Decommissioning Open Pits with Ecological Engineering

by
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ABSTRACT

Ecological Engineering, a biotechnological approach to the decommissioning of base metal mining wastes, is being tested on two open pits (Gloryholes) in Newfoundland, Canada. Pit #2 has an average pH of 3.5 and flows into Pit #1 where, through additional ground water contribution, the pH is circumneutral, ranging between 5.5 and 7.

The AMD in Pit #2 originates from underground workings and exposed massive sulphide on the pit walls. The overflow from Pit #1 averages about 10 L/s with less than 0.2 mg/L of Cu and 40 mg/L of Zn.

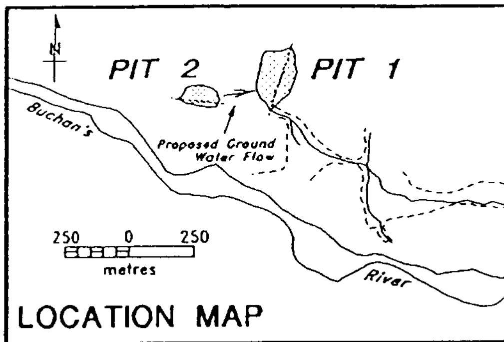
Ecological Engineering utilizes organic substrate as a source of carbon and nutrients for microbial populations which can generate alkalinity and reduce metals. In 1989, limnocorrals (enclosures of 4 m diameter and approx 3 m depth) were placed in both pits to test the most suitable organic amendment (peat and sawdust). Microbial alkalinity-generation was evident 95 days after placement of the amendment on July 4, 1989. The pH had increased after 120 days from 3.5 to 4.5 and by day 480 the pH was 7 in limnocorrals in Pit #2. Zinc concentrations in the limnocorrals in Pit# 2, dropped from an average of 35 mg/L to about 2 mg/L or less, by day 480.

A scaled-up experiment has been under way since August 25, 1990, where 390 m^3 are treated in Pit #2 and 750 m^3 in Pit #1. One hundred eighty days after placement of the amendment, zinc was reduced in the acid Pit #2 from 40 mg/L to 15 mg/L. Research is underway to determine those factors which limit microbial activity.

INTRODUCTION

The application of Ecological Engineering as a decommissioning technology 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 using microbiological processes for alkalinity-generation and metal reduction in 2 gloryholes, the Oriental East and West gloryholes.

In 1990, work was carried out in the pits to scale-up from experimental tests in enclosures (~43 m^3 experimental enclosures) to semi-enclosed of 750 m^3 in Pit #1 and 390 m^3 in Pit #2. Schematic 1 outlines the layout of both pits. The water flows from Pit #2 to Pit #1 where mixing of groundwater occurs and leaves the pit at about 10 L/s into a meadow, eventually finding its way to the Buchans River.

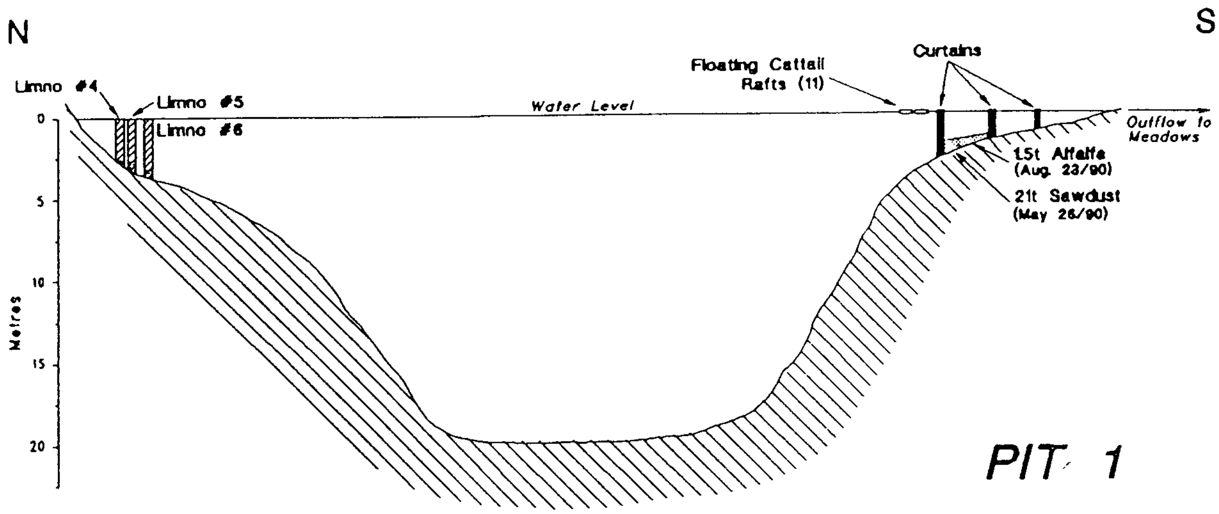


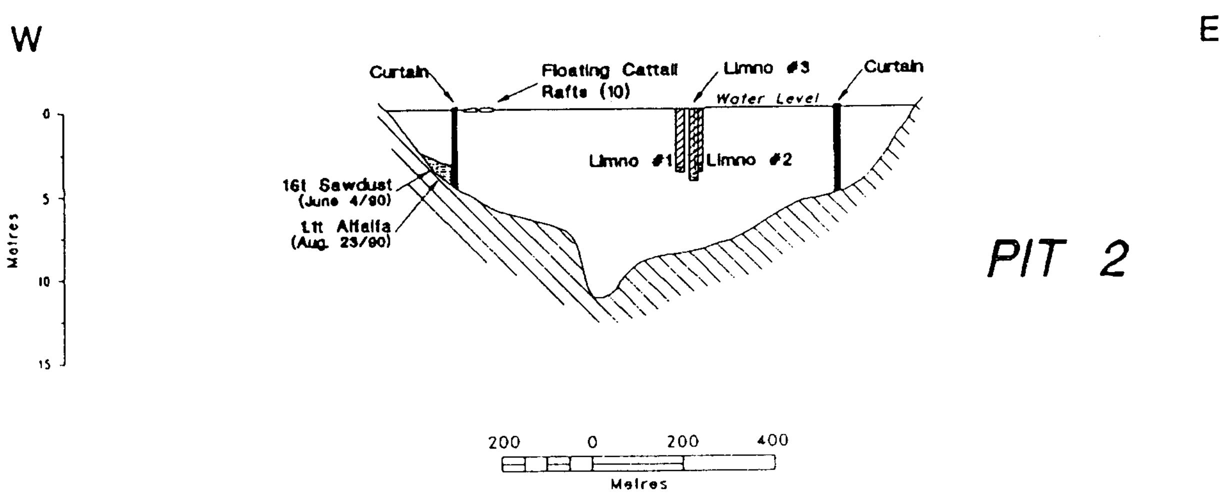
BUCHANS PROJECT
Buchans, Newfoundland

CROSS-SECTION of PIT 1 and PIT 2

December 5, 1991

Schematic 1





The overall objective is to achieve conditions which would facilitate the ARUM process (Acid Reduction Using Microbiology) in reducing Zn and Cu concentrations in both gloryholes. The ARUM process is expected to require little to no maintenance. By reducing the metal concentrations in Pit #2, metal loadings to Pit #1 will be reduced. In addition, a biological polishing system will be established in the outflow region of Pit #1, which is expected to reduce metal concentrations to acceptable levels. This paper describes the original experiments in 53 m^3 enclosures and the scale up work in the larger, semi-contained pit volumes behind curtains carried out to date.

METHODS

The water in the pits was isolated by using enclosures, which consist of four components; a laminated polyethylene plastic as an outer skin, a upper floating ring (filled with styrofoam), a lower anchorage ring, and stabilization ropes. The resulting open-ended cylinder has a 4 m diameter and a depth of about 4 m.

The experimental enclosures were numbered 1 to 3 in Pit #2 and 4 to 6 in Pit #1. The enclosures, 3 and 6, served as controls, i.e. did not receive amendment. Enclosures 1 and 4 received sawdust, and 2 and 3 received peat as the main amendment. In the first three months no noticeable changes took place, so, a mixture of nutrients, Biolyte CX-70, and alfalfa was added to the enclosures with amendments at that time, to initiate microbial activity. The layer of organic amendment was approximately a 1 m thick.

The set-up for the scale-up work was as follows. Sixteen tons of sawdust and 1.1 tons of alfalfa were added to the 390 m^3 volume of water behind a burlap curtain in Pit #2. Twenty-one (21) tons of sawdust and 1.5 tons of alfalfa were placed between two curtains in the outflow channel of the Pit #1, representing a volume of 750 m^3.

RESULTS AND DISCUSSION

Results are presented for the performance of the test enclosures. These limnocorrals have been operating with organic material for more than 700 days, covering two winter periods. The expected microbial processes were evaluated with metal mass balances of the organic material collected from the enclosures. The results of the scaled-up enclosures installed during l990 will be also be discussed.

1. Enclosures in Pit #1 and Pit #2

Figures 1a, 1b, and 1c present pH data for Pit #2 enclosures, and Figures 2a,2b, and 2c present zinc concentrations for the same enclosures since installation (July 1989).

After the placement of amendment into the limnocorrals, no change in metal concentrations was noted for 95 days. After 131 days, on November 12, just before freeze-up, a mixture of alfalfa, sawdust and biolyte was added to the all enclosures. Within 10 days of this addition a decrease in metal concentrations occurred. Later, however, through detailed investigations, it was found that the addition did not initiate the microbial activity.

Fig. 1a: Enclosure 1 pH
Sawdust

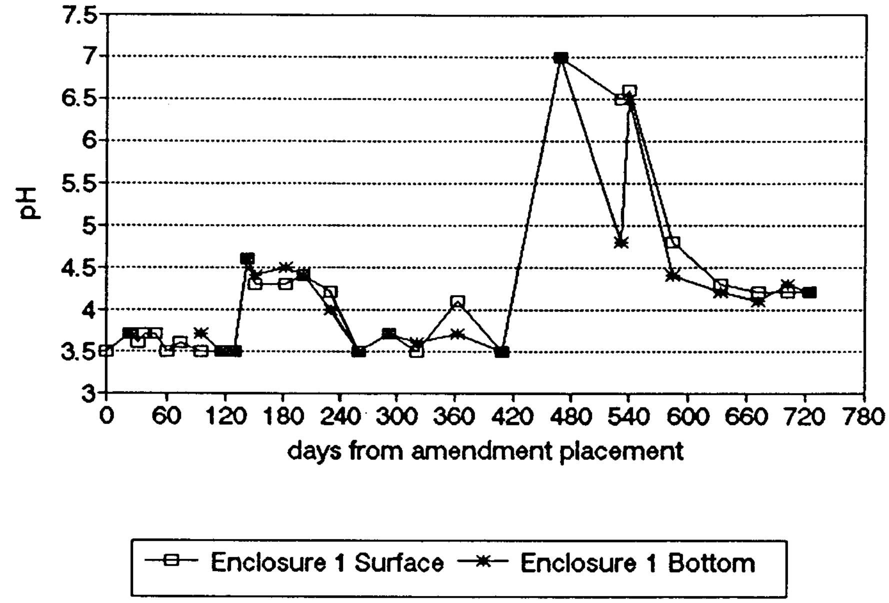
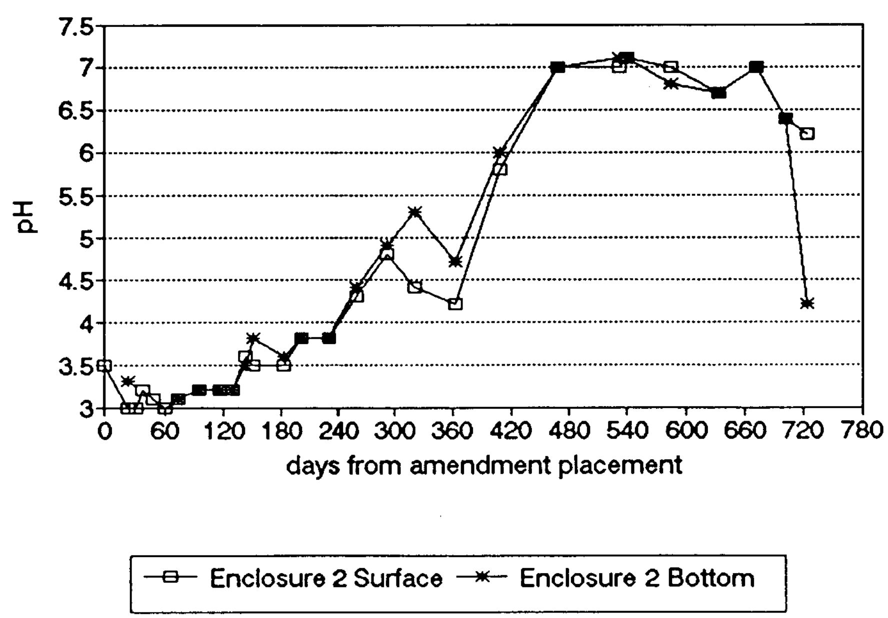
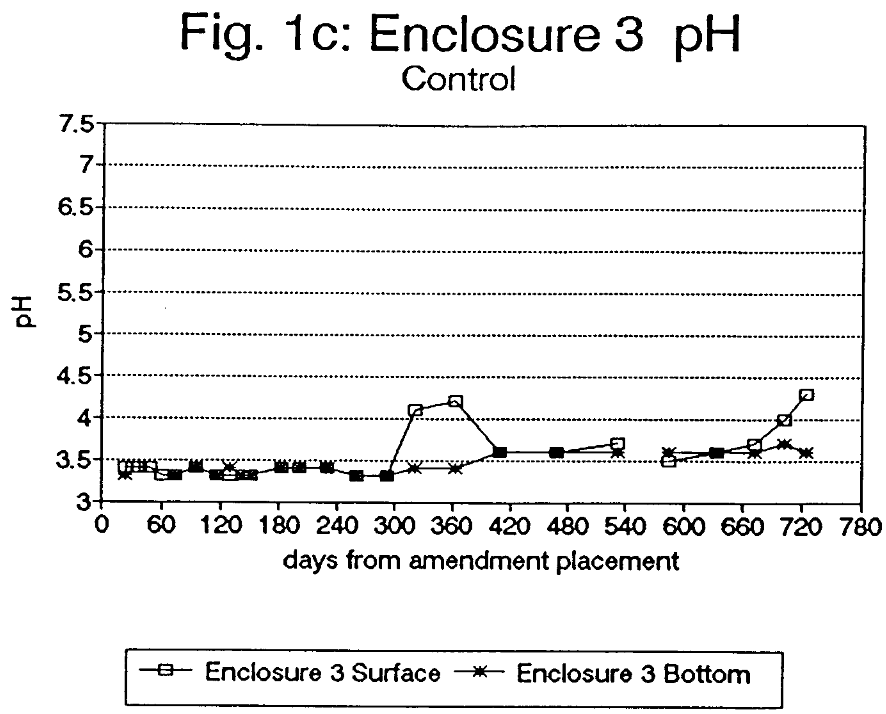


Fig. 1b: Enclosure 2 pH
Peat





The pH started to increase and zinc concentrations decreased, as expected (Figures 1a, 1b and 1c). Both surface pH values (taken just below the surface) and bottom pH values are presented. In enclosure 1, a pH increase was noted earlier than in enclosure 2. The onset of microbial activity differed between peat and sawdust. With time, however, both peat and sawdust assisted in raising pH.

In Figures 2a, 2b and 2c, the concentrations of zinc in the three enclosures are presented. It appears that peat produced a more stable low zinc concentration than sawdust. This stability, however, may not be attributable entirely to the suitability of the substrate for the microbial alkalinity-generation, but also, may be a reflection of the effectiveness of the enclosure (i.e. the peat enclosure being less leaky than the sawdust enclosure).

Data are presented in the same format for enclosures in Pit #1. Increases in pH were achieved in both experimental enclosures over the winter, starting at day 122 (Nov 3, 1989; Figures 3a, 3b,and 3c). Reductions in zinc were achieved over the same time period (Figures 4a, 4b, and 4c). Elevations in pH were especially noticeable for enclosure #5, which originally acidified from pH 6.5 to 3.2, after addition of the peat. The slight pH depression initially in enclosure 4 (sawdust) was likely due to organic acids released from the material.

Fig. 2a: Enclosure 1 Zinc Conc.
Sawdust

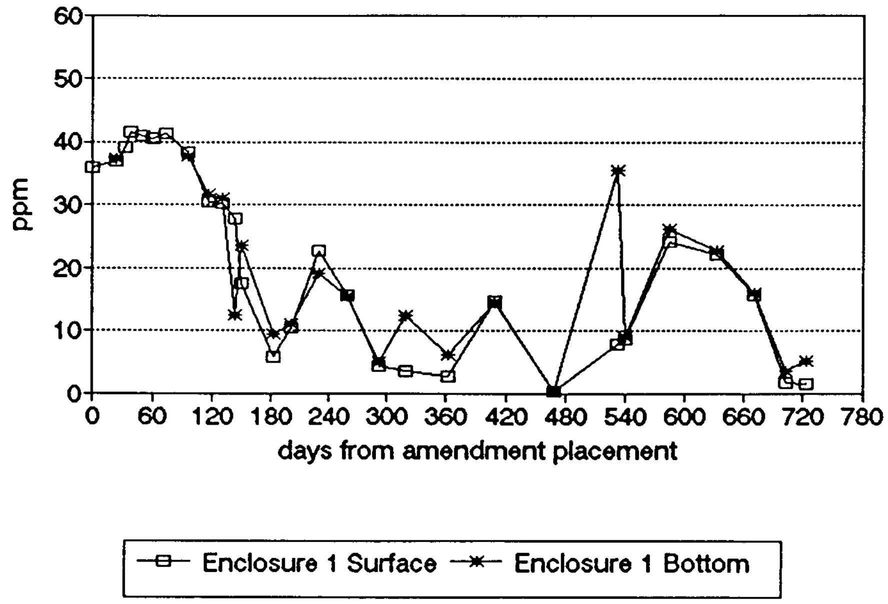


Fig. 2b: Enclosure 2 Zinc Conc.
Peat

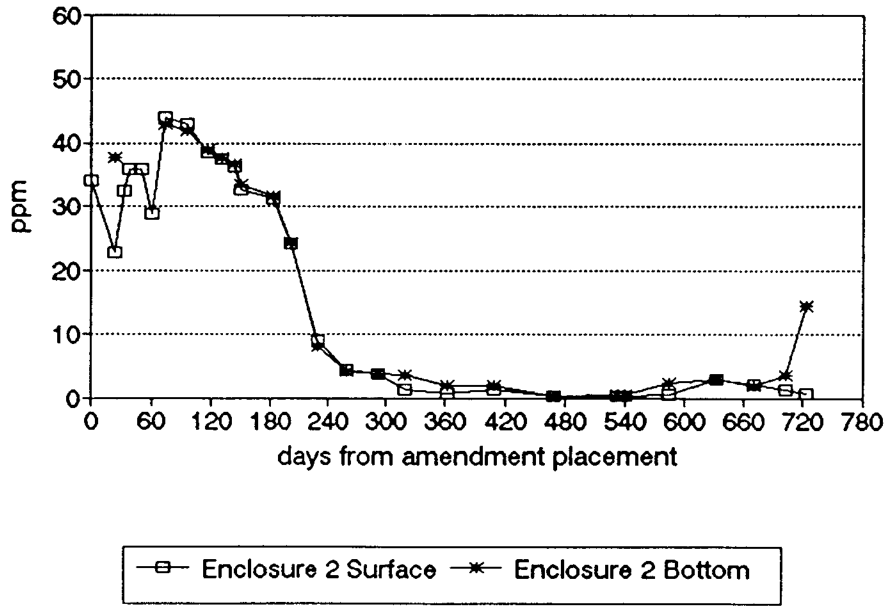


Fig. 2c: Enclosure 3 Zinc Conc.

Control

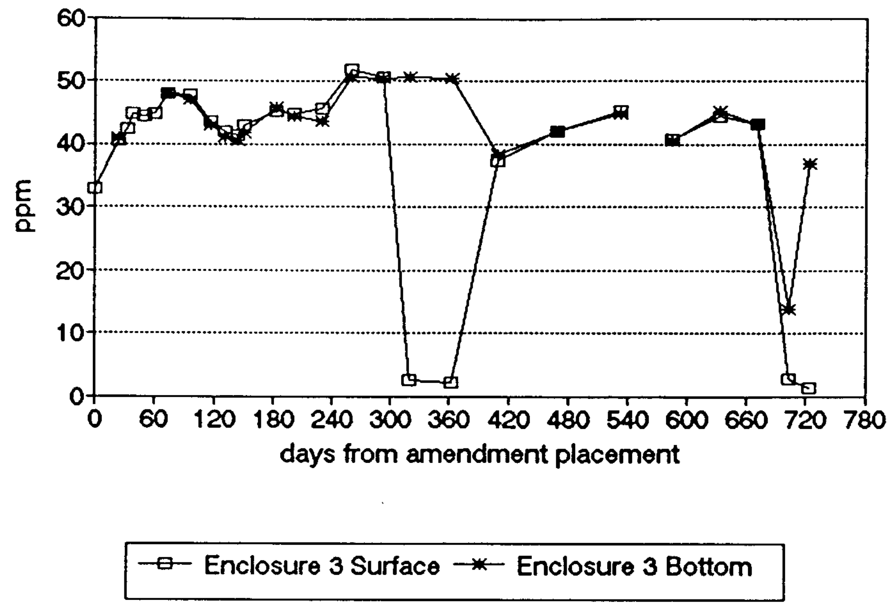


Fig. 3a: Enclosure 4 pH

Sawdust

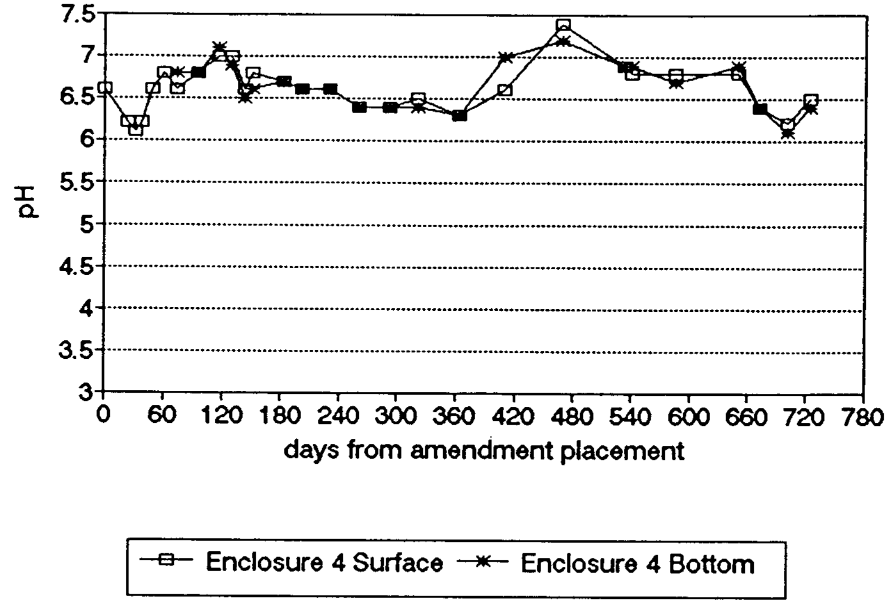


Fig. 3b: Enclosure 5 pH

Peat

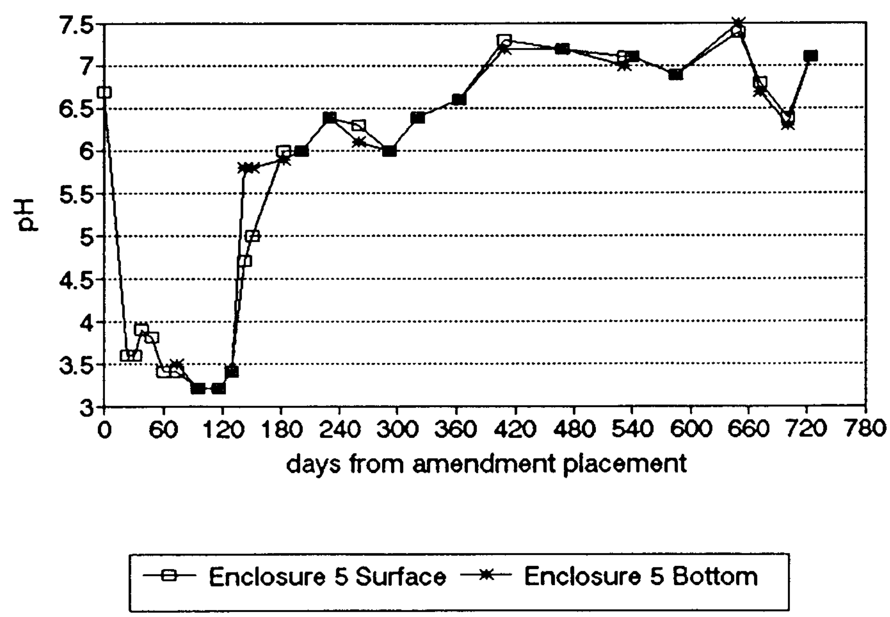


Fig. 3c: Enclosure 6 pH

Control

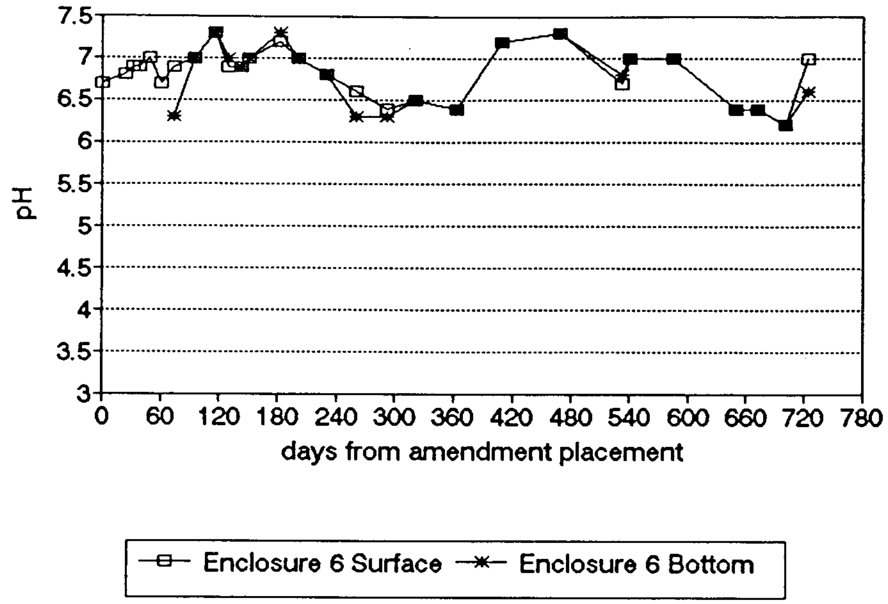


Fig. 4a: Enclosure 4 Zinc Conc.
Sawdust

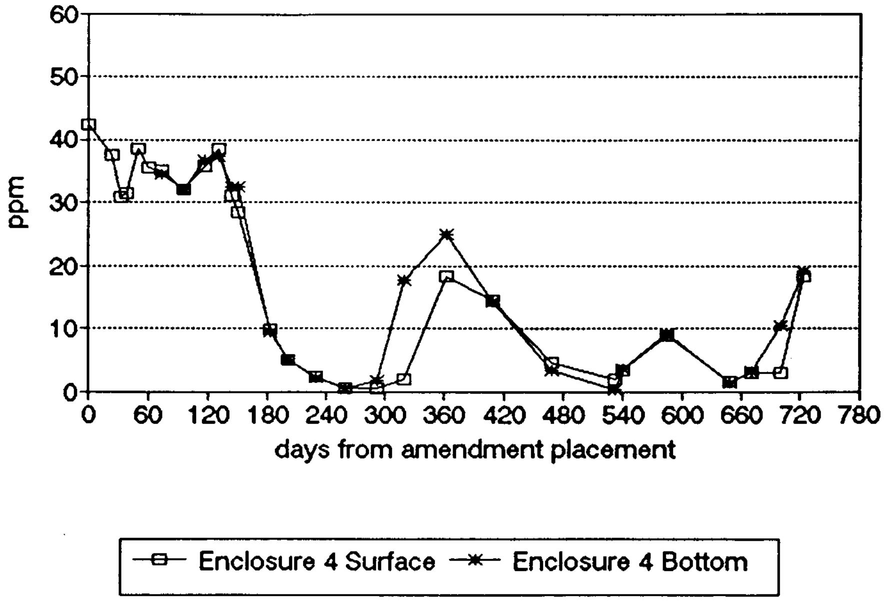
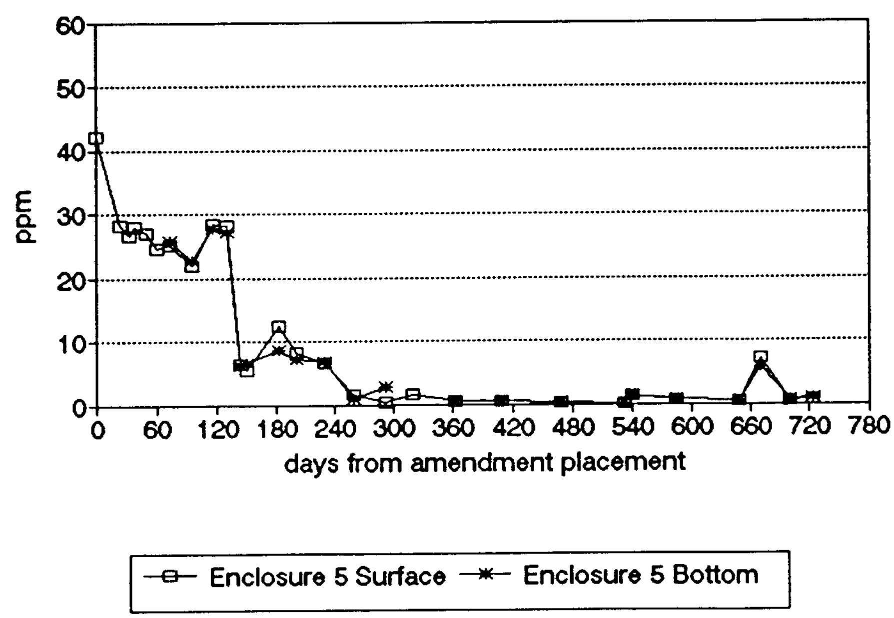
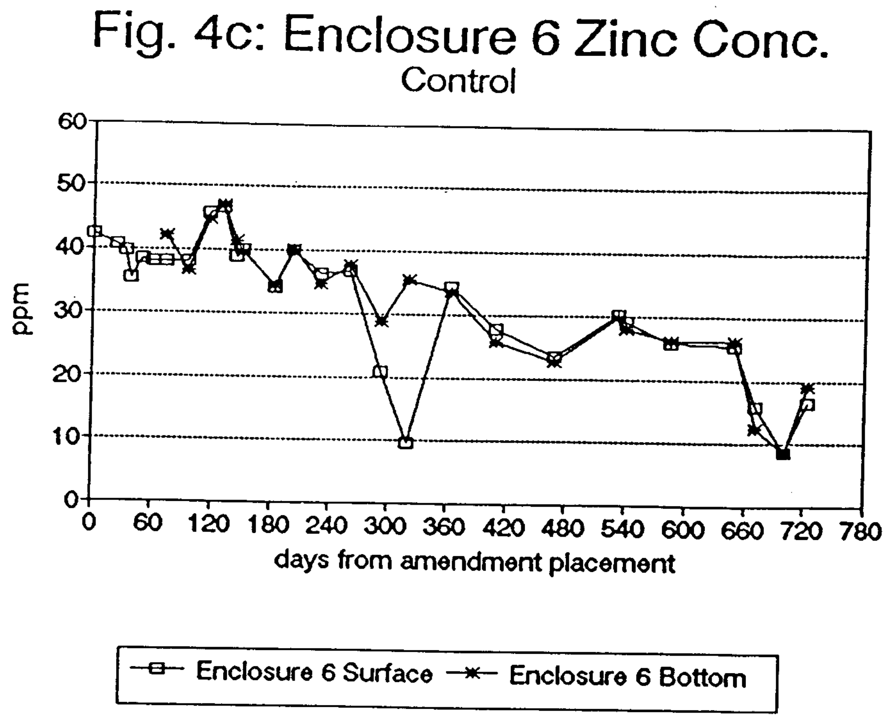


Fig. 4b: Enclosure 5 Zinc Conc.
Peat





Zinc concentrations in enclosures 4 (sawdust), 5 (peat), and 6 (control) are presented in Figure 4a, 4b and 4c. Zinc concentrations were reduced in enclosures #4 (sawdust) and #5 (peat). Pit #2 enclosures maintained the proper conditions for zinc removal for a period of 700 days. Zinc concentrations have decreased from initial concentrations (approximately 40 ppm) over 1990, to concentrations no more than 10 ppm, and as little as 1 ppm.

The decrease in zinc concentrations in the control enclosure 6 (Figure 4c) is a general reflection of the decreasing zinc concentrations in the pit, which at this time can only be marginally attributed to implemented Ecological Engineering measures. Extensive analyses of the geochemical and hydrological situation, long-term trends, and rates of contaminant release are underway to evaluate the effectiveness of the system as a whole.

2. The Evaluation of Metal Removal Processes

Data from the enclosures were evaluated with respect to the possibility of absorbtion of metals onto the organic matter added to the enclosure. If adsorption played a major role in decreasing zinc concentrations, a rapid drop would have be expected, not the measured, gradual drop. This strongly indicates that adsorption is not a significant metal removing process.

Additional organic matter was added to the limnocorrals in the form of a decomposition experiment after day 409. At that time zinc concentrations were still above 10 mg/L in enclosures 1 and 4. Addition of the organic carbon rapidly reduced zinc concentrations (Figures 2a, 4a).

Table 1 presents the concentrations of metals adsorbed by the organic matter in the limnocorrals. Although there was a great deal of variation in the data, adsorption or metal precipitation took place. For the most part, zinc and copper concentrations in the experimental enclosures were higher in the organic amendment after 31 (Pit #1) and 34 (Pit #2) days.

These data have been used to derive some estimates on adsorption of metal to organic material. Organic material with the largest surface area should adsorb the most metal per unit volume. Alfalfa and straw, however, are materials with relatively high concentrations of both Cu and Zn, while peat and sawdust have the highest surface areas per unit volume.

An approximation of the total amount of metal adsorbed can be made by subtracting the amount of metal in amendments before and after submergence for one month. The metal content and changes in total metal concentrations are presented in Table 2.

Table 1: Copper and zinc concentration (ug/g) of amendment at the time of addition, and after 31 days (Pit#1) and 34 days (Pit#2)

COPPER					
		Pit # 2		Pit # 1	
Amendment	Initial	Enclosure 1	Enclosure 2	Enclosure 4	Enclosure 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					
		Pit # 2		Pit # 1	
Amendment	Initial	Enclosure 1	Enclosure 2	Enclosure 4	Enclosure 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

Table 2: Changes in metal content of amendment and water in enclosures

Total metal content (g) in enclosures (vol. = 42.1 q.m)

COPPER						
	Encl. 1	Encl. 2	Encl. 3	Encl. 4	Encl. 5	Encl. 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						
	Encl. 1	Encl. 2	Encl. 3	Encl. 4	Encl. 5	Encl. 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 total metal content of the water and the amendment in the enclosures was calculated based on a volume of 42.1 m^3 and a dry weight based on the organic matter placed into the enclosures (7.9 kg alfalfa, 5.4 kg cattail, 4.3 kg peat, 6.9 kg sawdust and 8.0 kg of straw). For example, in enclosure 1, all organic material together contained 2.48 g of Cu and 47.1 g of zinc after 28 days. Of that total, 0.97 g of Cu and 20.7 g of Zn were adsorbed by alfalfa alone. Over that time period, the metal reduction in the water of the enclosure was equivalent to 8.2 g of Cu and 614 g of Zn. It is evident that in some enclosures the metal concentrations on the organic material can account for a portion of the metals removed from the water.

Although adsorption of metals cannot be discounted as part of the removal process, some of the metal reduction is probably due to microbially-mediated precipitation. Those organic materials which are easily degradable are those which would provide a carbon source for microbial alkalinity-generation and sulphate-reduction. Bacteria will preferentially colonize that surface with the most easily degradable carbon as a food source. The results of the mass balance calculations are therefore consistent with expected microbially-mediated processes. A severe "rotten egg" smell due to hydrogen sulphide production and the increases in pH in the limnocorrals also suggested an active microbial process.

Changes in metal content in the control enclosures indicated that water was moving in and out of the enclosures. Leakage in the control enclosures also meant that other enclosures could have also leaked to a certain degree.

Fig. 5a: Amendment Curtain

pH

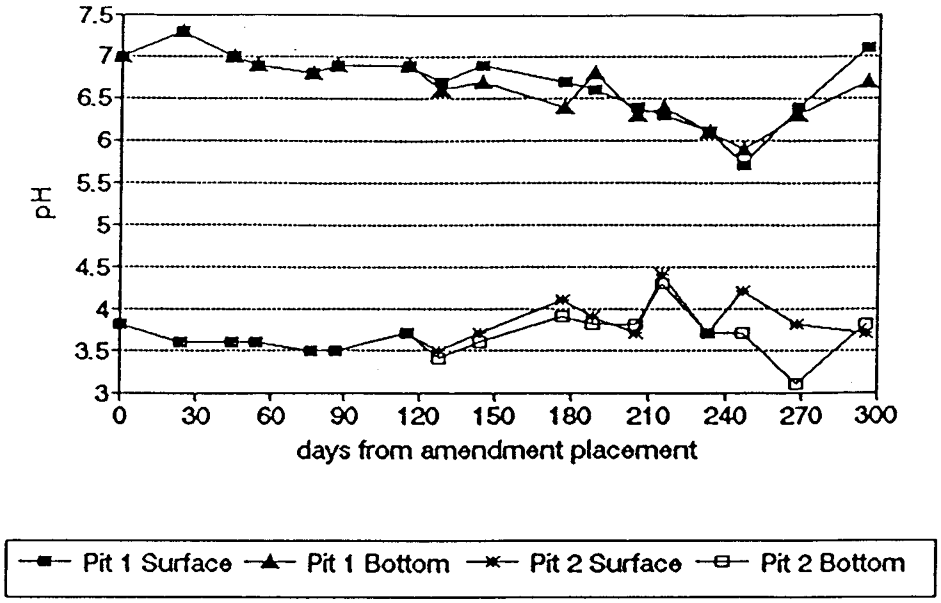


Fig. 5b: PITS

pH

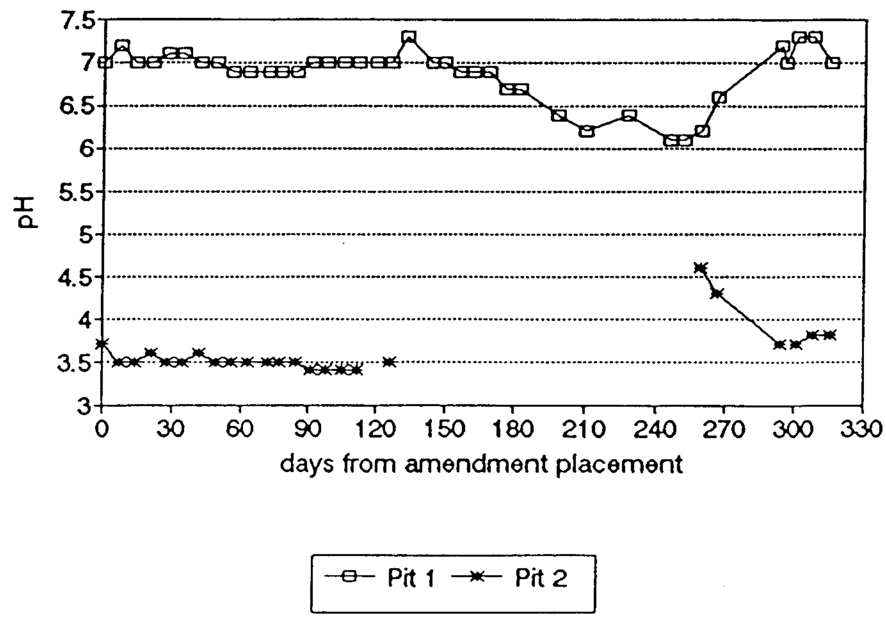


Fig. 6a: Amendment Curtain

Zinc Concentration

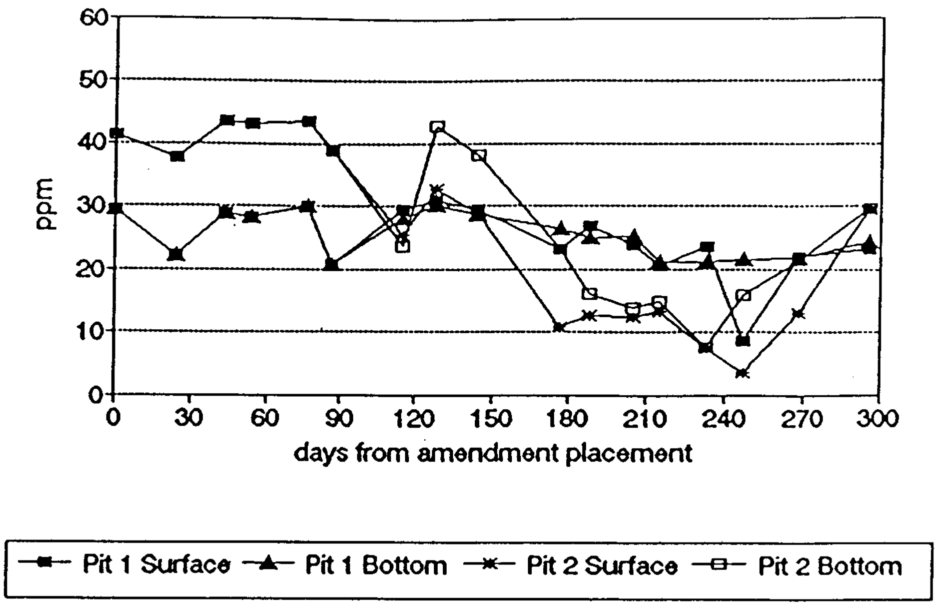
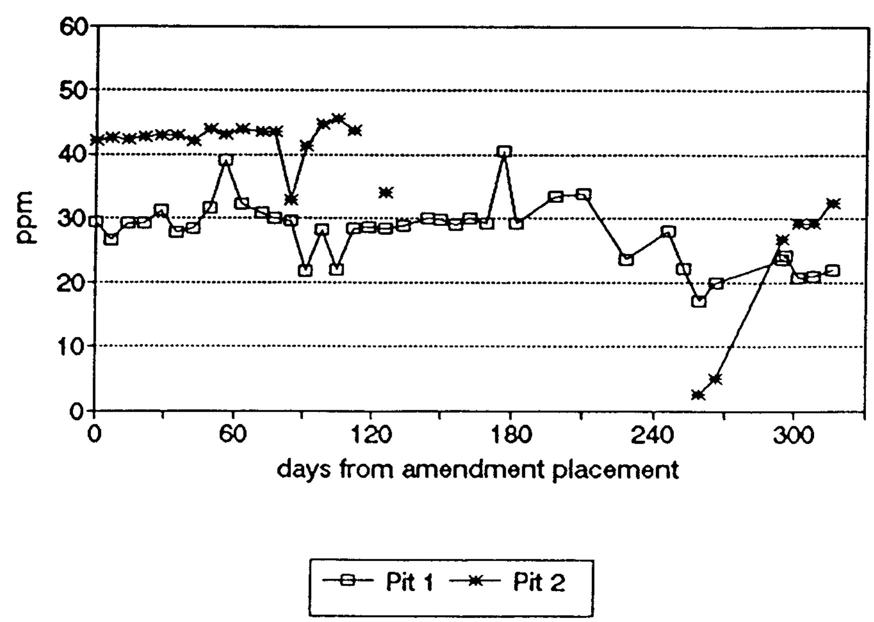


Fig. 6b: PITS

Zinc Concentration



3. Scaled-up Semi-enclosures - Curtains

The change in pH behind the curtain and in the pit proper are given in Figures 5a and 5b, as a function of time after curtain installation. Figures 6a and 6b give zinc concentration changes over the same period. Presented data are based on days since the curtain was set up (25th August, 1990).

It is evident that no significant pH increase could be noted after 200 days behind either curtain, as compared to open pit pHs (Fig 5b). The fluctuations in the zinc concentrations were due to ice melt in the spring. Scale-up of the system represents 0.40 % of the total volume of Pit #1 and 1.34 % of Pit #2.

Alkalinity-generation or pH increases in the test enclosures were not apparent prior to about 120 days. It can be expected that in the scaled-up system, microbial alkalinity-generation should also take more time especially since the volume is 6-9 times larger. Assessment of the organic material within the curtains indicated that a full microbial community had colonized the organic amendment layers.

In Figure 6a the concentrations of zinc in surface waters and samples collected just above the bottom behind the curtains of both pits are shown. The open pit concentrations are plotted in Figure 6b. Unfortunately, monitoring data from the open Pit #2 was not collected regularly. Reference must be made to the control enclosure in Pit #2 (Figure 2c).

It should be noted that in Pit #2, zinc concentrations generally fluctuated only with ice melt. Behind the curtain, a slow but steady zinc decrease was evident. In Pit #1, where the curtain is located near the overflow with a flow rate of 10 L/s, no significant zinc reductions behind the curtain were evident.

CONCLUSION

Both the microbiological and geochemical data support the conclusion that the observed metal removal is due to the ARUM process. The mixture added to initiate the microbial activity was found not be essential to the onset of the ARUM process. The portion of each gloryhole volume behind the curtains, being treated by the ARUM process, is less than 2% of the whole pit volume. Reductions in zinc concentrations in the final effluent may therefore be difficult to detect at this stage of the implementation of decommissioning programs. The results, however, are encouraging enough that Ecological Engineering is an option for a low concentration decommissioning technology.

ACKNOWLEDGEMENTS

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