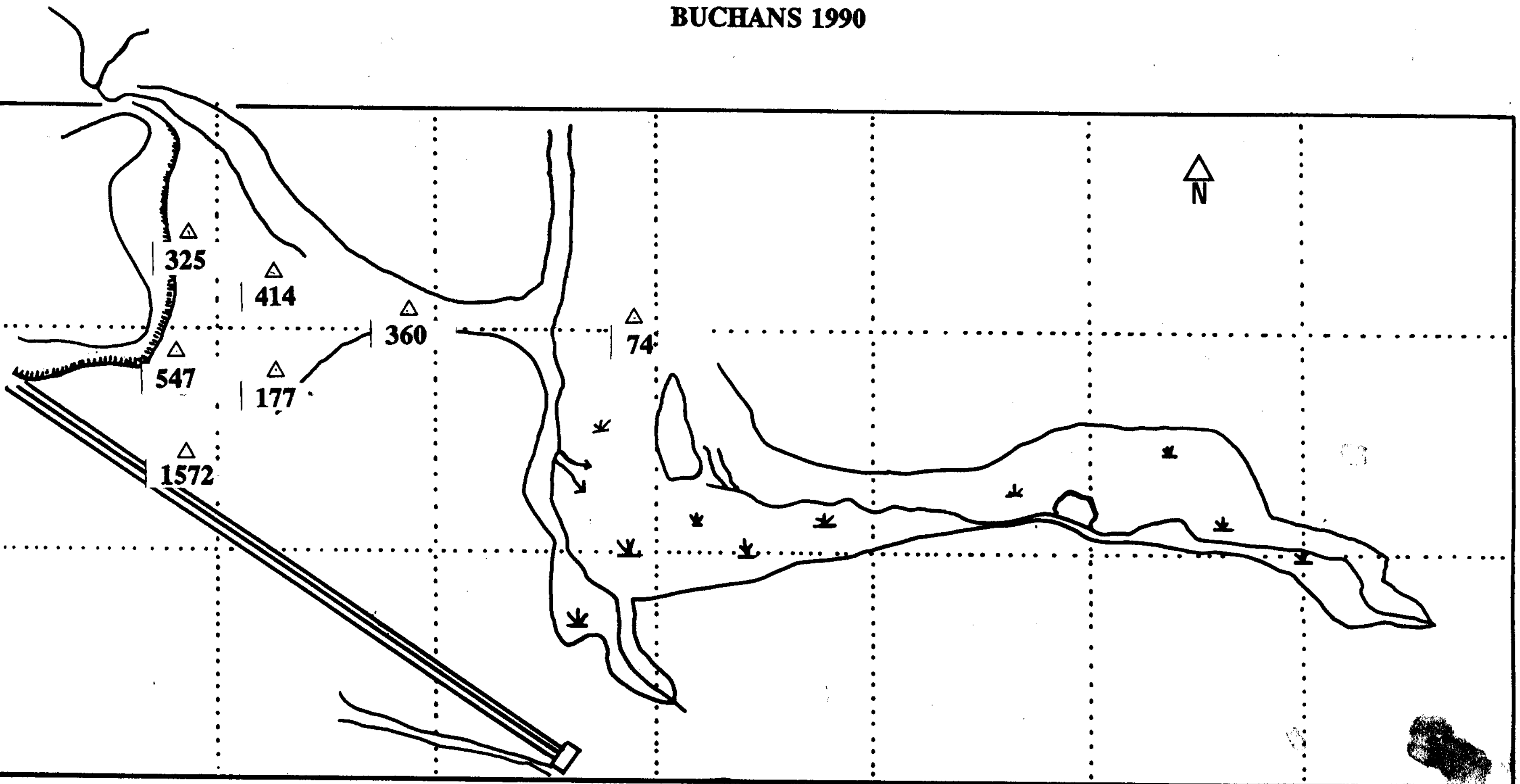


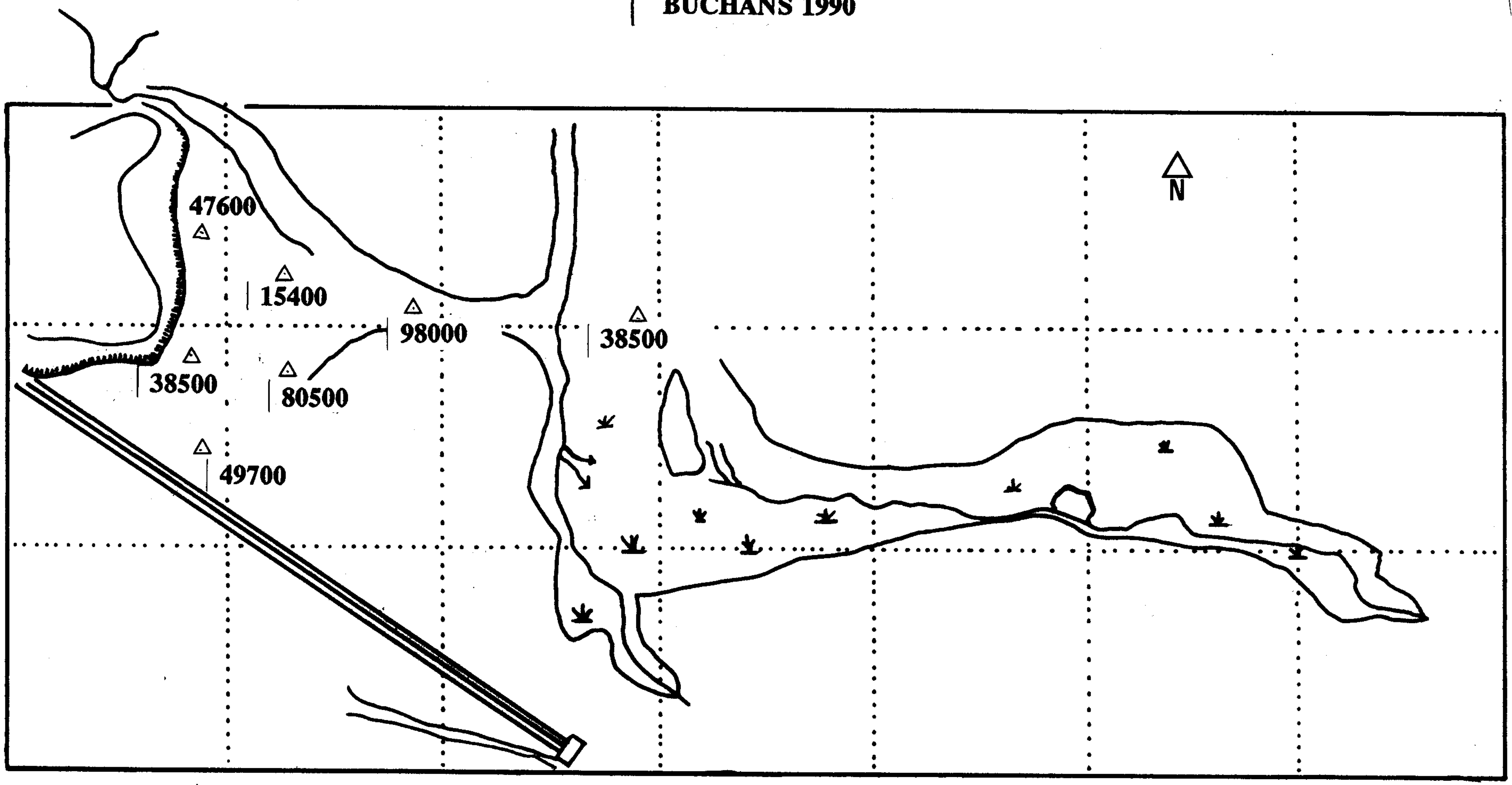
Fig.31b Metal Ion Conc. at Bottom
First and second meadow; 30-50 cm
100000
10000
1000
100
10
ug/g (log.scale)
Ab(tm)
Bb
Cb
Db
Eb
Fb
Gb
Sample station
Mn
Cu
Ni
Pb
Zn
Fe

BUCHANS 1990



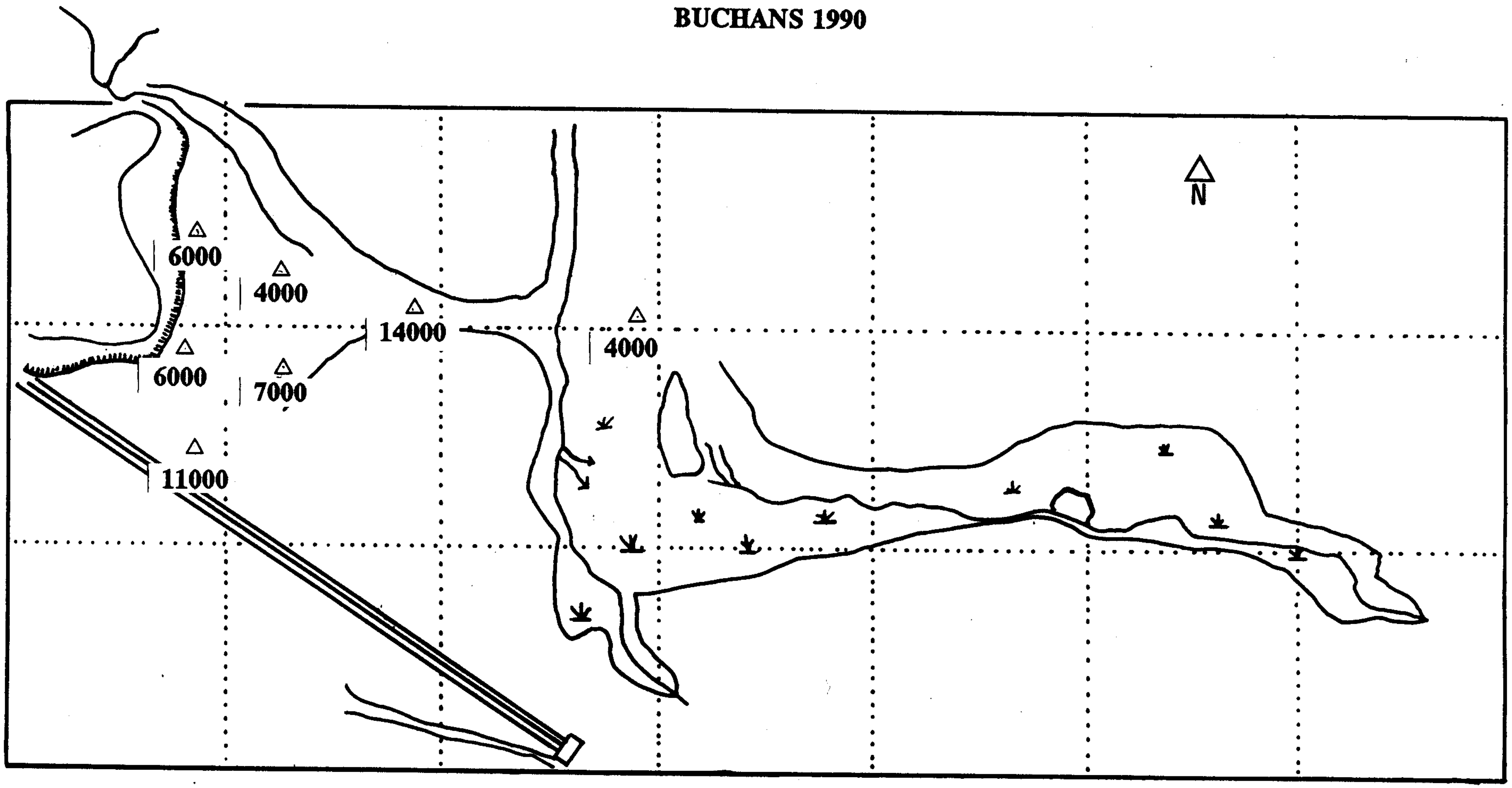
Schematic 5 | Concentration of Copper in top layer of soil (ppm)

BUCHANS 1990



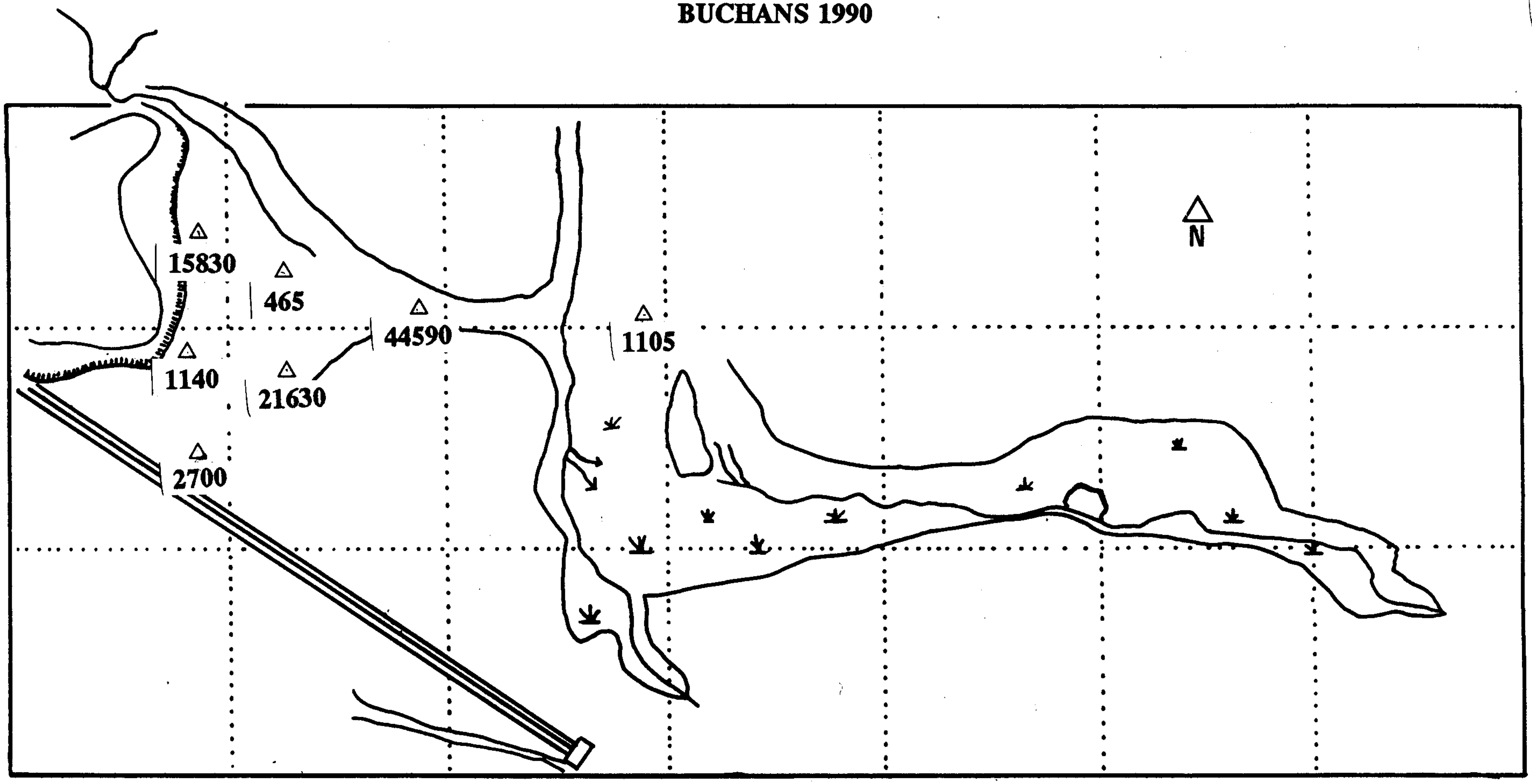
Schematic 6 **Concentration of Iron in top layer of soil (ppm)**

BUCHANS 1990



Schematic 7 | Concentration of Sulphur in top layer of soil (ppm)

BUCHANS 1990



Schematic 8 **Concentration of Zinc in top layer of soil (ppm)**

Fig.32a Conc.Al,K,Mg&Na in Surf.Samp.
First and second meadow; 0-13 cm

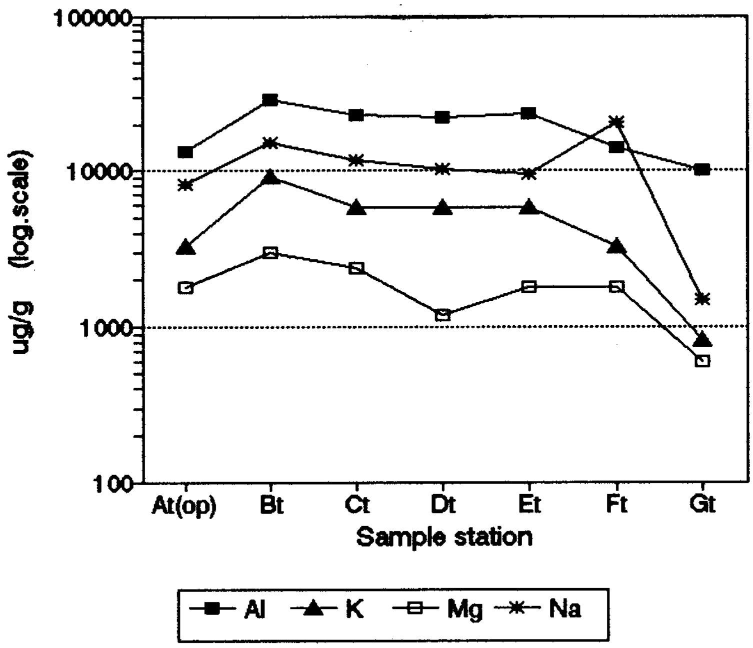
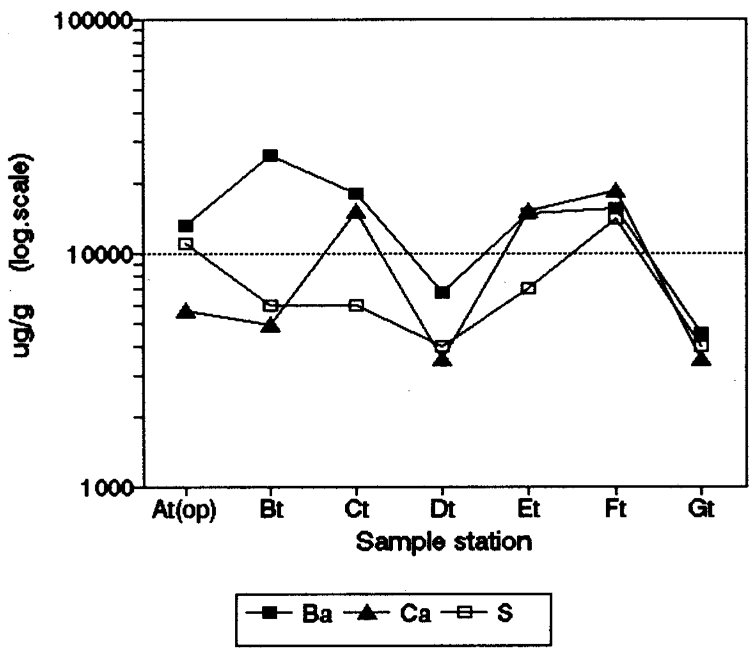
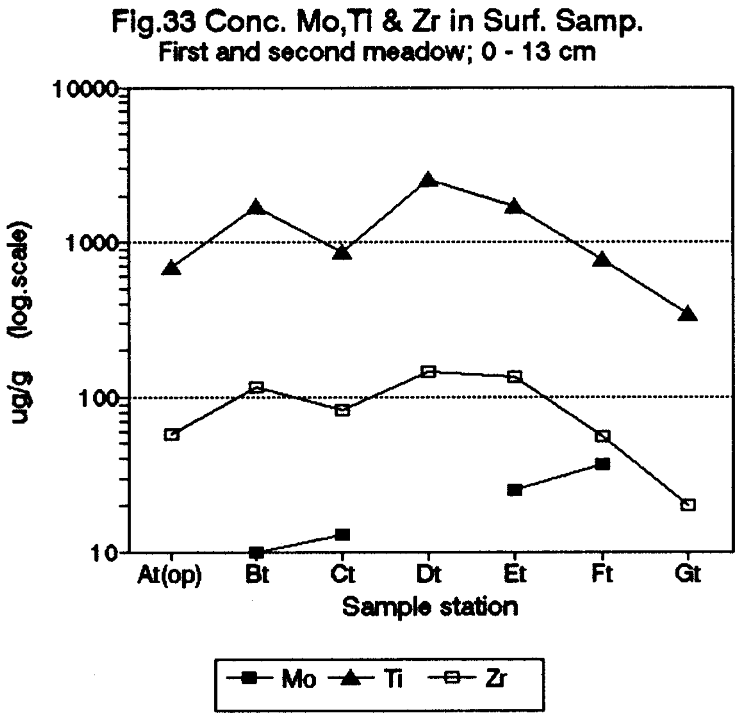


Fig.32b Conc. Ba,Ca&S in Surface Samp.
First and second meadow; 0-13 cm





The elements: Al, K, Mg, Na, Ba, Ti, and Zn are relatively common in the bedrock in the area and consequently in the waste rock in the Oriental mine dump. The observed decrease in the concentration of these elements in the direction of the Second Meadow may therefore reflect sediment transport pattern away from the mine dump into the First Meadow and depositional pattern within the Second Meadow.

Fig.34a Conc.Cd,Co,Cu,Ni,Pb&Zn in Surf.
First and second meadow; 0 - 13 cm

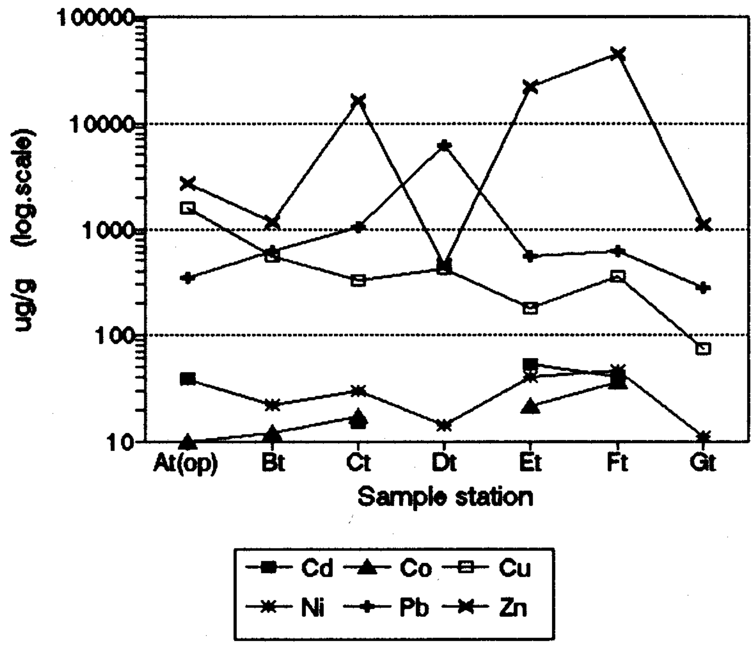


Fig.34b Conc. Fe & Mn in Surf. Samp.
First and second meadow; 0 - 13 cm

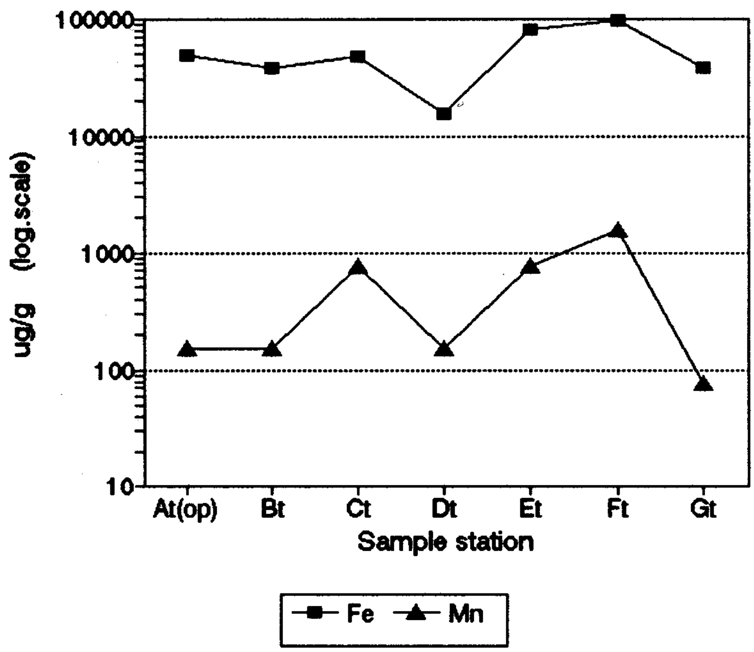
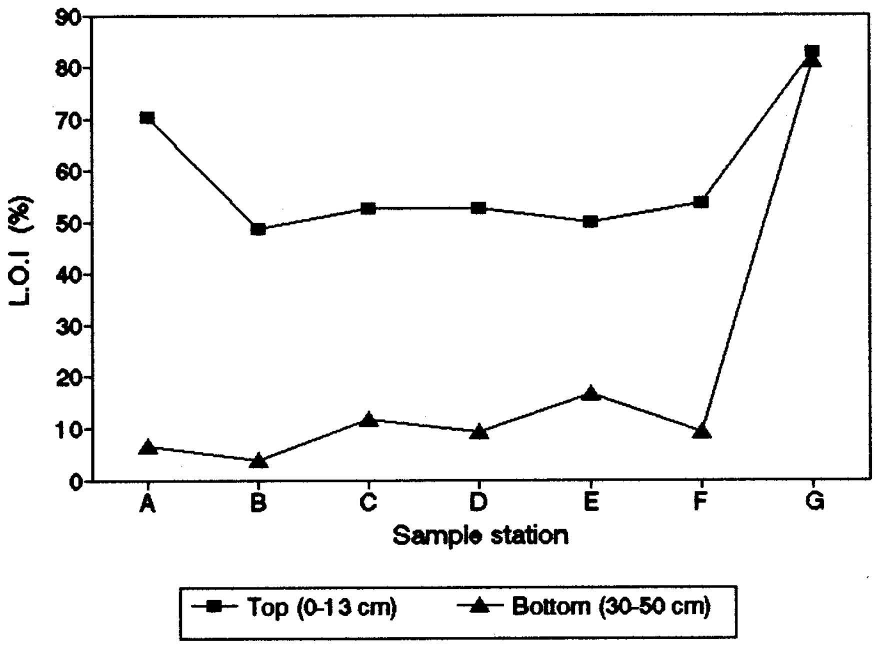


Fig.35 Percent Organic Matter(%L.O.I.)
First and Second Meadow



Several elements show considerable variation in concentration between the various sampling stations. It is well known that organic matter acts as a sink for metal ions. Sediment with a high organic content, therefore, shows generally elevated metal concentrations. The organic content in the samples is illustrated in Figure 35 (Note: it is assumed that the L.O.I. directly reflect organic matter content). This figure clearly shows that the top samples are organic rich. The relationship between the organic content and the concentration of Cu, Fe, Mn, Ni and Zn in the top samples is shown in Figure 36a. As can be seen in this figure, no correlation is present between the organic content and the concentration of the various metal ions.

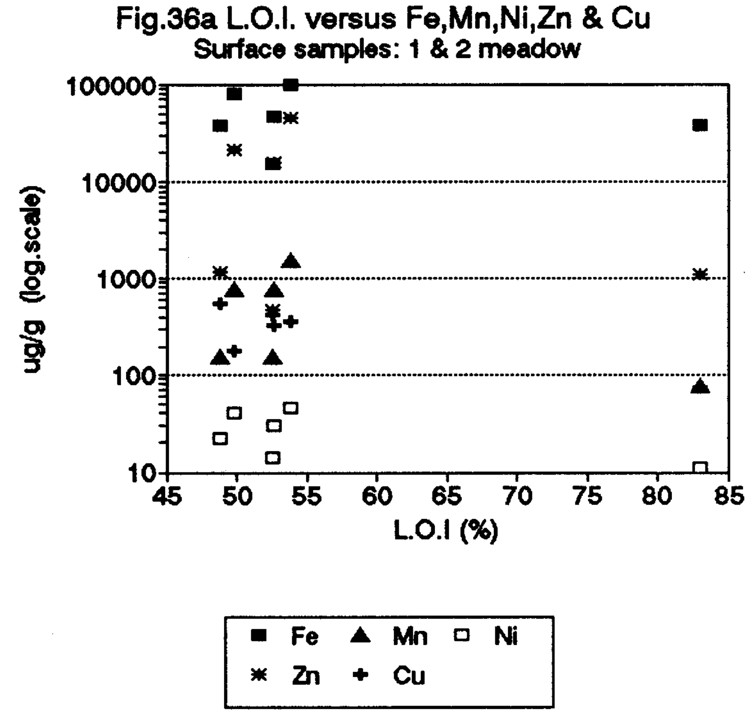


Fig.36a L.O.I. versus Fe,Mn,Ni,Zn & Cu
Surface samples: 1 & 2 meadow
100000
10000
1000
100
10
ug/g (log.scale)
45
50
55
60
65
70
75
80
85
L.O.I (%)
Fe
Mn
Ni
Zn
Cu

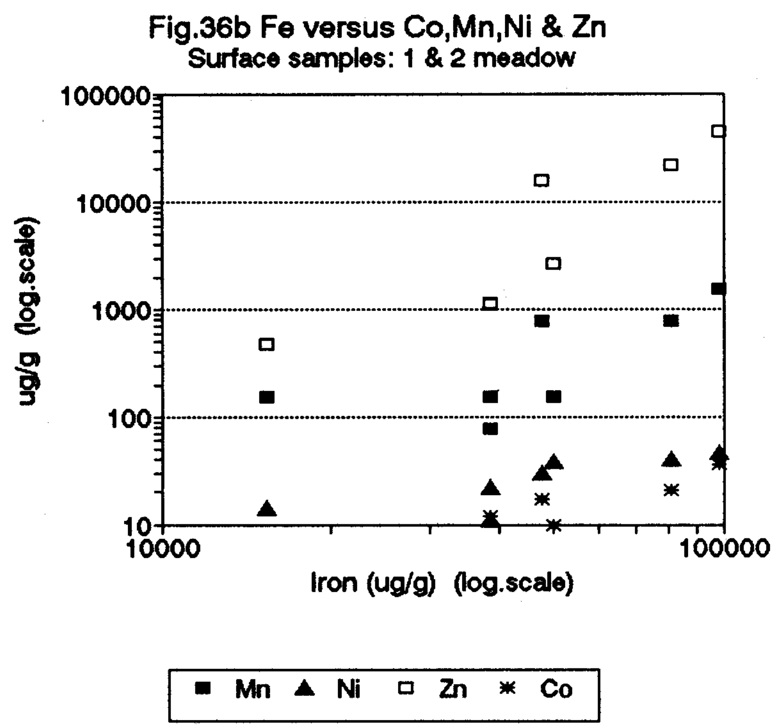


Fig.36b Fe versus Co,Mn,Ni & Zn
Surface samples: 1 & 2 meadow
100000
10000
1000
100
10
ug/g (log.scale)
10000
100000
Iron (ug/g) (log.scale)
Mn
Ni
Zn
Co

Table 14: Microbial Population in Amendments in Acid Pools

	ACID POOL 7 GOOD Jun-90	ACID POOL 7 BAD Jun-90	ACID POOL 9 Jun-90
pH	4.5	4.3	4.5
ATP (ng/ml)	35	300	910
SRB Postgate B	>100,000	>100,000	>100,000
SRB Postgate F	>100,000	10,000	10,000
IRB (/ml)	>100,000	<1	>100,000
Ammonifiers	>100,000	>100,000	>100,000

Fig. 37a Buchans
Cells 7 - 9 Dissolved Copper

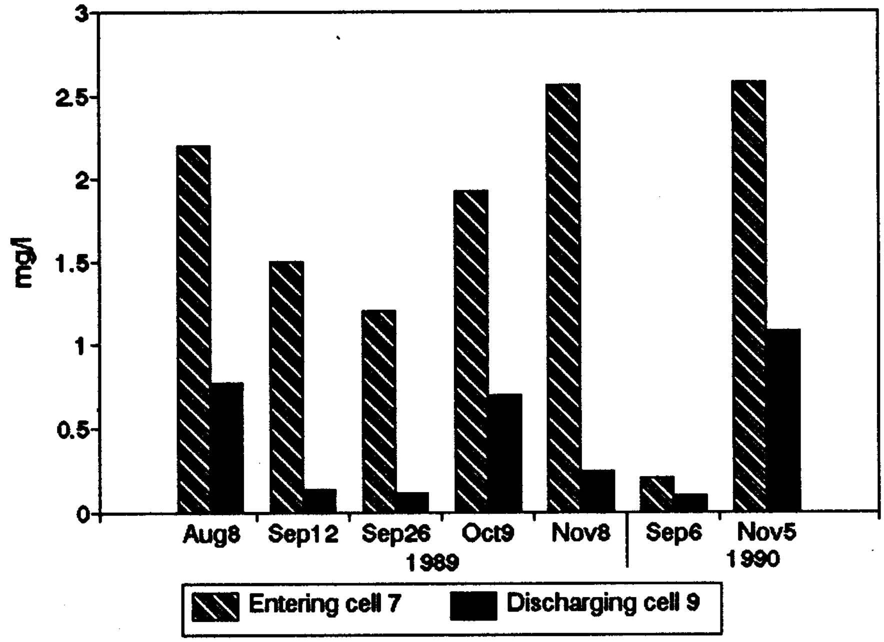


Fig. 37b Buchans
Cells 7 - 9 Dissolved Zinc

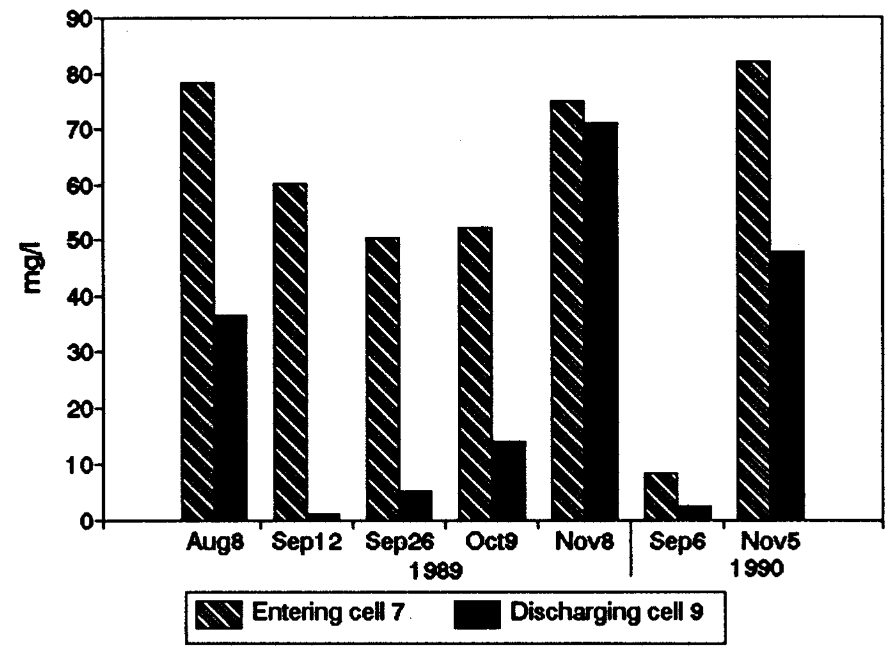


Fig. 38 Buchans
Cells 7 - 9 pH

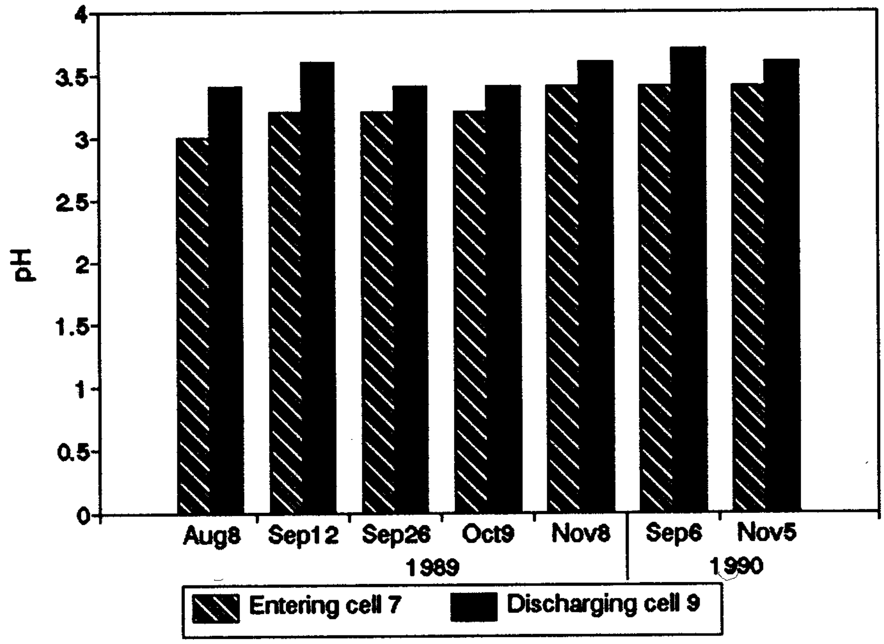
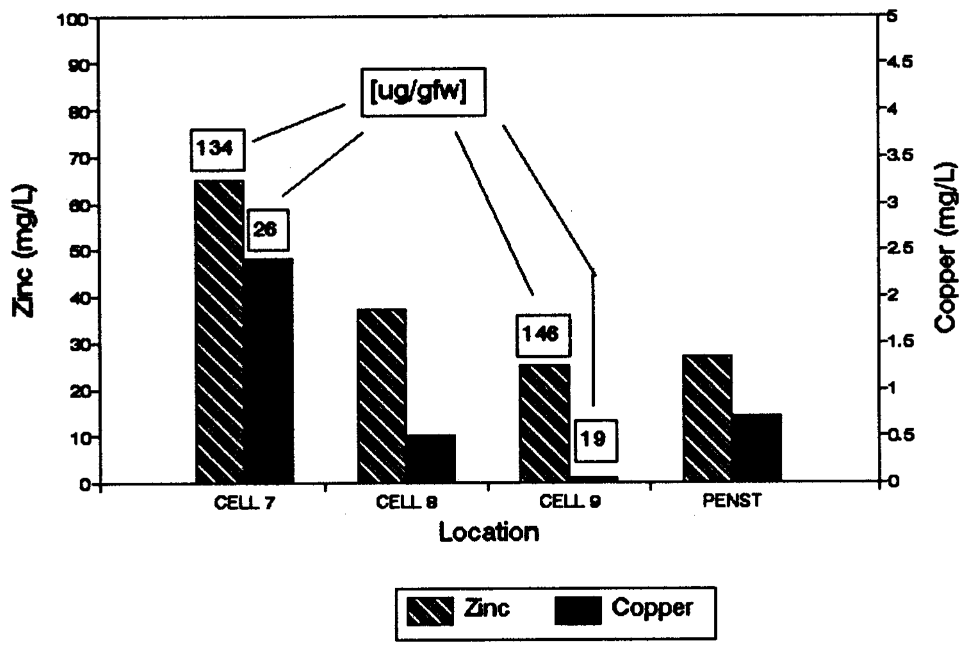


Fig. 39 Buchans Biological Polishing
Arum Cells, July 1990



LIST OF APPENDICES

APPENDIX 1: GEOCHEMICAL SIMULATIONS USING ANALYSIS OF SELECTED WATER *SAMPLES* FROM BUCHANS 1-1

RECEIVED AUG 0 9 1990

GEOCHEMICAL SIMULATIONS
using ANALYSES of SELECTED WATER SAMPLES from BUCHANS

INTRODUCTION

The geochemical simulation program PHREEQE was used to evaluate selected water analyses representing five points in the Buchans operation: Oriental West and East Pits, Lucky Strike Pit, Drainage Tunnel, and Sandfield Spring.

PHREEQE requires as input: pH, Eh (or pe), temperature, and concentrations of as many elements (or ions) in the water sample as possible. The program will calculate concentrations for all aqueous species represented by the element input, and degrees of saturation of the water with respect to numerous minerals that consist of various combinations of the elements found in the analysis.

PHREEDE can simulate several types of reactions, including (1) addition of inorganic reactants to a solution, (2) mixing of two waters, and (3) titrating one solution with another. In each of these cases PHREEQE can maintain the reacting solution at equilibrium simultaneously with one or more user-specified minerals.

The program calculates the following quantities during each reaction simulation:

1. pH.
2. pe (electron activity, representing Eh).
3. The total concentrations of elements.
4. The amounts of minerals (or other phases) transferred into or out of the aqueous phase during a reaction.
5. The distribution of aqueous species.
6. The saturation state of the aqueous phase with respect to specified mineral phases.

Table I lists the elements covered by the current version of PHREEQE, with their code numbers; Table II lists a selection of the secondary minerals (likely to be found as precipitates from various mine waters) that are included in the PHREEQE database.

ANALYSES USED

All analyses that include alkalinity and chloride values were evaluated for possible use in the simulations. Most of the available analyses were judged to be unsuitable, for various reasons (*see* Appendix A). The following analyses were used in sirnulations, as indicated:

(a) Sandfield Spring, no #, July 1989
(b) Drainage Tunnel, #944, April 1989
(c) Lucky Strike Pit, #943, April 1989
(d) Oriental East Pit, #939, April 1989
(e) Oriental West Pit, #941, April 1989
(f) Adjusting pH in (b) in several steps to 9.0, to check on changes in saturation index with respect to Zn minerals.
(g) Mixing of (a) with (c) in proportions ranging from 9:1 to 1:9.

As no temperatures or Eh values were measured during collection of the above samples, temperature values were assigned on the basis of earlier measurements, and pe values were estimated.

RESULTS

Output from the single-solution simulations was edited to reduce the amount of paper and printer time used. The printout for each of the five simulations (Appendix B) shows:

Sample identification
Concentrations of elements (mg/L) used in the simulation
Calculated total molalities
Description of the solution (pH, pe etc.)
LOG values for ion-activity products (IAP), equilibrium constants (KT), and their ratios (IAP/KT), for all minerals for which the "saturation index" LOG[IAP/KT] turned out to be positive, indicating saturation.

Ratios between SO_4^{2-} and HSO_4^- were extracted from the "SPECIES" output; they are listed in Table III.

DISCUSSION OF RESULTS

The ratios listed in Table III demonstrate that the bisulfate ion does not represent a significant portion of the total sulfur in any of the samples.

All samples show saturation (positive LOG[IAP/KT]) to various degrees with respect to several aluminum and iron minerals, which may be precipitated.

The sample from the Oriental West Pit shows only low saturation indices for a few Fe and Al minerals, due to its low pH.

All samples, with the exception of the sample from the Sandfield Spring, show minor saturation with respect to barite. unlikely to result in noticeable precipitation.

Only the samples from the Lucky Strike Pit and the Oriental East Pit show minor saturation with respect to zinc carbonate.

Simulations for the Drainage Tunnel discharge with pH increased in steps to 9.0 indicated that pH would have to rise to at least 7.3 before any $ZnCO_3$ (or smithsonite) could be expected to be precipitated from this discharge. At a pH of about 8.2 hydrozinkite or zinkite could be formed.

It should be pointed out here that apparent saturation with respect to a particular mineral does not necessarily mean that that mineral will be precipitated from the water. Where saturation with respect to several iron compounds and aluminum compounds is indicated, those with the highest saturation index will usually be the first to be precipitated.

It should also be stressed that the excessively large apparent saturation indices for some of the iron minerals (e.g., hematite and magnetite) are likely the result of the arbitrary choice of pe values.

The results of the simulations of mixing of Lucky Strike Pit water with shallow groundwater (represented by the Sandfield Spring analysis) showed that the water discharged from the Drainage Tunnel can be approximated by a mixture of one volume of Lucky Strike Pit water mixed with 9 to 10 volumes of shallow groundwater, with a minor addition of water with higher concentrations of Ba, F, K, and Ni. This suggests that water from the lower levels of the Lucky Strike mine, with higher concentrations of these and other elements, seeps into the tunnel, rather than water from the Lucky Strike open pit.

It is likely that each of the three pit waters is made up of at least three components:

(a) direct precipitation and surface runoff;
(b) shallow groundwater discharge; and
(c) water that has traveled through mine workings.

In addition, the low pH of the Oriental West Pit water likely reflects the addition of water carrying oxidation products from sulfides exposed in the walls of this pit.

The high zinc concentration in the Oriental East Pit water could possibly be reduced somewhat if the pH of the water in the Oriental West Pit could be raised by appropriate treatment. Reduction of the Zn and Cu concentrations in the current discharge from the Drainage Tunnel and the Oriental East Pit would require raising the pH in these waters to promote precipitation of Zn and Cu minerals. This would presumably be accompanied by precipitation of at least part of the remaining Fe and Al contents.

FURTHER STUDIES

Further simulations would have to be be undertaken if it is deemed desirable to define the various components that contribute to the mixtures represented by the three pit waters. There are at least six unknowns that would have to be determined for each of those three-component systems, i.e. the chemical compositions of the three components, and their proportions in the mixture.

Component (a) could be sampled and analyzed with little problem. Definition of components (b) and (c) would require careful sampling and analysis of water from selected shallow and deep boreholes near the three pits. Once the approximate compositions are known, approximate mixing ratios may be obtained through a detailed simulation exercise.

As the sulfur (sulfate) and bicarbonate concentrations in the only "complete" analysis of Drainage Tunnel discharge are open to doubt, this source should be sampled and analyzed again. Because of the uncertainty about the presence of carbonate species in the available samples, new samples should also be collected from the other sources at the same points as before.

It is stressed here again, that the Temperature, pH, and Alkalinity of the water should be measured/determined AT THE TIME OF SAMPLE COLLECTION. Ideally, Eh (electrode potential) should be measured at the same time.

ICP analysis of filtered/acidified samples should be complemented by analysis of filtered/non-acidified samples for: Cl, F, and N.

7 August 1990

Robert O. van Everdingen

TABLE I. ELEMENTS IN PHREEQE DATABASE

ELEMENT	CODE #	AT.(MOL) WEIGHT	
Ag	4	107.8680	Ag
Al	5	26.9815	Al
AS	6	141.9431	H_3AsO_4
B	7	61.8331	H_3BO_3
Ba	8	137.3400	Ba
Br	9	79.9040	Br
C	10	60.0094	CO_3
Ca	11	40.0800	Ca
Cd	12	112.3994	Cd
Cl	13	35.4530	Cl
CS	14	132.9050	CS
CU	15	63.5460	Cu+2
F	16	18.9984	F
Fe	17	55.8470	Fe+2
I	18	126.9044	I
K	19	39.1020	K
Li	20	6.9390	Li
Mg	21	24.3120	Mg
Mn	22	54.9380	Mn+2
N	23	62.0049	NO_3
Na	24	22.9898	Na
Ni	25	58.7100	Ni
P	26	94.9714	PO_4
Pb	27	207.1899	Pb
Rb	28	85.4699	Rb
S	29	96.0616	SO_4
Si	30	96.1155	H_4SiO_4
Sr	31	87.6200	Sr
U	32	270.0278	UO_2+2
V	33	82.9390	VO_2+1
Zn	34	65.3699	Zn
Mo	35	159.9376	MoO_4-2
Nd	36	144.24	Nd
Se	37	127.96610	$HSeO_3$-

TABLE II. SELECTED MINERALS FROM PHREEQE ORTABASE

	ALUMINUM
Boehmite	$AlO(OH)$
Oiaspore	$HAlO_2$
Gibbsite	$Al(OH)_3$
	$Al_4(OH)$
	$Al(OH)SO_4$
Alunite	$KAl_3(OH)_6(SO_4)_2$
	IRON
Lepidocrocite	$FeO(OH)$
Goethite	$HFeO_2$
Hematite	Fe_2O_3
Magnetite	Fe_3O_4
Magnesio-ferrite	$MgFe_2O_4$
Hercynite	$FeAl_2O_4$
Jarosite	$KFe_3(OH)_6(SO_4)_2$
Natrojarosite	$NaFe_3(OH)_6(SO_4)_2$
Siderite	$FeCO_3$
	ZINC
Zinkite	ZnO
Hydrozinkite	$Zn_5(OH)_6(CO_3)_2$
Smithsonite	$ZnCO_3$
	Others
Barite	$BaSO_4$
Gypsum	$CaSO_4$
Calcite	$CaCO_3$
Dolomite	$MgCO_3$

TABLE III. .COMPARISON of CONCENTRATIONS of $SO_4^=$ and HSO_4^-

in BUCHANS - APRIL 1989 SAMPLES

	pH units	$SO_4^=$ molality	HSO_4^- molality	Ratio %
Sandfill Spring	7.6	1.23983E-04	1.56657E-10	0.0001%
Drainage Tunnel**	6.6	1.33089E-03	1.46773E-08	0.0011%
Lucky Strike Pit	6.4	1.10007E-02	1.43366E-07	0.0013%
Oriental East Pit	6.2	1.12648E-02	2.34213E-07	0.0021%
oriental West Pit	3.5	4.46311E-03	5.45481E-05	1.2222%

$SO_3^=$, HSO_3^-, and H_2SO_3 all < 1.0E-20

** SO4 adjusted to 149 mg/l by PHREEQE

APPENDIX A - COMMENTS ON ANALYSES OF BUCHANS SAMPLES

Reference:

ASSAYERS ONTARIO LABORATORIES
CERTIFICATE OF ANALYSIS No. BOO-82/8787
Dated: April 13, 1989

We have two versions of this certificate for sample Nas. 931 to 937 from Buchans. They show the same values for all entries, except for SO4 in analysis #937: 542 mg/l in the first version, 54 mg/l in the second. Both values produce unacceptably large ion-balance errors (>35%), the first negative, the second positive. In the PHREEQE calculations. SO_4 was adjusted to obtain ion balance for #937.

In addition, the first version of the certificate shows Alkalinity values (as $CaCO_3$ in mg/l), even for the West Pit samples that had pH values between 3.3 and 3.5! Inquiry on our part prompted the second version, which lists the same values as Acidity (as $CaCO_3$ in mg/l). In the PHREEQE simulations, the values were used as Alkalinity.

Reference:

ASSAYERS ONTARIO LABORATORIES
CERTIFICATES OF ANALYSIS No. BOO-95/9166 and BOO-95/02
Dated: August 23, 1989

No pH values or temperatures are available for these Buchans samples (#1268 and #1269). Alkalinities were not determined; and HCO_3 was "not detected". Cl concentration given for the West Pit water is 10 times as large as any earlier Cl concentrations for the West Pit water. For these reasons, the analyses have not been used in any PHREEQE simulations.

The values for Sulfate in Certificate No.BOO-95/02 are exactly 3 times those given for S(ICP) in Certificate No.BOO-95/9166, raising the suspicion that they were derived by calculation rather than by separate analysis' In all earlier analyses, sulfate values were considerably larger than 3 times the IPC sulfur values for the corresponding samples.

Reference:

CHEMEX LABS LTD.
. CERTIFICATES OF ANALYSIS No.A8920243 and A8920244
Dated: 20 July and 13 July 1989

Field pH, conductivity and water temperatures are not available for these samples. SO_4 values (110 and 115 mg/l) for Oriental East Pit water are less than one quarter of the S values for all earlier and later samples from this pit. The SO4 value (450 mg/l) for the Oriental West Pit water is about twice as high as the S values for earlier and later samples. Therefore these analyses have not been used in PHREEQE simulations.

Incidentally, this certificate does give alkalinity values for two samples from the Oriental East Pit.

Reference:
ASSAYERS ONTARIO LABORATORIES
CERTIFICATE OF ANALYSIS No. BOO-??
Sample Date: 11 June 1990

Conductivity and temperature data are not available for these samples. Analyses included only ICP data. Therefore these analyses have not been used in PHREEQE simulations.

Reference:
ASSAYERS ONTARIO LABORATORIES
CERTIFICATE OF ANALYSIS No. BOO-??
Sample Date: 1 July 1990

ICP analyses are not available for these samples. Therefore these results could not be used in PHREEQE simulations.

NOTE:

It is stressed here again, that the Temperature, pH, and Alkalinity of the water should be measured/determined AT THE TIME OF SAMPLE COLLECTION. Ideally, Eh (electrode potential) should be measured at the same time.

ICP analysis of filtered/acidified samples should be complemented by analysis of filtered/non-acidified samples for: Cl, F, and N.

APPENDIX B

,SELECTED OUTPUT FROM PHREEQE SIMULATIONS

1. SANDFIELD SPRING
2. DRAINAGE TUNNEL
3. LUCKY STRIKE PIT
4. ORIENTAL EAST PIT
5. ORIENTAL WEST PIT

```
1 SANDFIELD SPRING
 0010011000 5 0          .00000
 ELEMENTS
 C          10          61.
             0           0.
 SOLUTION 1
 SANDFIELD SPRING WATER   - July 1989 (#unknown)
 15 10 2     7.60       7.27      4.00      1.00
    5  6.0000-02  10  5.370D+01  11  2.000D+00  13  1.800D+00  15  8.0000-03
   16  2.0000-02  17  1.0000-05  19  2.0000-01  21  2.0000-01  22  2.400D-02
   24  1.2000+00  27  1.2000-02  29  1.200D+01  31  6.000D-03  34  2.000D-02
 STEPS
   .500      .600      .700      .800      .900
 SOLUTION NUMBER 1          SANDFIELD SPRING WATER
```

TOTAL MOLALITIES OF ELEMENTS

ELEMENT	MOLALITY	LOG MOLALITY
AL	2.2239040-06	-5.6529
TOT ALK	8.8014380-04	-3.0554
CA	4.9903750-05	-4.3019
CL	5.0775060-05	-4.2943
CU	1.2590200-07	-6.9000
F	1.0527950-06	-5.9777
FE	1.7907340-10	-9.7470
K	5.1151920-06	-5.2911
MG	8.2269760-06	-5.0848
MN	4.3688720-07	-6.3596
NA	5.2200780-05	-4.2823
PB	5.7922000-08	-7.2372
S	1.2492870-04	-3.9033
SR	6.8482390-08	-7.1644
ZN	3.0597300-07	-6.5143

----DESCRIPTION OF SOLUTION----

```
                PH =  7.6000
                PE =  7.2739
      ACTIVITY H2O =  1.0000
    IONIC STRENGTH =   .0009
       TEMPERATURE =  4.0000
ELECTRICAL BALANCE = -1.00650-03
              THOR =  4.55280-03
  TOTAL ALKALINITY =  8.80140-04
        ITERATIONS =  9
      TOTAL CARBON =  9.50580-04
```

---- LOOK MIN IAP ----

PHASE	LOG IAP	LOG KT	LOG IAP/KT
BOEHMITE	10.3321	10.1423	.1899
OIASPORE	10.3321	8.2379	2.0943
FEOH)2.7	14.3996	10.5454	3.8542
GIBBSITE	10.3321	10.0362	.2959
GOETHITE	17.9721	14.8896	3.0826
HEMATITE	35.9443	24.8841	11.0602
MAGHEMIT	35.9443	33.5607	2.3835
MAGNETIT	39.0425	33.7132	5.3293
CUPROUSF	9.7980	2.2481	7.5500
CUPRICFE	42.6440	35.1995	7.4446
LEPIDOCR	17.9721	14.9554	3.0168
FE(OH)3S	17.9721	16.2554	1.7167

2. DT.OUT

```
0000012000 0 0 .          .00000
ELEMENTS
C          10            61.
            0             0.
SOLUTION 2
DRAINAGE TUNNEL WATER  -  April 1989 (#944)
16 10 2      6.60       7.15       6.00      1.00
   5  5.900D+01   8  4.0000-02  10  9.500D+01  11  5.780D+01  13  1.900D+01
  15  6.0000-01  16  9.900D+00  17  5.900D+00  19  5.100D+00  21  6.000D+00
  22  4.0000-01  24  2.300D+01  25  3.000D-01  29  1.490D+02  31  1.000D-01
  34  2.800D+01
SOLUTION NUMBER 2          DRAINAGE TUNNEL WATER
```

TOTAL MOLALITIES OF ELEMENTS

ELEMENT	MOLALITY	LOG MOLALITY
AL	2.1876880-03	-2.6600
BA	2.9138180-07	-6.5355
TOT ALK	1.557656D-03	-2.8075
CA	I.4427780-03	-2.8408
CL	5.3616700-04	-3.2707
CU	9.446316D-06	-5.0247
F	5.213359D-04	-3.2829
FE	1.0569430-04	-3.9759
K	1.3048800-04	-3.8844
MG	2.469051D-04	-3.6075
MN	7.2842790-06	-5.1376
NA	1.0009030-03	-2.9996
NI	5.1 122090-06	-5.2914
S	1.5518000-03	-2.8092
SR	1.1418160-06	-5.9424
ZN	4.285284D-04	-3.3680

----DESCRIPTION OF SOLUTION----

```
                PH =  6.6000
                PE =  7.1500
      ACTIVITY H20 =   .9998
   IONIC STRENGTH =   .0085
       TEMPERATURE =  6.0000
ELECTRICAL BALANCE =  8.7091D-04
              THOR =  2.02620-02
  TOTAL ALKALINITY =  1.55770-03
        ITERATIONS =  16
      TOTAL CARBON =  2.66930-03
```

3

---- LOOK MIN IAP ----

PHASE	LOG IAP	LOG KT	LOG IAP/KT
ALOH3(A)	13.2049	11.7295	1.4754
ALOHSO4	-3.0348	-3.2300	.1952
AL4(OH)1	36.5798	22.7000	13.8798
ALUNITE	9.8069	-1.5456	11.3525
BARITE	-9.7381	-10.2933	.5552
BOEHMITE	13.2049	9.9833	3.2216
DIASPORE	13.2049	8.0987	5.1062
FERRIHYO	22.3915	18.4189	3.9726
FE3(OH)8	53.4245	47.2878	6.1367
FEOH)2.7	19.4177	10.4889	8.9288
GIBBSITE	13.2049	9.9074	3.2974
GOETHITE	22.3915	14.7513	7.6403
HEMATITE	44.7832	24.5968	20.1864
JAROSITE	34.6949	31.2480	3.4470
MAGHEMIT	44.7832	33.4478	11.3354
MAGNETIT	53.4248	33.3151	20.1097
CUPROUSF	16.2996	2.1608	14.1388
CUPRICFE	52.4411	34.8679	17.5732
HERCYNIT	35.0516	31.0692	3.9823
MAG-FERR	54.1790	47.1523	7.0267
LEPIDOCR	22.3915	14.8989	7.4927
FE(OH)3S	22.3915	16.1989	6.1926

3. LUCKY STRIKE PIT

```
0000012000 0 0          .00000
ELEMENTS
C         10          61.
           0           0.
SOLUTION 2
LUCKY STRIKE PIT WATER  128 - April 1989 (#943)
16 10 2     6.40      7.27      8.80      1.00
   5 6.900D+01  8 3.000D-02  10 4.450D+02  11 5.770D+02  13 1.510D+02
  15 1.000D+00  16 8.000D-02  17 4.260D+01  19 8.000D-02  21 5.700D+01
  22 1.500D+01  24 2.190D+02  25 2.000D-01  29 1.560D+03  31 3.300D+00
  34 6.500D+01
SOLUTION NUMBER 2          LUCKY STRIKE PIT WATER
```

TOTAL MOLALITIES OF ELEMENTS

ELEMENT	MOLALITY	LOG MOLALITY
AL	2.565531D-03	-2.5908
BA	2.191384D-07	-6.6593
TOT ALK	7.316489D-03	-2.1357
CA	1.444250D-02	-1.8404
CL	4.272856D-03	-2.3693
CU	1.578723D-05	-4.8017
F	4.224421D-06	-5.3742
FE	7.652512D-04	-3.1162
K	2.052510D-06	-5.6877
MG	2.352060D-03	-2.6286
MN	2.739130D-04	-3.5624
NA	9.556595D-03	-2.0197
NI	3.417529D-06	-5.4663
S	1.629180D-02	-1.7880
SR	3.7783740-05	-4.4227
ZN	9.9753870-04	-3.0011

----DESCRIPTION OF SOLUTION----

PH =	6.4000
PE =	7.2739
ACTIVITY H2O =	.9990
IONIC STRENGTH =	.0596
TEMPERATURE =	8.8000
ELECTRICAL BALANCE =	3.5879D-03
THOR =	1.5600D-01
TOTAL ALKALINITY =	7.3165D-03
ITERATIONS =	15
TOTAL CARBON =	1.3980D-02

---- LOOK MIN IAP ----

PHASE	LOG IAP	LOG KT	LOG IAP/KT
ALOH3(A)	13.2627	11.5192	1.7436
ALOHSO4	-1,8660	-3.2300	1.3640
AL4(OH)1	37.9222	22.7000	15.2222
ALUNITE	10.1351	-1.5151	11.6502
BARITE	-9.3441	-10.2445	.9004
BOEHMITE	13.2632	9.7647	3.4985
OIASPORE	13.2632	7.9073	5.3559
FERRIHYO	22.6559	18.3411	4.3148
FE3(OH)8	54.2943	47.1323	7.1621
FEOH)2.7	19.9960	10.4111	9.5849
GIBBSITE	13.2627	9.7302	3.5326
GOETHITE	22.6564	14.5609	B.0954
GYPSUM	-4.6400	-4.8609	.2209
HEMATITE	45.3132	24.2015	21.1117
JAROSITE	37.7094	30.5860	7.1234
MAGHEMIT	45.3132	33.2923	12.0209
MAGNETIT	54.2961	32.7673	21.5288
SIOERITE	-10.1651	-10.3255	.1604
CUPROUSF	16.0867	2.0407	14.0460
CUPRICFE	52.4170	34.4117	18.0053
ZNCO3, 1	-9.8821	-10.2600	.3779
HERCYNIT	35.5097	30.4600	5.0497
MAG-FERR	55.0330	46.4787	8.5543
LEPIOOCR	22.6564	14.8211	7.8352
FE(OH)3S	22.6559	16.1211	6.5348

4. ORIENTAL EAST PIT WATER

```
0000012000 0 0          .00000
ELEMENTS
C          10           61.
            0           0.
SOLUTION 2
ORIENTAL EAST PIT WATER  E48  -  April 1989 (#939)
17 10 2     6.20      7.15      8.80      1.00
   5  6.700D+01   8  3.0000-02  10  4.060D+02  11  5.470D+02  13  1.210D+02
  15  3.000D-01  16  8.0000-02  17  5.610D+01  19  8.0000-01  21  5.700D+01
  22  1.500D+01  24  1.910D+02  25  4.0000-01  27  4.000D-01  29  1.584D+03
  31  3.000D+00  34  5.700D+01
SOLUTION NUMBER 2         ORIENTAL EAST PIT WATER
```

TOTAL MOLALITIES OF ELEMENTS

ELEMENT	MOLALITY	LOG MOLALITY
AL	2.4909200-03	-2.6036
BA	2.191166D-07	-6.6593
TOT ALK	6.674604D-03	-2.1756
CA	1.3690230-02	-1.8636
CL	3.4236030-03	-2.4655
CU	4.735699D-06	-5.3246
F	4.2240010-06	-5.3743
FE	1.0076600-03	-2.9967
K	2.052306D-05	-4.6878
MG	2.351826D-03	-2.6286
MN	2.7388580-04	-3.5624
NA	8.333918D-03	-2.0792
NI	6.8343780-06	-5.1653
PB	1.93661 ID-06	-5.7130
S	1.6540800-02	-1.7814
SR	3.4345440-05	-4:4641
ZN	8.746777D-04	-3.0582

----DESCRIPTION OF SOLUTION----

PH =	6.2000
PE =	7.1500
ACTIVITY H20 =	.9990
IONIC STRENGTH =	.0581
TEMPERATURE =	8.8000
ELECTRICAL BALANCE =	2.61710-03
THOR =	1.67391)-01
TOTAL ALKALINITY =	6.67460-03
ITERATIONS =	15
TOTAL CARBON =	1.6361D-02

---- LOOK MIN IAP ----

PHASE	LOG IAP	LOG KT	LOG IAP/KT
ALOH3(A)	13.1741	11.5192	1.6549
ALOHSO4	-1.5408	-3.2300	1.6892
AL4(OH)1	37.9814	22.7000	15.2814
ALUNITE	11.4975	-1.5151	13.0126
BARITE	-9.3271	-10.2445	.9174
BOEHMITE	13.1745	9.7647	3.4098
DIASPORE	13.1745	7.9073	5.2672
FERRIHYO	22.2065	18.3411	3.8654
FE3(OH)8	53.2699	47.1323	6.1377
FEOH)2.7	19.5780	10.4111	9.1669
GIBBSITE	13.1741	9.7302	3.4439
GOETHITE	22.2069	14,5609	7.6460
GYPSUM	-4.6509	-4.8609	.2101
HEMATITE	44.4143	24.2015	20.2128
JAROSITE	37.1890	30.5860	6.6030
MAGHEMIT	44.4143	33.2923	11.1220
MAGNETIT	53.2717	32.7673	20.5044
SIDERITE	-10.1281	-10.3255	.1975
CUPROUSF	15.1147	2.0407	13.0741
CUPRICFE	50.6717	34.4117	16.7600
ZNCO3, 1	-10.1742	-10.2600	.0858
HERCYNIT	35.2068	30.4600	4.1468
MAG-FERR	53.7332	46.4787	7.2544
LEPIDOCR	22.2069	14.8211	7.3858
FE(OH)3S	22.2065	16.1211	6.0854

8

5. ORIENTAL WEST PIT
0000012000 0 0 .00000
ELEMENTS
C 10 61.
0 0.
SOLUTION 2
ORIENTAL WEST PIT WATER W8B - April 1989 (#941)
17 10 2 3.50 7.15 8.80 1.00
5 6.200D+01 8 6.000D-02 10 2.700D+02 11 1.590D+02 13 8.000D+00
15 2.200D+00 16 3.700D+00 17 9.100D+00 19 1.800D+01 21 1.600D+01
22 4.200D+00 24 4.300D+01 25 4.000D-01 27 2.900D+00 29 6.390D+02
31 5.000D-01 34 7.600D+01
SOLUTION NUMBER 2 ORIENTAL WEST PIT WATER

TOTAL MOLALITIES OF ELEMENTS

ELEMENT	MOLALITY	LOG MOLALITY
AL	2.300894D-03	-2.6381
BA	4.374468D-07	-6.3591
TOT ALK	4.430811D-03	-2.3535
CA	3.972285D-03	-2.4010
CL	2.2594780-04	-3.6460
CU	3.466614D-05	-4.4601
F	1.950095D-04	-3.7099
FE	1.631596D-04	-3.7874
K	4.609402D-04	-3.3364
MG	6.589771D-04	-3.1811
MN	7.655041D-05	-4.1161
NA	1.872856D-03	-2.7275
NI	6.822114D-06	-5.1661
PB	1.401524D-05	-4.8534
S	6.6607341)-03	-2.1765
SR	5.713968D-06	-5.2431
ZN	1.164144D-03	-2.9340

----DESCRIPTION OF SOLUTION----

PH = 3.5000
PE = 7.1500
ACTIVITY H20 = .9405
IONIC STRENGTH = .0289
TEMPERATURE = 8.8000
ELECTRICAL BALANCE = 3.67510-03
THOR = 1.39690+01
TOTAL ALKALINITY = 4.43080-03
ITERATIONS = 23
TOTAL CARBON = 3.4820D+00

---- LOOK MIN IAP ----

PHASE	LOG IAP	LOG KT	LOG IAP/KT
ALOHSO4	-2.6679	-3.2300	.5621
ALUNITE	1.6312	-1.5151	3.1463
BARITE	-9.2596	-10.2445	.9848
FEOH)2.7	11.2878	10.4111	.8767
HEMATITE	26.9706	24.2015	2.7691
CUPROUSF	4.7984	2.0407	2.7578
CO2(GAS)	-16.4070	-18,1823	1.7754

APPENDIX 2: PHENOTYPIC PLASTICITY TO ENHANCE PLANT SURVIVAL IN ALKALINE WASTE WATER

CANADIAN LAND RECLAMATION ASSOCIATION
CONFERENCE, 1990

Phenotypic Plasticity to Enhance Plant Survival In Alkaline Waste Water

M. P. Smith, The Viridis Group Inc., Toronto, Ontario

ABSTRACT

Biological polishing of alkaline waste water in the mining industry in being tested, utilizing populations of a group of attached algae, the Characeae. The underwater meadows of these algae perform as self-renewing filters. For successful introduction to the waste water, hardy plant material could assist in establishing populations in the waste water ponds, where the Chara Process is to be utilized. The phenotypically plastic characteristics of this algal group are used to produce plant material conditioned for establishment of populations in the waste water pond.

Characean species' capacity to morphologically/physiologically alter in response to waste waters is tested in laboratory by a steppedtransition from fresh to waste water chemistry and compared to material directly transferred from fresh to waste water. The results suggest a distinct developmental response between the two species examined to waste water solutions.

INTRODUCTION

A biological polishing process for mining-related alkaline waste water, utilizing populations of a group of submerged macrophytic algae, the Characeae, is under development. The results of our field investigations and a pilot demonstration have, to date, indicated that the Characean populations' structure, growth rates and contaminant uptake rates can serve as long term, self sustaining treatment systems for alkaline waste water (Smith & Kalin, 1989).

Implementation of the Chara Process in a waste water pond requires that the transplanted Characean biomass survives and grows. Waste waters from mining activities are commonly high in the major ions' concentrations (such as sodium, calcium, magnesium, chloride and sulphate), which results in high specific conductance (measured in umhos/cm), relative to those of freshwater ecosystems.

Transplanting of biomass to waste water solutions has, in some waste water solutions, resulted in cell death due, in part, to plasmolysis (low to high conductance) or cell rupture (high to low conductance), upon this instantaneous change in solution conductance surrounding the cells (Kalin & Smith, 1985). However, Hoffman and Bisson (1986) have shown that biomass can be physiologically conditioned, due to the phenotypic plasticity of the algae.

Conditioning techniques employ these plants' phenotypic plasticity, or the ability of an individual organism to alter its physiology/morphology in response to non-lethal changes in environmental conditions, such as solution-specific conductance. This inherent ability is particularly important in plants, whose sessile life style requires them to deal with ambient conditions (West-Eberhard, 1989), and is especially important to aquatic macrophytes, obligately immersed in the ambient aquatic environment (Schlichting, 1986).

Introducing plant material gradually to waste water might be a route by which living biomass can be cultured with altered morphological and/or physiological tolerances. This would facilitate a broader application range of the Chara Process for waste water treatment.

This paper reports on investigations with two species of _Chara_ to produce biomass which is conditioned for waste water.

METHODS AND MATERIALS

Water Characteristics and Hardening Solutions

The characteristics of the waste water are compared to those of the natural waters for C. _vulgaris_ and C. _buckellii_ in Table 1. High concentrations of all major cations and anions in the waste water

TABLE 1: Major constituents and metals of importance in test solutions (Sea water composition included for comparison)

CONSTITUENT (mg/l)	TAP WATER (TORONTO)	Zn/Cu MINE: ABANDONED OPEN PIT WATER	ARTIFICIAL WALDSEA LAKE WATER	SEA WATER
Sodium	19	191	3,070	10,561
Magnesium	9	57	2,670	1,272
Calcium	43	547	320	400
Potassium	6	0.8	310	380
Manganese	<0.01	15	N.A.	0.01
Sulphate	36	597	11,600	2,652
Chloride	27	121	4,400	18,980
Bi/Carbonate	103	406	480	28
Phosphate	<0.01	0.2	N.A.	<0.1
Zinc	<0.01	57	N.A.	0. 0.1
Copper	<0.01	0.30	N.A.	0.09
Aluminum	0.20	67	N.A.	1.9
Iron	<0. 01	56	N.A.	<0.01
pH	8.20	6.20	8.30	8 - 9
Conductivity (umhos)	350	2,300	20,000	48,000

N.A. Not Added to Artifical Solution

from the open pit is evident, when compared to Toronto tap water (Table 1). This tap water has the same range of conductivity as surface water supporting Chara vulgaris, and it lends itself well to laboratory culture of this species, relative to specific solutions normally used for algal cultures.

Chara buckellii, which grows in saline lakes in Saskatchewan (Canada), thrives in waters with very high concentrations of major cation and anions. A high-salinity culture solution has been developed, referred to artificial Waldsea Lake Water. The conductivity of this solution (20,000 umhos/cm) is higher than both the waste water from the open pit and tap water solutions, but is lower than sea water (Table 1).

Open pit solution (OPS) was collected on February 12, 1990 and shipped to the laboratory, where it was stored at room temperature. Tap water was the base for solutions added to treatments testing Chara vulgaris (Table 2a). Four solutions were made up from tap water and OPS; 3:0 (3 parts T-H_2O to 0 parts OPS), 2:1, 1:2 and 0:3 (full strength OPS).

TABLE 2a: Concentrations of major constituents and metals of importance, and measured pH and conductivities, of Chara vulgaris growth test solutions.

CONSTITUENT (mg/l)	3:0 TAP WATER		2:1 (calculated	1:2 [ ] estimates)	0:3 OPEN PIT SOLUTION
Sodium	19		76	134	191
Magnesium	9		25	41	57
Calcium	43		211	379	547
Potassium	6		4.3	2.5	0.8
Manganese	0.01	*	5	10	15
Sulphate	36		223	410	597
Chloride	27		58	90	121
Bi/Carbonate	103		204	305	406
Zinc	0.01	*	19	38	57
Copper	0.01	*	0.1	0.2	0.30
Aluminum	0.20		22	45	67
Iron	0.01	*	19	37	56
pH: Avg	7.76		7.31	7.28	7.38
Max	8.21		7.68	7.66	7.72
Min	7.27		6.91	6.93	6.99
Conductivity: Avg	489		1,226	1,707	2,231
(umhos/cm) Max	720		1,380	1,980	2,410
Min	350		1,050	1,520	2,100

TABLE 2b: Concentrations of major constituents and metals of importance, and measured pH and conductivities, of Chara buckellii growth test solutions.

CONSTITUENT (mg/l)	3:0 ARTIFICIAL WALDSEA LAKE WATER		2:1 (calculated	1:2 [ ] estimates)	0:3 OPEN PIT SOLUTION
Sodium	3,070		2,110	1,151	191
Magnesium	2,670		1,799	928	57
Calcium	320		396	471	547
Potassium	310		207	104	0.8
Sulphate	11,600		7,932	4,265	597
Chloride	4,400		2,974	1,547	121
Zinc	0.01	*	19	38	57
Copper	0.01	*	0.1	0.2	0.30
Aluminum	0.01	*	22	45	67
Iron	0.01	*	19	37	56
pH: Avg	8.25		8.24	8.06	7.73
Max	8.37		8.41	8.33	8.17
Min	8.03		8.03	7.86	7.55
Conductivity: Avg	18,900		13,706	9,216	2,333
(umhos/cm) Max	21,000		14,800	10,400	2,750
Min	17,050		12,800	8,500	2,150

* Concentration set at detection limit

Artificial Waldsea Water (AWW) was the base for solutions added to treatments testing Chara buckellii (Table 2b). Four solutions were made up from AWW and OPS; 3:0 (3 parts AWW to 0 parts OPS), 2:1, 1:2 and 0:3 (full strength OPS). Upon evaporation, water levels in the jars were compensated with distilled water daily.

Plant Material

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

Chara buckellii: Plant material was collected during September 1988 from a natural population in Waldsea Lake, Saskatchewan. New shoot production has been repeatedly promoted in the laboratory through four cycles. Biomass was cultured under fluorescent lighting in aquaria containing a layer of sediment from the C. vulgaris source site, overlain with silica sand and filled with artificial Waldsea Lake solution. On February 20, 1990, the final culture was set-up to produce shoots specifically for this experiment.

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

Experimental Methods

Growth trials are performed at room temperature (21 to 24° C) beneath cool white fluorescent light banks. All treatments were set up in new 2 litre wide-mouth glass jars. Each treatment was underlain by 4 cm of screened, homogenized sediment, overlain with a 1 cm thick layer of sand. After substrate addition, 1.8 1 of the experimental solution were dispensed parallel to the substrate layer so as to keep turbidity minimal.

Using forceps-tipped tongs, 5 shoots were implanted vertically into the substrate to as to just bury the basal node. All precautions were taken so as to not damage or kill internodal cells comprising the shoots' axes.

Chara buckellii and C. vulgaris shoots were planted on the same day. However, due to poor C. vulgaris shoot condition, even in the controls, this species was replanted 15 days later. Therefore, results are expressed after 23 days for C. buckellii, but only 8 days for C. vulgaris.

Vegetative Growth Responses

Many features of vegetative 'habit and development pattern are consistent across all species of the Characeae (Figure 1).

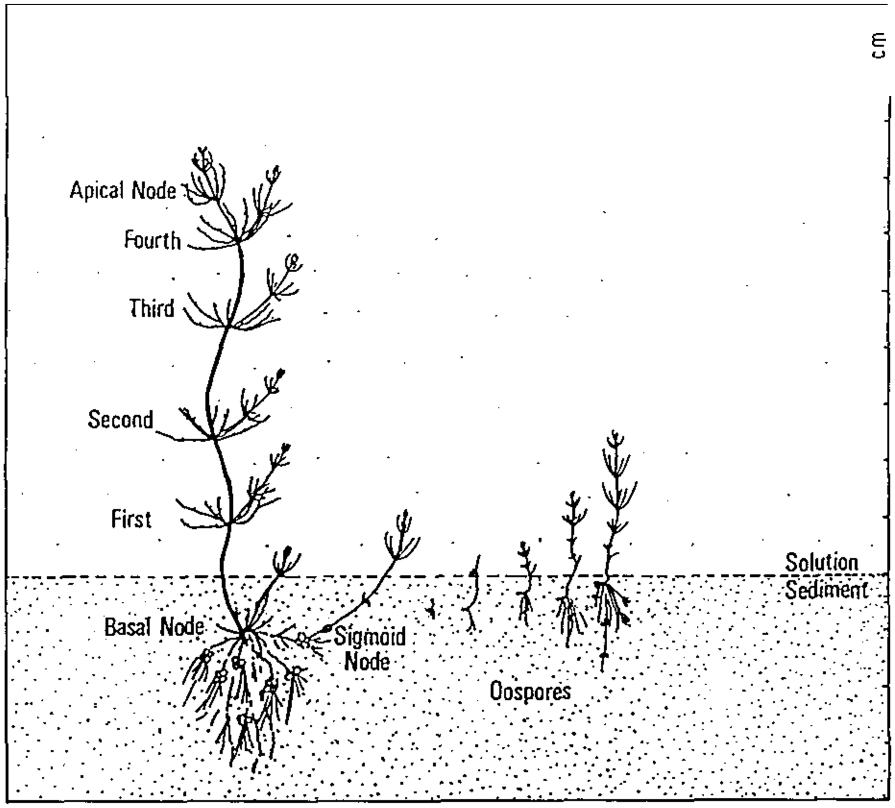


Figure 1: General morphological structure and meristematic regions of Chara species.

Fundamentally, the plants are comprised of a series of nodes, each separated by a elongated, giant internodal cell. Each node is, in part, comprised of meristematic (or growing region) cell complexes capable of generating both new shoots (nodes and internodes) and rhizoids, fine root-like cells for plant anchorage (see Figure 1, basal node).

Under ideal growing conditions, the apical node is the primary region of shoot growth, through hormonal repression of lower nodes (Figure 1), but, with either distancing of the apical from lower nodes, or apical node damage, inhibition of lateral shoot development from lower nodes is released (e.g., the basal, and first through fourth nodes: Figure 1).

In summary, new shoots grown in, and adapted to solution characteristics, may develop from any node of the original shoot. Two additional modes of new shoot production, originating from first, rhizoidal sigmoid nodes, and second, from oospores formed during sexual reproduction, are possible under more specific environmental conditions.

The pH, conductivity and temperature of the solutions were recorded weekly. Shoot axes' and branchlets' cell survival, the development of new whorls from the apical and lateral meristems, and overall plant colour and condition were recorded weekly.

RESULTS *AND* DISCUSSION

In Figure 2, the sum of the number of whorls generated 18 plants per treatment (3, 5, 5 and 5 plants in four replicate jars) are summarized for day 8 (C. vulgaris; Figure 2a) and day 23 (C. buckellii; Figure 2b), according to the specific node from which new whorls originated. In addition, these figures express the number of new whorls generated by a particular growth loci as percentages of the total number of whorls generated within the treatment.

Overall, under these laboratory conditions, survival of, and new whorl production by, at least some portions of both Chara vulgaris and C. buckellii plants were observed in all treatments, including the 0:3 (full strength OPS) treatments.

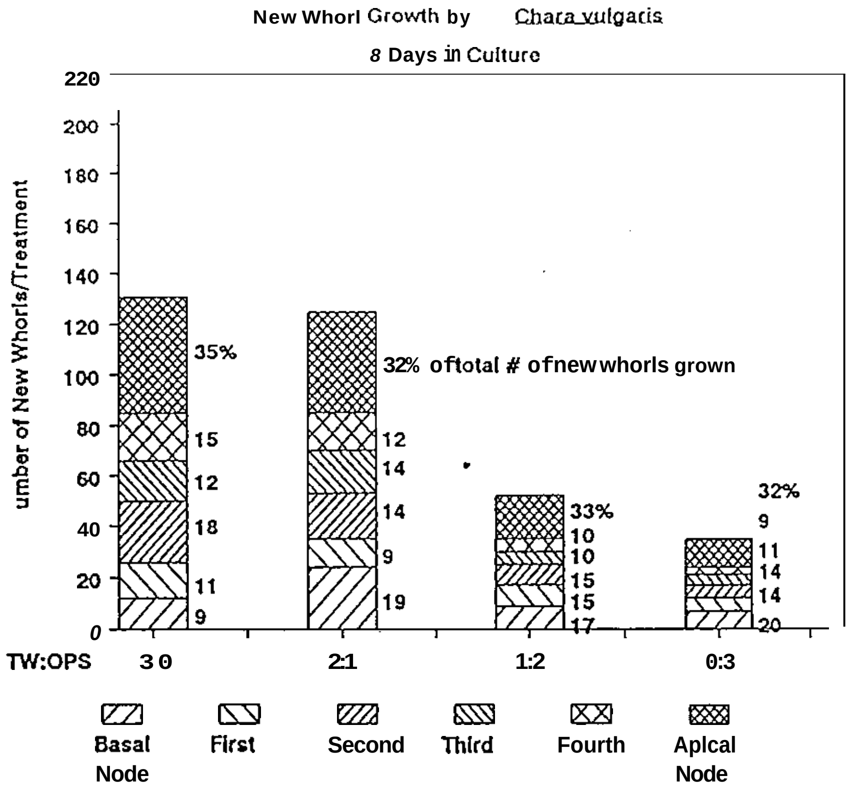
Under (otherwise) ideal conditions in the laboratory, new whorl production of Chara vulgaris plants was more than halved by day 8 in the 1:2 and 0:3 treatments, to less than 35 whorls (or less than two new whorls per plant), compared to the control (3:0).

The proportions of the number of new whorls generated by C. vulgaris, from the six possible growth loci, were similar between treatments with increasing conductivity, the apical node remaining largely responsible for new whorl generation. Even in the 1:2 and 0:3 treatments, the apical node remained largely responsible for new whorl production.

These results suggest that a conductivity increase, during a single culture solution transfer, of more that 1.5 times (2:1 treatment: Figure 2a), but less than 2.5 times (1:2, 0:3 treatments), is at a limit where individuals of this species can effectively adjust to the change in conductivity.

Similar whorl production by C. buckellii were observed in the 3:0, 2:1 and 1:2 treatments, but in the 0:3 treatment, production abruptly diminished to less than a tenth of the control (3:0) as of day 23. C. buckellii shoot production was unaffected by a 0.5 times decrease in conductivity (1:2 treatment: Figure 2b), while further reduction of conductivity to 0.9 times (relative to the control) appears beyond the plants' ability to adjust to instantaneous conductivity changes.

In contrast to C. vulgaris, although the apical node of C. buckellii was the major locus responsible for new whorl production in the 3:0 treatment (30% of all new whorls), with increasing conductivity across the treatments, basal nodes of C. buckellii located below the treatments' substrate surface became the major



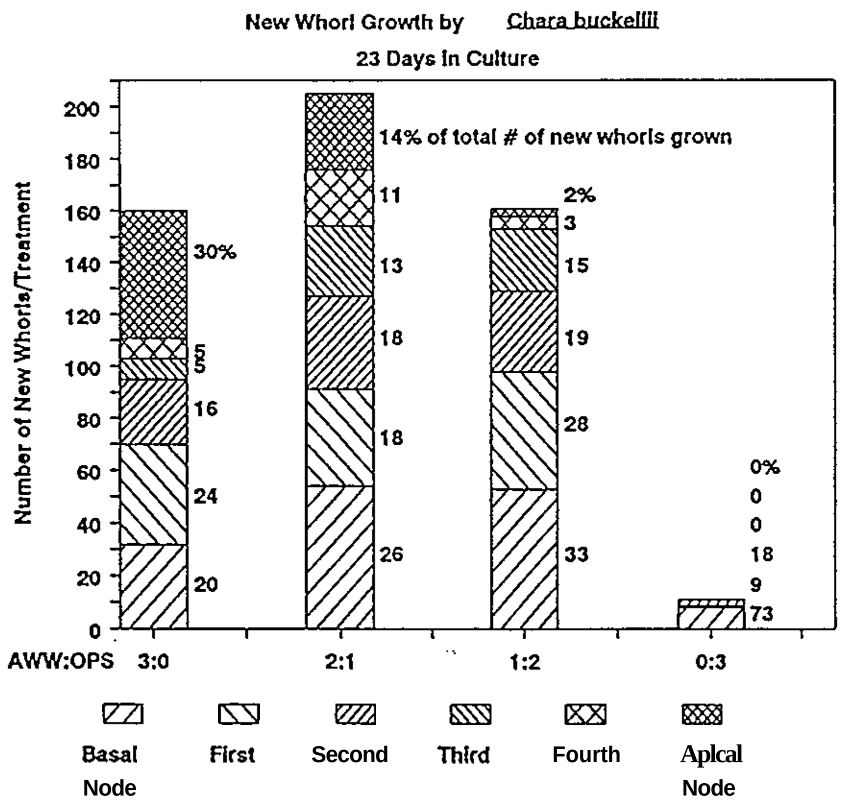


Figure 2: New whorl growth by Chara vulgaris after 8 days (Figure 2a) and Chara buckellii after 23 days (Figure 2b) in culture solutions with increasing proportions of open pit solution.

locus of new whorl production, relative to other growth loci (73% of the new whorls in 0:3 treatment; Figure 2b).

CONCLUSIONS

These growth responses indicate that both species tested can, due to their phenotypic plasticity, potentially be hardened to produce populations which survive transplant to waste water conditions.

ACKNOWLEDGEMENTS

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The Development of Techniques Towards Floating *Typha* Mat Populations Integral to the ARUM Process

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ABSTRACT

Floating *Typha* populations are being examined as potential long-term sources of organic carbon, required for microbial alkalinity generation in the **ARUM** (Acid Reduction Using Microbiology) process. Establishment of the *Typha* populations from seed currently appears the most effective means of establishing floating *Typha* mat populations. Several practical techniques for germinating *Typha* seeds, promoting *Typha* seedling development, and transplanting juvenile or mature plants to floating rafts, were tested during this work. Maintenance of constant substrate moisture, selection of substrates with circumneutral pH's, and provision of nutrients both during seedling establishment and transplant have been identified as key measures.

1.0 INTRODUCTION

The extremely high productivities of cattail, or *Typha* populations (Wetzel, 1983), their exceptional capacity to colonize harsh environments (Kalin, 1984; and others), and their rapid spreading capacity (Dykyjova & Kvet, 1978), make populations of this species a practical, natural organic carbon source integral to the functioning of the ***Acid** Reduction Using Microbiology* (ARUM) ***Process.*** **This** process is an engineered, self-maintaining biological treatment system for acid mine drainage, under development by Boojum Research Limited.

An effective, economical means of establishing floating or rooted cattail stands over large areas can probably be achieved only by techniques using *Typha* seeds, through:

1) maximizing the rate of colonization by *Typha*.
2) reducing transplant-related labour costs, and
3) facilitating construction of floating populations.

Most *Typha* species populations' distributions are limited to areas with water depths less than 2 meters, as these populations are anchored to the sediment via their root-rhizome systems. **A** significant portion of the plant's photosynthetic shoot must emerge above the water for efficient gas exchange. This commonly restricts these populations to shallow areas, or the perimeters of deeper ponds and lakes (Dickerman & Wetzel, 1985).

However, there are examples of *Typha* populations where large areas of bottom-bound mats of *Typha* rhizomes and roots have broken free, and their overall low density have forced the populations to float perennially above open water (Hogg & Wein, 1987; Mallik, 1989). These natural, perennially floating mat populations are strong evidence that *Typha* populations can in fact survive and proliferate without direct contact with bottom sediment.

Recent, detailed studies of these *Typha* mat populations indicate that the major plant components contributing to mat formation and maintenance are the *Typha* rhizome and roots. Thus, these mats are maintained primarily by the plant components within the mat, rather than through deposition of leaf biomass from above (Hogg & Wein, 1987). Although not addressed by workers to date, it could be surmised that any contribution by the floating *Typha* mats to the underlying sediment floor would primarily originate from the sloughing of organic matter from the bottom and sides of the mats.

Within the context of the development and implementation of the ARUM process, integration and utilization of floating *Typha* mats as the fixed carbon source, contributing to the nutrition of key microbial populations, offers significant advantages over integration of the common growth configuration, bottom-bound emergent macrophyte populations. These advantages include:

a) Supply **of** particulate organic matter from above the water column and sediment, where key microbial processes are under way.

b) Open water flow between the system floor and the *Typha* population, maximizing retention time of water within the ARUM system.

c) Prevention of short-circuiting of water, as the *Typha* population configuration is suspended above, and out of the way of, the flow path.

d) With sediment accumulation on the system floor, water levels **can** be periodically raised as the system matures, maintaining optimal water depths beneath the floating *Typha* mat in the long term.

e) The percent area covered by, and the configuration of, floating *Typha* mats should provide significant control over the rate, and location of, oxygen diffusion into the microbially active zones of the ARUM System.

It appears that several criteria must inherently be met in order to sustain the configuration of these floating *Typha* mats populations:

a) **A** combination of nutrient acquisition from the surrounding water, and nutrient recycling within the floating mats, must be meeting the complete nutrient requirements of the floating *Typha* mat population, in order that *Typha* population continues as the dominant species.

b) During growth of **new** plant biomass, morphological buoyancy features, such as aerenchyma and gas-filled hollows within rhizomes and roots, must continue to develop, contributing to the floating mat's positive buoyancy.

c) Gas (H_2S, CO, N, CH_4) generated by microbial activity below and within the floating mat may have to be effective trapped within the floating mat, thereby contributing to its overall positive buoyancy.

d) Structurally, the *Typha* roots and rhizome matrix must maintain consolidation of organic matter within the floating mat, in order that the emergent shoots of Typha remain erect over the growing season, and the mats remain intact perennially, despite wind and wave erosion of the floating *Typha* mats at their perimeters.

e) The overall growth rates of low-density roots and rhizomes must at least counterbalance the accumulation of higher density organic matter within the mat, generated by the products of shoots, root and rhizome decay.

2.0 OBJECTIVES:

The objectives of this research are:

1) Examination **of** the conditions required for *Typha* seed germination under controlled laboratory conditions.

2) Examination of the conditions for *Typha* seed germination and seedling establishment on floating seed beds under greenhouse conditions.

3) Examination of the effectiveness of various treatments applied to floating *Typha* mat structures, supporting the development of seedlings and mature transplants towards establishment, growth and successful overwintering.

3.0 **MATERIALS** AND METHODS:

3.1 Seed Germination and Seedling Establishment in the Laboratory

. Detailed Objective: The objective of this experiment is to examine the germination of *Typha* seeds, and the growth of *Typha* seedlings in the laboratory, with variation in water depth, relative humidity, nutrient supply and fungicide addition.

The experiment was designed in order that the specific conditions of germination and seedling establishment could be applied in greenhouse conditions, increasing the likelihood of creating a large supply of seedlings for transplant to the field.

The Experimental Design

The experimental design employed was as follows:

2	x	2	x	**3**	x	**3**
High/Low		Added/Not Added		None/Low/High		Gradient/Moist/Float
% R.H.		FUNGICIDE		FERTILIZER		WATER DEPTH

The experiment was initiated February 28, 1990 when, in each treatment, six replicates of approximately 100 seeds were planted. Water levels were adjusted every second day with tap water to compensate for water losses due to evaporation. A total of **36** treatments were set up, each treatment varying by one of the following variables (see Tables **1** and 2 for lay-out).

Relative Humidity: Half of the treatments were performed in a growth chamber where moist air was injected periodically over each light period. The other half of the treatments did not have moist air injection. However, over the course of the experiment, evapotranspiration, indicated by water loss from trays, **was** higher in the 'High Humidity' treatments than the 'Low Humidity' treatments, and the results were interpreted according to these observations.

Fungicide: A **5** ml dose of the product "No-Damp''(Plant Products Co. Ltd., Bramalea, Ontario, 2.5% Benzoxine) was applied, prior to seed planting, to half of the ,treatments' water supply, each **3.3** litre in volume ("F+"). No fungicide was applied to the remaining half of the treatments ("R-").

Fertilizer: A ***5*** cm^3 dose of the product ''Flowering Plant fertilizer" (Plant Products Co. Ltd., Bramalea, Ontario, **15-30-15** N-P-K) applied to one-third of the treatments constituted the low fertilizer treatment **("N+").** A 10 cm^3 dose of the fertilizer to one-third of the treatments constituted the high fertilizer treatment ("N++").

TABLE 1: NUMBER OF SEEDLINGS AFTER 16 DAYS

		LOW HUMIDITY									
		NO FUNGICIDE					FUNGICIDE				
		BEACH	WATER LEVEL	BELOW WATER	SUSPENDED	FLOATING	BEACH	WATER LEVEL	BELOW WATER	SUSPENDED	FLOATING
NO FERT	X	68	44	18	45	39	100	19	13	68	35
	S.D.	46	41	16	40	43	0	10	5	45	46
	N	6	6	6	6	6	5	6	6	6	6
	SUM	406	262	107	271	235	500	113	80	410	207
LOW FERT	X	60	4	31	69	59	40	20	9	55	10
	S.D.	43	4	35	44	45	43	19	18	45	14
	N	6	6	6	6	6	6	6	6	6	6
	SUM	361	22	185	414	351	240	117	56	330	61
HIGH FERT	X	12	12	21	62	68	14	1	1	28	42
	S.D.	7	5	14	41	45	10	1	1	15	31
	N	6	6	6	6	6	6	6	6	6	6
	SUM	73	74	125	370	408	82	3	5	165	252

		HIGH HUMIDITY									
		NO FUNGICIDE					FUNGICIDE				
		BEACH	WATER LEVEL	BELOW WATER	SUSPENDED	FLOATING	BEACH	WATER LEVEL	BELOW WATER	SUSPENDED	FLOATING
NO FERT	X	43	13	100	62	20	27	48	28	42	29
	S.D.	18	17	0	40	10	34	27	16		13
	N	6	6	6	6	6	6	6	6		6
	SUM	260	80	600	372	120	161	290	170	250	175
LOW FERT	X	63	6	14	60	72	60	32	1	38	45
	S.D.	28	7	20	31	40	43	35	0	19	11
	N	6	6	6	6	6	6	6	6	6	6
	SUM	375	34	81	360	430	357.	191	4	225	270
HIGH FERT	X	20	34	19	37	55	25	6	0	38	24
	S.D.	16	37	15	34	35	14	7	0	30	20
	N	6	6	6	6	6	6	6	6	6	6
	SUM	120	203	112	220	330	152	38	0	230	146

TABLE **2:** NUMBER OF SEEDLINGS AFTER **46** DAYS

LOW HUMIDITY

		NO FUNGICIDE					FUNGICIDE				
		BEACH	WATER LEVEL	BELOW WATER.	SUSPENDED	FLOATING	BEACH	WATER LEVEL	BELOW WATER	SUSPENDED	FLOATING
.NO FERT	X	27	5	6	47	34	47	15	20	54	41
	S.D.	24	7	7	41	33	36	13	0	38	36
	N	6	6	6	6	6	6	6	6	6	6
	SUM	159	30	36	279	203	279	91	120	325	243
LOW FERT	X	25	2	14	34	27	26	11	24	25	8
	S.D.	14	4	17	29	23	22	15	35	19	6
	N	6	6	6	6	6	6	6	6	6	6
	SUM	149	14	85	202	161	153	64	146	151	46
HIGH FERT	X	4	5	3	6	33	9	10	12	44	19
	S.D.	1	7	3	6	24	6	7	4	31	16
	N	6	6	6	6	6	6	6	6	6	6
	SUM	25	28	18	37	198	56	59	70	261	114

HIGH HUMIDITY

		NO FUNGICIDE					FUNGICIDE				
		BEACH	WATER LEVEL	BELOW WATER	SUSPENDED	FLOATIN	BEACH	WATER LEVEL	BELOW WATER	SUSPENDED	FLOATING
NO FERT	X	39	11	20	26	20	26	14	19	24	34
	S.D.	15	10	0	13	13	35	13	17	16	14
	N	6	6	6	6	6	6	6	6	6	6
	SUM	235	66	120	156	118	155	86	116	142	206
LOW FERT	X	28	2	0	47	53	26	17	2	27	40
	S.D.	4	4	0	20	29	16		2	13	14
	N	6	6	6	6	6	6		6	6	6
	SUM	168	13	0	284	320	157	102	10	161	242
HIGH FERT	X	16	12	13	25	36	19	4	0	24	27
	S.D.	9	12	9	15	31	9	4	0	18	17
	N	6	6	6	6	6	6	6	-6	6	6
	SUM	94	74	75	151	218	113	23	0	142	163

Water Depth: All growth trials were being performed in **3.3** L aluminum trays. Three set-ups providing variations in soil moisture content were constructed.

The first set-up, termed the Gradient Seedbed ("G"), consisted of a wire frame, with a fibreglass screen floor and covered with 1cm layer of soil. This seedbed was set at an angle from the lip of the aluminum tray at one end to the depth of the tray as the other end. The tray was filled with water so that half of the wire seedbed is submerged. Six replicates of approximately **100** seeds each were implanted on the beach zone, at the water line and in the submerged area.

The second set-up, termed the Varying Seedbed ("V"), consisted of a wire frame with a fibreglass screen floor and covered with 1cm layer of soil. The set-up was suspended so that the bottom of the seedbed barely contacts the water surface, maintaining seedbed moisture. However, with water loss from the trays by evapotranspiration, the degree of saturation varied over the two day period between waterings.

The third set-up, termed the Floating Seedbed ("F"), consisted of a styrofoam frame with a fibreglass screen floor and covered with a **1** cm layer of soil. The styrofoam frame maintains the soil surface **1-2** mm above the water surface. Six replicates of approximately 100 seeds were planted on the surface.

Parameters Measured: Observations of germination frequencies and seedling development, in terms of shoot and root growth, were recorded on days **3,** 9, **13,** 16 and **46.**

3.2 Greenhouse Conditions: Germination **and** Seedling Establishment

Objective

Using the information gained from laboratory germination and seedling establishment experiment (see Section 4.1), the objective was production of a large number of seedlings for transfer to floating rafts in neutral water (East Oriental Pond) and acid water (Oriental West Pit) in the glory holes in Buchans, Newfoundland.

An 'A' frame greenhouse was designed and built in Buchans, **2** km from the glory holes, the sites of seedling transplant.

The greenhouse is **3.7 x 11** m at the base, reaching, at the apex, **2.4** m in height. The greenhouse was constructed from a wooden frame, and covered with thick, clear, plastic sheeting, sealing the greenhouse draft-tight. Electric heaters with thermostats were installed to maintain minimum air temperatures, and a water line installed to supply water during germination and seedling growth.

Within the greenhouse were constructed eight **1.22** m wide, by **2.44** m long, by 0.6 m high water-tight open-topped plywood boxes, sealed with silicone gel sealant. These eight boxes were filled with Buchans tap water to a height of 0.5 m within the boxes.

These boxes' dimension permitted installation of 16 plastic germination trays, in a **4** tray by **4** tray configuration, held floating on the box water surface by a frame constructed from plywood and styrofoam sheeting with squares cut the size of the 16 trays.

Two square holes were cut out of the floor of each tray, in order to maintain maximal moisture content in the substrate within the trays. The trays were lined with burlap cloth, hot-glued to the tray lip perimeter, in order to contain the substrate.

Two types of substrate were placed in each trap. **A** base layer, **4** cm thick, composed of a sandy till characteristic to the Buchans area, was placed over the bottom of each tray. **A** second **4** cm thick layer of substrate was placed over the till layer. This substrate was composed of black, high organic peat collected locally, then sifted through a 0.5 cm minus mesh, to remove larger debris.

Greenhouse Conditions- Monitoring and Control

The seeds were planted May 11, 1990, a time when night temperatures could potentially decrease to 0 *C* and below. Therefore, using the installed heaters, the greenhouse was maintained at a minimum of 22° *C*.

Water levels were maintained by addition of Buchans tap water. From observations of uneven decreases in water levels, leaks were detected in some boxes. These boxes were drained, patched refilled, and the trays re-installed.

Ambient sunlight through the translucent plastic sheeting was the only illumination provided. The tray seed beds were adjusted by weights so to maintain moist, but not wet, surfaces over the trays.

Seeding: First Trial

Typha latifolia seed heads were collected from the Bluffer's Park, Scarborough, Ontario on March, 13, 1990 and stored at refrigerator temperatures. The seed heads were transported intact to Buchans. **A** total of **43** seed heads were used to seed the 128 trays, or about **0.3** seed heads per tray. Seeds were separated from other seed head parts by fluffing the seed heads in **20** 1 of dilute detergent-warm water solutions. The detergent assists wetting of the pericarp surround the seed, which results **is** spontaneous release of the seed. **As** the seeds are more dense that water, while air bubbles within the other seed head parts render them less dense that water, seeds sink for collection at the bottom, while the remaining floating debris can be scraped off.

Seeds released from the seed heads were allowed to settle, and the concentrated seed slurry collected and excess water decanted. The seed slurry was homogenized with an additional 32 litres (by moist volume) of the black, high organic peat. **A** thin layer of 250 ml of the seed-peat mixture was applied over each tray surface and patted down by hand to draw moisture to the surface, in order to promote a high moisture content in the peat around the seeds in spite of surface evaporation.

After planting, 250 g of the product "Flowering Plant Fertilizer" (Plant Products Co. Ltd., Bramalea, Ontario, 15-30-15 N-P-K) was added to the water in each box supporting the floating germination trays.

Seeding: Second Trial

Close examination, after 30 days, of the seedlings growing in the greenhouse (June 10,1990), revealed that the *Typha* seedlings reported growing were, in fact, a grass species' seedlings, 'while very few plants were *Typha*.

Although germination was recorded within 7 days, very few plants had established by 30 days after planting. Establishment only took place at the perimeters of the trays, where wicking of box water up the sides of the trays via the burlap provided better conditions for establishment.

Measurements of pH revealed that in the centre of the trays, the pH of the saturated peat was only **3.9** to 4.1, while the pH of the peat ranged from 4.2 to 5.4. The pH of water within the boxes underlying the trays ranged from 6.3 to 7.2. Agricultural limestone was added in order to increase the pH of the peat substrate. Remeasurement of the pH indicated that this limestone addition procedure increased the pH in the middle of the trays to pH 6.1.

On June 12,1990, half of the peat layer was removed from each tray, and mixed with 2 l of sand and 200 cm^3 of agricultural limestone. The mixture was replaced over each of the trays.

The trays were re-seeded with *Typha* seeds by the following procedure. Fifteen seed heads were separated, fluffed and wetted with a small amount of dish detergent in a 20 l bucket. The seeds were separated as during the first planting. The seed slurry was homogenized with 32 l of moist till and 300 cm^3 of limestone. The mixture was evenly distributed over the trays, patted down and watered.

3 3 Floating *Typha* Mats: Construction and Transplant

A wooden frame design, based on a superstructure of 2"x 6" wooden frame 5 to 6' by 10 to 12' in area, was employed, where netting is attached at the base to create a large basket to contain organic substrates. **A** burlap layer was fixed over the netting floor, to ensure containment of sphagnum moss biomass, the substrate used to support newly transplanted seedlings or mature plants. Styrofoam strips were attached to the frame edges in order to maintain the correct level of buoyancy and saturation of the mats.

Twenty rafts were constructed. Ten were launched and anchored into position into the Oriental West Pit, where the pH ranges from **6** to 7. Ten more were launched into Oriental East Pit, where the pH ranges from **3** to **4.**

On July **25,** 1990, the plastic trays enclosing the seedling growth substrate were removed, and the blocks of amendment consolidated by the seedlings' root network were cut into thirds, each representing a clump ready for transplant on July **26.** Mature plants were excavated from a local *Typha* population in the week of July **26** for transplant to the floating rafts.

Rafts were designated as either seedling or mature transplant rafts. Slow release fertilizer and bone meal were added alone or together for comparison of establishment and growth with control (no amendment) conditions. The transplant pattern, in terms of the specific number of seedling clumps and mature plants transplanted to the rafts, and the amendment applied to the floating mat surfaces, is given in Table **3.**

4.0 RESULTS AND DISCUSSION

4.1 Seed Germination and Seedling Establishment in the Laboratory

After **16** days, approximately **12,600** seedlings had germinated and survived the **32** treatments. However, after **46** days, only approximately **7,700** seedlings, or **61%,** were surviving, indicating that with development, significant thinning within the planted areas had occurred (Table **4).**

A moist, but not wet, seedbed appears optimal to seed germination, indicated by the highest germinations observed in the beach and suspended moisture treatments, and the poorest germination results in the below water treatments (Table **4).** However, the suspended and floating treatments appear most favourable for seedling establishment. Overall, it appears that floating seed beds would provide the most appropriate conditions for germination and seedling establishment.

Examination of the germination data indicates that seed germination is inhibited by increasing concentrations of fertilizer, but low levels are tolerated by seedlings during establishment (Table **4).** Therefore, addition of low levels of fertilizer after germination to promote seedling growth appears the best timing.

Variation in humidity does not appear to affect either seed germination or seedling establishment in the laboratory. The addition of fungicide promoted seedling germination, but, between **16** and **46** days, a comparable number of seedlings died, indicating the fungicide does not overall increase the density of seedlings during establishment (Table **4).**

Table 3: Floating Typha Mats- Experimental treatments and growth results, October 26. 1990

WEST PIT	RAFT 1	RAFT 2	RAFT 3	RAFT 4	RAFT 5
Initial Treatment	N+B, Seedlings	N+B, Seedlings	N+B, Seedlings	N+B, Mature	B, seedlings
Initial # clumps: S,L	19 S, 10 L	19 S, 10 L	19 S, 10 L	20 plants	19 S, 10 L
Ht Classes remain?	no	no	no	N.A.	no
Seedling Ht size range	10 - 45 cm	10 - 40 cm	< 10 . 40 cm	N.A.	10 - 14 cm
New shoots from Mature	N.A.	N.A.	N.A.	20 new,40cm max	N.A.

	RAFT 6	RAFT 7	RAFT 8	RAFT 9	RAFT 10
Initial Treatment	F, Seedlings	Seedlings	B, Mature	F, Mature	Mature
Initial # clumps: S,L	23 S, 3 L	24 S, 0 L	20 plants	20 plants	20 plants
Ht Classes remain?	no; 3 dead	none originally	N.A.	N.A.	N.A.
Seedling Ht sire range	9 - 10 cm	max 7 cm	N.A.	N.A.	N.A.
New shoots from Mature	N.A.	N.A.	5 shoots	5 shoots	4 shoots

EAST PIT	RAFT 11	RAFT 12	RAFT 13	RAFT 14	RAFT 15
Initial Treatment	F+B, Seedlings	F+B, Seedlings	F+B, Seedlings	F+B, Seedlings	B, Seedlings
Initial # clumps: S,L	19 S, 10 L	19 S, 10 L	19 S, 10 L	29 L	19 L, 10 S
Ht Classes remain?	No	NO	No	N.A.	NO
Seedling Ht size range	40 - 80 cm	30 - 80 cm	30 -70 cm	30 - 90 cm	10 - 40 cm
New shoots from Mature	N.A.	N.A.	N.A.	N.A.	N.A.

	RAFT 16	RAFT 17	RAFT 18	RAFT 19	RAFT 20
Initial Treatment	F, seedlings	Seedlings	B, Mature	F, Mature	Mature
Initial # clumps: S,L	19 L, 10 S	19 L, 10 S	20 plants	20 plants	20 plants
Ht Classes remain?	no	no	N.A.	N.A.	N.A.
Seedling Ht size range	30 - 70 cm	< 10 - 30 cm	N.A.	N.A.	N.A.
New shoots from Mature	N.A.	N.A.	16 shoots,40cm max	32shoots,90cm max	8 Shoots,10cm max

N.A. Not Applicable
N.R. Not Recorded

N = Slow-Release Fertilizer Added
B = Bone Meal Added

Table **4:** The number of seedlings **16** and **46** days after planting, summed by independent variables applied during laboratory experiment (summarized from Tables 1 and 2).

Water Level					
	Seedbed on Beach	Seedbed At at W.L.	Seedbed Below W.L.	Seedbed Suspended At W.L.	Seedbed Floating
16 days	3090	1430	1530	3620	2990
46 days	1740	650	800	2290	2230

Addition of Fertilizer			
	No Fertilizer	Low Fertilizer	High Fertilizer
16 days	5070	4460	3110
46 days	3170	2630	1920

Humidity Level		
	Low Humidity	High Humidity
16 days	6290	6360
46 days	3800	3720

Fungicide Addition		
	Fungicide	No Fungicide
16 days	7360	5280
46 days	4000	3720

Typha seeds did not require a cold treatment. This concurs with McNaughton **(1966),** who determined that seeds are already viable when still on the inflorescence. However, reports in the literature indicate that, for a seed to germinate, there must be sufficient moisture to maintain a saturated seed (Bedish, **1967;** Weller, **1975;** Leck & Graveline, **1979),** light intensities approaching that of full sunlight (Sifton, **1959;** Kadlec & Wentz, **1974;** Sharma & Gopal, **1979)** including red and infrared (Sifton, **1959)** and temperatures ranging from 20 to **30** °C for high frequencies of germination (Morinaga, **1926;** Thompson et al., **1977).** Clearly, any of the treatments in the present laboratory conditions provided all these requirements to some degree, as in all treatments, seeds germinated and seedlings established.

Seedling establishment is likewise been reported to be dependent upon similar moisture, light and temperature conditions as seeds for germination (Yeo, **1964;** Bedish, **1967;** Weller, **1975;** Sharma & Gopal, **1979),** but is also sensitive to water and sediment chemistry (McMillan, **1959;** Kadlec & Wentz, **1974).**

4.2 Greenhouse Conditions: Germination and Seedling Establishment

Seeding: First Trial

As described in Section 3.2, close examination on day 30 of the first seed planting trial, revealed that very few plants growing on the greenhouse flats were *Typha* seedlings. The few *Typha* seedlings present were confined to the perimeter of the trays, where wicking of box water up the sides of the trays through the burlap may have maintained better substrate conditions, such as overall higher pH, at the edge of each tray.

On retrospect, poor germination of *Typha* seeds may have been expected. **A** follow-up lab examination, just after the first planting (May 11, 1990), of the pH of till and peat substrate slurried with distilled water revealed that the pH of the till substrate was 5.7 and the pH of the peat lower yet, pH 3.68. Combined, the two slurries' pH was 4.07. With addition of the same fertilizer, but at a higher concentration than that applied in the greenhouse conditions, the pH only increased to 4.1. At the time, however, germination and growth was reported from Buchans, and suspicions were not raised until direct examination of the seedlings on June 10, 1990.

Remeasurement of the pH indicated that this liming procedure increased the pH from the prior pH 3.9 in the middle of the trays to pH 6.1. Over the next 43 days, a dense seedling population established evenly over all eight seed bed flats. However, two types of seedlings had differentiated according to which box they were growing in; shorter chlorotic seedlings, 5 to 15 cm tall, and larger, greener seedlings, 15 to 25 cm tall.

Sampling of the bulk solution in each box indicated that those boxes with poor seedlings (Boxes 1, 2, 3, 4 and 8) contained very low concentrations of nutrients, and were the same boxes which required mending after leaks were detected. The healthy seedlings were in boxes (Boxes 5, 6 and 7) with much higher nutrient concentrations, where no water had leaked, and the nutrient concentrations were not diluted (see Table 5 below).

Table 5: Nutrient concentrations in boxes underlying trays, 43 days after seeding.

	pH	Cond	[K]	[P]	[Ca]
Box 1	5.83	98	1.9	0.3	1.5
Box 2	5.96	115	6.4	0.8	1.5
Box 3	6.67	185	6.3	<0.01	1.3
Box4	6.25	49	<0.1	<0.01	2.1
Box5	6:30	370	27	25	2.1
Box 6	6.19	440	35	39	1.9
Box7	5.99	312	21	23	5.3
Box 8	5.94	135	2 7	0.5	3.8

Overall, both size classes of seedlings appeared mature enough, in terms of plant height and root development, for transplant to field conditions without significantly damaging the plants.

4 3 Floating *Typha* Mats: Plant Establishment and **Growth**

Seedlings and mature transplants survived transplant, and established and grew to various sizes on all rafts under the conditions of both Oriental East and West Pits (Table 3).

The best conditions for seedling establishment, growth and development were provided by the rafts located in the circumneutral Oriental East Pit, where rafts were amended with fertilizer and bone meal. Neither the rafts amended with fertilizer or bone meal alone provided conditions for the excellent seedling development observed when the amendments were combined. However, very poor growth of seedlings was observed on the unamended raft, indicating the bone meal and fertilizer, when applied alone, did promote some growth of seedlings.

Overall, the shoots of seedlings were shorter, the plants produced fewer and smaller rhizomes and root development was poorer in the acidic conditions of the West Oriental Pit (Figure **1).** However, the seedlings responded to combined fertilizer and bone meal, bone meal or fertilizer alone, or no amendment, in a very similar manner is in the East Oriental Pit.

Mature *Typha* shoots transplanted to floating rafts in Oriental West Pit produced very few new shoots when bone meal or fertilizer alone were added **(4** to ***5*** new), compared to the development of 20 new shoots on the raft where both fertilizer and bone meal where added (Table **3).** Although a comparable combined fertilizer and bone meal amended float was not set up in Oriental East Pit, when either fertilizer or bone meal was added to the raft, the transplanted mature plants developed more new shoots **(32, 16** new respectively) than on the rafts with no amendment (8 shoots).

5.0 CONCLUSIONS

Several practical techniques, for germinating *Typha* seeds, promoting *Typha* seedling development, and transplanting juvenile or mature plants to floating rafts, have emerged from this work.

Maintenance of constant substrate moisture, selection of substrates with circumneutral pH's, and provision of nutrients both during seedling establishment and transplant have been identified as key measures.

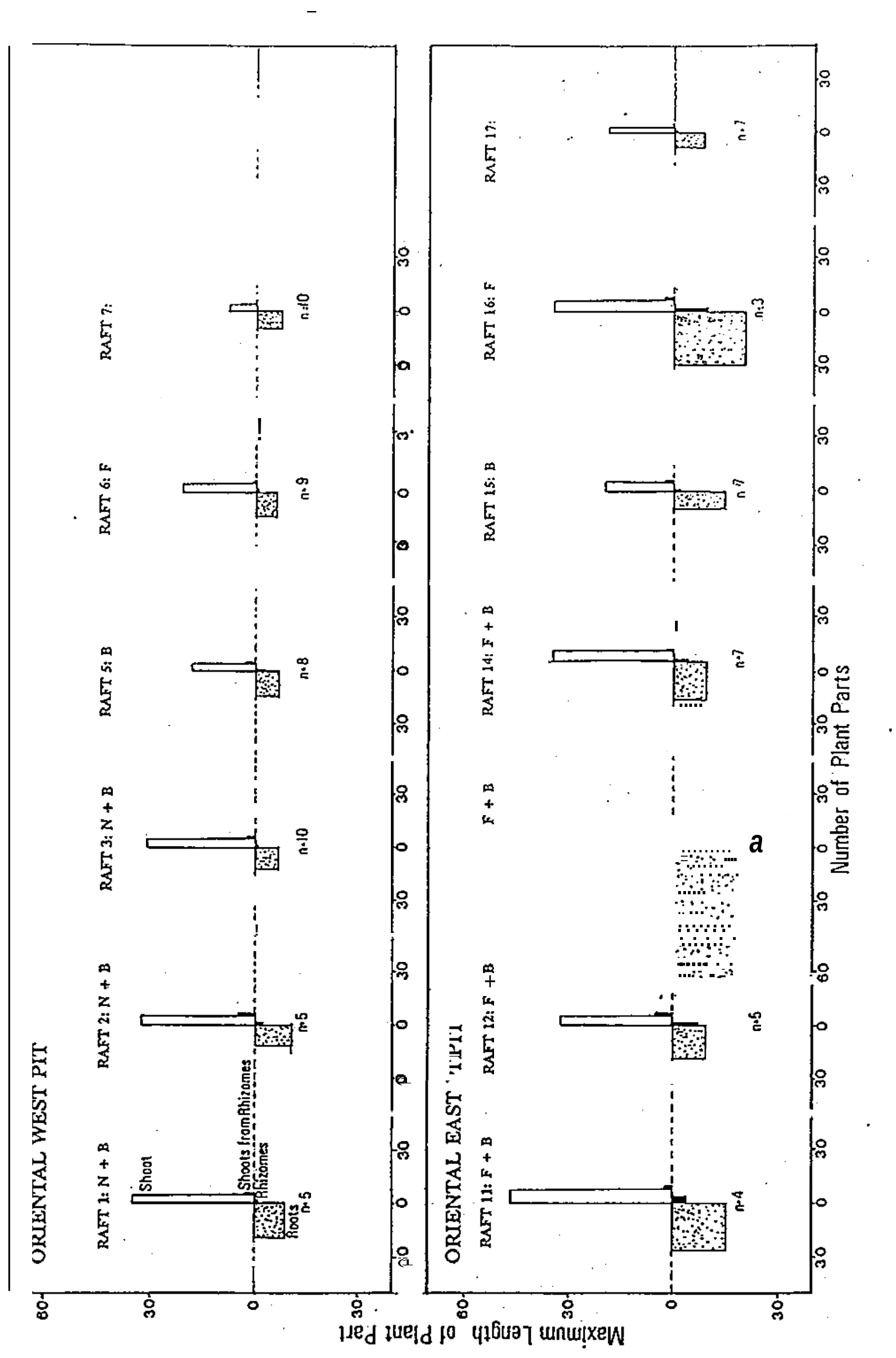

Figure 1: Graphical presentation of seedling development observations (seedling shoot, rhizome, root and new shoot: length and number) **94** days after transplant to rafts on the Oriental West and Oriental East Pits.

The suitability of the raft design, and the development of improved designs, in terms **of** providing suitable conditions for juvenile and mature plant survival during overwintering, is clearly the next phase of research. Detailed monitoring of root and rhizome development will be required, as maximal development of these plant parts are required for both overwintering success and maintenance of the buoyancy of the mats.

6.0 REFERENCES

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BUCHANS :COST
OPTIMIZATION OF AMENDMENT

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August *3,1990*

1.0 INTRODUCTION

The following experiments were conducted to estimate the optimum ratio of sawdust, alfalfa, and Biolyte CX-70 for the ARUM process in the Oriental West site of Buchans for Asarco Mining.

2.0 METHODS

Mixtures of sawdust and alfalfa obtained by Boojum Research were prepared in triplicate in 1 litre Mason jars according to Table I. Extra replicates of the mixtures were prepared for the 100% sawdust and the 50%/50% sawdust/alfalfa combinations. Water from the Oriental West site (350 ml aliquots) was added to each jar. After two weeks each jar was innoculated with 2 ml of a suspension of a sawdust amendment sample from Oriental East in which sulphate reduction was occurring.

The jars were also innoculated with a mixture of Biolyte CX-70 and bran which had been homogenized for two 15 second intervals in a Waring blender. Bran was added to the Biolyte as a carrier since relatively small amounts of product were being used. One set of the triplicate sawdust/alfalfa mixtures received 1% Biolyte as product (V/V of unhydrated amendment), a second set received 0.3% while the third set received 0.1%. The extra 100% sawdust and 50%/50% sawdust/alfalfa preparations received bran without Biolyte as controls. Oriented West sample water was then added to fill the jars to 1 inch from the top. The jars were then monitored visually each week and after several weeks pH measurements were made.

Another study to assess the potential benefit of using potato waste and to define the value of Biolyte was conducted using a similar protect. A third experiment was conducted to examine the effect of increased water/amendment ratios, the effects of iron addition, and the effects leaching of the alfalfa amendment. This experiment was conducted in 1.2 litre fleakers which permitted greater volumes of water to be added to the amendments. Sample aliquots removed for VFA analyses were stored frozen and then filtered through a 0.22 micron cellulose nitrate filter prior to analysis by gas chromatography.

3.0 RESULT AND DISCUSSION

Table II summarizes the data of the first experiment conducted to estimate optimum mixtures of sawdust, alfalfa, and Biolyte CX-70. The experiment summarized in Table III examined more carefully the requirement for Biolyte, while the experiment summarized in Table IV tested the effect of increasing the ratio of water to amendment, the effect of iron addition, and the effect of leaching the alfalfa amendment.

It can be seen that all treatments increased the alkalinity of the water (Table II) The least successful treatments were 100% sawdust with 0.1% Biolyte and 0% Biolyte. The most successful treatments were 10% alfalfa/90% sawdust and 20% alfalfa/80% sawdust with 0.1% Biolyte (Table II). Data in Table III indicate that potato (waste) is a potential substitute for alfalfa. The addition of Biolyte CX-70 did not improve and may be detrimental to alkalinity generation (Table II and Table III). Higher percentages of alfalfa appeared detrimental to alkalinity generation in test vessels containing similar volumes of water and amendment (Table II). In test vessels where water volumes greatly exceeded amendment volume these problem did not occur (Table IV).

The test amendments which had the lowest alkalinity generation tended to have the most putrid/rancid odour. Gas chromatography analyses revealed that these samples tended to have higher amounts of volatile fatly acids (VFA's) than the most successful treatments (Table II). Biolyte CX-70 appeared to stimulate VFA production, particularly when the alfalfa concentration were less than 40% (Table II). The highest pH levels were acheived when sulphate reduction was evident and VFA levels were lowest (Table II). Possibly excess VFA production can inhibit sulphate reducing bacteria.

Excessive VFA production may only be a problem in regions with large volumes of amendment and low (or no) flows as data in Table IV suggests. Table IV also shows that there appears to be water soluble nutrients in alfalfa which stimulate alkalinity and VFA production (as indicated by putrid/rancid odour).

4.0 Conclusions

Mixtures of 10% alfalfa/90% sawdust to 20% alfalfa/80% are optimal for the **ARUM** process in this site.

Biolyte CX-70 does not appear to benefit the ARUM process when alfalfa/sawdust amendments are used.

Potato waste is a potential substitute for alfalfa in the ARUM process.

Table I Sawdust/Alfalfa Amendment Mixtures

Percent Sawdust	Percent Alfalfa	Sawdust (g)	Alfalfa (g)
100	0	57	0
90	10	51.3	5.7
80	20	45.6	11.4
70	30	39.9	17.1
60	40	34.2	22.8
50	50	28.5	28.5

Each of these mixtures was prepared in triplicate and added to a mason jar before addition of Oriental West water, Biolyte CX-70, and inoculum from a sample containing sulphate reducing bacteria.

Table 11 Optimization of amendment composition: Screening Test

Amendment Composition		CX-70 Supple-ment (V/V %)(1)	pH(2)		Butyric Acid after 6 wks	Propionic Acid after 6 wks	Acetic Acid after 6 wks
Sawdust (% W/W)	Alfalfa (% W/W)		After 5 wks	After 6 wks	(mg/l)	(mg/l)	(mg/l)
100%	0%	1.0%	4.5	4.6	<100	<100	<100
100%	0%	0.3%	4.2	4.4	<100	<100	<100
100%	0%	0.1%	4.0	4.0	<100	<100	<100
100%	0%	0%	4.0	4.0	<100	<100	<100
90%	10%	1.0%	4.4	4.4	- (4)	- (4)	- (4)
90%	10%	0.3%	4.5	4.4	-	-	-
90%	10%	0.1%	6.5	6.6(3)	-	-	-
80%	20%	1.0%	4.7	4.7	761	284	804
80%	20%	0.3%	4.9	5.0	<100	<100	<100
80%	20%	0.1%	6.2	5.8(3)	<100	<100	<100
70%	30%	1.0%	4.5	4.7	955	653	1242
70%	30%	0.3%	4.8	4.9	526	<100	694
70%	30%	0.1%	5.6	5.3	<100	<100	<100
60%	40%	1.0%	4.9	5.0	633	480	913
60%	40%	0.3%	4.5	4.6	1705	565	1258
60%	40%	0.1%	4.8	4.8	736	427	532
50%	50%	1.0%	4.7	4.7	2205	718	871
50%	50%	0.3%	5.0	5.2	1386	395	661
50%	50%	0.1%	4.9	5.1	724	282	484
50%	50%	0%	4.9	5.0	1660	1000	500

1 Biolyte **CX-70** was added as a percent volume **of** unhydrated amendment volume.

2 Initial pH was **3.5**

3 H_2S odour detected

4 This sample set was accidently lost prior to **VFA** analysis.

Table III Biolyte Requirement and Starch Tests

Amendment Composition			Biolyte CX-70	pH After Incubation Period 2			
Sawdust (% w/w)	Alfalfa (% w/w)	Starch (% w/w)		2wks	3 wks	4 wks	5 wks
90%	10%	0%	No	4.7	4.6	4.6	4.6
90%	10%	0%	No	4.6	4.5	4.4	4.5
90%	10%	0%	Yes	4.6	4.7	4.6	4.7
90%	10%	0%	Yes	4.5	4.5	4.4	4.4
90%	0%	10%	No	5.0	4.9	4.8	4.8
90%	0%	10%	No	4.9	4.8	4.8	4.9
90%	0%	10%	Yes	4.8	4.8	4.7	4.7
90%	0%	10%	YES	4.8	4.7	4.7	4.6

1 Biolyte was added at 0.1% (V/V) of the unhydrated amendment volume.

2 initial pH was 3.5

Table IV Effect of increased water/amendment ratio, addition of iron filings, leaching of alfalfa amendment.

Amendment composition	Water/Amendment Ratio (V/V) after Hydration	pH after incubation period				Comments
		2 wks	3 wks	4 wks	5wks	
50% Sawdust/50 % Alfalfa (w/w)	0.6	-	-	-	4.9	This data was obtained from Table I. Odour after 2 wks was putrid.
50% Sawdust/50 % Alfalfa (w/w)	1.5	5.2	5.7	6.5	6.4	Putrid and H_2S odour detested after 3 wks. After 5 wks, sulphide level was 0.85 ppm
50% Sawdust/50 % Alfalfa (w/w) plus 0.5 cm layer of iron filings	1.5	5.8	5.7	6.1	6.6	Water turned brown/black after 3 wks odour was putrid no HoS odour until 5 wks. After 5 wks sulphide level was 0.15 ppm
50% Sawdust/50 % leached alfalfa	1.5	4.8	4.8	4.7	5.0	No putrid or H_2S odour detected. Sulphide level was 0.1 ppm after 5 wks.

SEQUENTIAL NUTRITIONAL ANAYLSES OF **AMENDMENTS**

FOR

BUCHANS, ASARCO MINING

J. CAIRNS

E.MANICCIA-BOZZO

L. BROGNO

August 3,1990

1.0 PURPOSE

To perform sequential nutritional analyses on ARUM amendment samples from the Buchans site, Asarco Mining, Nfld.

2.0 METHODS

The procedure used was a simplified version of forage file analysis (1).Fig. 1 is an outline of the procedure.

3.0 RESULTS

Results are summarized in Table I. Table II shows analyses of amendments before exposure to AMD.

4.0 COMMENTS

As amendment is degraded, the % loss after HCL extraction should decrease as should the % loss after H_2SO_4 digestion. *As* the same time, the % remaining after H_2SO_4 digestion should increase and become the major component. With the exception of the "E. Oriental Sawdust Cell-Eckman 6/11/90' sample, it appears the negligible degradation has occurred.

5.0 REFERENCE

Goering, H.K., and P. J. Van Soest (1970) Forage fibre analysis. Agricultural handbook No. **379.** US Department of Agriculture. Washington, D.C.

TABLE 1 - SEQUENTIAL NUTRITIONAL ANALYSES OF BUCHANS AMENDMENTS, JUNE, 1990

Sample Label	% Loss from Original after Acetone Extract	% Loss from Original after HCl Reflux (% Rapidly Degradable)	% Loss from Original from H_2SO_4 (% Total Degradables)	% Remaining (Lignin and Cutin and Minerals)
W. Pit 6/11/90 Panel #2 Peat	13	54	73	27
Peat 6/11/90	0	43	84	16
Acid Pool #7 Good	7.2	54	83	17
Acid Pool #9	8.3	53	78	22
Acid Pool #7	14.5	50	70	30
E. Oriental S. Limnoc	10.0	45	83	17
E. Oriental Sawdust Cell Eckman 6/11/90	17.0	24	50	50
Limno & Peat East Oriental 6/11/90	12.0	47	59	41

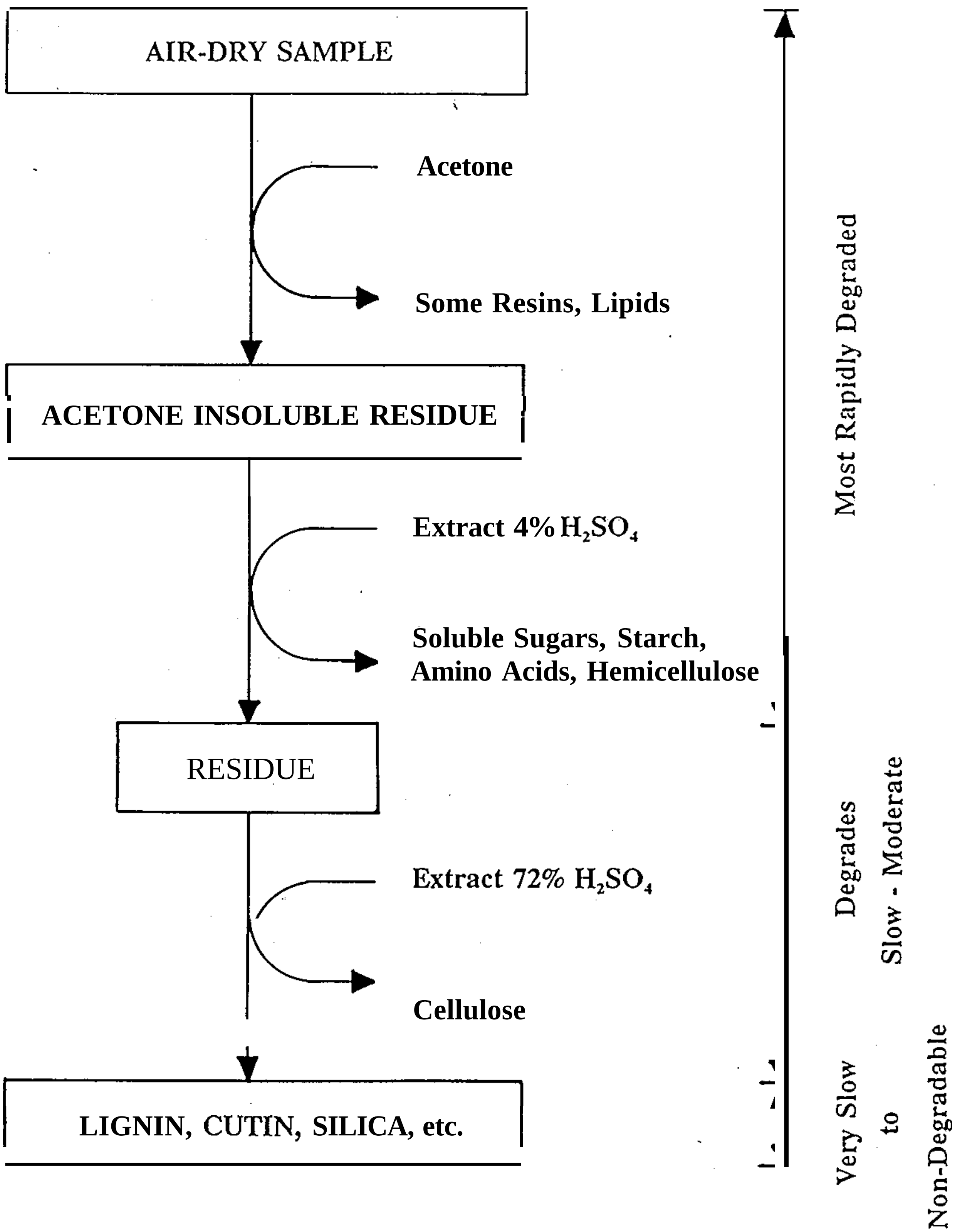
TABLE 2 SEQUENTIAL NUTRITIONAL ANALYSES OF VARIOUS AMENDMENTS BEFORE EXPOSURE TO AMD

	Total % loss from Acetone Ext.	Total % loss after 4% HCl	Total % loss after 72% H_2SO_4	% Remaining after 72% H_2SO_4
SAWDUST 1	1.5	29	66	34
SAWDUST2	7.2	29	76	24
Peat	9.0	40	55	45
Straw	6.0	33	76	24
Cattail	5.0	42	69	31
Alfalfa 3	5.1	45	83	17
	Lipids (resins)	soluble sugars, starch amino acids, hemicellulose		

Total degradable (as 100% Bio-available)

1 Feb 23/90 sample
2 July/90 sample
3 July/90 sample

SEQUENTIAL NUTRITIONAL ANALYSIS OF AMENDMENTS



APPENDIX **6:** BUCHANS SAMPLE DESCRIPTIONS

SAMPLE DESCRIPTION BUCHANS

Station: A

0 - 7
Dark to very dark, brown ,non woody, fine fibrous Peat containing non woody particles, coarse fibres and woody, coarse fibres. Moss (non Sphagnum) on top.

7 - 15
Very dark brown - black, amorphous-granular Peat containing non woody, fine fibres and some non woody and woody particles.

15 - 30
Dark brown (slightly lighter than above), fine fibrous, silty Clay Loam crisscrossed by non woody, coarse fibres.

30 -43
a/a. Dark - very dark brown. Traces of coarse sand towards bottom.

43 - 50
Very fine - coarse grained, light brown, brown, fine fibrous, silty Sand, occasionally gravel, woody, non woody fibres and particles.

Station: B

0 -3
Dark brown - black Peat. Predominantly amorphous-granular, containing woody, fine fibres held in a woody, fine to coarse fibrous framework. Contains woody and non woody particles.

3 - 15
Brown, grey brown, dark brown, amorphous-granular Peat containing non woody, fine fibres, occasionally woody, coarse fibres and particles.

15 -25
Brown, amorphous. non woody, fine fibrous Peat held in a fine - coarse fibrous, non woody framework.

25 - 30
Brown, organic rich Clay containing non woody, fine to coarse fibres.

30 -35
Grey brown, light brown, very fine - coarse grained, silty Sand. Clay rich in top.

Station: C

0 -5
Dark brown Peat, predominantly amorphous-granular, containing non woody, fine and coarse fibres. Woody, coarse fibres i/p.

5 - 20
Dark brown, black Peat, predominantly amorphous-granular, containing non woody, fine and coarse fibres.

20 - 25
Dark brown, black Peat, predominantly woody, fine fibrous, containing non woody, fine and coarse fibres and woody particles.

25 - 40
Dark brown, black Peat, predominantly amorphous-granular, containing non woody, fine and coarse fibres. Clay i/p, particularly towards bottom. Coarse sand i/p.

40 - 45
Grey, dark grey, very fine - very coarse, silty Sand. Clay i/p. Fine gravel i/p (occasionally up to 2.5 cm). Contains non woody, fine and coarse fibres.

Station: D

0 - 6
Black, very fine grained, organic rich, sandy Silt containing non woody, fine fibres.

6 - 15
Dark brown, sandy Silt. Black, organic, silty matrix with light brown, very fine - coarse sand and occasional small, gravel sized, pebbles. Towards bottom inclusions of amorphous-granular, organic material containing non woody, fine - coarse fibres.

15 - 30
Very dark brown, non woody, fine fibrous and amorphous Peat containing coarse fibres. Fine to coarse sand i/p. Occasional gravel sized pebbles (2 cm) towards bottom.

30 -50
Dark brown, brown, sandy Silt with very fine - coarse sand and gravel (up to 2.5 cm) and non woody, fine - coarse fibres and plant remains.

Station: E

0 - 13
Dark brown, black, organic Silt with non woody, fine fibres. Fine sand i/p near bottom.

13 -19
Brown, light brown i/p, very fine - coarse, silty Sand. Non woody, fine fibres i/p. Gravel (up to 2 cm) layer at bottom.

19 -24
Dark brown, very fine - coarse grained, silty Sand with strong organic component and non woody, fine and coarse fibres.

24 - 50
Dark brown, very fine - coarse grained, silty Sand containing non woody, fine and coarse fibres. Very coarse grained i/p. Occasionally gravel sized pebbles.

Station: F

0 -10
Dark brown, blackish, organic rich, very fine grained, sandy Silt with woody, coarse fibres and particles, occasional small stick, and non woody, fine fibres.

10 - 25
Light brown, very fine - coarse grained, silty Sand with non woody, fine and coarse fibres. Occasionally clay rich lenses. Gravel sized pebbles (up to **1.5** cm) i/p. Slight **H_2S** smell when broken apart.

25 - 40
Brown, very fine - fine, occasionally coarse grained, silty Sand containing non woody, fine and coarse fibres. Occasional gravel sized pebbles (up to **2.5** cm).

Sample: G

0 - 10
Dark brown Peat, predominantly amorphous-granular, containing non woody, fine and coarse fibres held together by a non woody, **fine** fibrous framework.

10 -30
Dark brown Peat, a/a. Locally containing clay.

30 - 50
Dark brown Peat, a/a.