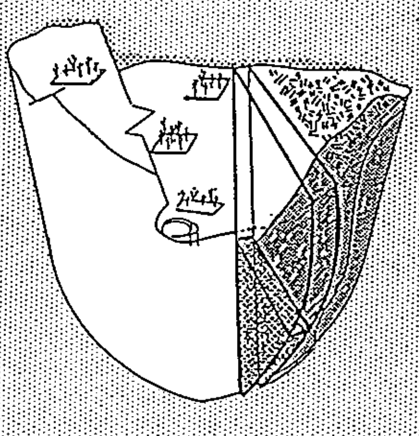
Boojum
RESEARCH LIMITED

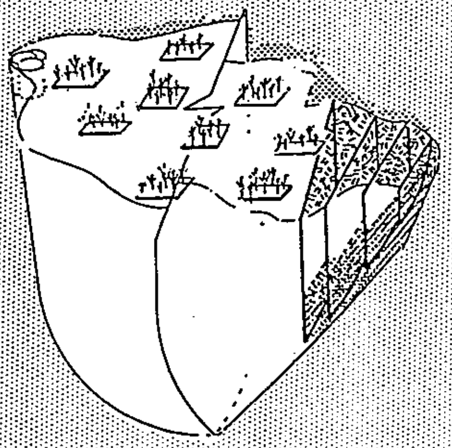
Phase 1

Report

Feasibility Study

Ecological Engineering
Close-Out Scenario





For
Asarco Incorporated
Buchans Unit

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JANUARY 1990

prepared by
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SUMMARY

In 1988 a brief assessment of the Buchans mining area was carried out by Boojum Research. Based on the findings it was recommended that Ecological Engineering and Biological Polishing, a novel technology for waste water treatment at close -out for base metal mining operations might be applicable to the tailings, both Oriental pits and Lucky Strike.

The 1989 study addressed those aspects, which required confirmation prior to implementation of the proposed self-stustianing, maintanance free biological treatment systems. It was necessary to idendify the sources of water to the Oriental pits, to determine controlling factors of the observed naturally occuring precipitation processes and to identify organic amendments for microbial alkalinity generation for the pits.

The hydrological / geochemical investigation based on background data indicated, that acid generation occurs underground and not only in the Oriental West pit. More water than can be accounted for by precipitation is entering the Oriental East pit and is contributing zinc, but negigible quanties of copper to the envrionmental loadings. However the zinc concentrations are on a decreasing trend. In the long term the water characteristics of the Oriental pits will change.

Two natural precipitation processes have been observed to occur in the meadows. The brown precipitate is a zinccarbonate whith coprecipitation other elements. It formation is controlled mainly by temperature and ponding. The field tests in the first meadow, indicate that the precipitate can be filtered biologically.

A slight reduction in concentrations of dissolved zinc of 8 mg/l was achieved leaving the final pond, with a retention time of approximately 35h and flow of .... . However dissolved copper concentrations, although low , increased in the ponds from 0.04 mg/l in pond 1 to 0.12 leaving pond 6. It was not possible to identify the white precipitate, which is richer in copper than in zinc, as its significane was evident only at the end of the experimental period. It is concluded that precipitate formation and filtration can be optimized.

Sawdust and peat were tested as organic amendments to inditate the ARUM process. It was evident, that through a starter addition of alphalpha and biolyte CX-10 microbial alkalinity was generated. Reductions of zinc concentrations were achieved from an average of 50 mg/l to 10 mg/l in both pits.

All assessment and the experimental results indicate, that Ecological Engineering is ideed applicable, and a close out scenario has been developped in detail. The Lucky Strike pit can likely be developped into a natural lake with acceptable water quality. In both Oriental pits, the application of the ARUM process

may effectively produce sufficent alkalinity to reduce the zinc loading to acceptable environmental levels.

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1 INTRODUCTION

An investigation of the Buchans area was carried out by BOOJUM RESEARCH LIMITED in **1988** to identify an approach by which the quality of the water leaving the waste management area could be improved. Based on the results of this **1988** study, an experimental program for **1989** was formulated which addressed the utilization of natural processes and the application of Ecological Engineering measures. The strategy devised could lead to a self-sustaining, maintenance-free treatment system by the application of Ecological Engineering measures. In the tailings areas, through these measures, colonization of indigenous species could be enhanced and expedite the natural recovery which is slowly taking place. Of primary importance however, are the effluents from the Oriental mine, and the **1989** experimental program focused on this main source of metals to the Buchans river.

Understanding the hydrological conditions comprised the first phase of the plan in **1989.** This assessment was based on a review of a large monitoring data base and historic information provided by ASARCO. A report was issued in April **1989** which described the geochemical and hydrological conditions of the area and contained recommendations of the work to be carried out during the summer program. This work was required to enable firmer conclusions to be drawn with respect to the various available treatment options. Section 3 presents highlights of those findings, the details and supporting evidence for which were provided in the Phase 1 report.

Based on the 1988 findings, it was thought that an investigation of the natural precipitation and filtration processes occurring in the meadows receiving the Oriental East pit effluent, would identify those factors which would optimize these processes. Any success would be applied to the development of a natural treatment system for the Oriental effluent, and accordingly, experiments were carried out in the laboratory, in the Oriental East pit and in the first meadow. The results on these natural precipitation and filtration experiments are reported in Section 4.

One of the Ecological Engineering processes designed to achieve an environmentally acceptable and potentially completely maintenance-free treatment system is currently under development by BOOJUM. This system is referred to as ARUM (Acid Reduction Using Microbiology). Although the research in this area is not yet complete, encouraging results are being obtained from ongoing field tests at other acid generating waste sites in Ontario and Nova Scotia. Tests were therefore carried out to determine if the ARUM process could be applied in the Oriental pits and acidic seepages emerging from the waste rock pile to improve water quality.
Organic matter, which was obtainable in large quantities at a reasonable cost, was tested for use as amendments to initiate

microbial alkalinity generation in the Oriental East and West pits and in pools created with acidic seepages from the waste rock pile. The results of these experiments are reported in Section 5.

Predictions of the long-term water characteristics axe necessary, as the water treatment system for the Oriental pits is expected to provide a long term solution. It would be unreasonable to expect long-term performance of the treatment system in the absence of an understanding of those factors which affect contaminant generation.

Acid generation is a natural phenomenon which proceeds at rates which are determined by factors such as the type of pyritic material, the location of the material and its contact with air and water. These factors are specific for each mining operation. Neutralization of generated acid can occur if the environment contains alkalinity-generating materials. If acid consumption equals or exceeds acid production, the resulting water composition will differ from those waters where acid production is greater than its consumption. Both processes are rate- limited and occur until both source materials are exhausted. Depending on the rate of the processes and the inventory of the materials therefore, the water characteristics will be subject to change in either the short or long term.

Determining water treatment options for the long term requires an understanding of the interaction of precipitation and run-off, ground water flow paths in relation to the location of the acid generating material, and the alkalinity generating material. In both the short and long term, it is the interaction of these media which will govern the contaminant generation.

The hydrological findings and the experimental results are combined in Section 6 to identify the treatment options which are to be tested in the 1990 program.

2: METHODS AND MATERIALS

2.1 Field Investigations

Limnocorrals: Water was isolated in the Oriental pits by using limnocorrals which consist of four components: the limnocorral skin, the upper flotation ring, the lower anchorage ring and stabilization apparati. The skins, manufactured by Porcupine Canvas in Timmins, are made of Fabrine TE, a laminated polyethylene waterproof translucent material. An open-ended vertical cylinder 4 m in diameter and 4 m high is sewn together. A pocket of 0.3 m diameter with zipper is sewn into the top circumference of the cylinder. The pocket holds a steel ring and is zippered closed after styrofoam pieces are packed on to the steel ring. The bottom circumference of the cylinder has a 0.1 m diameter pocket for a steel anchorage ring which is buried into the sediment. Grommets are sewn to the side walls to adjust the walls with ropes. The corrals are held in place with ropes and concrete blocks anchored at the bottom. The steel rings and the styrofoam were prepared by ASARCO. Following assembly, the corrals were located in place on May 17 and 18, 1989.

Four corrals were charged with either peat or sawdust to provide a layer approximately 3 feet deep at the bottom of the corrals. Three corrals are located in each pit, one of each amendment type and one as control. Limnocorral 1 in the Oriental West pit was charged with 4550 lbs. of sawdust on May 19, Number 2 received 4890 lbs. of peat on June 1, and Number 3 served as a control. Limnocorral 4 in the Oriental East pit received 4550 lbs. of sawdust on May 25 and Number 5 received 4800 lbs. of peat on June 2, with Number 6 serving as a control.

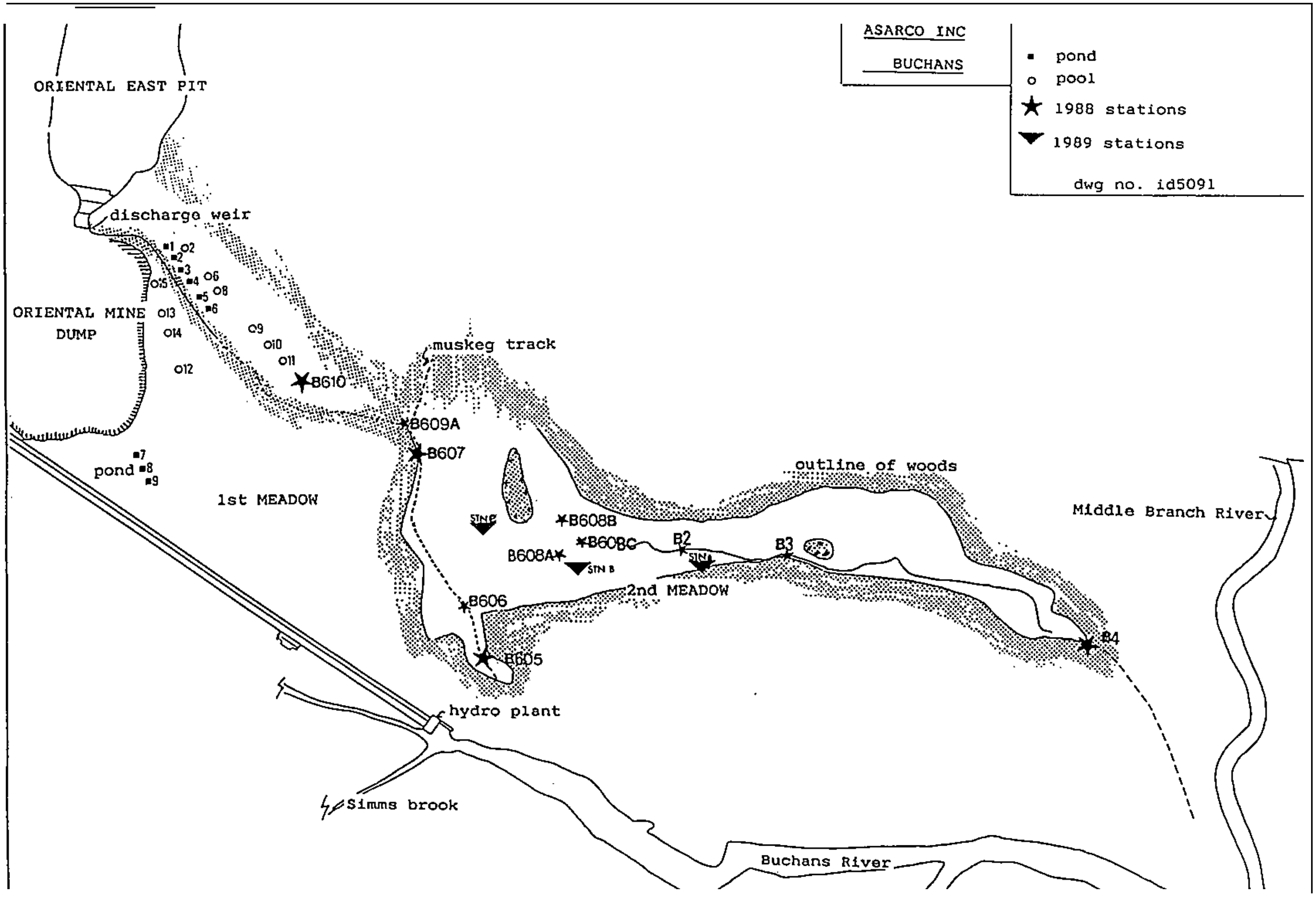
Biolyte additions: On 5th of October 1989, amendments were made to limnocorrals 1, 2, 4 and 5. Alfalfa hay mixed with sawdust at ratio of 1:10 was pre-treated with 2 % Biolyte pellet/water suspension for 24 h, soaking both the hay/sawdust mixture and the bacterial cultures with tap water. The pre-treated mixture was transported in plastic bags and added to the limnocorrals in each pit which had previously received peat and sawdust. Phosphate and nitrogen were added in solution to achieve a 1:3 ratio in the limnocorral. This was intended to be starter addition to the bacterial populations.

Curtain and brush placement: Three log booms were located across the outlet from Oriental East pit in the latter part of May. Burlap material was suspended from two of the curtains located closer to the outflow (Map 1), and the third curtain was suspended with polypropylene rope 1 m below the surface of the water. The third curtain was constructed of Fabrine, which was weighted to the bottom with rebar rods. This barrier was designed to force the water flowing towards the outlet to decant across the top of the fabrene barrier to enhance settling of suspended solids. In the Oriental West pit, only one log boom with a burlap curtain was placed.

The proposed function of the curtains is to provide surface area for growth of algae which in turn accumulate precipitate. In addition to the curtain, alder brush cuttings were placed inside the area isolated by the log booms. The purpose of these cuttings was to provide additional substrate surface area for deposits of precipitated solids.

Introduction of aquatic moss: Towards the end of June, moss bags were located in eaah pit at a depth of approximately 3 metres. The bags were constructed of window screen sewn into a bag. A rock served as a weight to keep the bag in place and styrofoam markers were attached to each bag for retrieval.

Settling ponds: In the first meadow receiving the outflow from the Oriental East pit, channelling has occurred and a rapid flowing stream has developed over time. In order to provide slow flowing and ponding conditions, six ponds were constructed using a timberjack (Map 1). Each pond was constructed to approximately the same dimensions. The average dimensions for each pond were 0.6 m deep and 9 m in diameter providing a volume of approximately 40 m^3. A channel links the ponds together in series. A side stream was diverted from the main fast flowing stream to feed the pond system. This provided slow flowing conditions whereby precipitated solids could settle. Following construction of the ponds which was completed by June, alder brush was placed in each of the six ponds.



MAP 1 Experimental Pools and Limno Corrals in First Meadow and Oriental East Pit

Flow rate measurements were performed on each of the ponds using a magnetic PVM 2A velocity meter. Adjustments were made to the inflow until residence time was achieved, which was at least 24 hours.

Precipitate sampling: The brush substrate with the deposited solids was carefully collected by clipping off branches into a plastic bag. The precipitate was washed through a nylon screen and allowed to settle for at least 24 h. The brush was oven-dried along with the precipitate to facilitate the determination of a ratio of precipitated solid to substrate. Precipitate was collected twice, after placement of brush.

At the same time as diverting the side stream into the pond system, the main channel from the Oriental East pit was subdivided to split the flows and thereby diffuse the flow from Oriental East pit across a wider surface area of the first meadow.

Oriental Waste Rock Pile seepage: Acidic water flowing from the waste rock pile was pooled in 3 similar ponds (Map 1). Their construction was completed by July 8. Hay was placed as amendment to enhance microbial alkalinity generation. These test ponds are also connected with channels in series.

Water sampling: Water was collected in polypropylene bottles. Routinely, 1 litre samples were collected for assaying of acidity, sulphate and chloride. 250 ml of each sample was filtered (0.45 um) and acidified with nitric acid to a pH of 1 or less within 24 h of collection.

Routine determinations of pH, conductivity and temperature were carried out in the field. pH measurements were obtained using an Orion pH meter, calibrated with a portable buffer pack pH 4, 7, and 10 after D 1293 of ASTM Standards. Conductivity measurements were obtained using a YSI Conductivity meter, model 33 SCT, following procedure D1125 of ASTM standards. Zinc concentrations were determined as a survey tool using a Taylor K-1511 Zinc commercial package. pH adjustments were required to utilize this method.

Phytoplankton and periphyton samples for identification were preserved with Lugol's preservative. Solid samples in the field were collected in 1 litre and 250 ml whirl pack plastic bags. Sample labelling and coding was standardized for all field personnel to record site name, location, sample type, and date.

2.2 Laboratory methods

Static leach test: Experiments were designed to determine the potential chemical changes which take place in subsurface waters flowing between the Oriental pits. Backfill material was subjected to static leaching with water from the Oriental East, West pits, Forebay, and Backfill Spring. The backfill used, resembled as closely as possible, the backfill for the mine.

The 20 1 plastic containers were charged with the backfill material and the respective waters were added to fill up to the level of the fill material. The containers were then covered to avoid loss of water due to evaporation. Four containers were set up for each of the four water sites to be sampled at 20, 40, 62, and 120 day intervals. At the completion of each leach period, samples of the four waters were taken for chemical analysis. The experiment is still in progress with exposure completed up to the 62 day interval.

Backfill Acid Consumption: The capacity for backfill material to consume acid was determined in the laboratory. 50g (undried, as collected) of backfill was placed in glass jars with 200 ml of distilled water to make a slurry. The slurry was stirred with a magnetic stirrer to keep the material in suspension and allow immediate contact with the 0.01 N sulphuric acid. The pH of the slurried mixture was 6.0. The slurry was titrated with 1.0 ml aliquots. When the neutralizing capacity of the backfill material had increased the pH of the slurry back to 6.0, additional acid was added until the slurry showed no more tendency to return to pH 6.0 and remained at a pH of 4.0 for a period of 6 hours. The procedure was duplicated for each grain size. Grade 1 was the natural backfill material as it was collected, grade 2 was backfill ground to 1 mm grain size, and grade 3 was fine powdered backfill used for x-ray diffraction analysis.

Tailings Experiment: Experimentation to determine the tendency of tailings material from the Buchans site to generate acidity over time was initiated in May 1989. This procedure was similar to the leach test. Barite rich and Barite free tailings were mixed with water and allowed to sit over a period of months. In order to provide other physical and chemical conditions which may be necessary to initiate acid generation, air was supplied to one tailings water mixture and concentrated Sulphuric acid was added until the tailings material no longer had any capacity to neutralize acid. The experiments are carried out at room temperature and are monitored for pH, conductivity and temperature at regular intervals. The experiment is still in progress.

Tests on limnocorral amendments: The following experiment was conducted to examine the potential of Biolyte CX-70 to stimulate the ARUM processes in the Oriental pits with sawdust and peat. The work was carried out by Dearborn Environmental.

Sawdust Pre-treatment: Sawdust for these experiments was the same as that placed into the Limnocorrals. The microorganisms in the Dearborn Biolyte CX-70 product were permitted to grow and establish themselves on dampened sawdust prior to their introduction into Oriental water. This was done in order to maximize their survival prior to their exposure to the acidic Buchans site water.

Untreated sawdust sample was added to a depth of approximately 8 cm into two 23 cm by 28 cm plastic cakettes. It was made damp by adding 500 mL of BOD (Biological Oxidation Demand) dilution water and mixing. BOD dilution water was used to ensure an adequate supply of mineral nutrients. Two grams of CX-70 were added to one cakette, while the other cakette received 6 grams of CX-70. The contents of the cakettes were thoroughly mixed, then covered loosely with aluminum foil.

The cakettes were incubated at ambient temperature and checked weekly for dryness. When necessary, double deionized water was added to maintain the dampness of the sawdust.

An additional cakette was similarly maintained except this cakette contained sawdust which had been removed from the Oriental West limnocorral by Boojum Research on June 30, 1989. This amendment also received 500 mL of BOD dilution water after it had been added to the cakette.

Alkalinity Generation Tests: The following five amendments were tested for their ability to induce microbial alkalinity generation:

1. Sawdust pre-treated with Biolyte CX-70 (0.4 kg per m^3 of sawdust) as described above.
2. Sawdust pre-treated with Biolyte CX-70 (1.2 kg per m^3 of sawdust
3. Sawdust obtained from the Oriental West site and incubated before testing under the same conditions as amendments No. 1 and 2, but without Biolyte CX-70.
4. Sawdust obtained from the Oriental West site and not pre-treated.
5. Peat obtained from the Oriental West site and not pre-treated.

Fleakers (1.2 L capacity) were filled to the 300 mL level with each of the above amendments. Water from the Oriental West site was then added to the 1.2 L level.

After two days of incubation at ambient temperature, the bottom of each fleaker was inoculated with 2 mL of a straw amendment sample from another site. This amendment was added to ensure that alkalinity generating microbes were present in the fleakers. It had been found that the straw amendment has 10^4, 10^4, and 10^3 ammonifiers, iron reducing bacteria, and sulphate reducing bacteria, respectively.

After this inoculation, incubation at ambient temperature was continued and the pH of the water above the sawdust was measured at several intervals throughout the incubation period.

Suspended solids and precipitate quantification: The filter paper from the 0.45 um filtration carried out on site was pre-weighed. The solid fraction retained on the filter paper was then dried at 103° C to constant weight for the determination of suspended solids after procedure D 3977 of ASTM standards.

Filtration capacity of brush: Solid samples collected from the 6 precipitation ponds were washed to remove the substrate from the precipitate. The brush was separated into woody fractions and leaves dried at 60°. The material was homogenized with a Whiley mill ground to 20 micron. The precipitate was ground with a hand mortar.

Precipitation Experiment No. *4:* Large water samples were collected from the four sites. Not all samples were obtained at the same time for a number of sites, and the sample origin for the various experiments will be outlined below. For each location, the bulk sample was split into 4 sub-samples as follows:

Cf - control sample, no treatment;
O- - de-oxygenated, bubbled with N_2;
O+ - aerated with bubbler;
P - dissolved K_2HPO_4 added;
Cs - sample sent for analysis at the start of the experiments

Samples were collected from the Oriental East Pit on July 31, 1988 and March 2, 1989. The (O-) sub-sample was taken from the March 2, 1989 bulk sample, subsequently the remaining water was mixed with the July 31, 1988 sample and used for sub-samples (Cs), (Cf), (O+), and (P).

Samples were collected from the Oriental West Pit on July 31, 1988 and March 2, 1989. The waters were mixed and the mixture was then used for all sub-samples.

Whenever two samples collected on different dates were mixed, neither the proportions of the two original samples nor the chemical analyses of the two waters were known.

At 24-hour intervals, the pH, conductivity, and temperature were measured in each of the sub-samples. Chemical analyses were performed on the samples at the start and the end of the experiment. After the various sub-samples were created and the suspended material had settled, a 250 ml aliquot was taken of the supernatant liquid and filtered through a 0.45 micron filter under standard conditions. The filtrate was acidified and the filter residue dried and weighed. Both filtrate and filter residue were analyzed (Cs). In addition, an unacidified sample was submitted for analysis of nitrate, ammonium, chloride, and sulphate. At the end of the experiment, a 250 ml sample was again obtained of the clear water portion of the sub-samples. This sample was filtered, acidified and submitted for analysis. Following the sampling of the clear water portion, the remaining water and precipitate were homogenized. Care was taken to ensure that all solids adhering to the wall of the jar were also removed and suspended. While continually mixing a 250 ml sample was withdrawn. This sample was then filtered through a pre-weighed and conditioned filter paper under standard laboratory conditions. The filtrate from these samples was not retained, but the solid cake was dried, cooled, and weighed under standard conditions. Subsequently the filter residue was submitted for analysis. Following the removal of all the samples, the remaining volume in the jars was measured using calibrated beakers.

Two blank filter papers were also analyzed to obtain background data on the elemental concentrations within the filter papers.

Analytical methods: Concentration of copper and zinc for the experiments which required more frequent monitoring were determined by Atomic absorption by ASARCO. A more complete analysis of water was determined by Chemex Laboratories. Most analyses of either solids or water were carried out by using ICP (Inductively Coupled Plasma Spectrophotometry) at Assayers Ontario Limited. Alkalinity and Acidity were determined by titration after ASTM. D1067 using both colour indicators and the pH meter.

3 HYDROLOGY AND GEOCHEMISTRY

An extensive data set on the monitoring of water chemistry, mine flows, mine operation and flooding records was made available, and this information was used to focus on the following objectives:

1. A determination of the ranges of metal concentrations, flow rates and metal loadings which may have to be handled by a natural treatment system

2. An assessment of the "natural" processes which affect pH and contaminant concentrations in the effluents to be treated

3. Some predictions on the potential long term changes in metal loading from the contaminant sources of the site.

Reference may be made to the document entitled Geochemical and Hydrological Considerations for the Buchans area. Phase 1, R.O. Van Everdingen. April 1989. The Phase 1 report contained a series of recommendations for work to be carried out as part of the summer program, and the resulting information is integrated in this section.

3.1 Metal loadings from contaminant sources

In Table 1, annual loadings of copper and zinc from all sources of water ultimately reaching the Buchans river are presented for a three year period between **1986** and 1989. The metal loadings from both tailings ponds do not correlate well with precipitation, where flows should be lower in drier years, such as **1987**, and higher in

TABLE 1: Metal Loading from contaminant sources in the Buchans area

METAL LOADINGS

Average Concentrations and Annual Cu. and Zn. Loadings

LOCATION	YEAR	cu ppm	Zn ppm	Av. Flow 1/s	Cu kg/yr	Zn kg/yr
TAILINGS POND 1	1986	0.037	2.956	27.1	32	2,523
	1987	0.032	1.991	31.4	38	1.969
	1988	0.036	1.752	59.5	68	3.287
	1989	0.035	1.793	35.7	39	2,019
TAILINGS POND 2	1986	0.046	5.208	6.2	9	1,015
	1987	0.035	4.117	6.7	9	868
	1988	0.037	3.925	6.2	7	773
	1989	0.038	3.399	5.5	6.6	590
SIMMS BROOK	1986	0.030	1.732	58.4	55	3,188
	1987	0.033	1.379	70.3	69	3,056
	1988	0.032	1.380	88.5	89	3,852
	1989	0.037	1.266	63.9	75	2,551
ORIENTAL EAST PIT	1986	0.506	51.00	11.5	184	18,572
	1987	0.032	77.03	8.6	12	20,841
	1988	0.04	54.15	10.1	13	17,238
	1989	0.043	41.57	9.4	12.7	12,323
DRAINAGE TUNNEL	1971	3.63	71.72	24.A	2.795	55,229
(OLD BUCHANS)	1972	3.23	67.03	35.3	3.605	74.683
	1973	0.52	23.49	11.7	192	0,695
	1974	0.61	31.02	10.0	193	9,813
	1986	0.098	34.23	15.8	49	17,028
	1987	0.061	26.79	9.3	20	7.890
	1988	0.064	20.28	7.6	15	4.803
	1989	0.099	22.58	6.8	21	4.842

years with above normal precipitation, namely 1986 and 1988. This may be due to the type of terrain encountered in the tailings drainage basin which limits accurate flow measurements, particularly in the case of Simms Brook and tailings Pond 1. These drainage basins experience wide fluctuations in flow.

It is interesting to note however, that the copper and zinc loadings do change in a similar way over time. An increase in zinc was noted in tailings Pond 1 drainage , while a decrease was found in tailings Pond 2 drainage. An increase in copper was also found in drainage from Pond 1, while a decrease was noted in drainage Pond 2. These findings suggest that the dissolution of copper and zinc differs for the two ponds or that these metals emanate from different sources. The metal loading at Simms Brook should reflect those of the tailings drainages. The combined water discharge from the tailings ponds represent only 54% of the Simms Brook discharge in 1987, and approximately 74% in 1988. Therefore, one would expect lower concentrations but similar loadings.Somewhat higher loadings are noted in Simms Brook for Cu, but Zn loadings are within the range expected from the tailings. It is possible that whereas a source of copper exists within the drainage basin outside the ponds, one does not exist for zinc. Although the copper concentrations in Simms Brook are low, and thus more prone to analytical error, the different behaviour of copper and zinc is similar to that of other contaminant sources in the Buchans area discussed below. The metal loadings from the Drainage Tunnel reflect the changes made by ASARCO in reducing the flows from the tunnel and thereby reducing contact with the slimes which have accumulated in the tunnel. A decrease over time in the metal concentrations suggest a possible depletion of metals in the source material.

These differences in metal loadings from the tailings and the drainage tunnel, based on annual averages of concentrations and flows, indicate that different materials may be the sources of metals, in addition to a difference in dissolution processes. This is further exemplified by the metal loadings and concentrations from the largest source, i.e. the Oriental pits. Here, the copper loadings have been fairly stable since 1984 (about 13 kg per annum). The zinc loadings, on the other hand, have decreased somewhat (from 20.8 tonnes in 1987 to 17.2 in 1988).

An examination of the concentrations of copper and zinc over the past three years confirms that dissolution of copper had remained the same since 1987 (Figure 1A), while the zinc concentrations exhibit a downward trend (Figure 1B). Although a distinct difference of zinc concentrations was evident since 1987 between the Oriental East and West pits, the consistent downward trend of

FIGURE 1A: Copper concentration in the Oriental East and Oriental West pits (1987 - 1988)

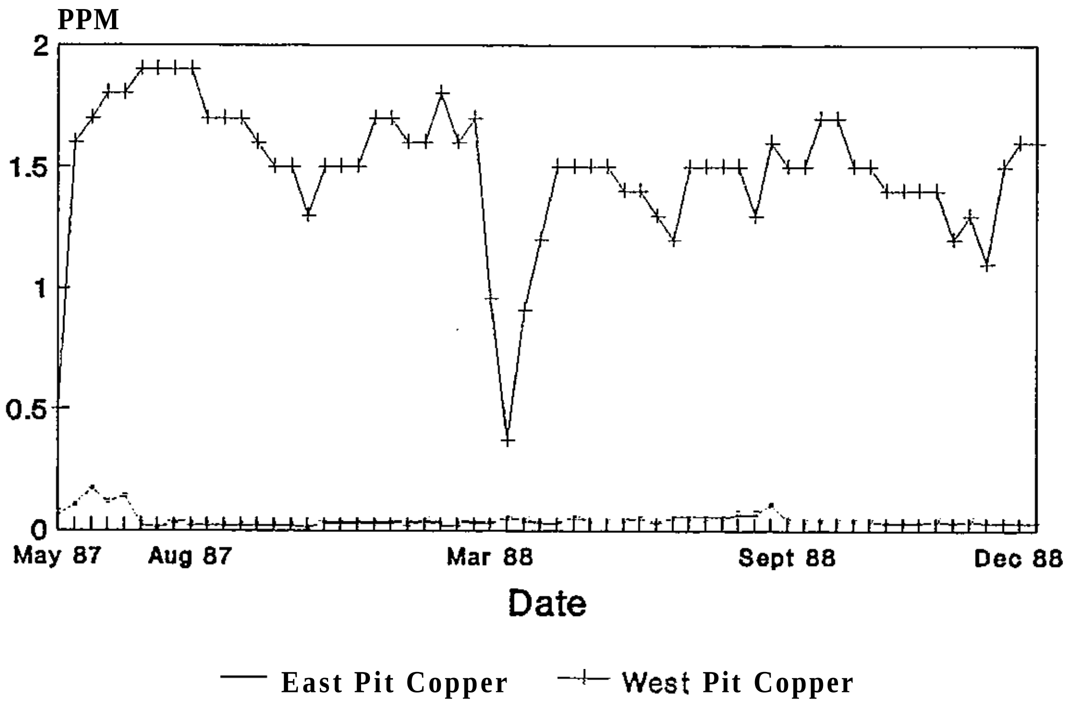
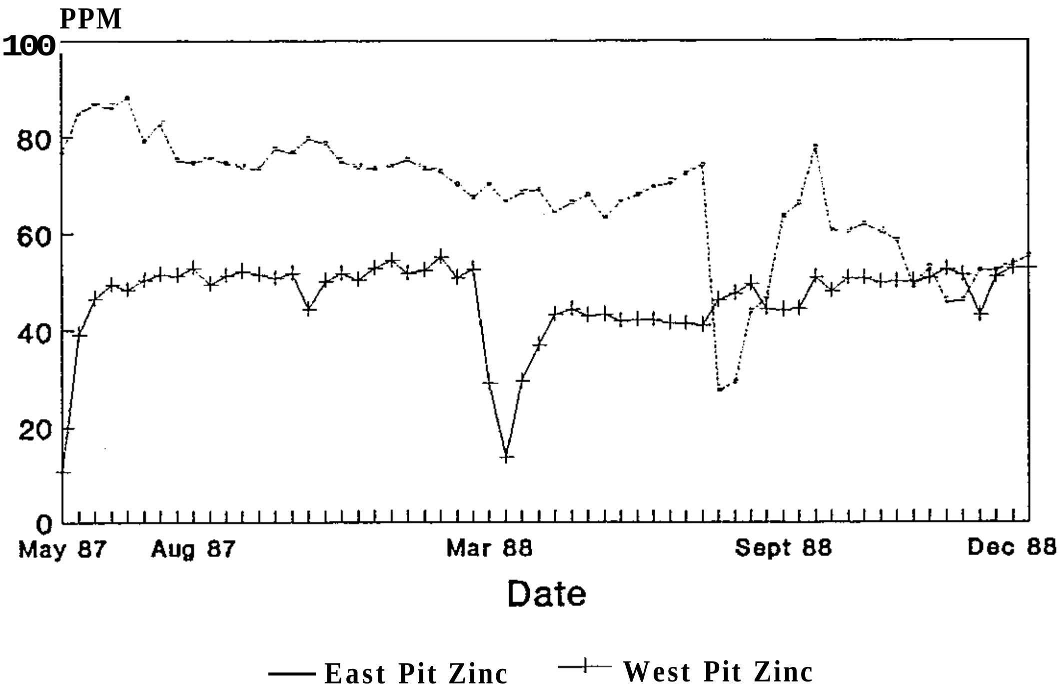


FIGURE 1B: Zinc concentrations in the Oriental pits (1987 - 1988)



zinc concentrations by 1989 in the Oriental East pit has resulted in equal concentrations in both pits (see Figure 2A). The copper concentrations in 1989 continues to exhibit a difference of an order of magnitude (Figure 2B). The origin of the changes in zinc concentrations clearly warrants further assessment.

During flooding of the mine workings the hydraulic connection between the Oriental pits was confirmed. The East pit filled up when water was run from the Hydro Penstock into the West pit. Flooding started in May 1985 and water started to rise in the East pit in Early August of the same year and was overflowing in March 1986. The connection allows the water level in the West pit to remain constant (at about 0.5 feet above that of the East pit), while the East pit overflows. Although a major portion of the mine workings had been backfilled with sand, reducing the efficiency of the hydraulic connection, the main supply tunnels, access and ventilation raises were left open and provide a flow path between the two pits.

It was postulated that subsurface flow from the West pit to the East pit would have to affect the chemistry of the water. This could occur by:

FIGURE 2A: Zinc concentrations in the Oriental pits - 1989

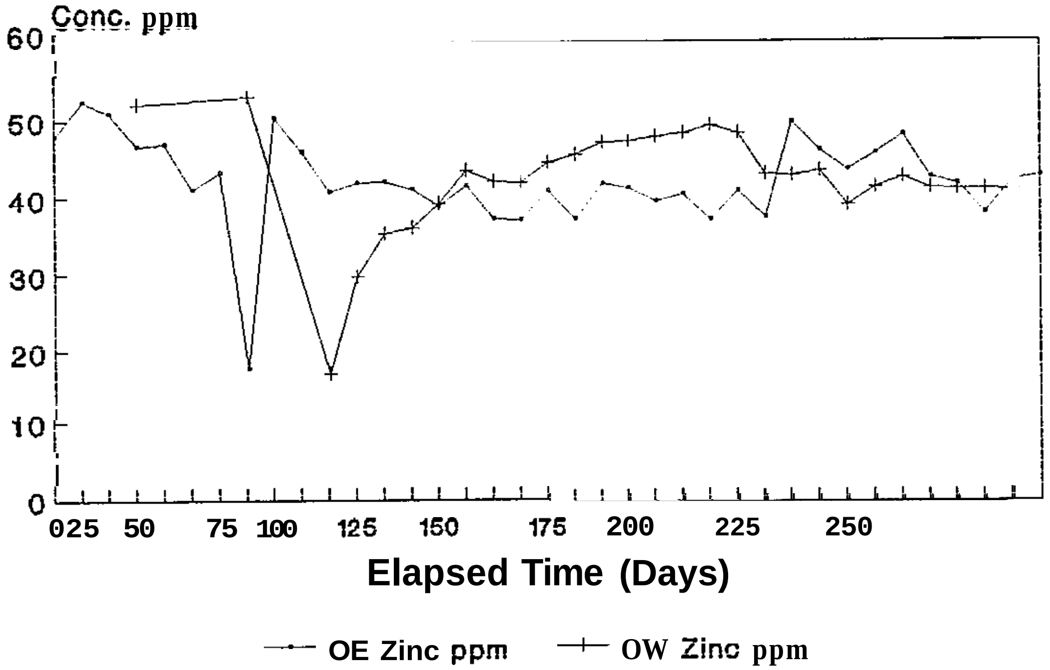
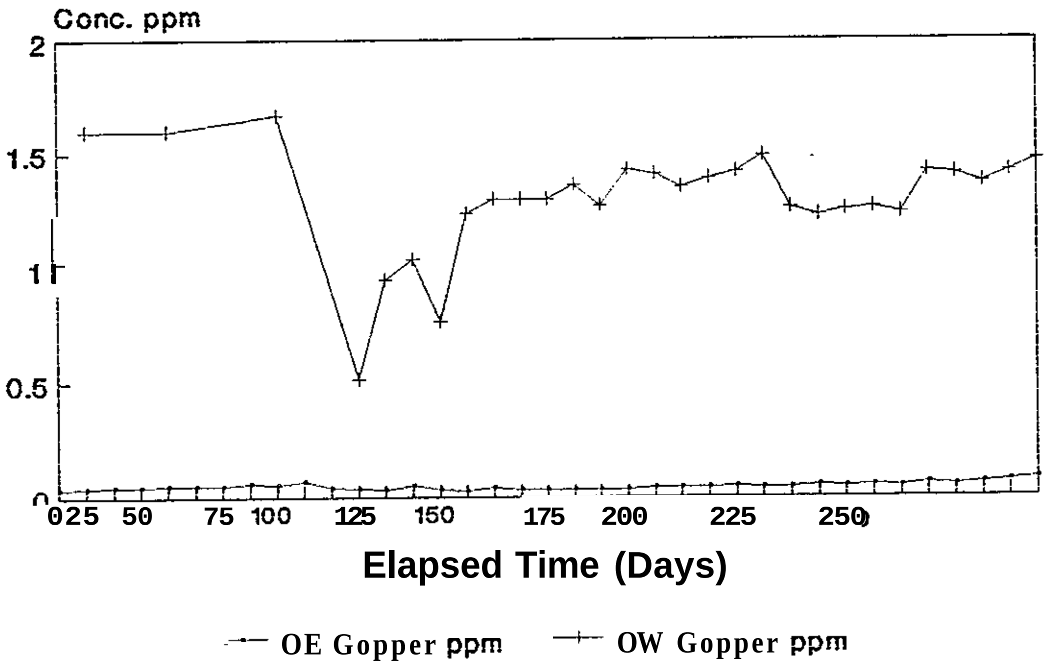


FIGURE 2B: Copper concentrations in the Oriental pits - 1989



1. neutralization through contact with and dissolution of minerals from the backfill sand;
2. precipitation of metals (which process would have to differ between copper and zinc): and
3. subsurface flow entering the East pit from other sources than the West pit which does not contain copper and passes by a source of zinc which was being depleted in the last three years.

In order to gain further insight into the changes in the zinc concentrations, it is necessary to examine those processes which affect pH and thereby the water characteristics.

3.2 Factors affecting contaminant concentrations

The Oriental West pit water is acidic, with a pH of around 3.5. The East pit water exhibits a pH of 6.8 in 1989. These differences can arise as the result of different material present in the respective pits. It can occur as the acidic water passes between the Oriental West and East pits, or as a result of the addition of neutralizing water to the East pit.

It was noted during the 1988 investigation that the Oriental East pit also exhibits a distinct temperature, conductivity and oxygen gradient (Figure 3) which is not present in the West pit (Table 2). In 1989, the temperature stratification was maintained during the summer months exhibiting the cooling of the surface water in October. In Table 3, the corresponding oxygen and conductivity profiles are presented for the Oriental East pit. Distinct stratification can be noted in temperature, conductivity and oxygen values at depths of about 5 to 6 meters. The obtaining of data from the boat is hampered by the drifting of the boat and the lowered probes. To identify the precise depths at which the pits stratify, measurements were carried out in the ice-covered pits in the spring of 1988 and 1989.

Using the temperature data collected in the ice-covered pits, the flow path between the pits is depicted in Schematic 1. Water enters the Oriental West pit, in which the temperature increased linearly with depths, suggestive of a diffuse homogenous inflow of water rather than from a point source. In the East pit, the temperature increased much more rapidly, to a depth of about 6m, below which the rate of temperature increase with depth was lower (Figure 4).

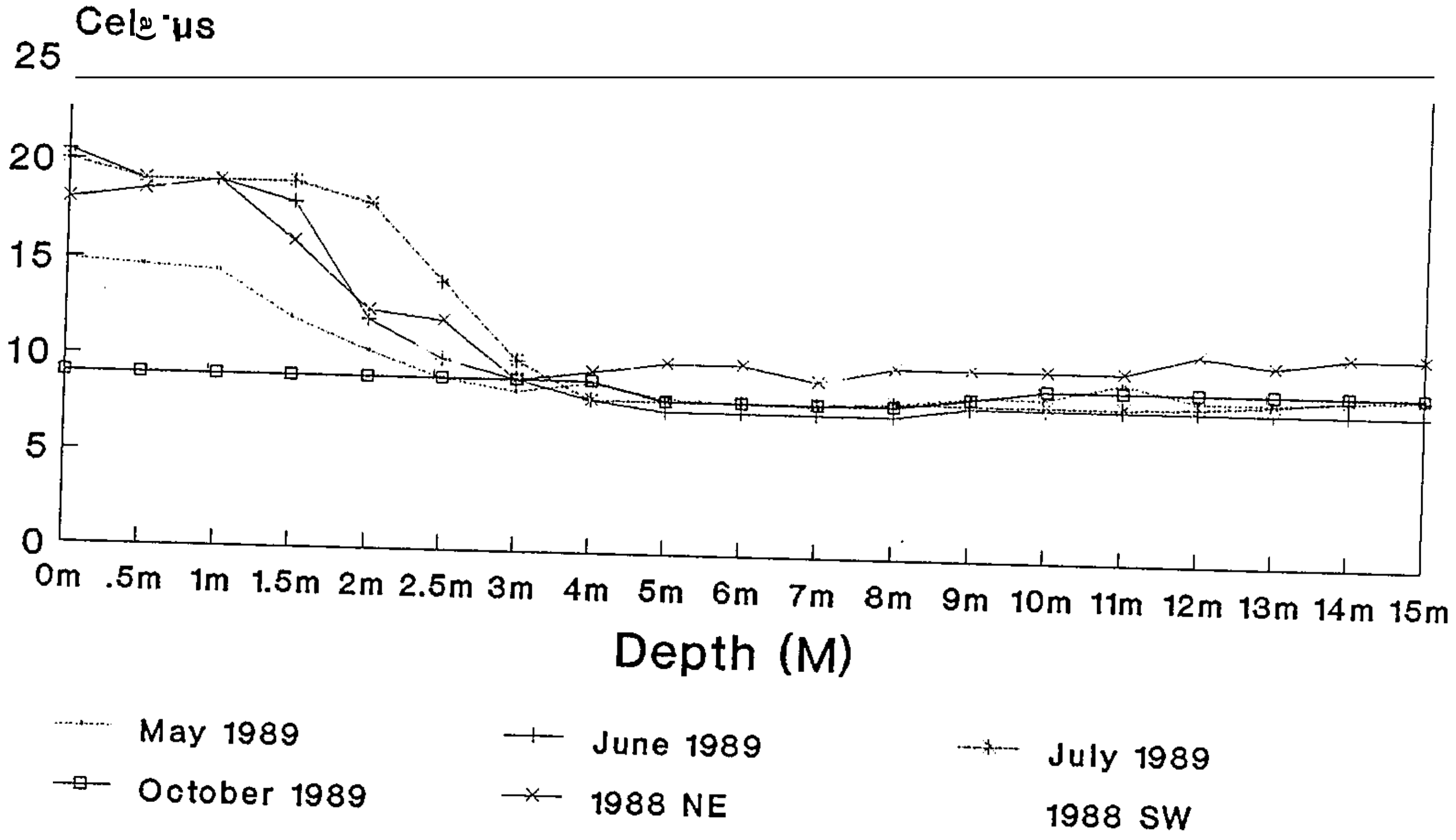


FIGURE 3: Summer temperature stratification in the Oriental East pit 1988 and 1989

TABLE 2A: **Conductivity, temperature and oxygen profiles in the Oriental West pit middle**

ORIENTAL WEST PIT PROFILES : CONDUCTIVITY,TEMPERATURE,OXYGEN.

Location : Middle

Depth	June	July	June	July	June	July
	Conductivity		Temperature		Oxygen	
0m	700	1025	19.5	20	10	8.8
.5m						
1m	700	975	19.5	20	10	8.6
1.5m						
2m	700	900	19.5	20	10.2	8.5
3m	700	850	19	19.5	10.5	8.4
4m	700	850	18.5	19.5	11.2	8.2
5m	850	875	18	19.5	11.3	7.9
6m	850	875	17.5	19.5	11.3	5.2
7m	850	875	17.5	19.5	11.3	4.8
8m	850	875	17.5	19.5	11.3	4.8
bottom						

TABLE 2B: **Conductivity, temperature and oxygen profiles in the Oriental West, behind the curtain**

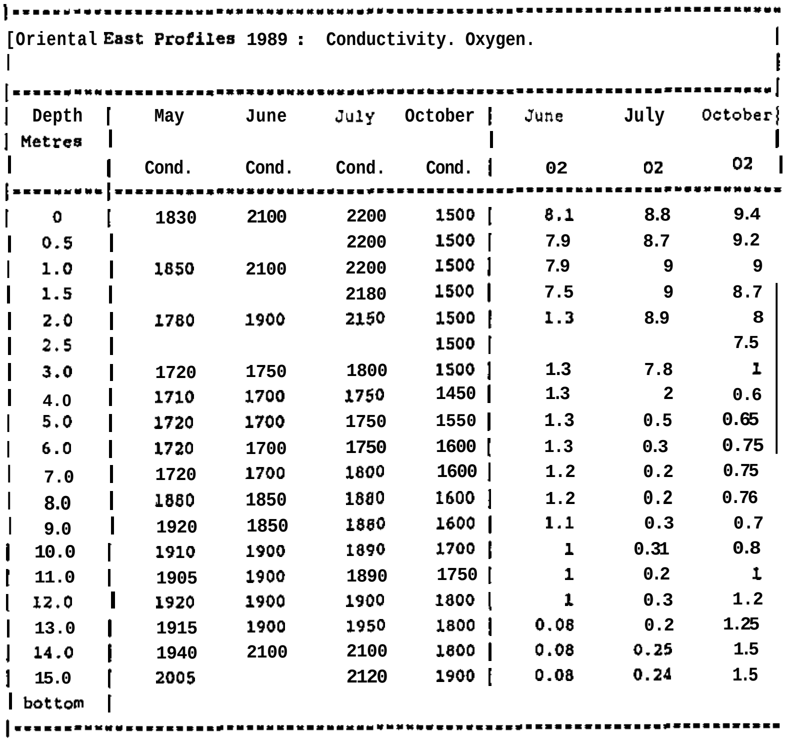
ORIENTAL WEST PIT PROFILES : 1989

Conductivity, Temperature, Oxygen.

Location : Behind Curtain

June	July	October	June	July	October	June	July	October
Conductivity			Temperature			Oxygen		
750	900	600	20	20	13	10.2	9.8	11.3
	900			20			9.8	
730	875	600	20	20.5	13	10	10.1	11.5
	a75			20.5			9.4	
730	875	600	20	20.5	12	10	9.4	11.8
750	875	700	19	21	12	10	8.4	11.9
730	875	700	19.5	21	12	10	8.3	12
Bottom								

TABLE 3: Oxygen and conductivity profiles in the Oriental East pit - **1989**



Oriental **East Profiles** 1989 : Conductivity. Oxygen.

Depth Metres	May Cond.	June Cond.	July Cond.	October Cond.	June 02	July 02	October 02
0	1830	2100	2200	1500	8.1	8.8	9.4
0.5			2200	1500	7.9	8.7	9.2
1.0	1850	2100	2200	1500	7.9	9	9
1.5			2180	1500	7.5	9	8.7
2.0	1780	1900	2150	1500	1.3	8.9	8
2.5				1500			7.5
3.0	1720	1750	1800	1500	1.3	7.8	1
4.0	1710	1700	1750	1450	1.3	2	0.6
5.0	1720	1700	1750	1550	1.3	0.5	0.65
6.0	1720	1700	1750	1600	1.3	0.3	0.75
7.0	1720	1700	1800	1600	1.2	0.2	0.75
8.0	1880	1850	1880	1600	1.2	0.2	0.76
9.0	1920	1850	1880	1600	1.1	0.3	0.7
10.0	1910	1900	1890	1700	1	0.31	0.8
11.0	1905	1900	1890	1750	1	0.2	1
12.0	1920	1900	1900	1800	1	0.3	1.2
13.0	1915	1900	1950	1800	0.08	0.2	1.25
14.0	1940	2100	2100	1800	0.08	0.25	1.5
15.0	2005		2120	1900	0.08	0.24	1.5
bottom							

Extrapolating the West pit temperatures linearly to a depth of 20 m, the same temperature is reached as that found in the bottom of the East pit (Figure 4). The arrows in Schematic 1 depict the downward movement of relatively cold water in the West pit and its discharge to the East pit, combined with an upward movement of somewhat warmer ground water, which enters the lower portion of the East pit. These observations correspond with the distinct thermocline, around 3 to 5 m noted during the summer above the *6* m depth in the East Pit and in the unstratified West Pit (Table 2, Fig.3).

SCHEMATIC 1: Proposed Ground water flow paths between Oriental East and West pits

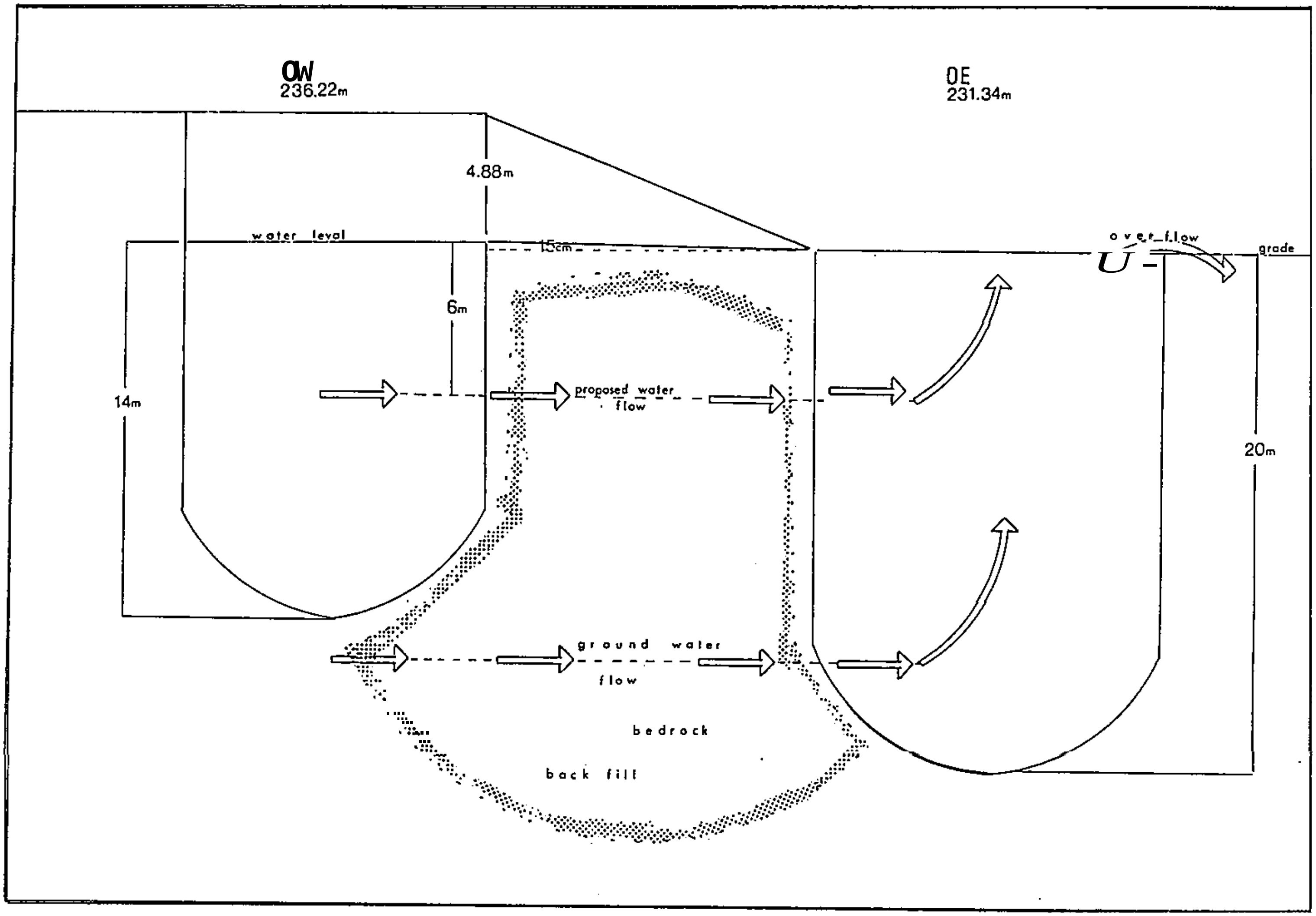
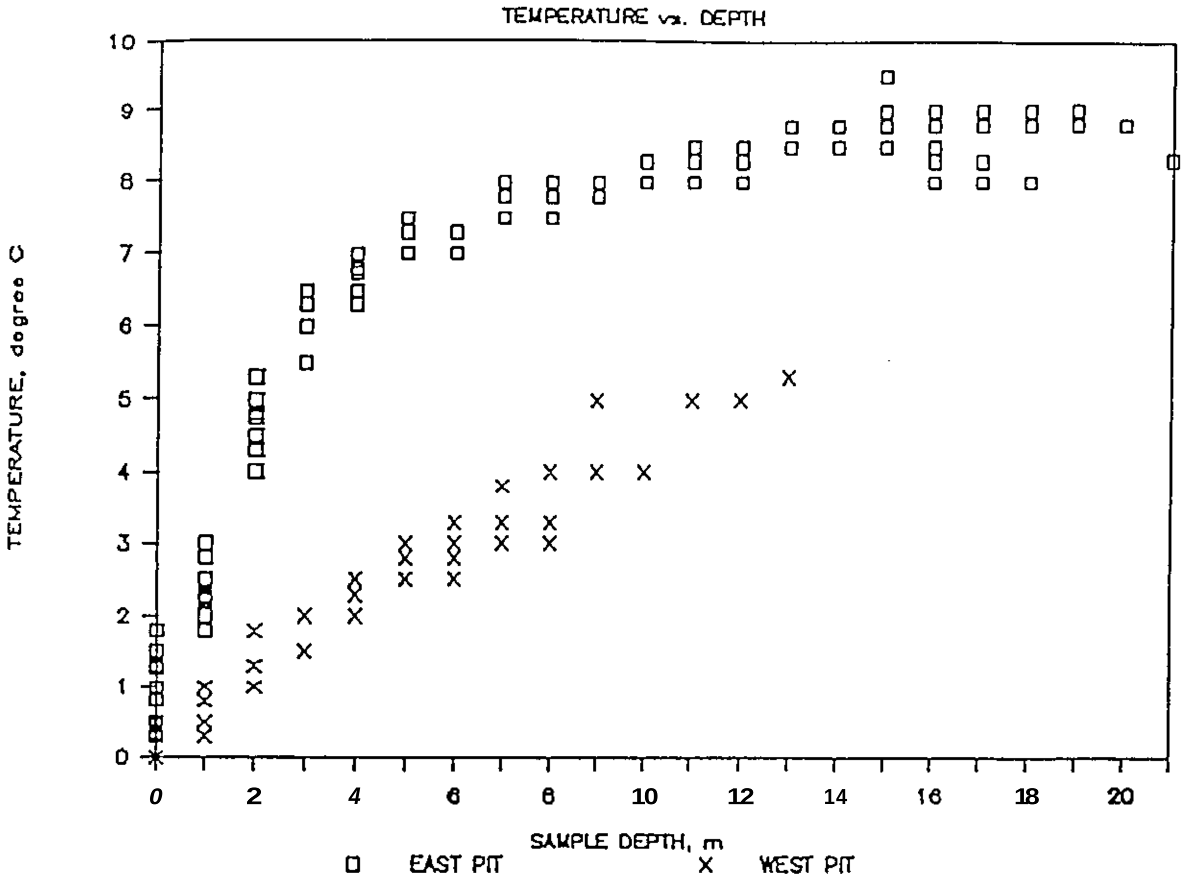


FIGURE *4:* Temperature comparisons between Oriental East and Oriental West pits with ice cover - 1989



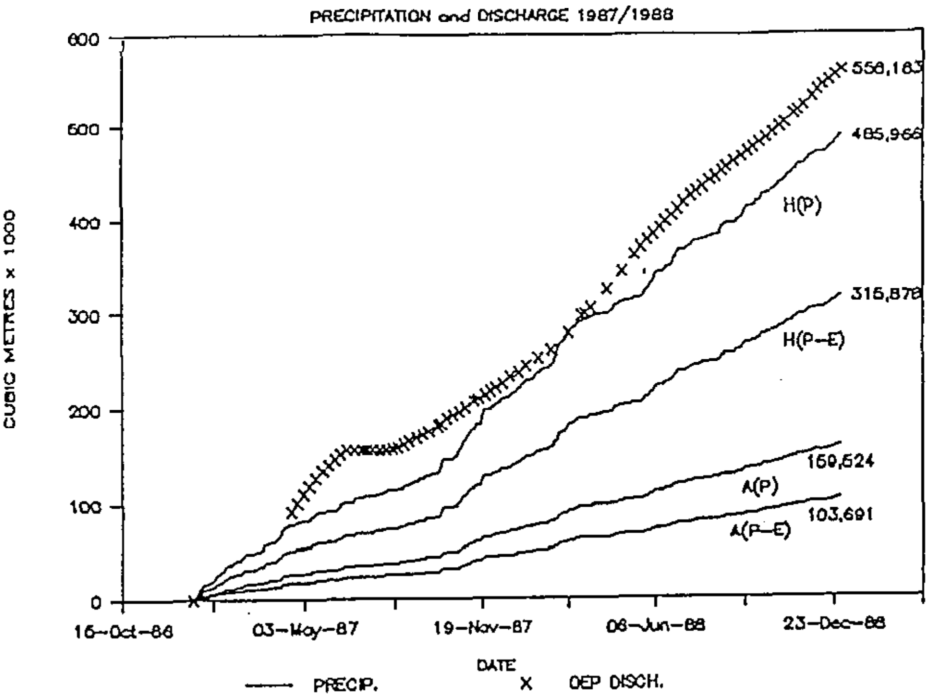
As the path of the water between the pits has been defined, the origin or source of the water to the Oriental mine has to be determined. In order to do so, an assessment was carried out of the drainage basin or the watershed supplying the pits with water. Two sets of values for pit volumes and watershed areas are available, representing ASARCO data and values from a report by Helwig (1984). In addition, calculated inflow and fill times of the mine workings have been taken into consideration in the assessment.

The results of the watershed evaluation are given in Figure 5, as the cumulative discharge from the Oriental East pit during 1987 and 1988. Taking the different values for the watershed areas, four curves of cumulative precipitation for the same period were produced. These are based on:

- ASARCO values and precipitation minus evaporation: (A (P-E)
- ASARCO values and total precipitation: A(P)
- Helwig values and precipitation minus evaporation: H(P-E); and
- Helwig values and total precipitation: H(P).

It is evident from the comparison presented in Figure 5 that all of the estimates of the size of the combined Oriental pit watershed are too small, as more water leaves the pit than can be accounted

FIGURE 5: Cumulative discharge from the Oriental watershed



for. The more likely explanation for the excess water is that the Oriental pits are receiving ground water discharge from a more distant source (or sources) via old mine workings or via one of the tunnels from the Old Buchans or Lucky Strike mines. The latter option would explain the consistently low pH in the West pit.

The sulphide showing in the pit does not appear to be the sole source of the acidity. The exposed face of the sulphide to air and precipitation shows no clear acid mine drainage streaks, which should be present if the showing was actively generating acid. The submerged part of the massive sulphide would generate acid at a lower rate. Furthermore, no indication of increased conductivity in close proximity to the face was detected in the more enclosed area behind the experimental curtain placed into the pit (Table 4). The slight increases in carbon, potassium, iron and lead noted are likely due to the added brush. Thus, acid generation appears to occur in the underground workings. If chalcopyrite is generating acid, this would provide the copper source for the copper in the Oriental West water.

Geochemical comparisons can be used as a tool to ascertain the types of water which, through mixing, would determine the characteristics of the Oriental effluents. This is achieved by using the logarithms of elemental concentrations in millimole/1 to allow a comparison of the changes in the widely varying elemental concentrations. Water samples, collected in spring 1989 from the ice-covered pits, the bottom of the West pit, the Oriental East pit, Lucky Strike glory hole and from the drainage tunnel, were used for this comparison. These samples would preclude mixing of water with precipitate.

The comparisons reveal that water in the bottom of the West pit, although higher in concentrations, is similar in relative elemental composition to the effluent from the Drainage tunnel. On the other hand, the relative elemental composition of the Lucky Strike water

TABLE 4 : **Water charateristics of Oriental West behind curtain and open pit**

ORIENTAL WEST PIT WATER CHARACTERISTICS

SAMPLE DATE		01-Aug-89	04-Oct-89
SAMPLE VOLUME		250 ml	250 ml
ASSAYERS CODE		1268	1376
SAMPLING LOCATION		O. WEST MIDDLE BOTTOM FA	O. WEST BEHIND CURTAIN PA
ELEMENTS PPM	Al	4.1	5.6
	B	0.06	0.05
	Ba	0.1	0.04
	Bi <	0.01	0.5
	C <	0.01	50
	Ca	132	147
	Cd <	0.01	'0.4
	Ce	0.01	0.02
	Co <	0.01	0.1
	Cr <	0.01	0.03
	C"	1.5	1.6
	Fe	0.7	1.8
	K <	0.01	2.1
	La	0.05	0.06
	Mg	13	14
	Mn	2.7	3.1
	Mo <	0.01	0.4
	Na	8.1	7.3
	Nb <	0.01	0.1
	Ni	0.02	0.07
	P <	0.01	0.2
	Pb	17	1.8
	S	291	168
	Sb <	0.01	0.03
	Se <	0.01	0.01
	si	8.5	9.6
	Sn <	0.01	0.01
	U	0.06	0.01
	V <	0.01	0.02
	W	1.2	0.1
	Y	0.03	0.03
	Zn	53	57
	Zr <	0.01	0.01
	Chloride	80	
	Acidity	152	75
	Sulphate	873	

is similar to that of the East pit (Figures 6A, 6B and 6C). The West pit water is relatively high in Mn, Ca, Sr, SO, and HCO_3, and relatively low in Fe, Al, Cl and F, which presumably reflects the effects of acid mine drainage, mixing with ground water, with precipitation and with run-off. These comparisons suggest that the water in the Oriental West and the Drainage Tunnel result from a mixing with waters which have gone through a bedrock/backfill environment similar to their own, whereas the water in Lucky Strike and Oriental East result from a mixing with water which has passed through a bedrock which is different in nature to that of the Oriental West and Drainage Tunnel. The differences in water types however, is most noticeable with respect to sulfides, carbonates and silicates, in addition to NaCl.

To ascertain that no other undetermined, significant water chemistry in the watershed to the Oriental workings exists, a survey of the surface water was carried out for all imaginable sources of water in the vicinity. Water was collected at different locations in the Backfill pit until it joins the Buchans River: from the Queen Mary pond north of the Oriental pits: and from the Forebay. In Table 5, the characteristics of these waters representing either surface or ground water/subsurface flow are summarized,. Essentially, the chemical analyses of these samples do not suggest any major differences in elemental composition.

FIGURE 6A: Geochemical comparison of Oriental East and Oriental West bottom water

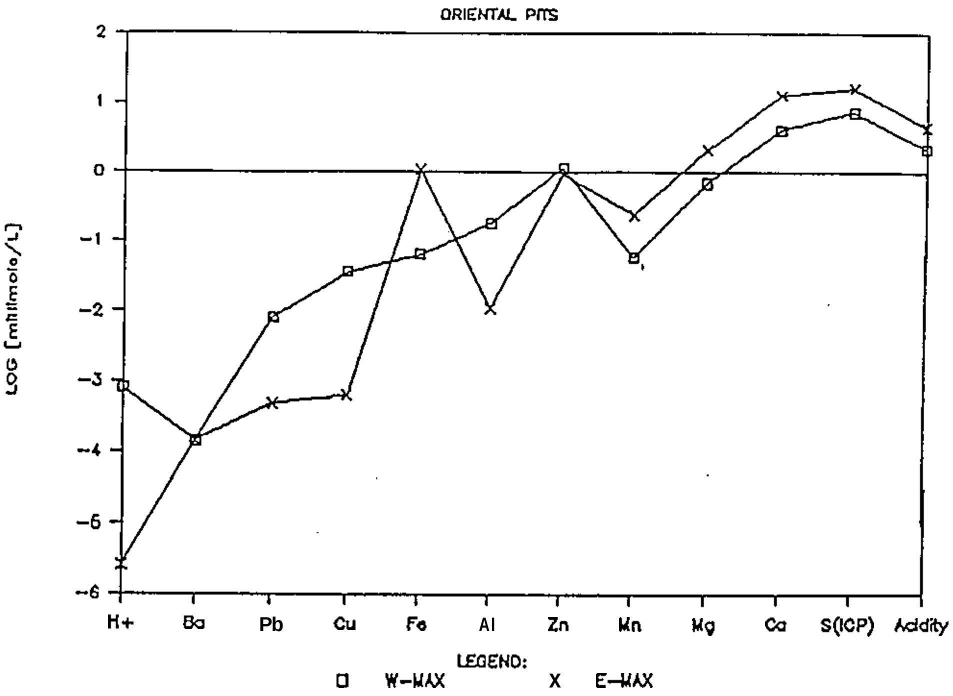


FIGURE 6B: Geochemical comparison of Oriental East, Oriental West and Drainage Tunnel

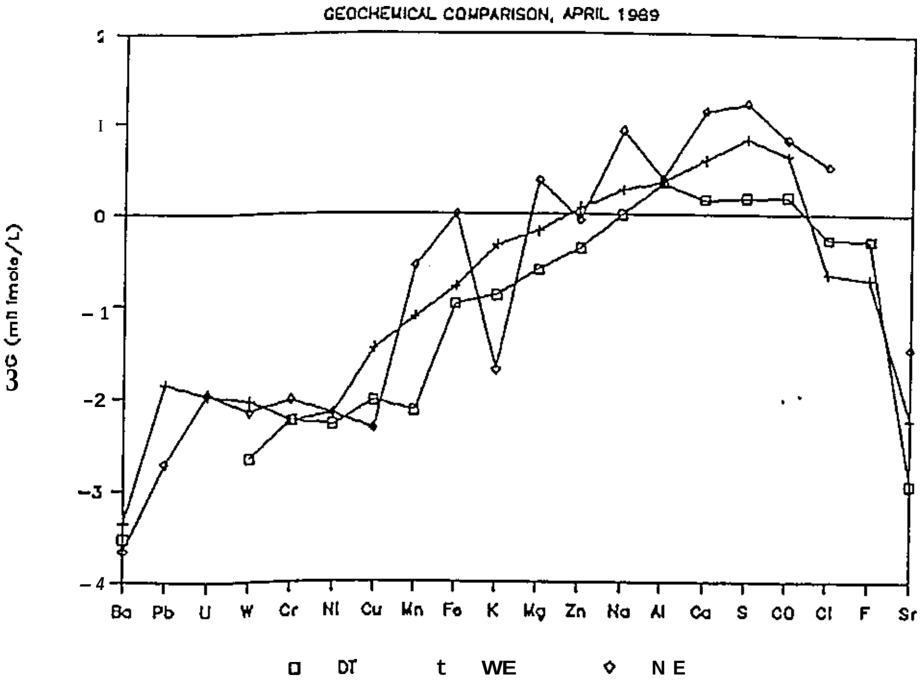
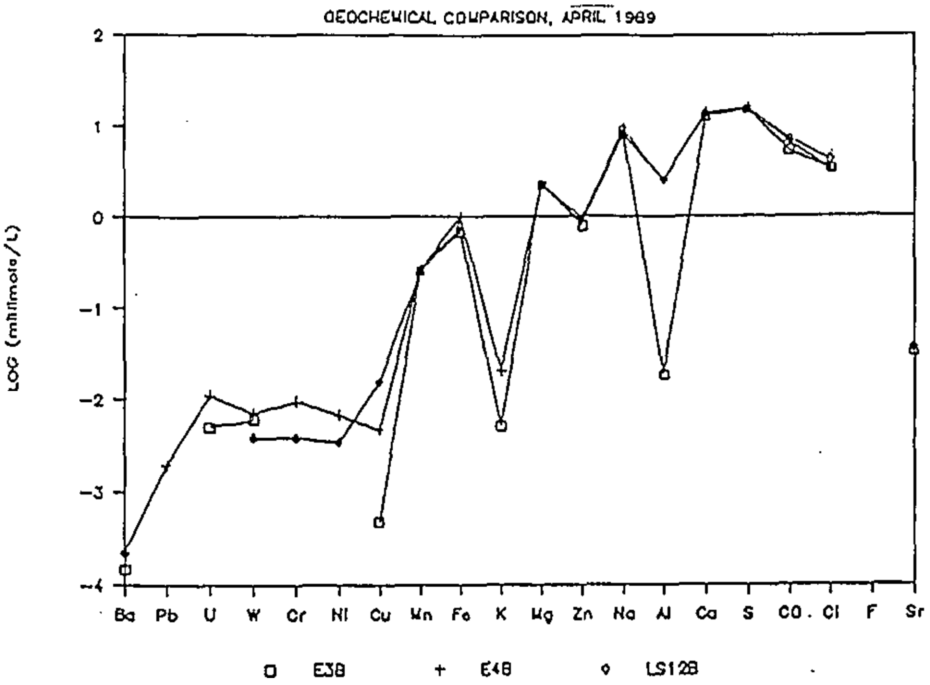


FIGURE 6C: Geochemical comparisons of Oriental East and Lucky Strike water



To establish for example whether contact with backfill could indeed account for the differences between the Oriental East and West pits, static leach experiments were carried out using backfill material.

The characteristics of the water from Forebay, the Backfill pit, Oriental East and Oriental West, are given in Table 6. They differ distinctly with respect to zinc and copper concentrations between both pits, with little difference in elemental composition noted between water from the Forebay and the Backfill. Thus, the backfill leaching experiment was carried out with water from the Forebay and the Backfill pit to provide a comparison with Oriental East and West water.

30-JUN-89 PARAMATER DESCR DESCRIPTION	buchan st	forbay	sandfill spring	sandfill pool	queen mar	sandy lake	oe mid surfac	oe mid 5 m dow	oe behind curtain	oe limnocoral	ow mid surface
FIELD pH	5.46	6	5.48	5.92	5.85	5.75	5.55	5.36	5.37	6.8	3.5
pH	7.9	7.8	7.6	7.9	7.5	-	7.3	7.2	-	-	3.5
Alkal *	43.9	4.5	44	48.5	7.5	-	155	176	-	-	
Cl	2.2	1.2	1.8	2.6	2.2	-	110	136	-	-	2.4
Sulphate	5	2	4	4	8	-	1150	1100	-	-	450
F	0.11	-	0.16	0.18	-	-	0.39	0.36	-	-	0.13
Nitra	0.04	-	0.05	0.02	0.01	-	0.01	0.06	-	-	0.02
Ph tot	0.01	0.02	_	0.05	0.01	-	0.02	0.02	-	-	0.08
Org. C tot	-	5	-	1	8	-	5	5	-	-	-
Inorg. C tot	8	2	8	9	2	-	41	38	-	-	-
AL	-	-	-	-	-	-	-	-	-	-	4.4
Be	-	-	-	-	-	-	-	-	-	-	1
Ca	14	2	2	18.5	5.4	0.013	380	390	380	330	105
cu	0.006	0.01	0.008	0.002	0.028	0.004	0.032	0.024	0.008	24	1.37
Ag	-	-	0.001	0.001	-	-	0.001	0.001	2	0.001	0.001
Sr	0.028	0.014	0.006	0.034	0.014	0.024	1.93	2.1	1.88	1.68	0.35
Na	3.2	1.6	1.2	4	1.6	3.4	105	115	100	96	5.2
K	0.4	0.4	0.2	0.6	0.4	0.4	3.6	4	3.2	10.5	1.2
W	-	-	-	-	-	-	0.02	0.04	0.02	0.02	0.02
Zn	0.026	0.02	0.02	0.008	0.41	-	-	-	-	-	-
P	-	0.02	0.02	0.08	0.1	0.002	0.14	0.16	0.14	0.12	0.12
Pb	0.004	0.008	0.012	0.008	0.02	-	0.016	0.008	0.02	0.016	1.8
Bi	-	-	-	-	-	-	0.012	0.004	0.012	0.004	0.004
Cd	0.002	0.003	0.002	0.003	0.003	-	0.007	0.06	0.007	0.005	0.12
Co	-	-	-	-	-	0.002	0.04	0.04	0.038	0.034	0.022
Ni	-	-	-	-	-	-	0.016	0.014	0.018	0.01	0.018
Ba	-	-	-	-	0.1	-	0.02	0.02	0.02	0.04	0.02
Fe	-	-	-	-	0.4	-	0.6	21.8	6.4	7	1.2
Mn	0.012	0.026	0.024	0.006	0.014	-	-	-	-	-	2.6
Mg	1.4	0.4	0.2	2	0.8	1.4	41	42	40	37	11.5

* mg\l Caco3

TABLE 5: Surface water in the vicinity of the Oriental drainage basin

TABLE 6: Water characteristics used in the leach experiment

CHARACTERISTICS OF LEACH TEST WATERS

DATE	Sept 3 89	Sept 3 89	Sept 3 89	Sept 3 89
ASSAY CODE	1360	1361	1359	1362
PROCESSING CODE	WH	WH	WH	WH
SITE LOCATION	Oriental West	Oriental East	Forbay	Sandfill Pit
pH	3.2	6.6	6.8	7.4
CONDUCTIVITY	830	2190	19	83
ELEMENTS PPM				
Al	4.7	0.03	0.03	< 0.01
As	0.8	0.9	< 0.01	< 0.01
Ba	0.05	0.02	0.02	< 0.01
Bi	0.02	0.02	< 0.01	< 0.01
C	< 0.01	1202	< 0.01	< 0.01
Ca	135	457	2.3	16
Cd	0.3	0.2	< 0.01	< 0.01
Co	0.09	0.1	< 0.01	< 0.01
Cu	1.4	< 0.01	< 0.01	< 0.01
Fe	1.2	< 0.01	0.01	< 0.01
K	2.9	2.1	3	< 0.01
Mg	14	45	0.4	1.5
Mn	2.9	11	< 0.01	0.02
Mo	0.3	0.3	< 0.01	< 0.01
Na	7.3	147	2.3	4.8
P	2.9	2.8	< 0.01	< 0.01
Pb	1.4	< 0.01	< 0.01	< 0.01
S	362	825	1.5	4.5
Si	8.9	8.3	1	8
Sr	0.4	2.6	< 0.01	0.03
Zn	58	37	< 0.01	0.09
Chloride	1086	2475	4.7	13.6
Acidity/Alkalinity	141	167	14.2	19.5
Sulphate	7	91	8	6

The static leaching tests were performed for a period of 62 days. In Figures 7A and 7B, the concentrations of Al, Cu, Fe, Ca and Zn Si Na and K respectively, are presented for the backfill leached with BAckfill spring water, and in Figures 8A and 8B, the concentrations of the same elements resulting from leaching backfill with Forebay water are presented.

The interactions of these two types of water with the backfill is different from the elements, A, Fe, Si, Ca and K. However, with respect to Cu, Zn and Na, little difference can be noted over the period of the experiment, as the composition of the backfill material in each container cannot be assumed to be homogenous, only general concentration trends are relevant. The results suggest that the backfill material is chemically active with both Forebay and Backfill waters, but no significant difference exists between the two types of water.

In Figures 9A and 9B, the concentrations Al, Cu, Fe, Ca Zn, Si and K are presented in the leachate from the backfill, with Oriental East water and Oriental West water. When Oriental West water contacts the backfill, significant reductions of all three elements are noted after 20 days.

FIGURE 7A : Backfill leach with Backfill spring concentrations of Al, Cu, Fe and Ca

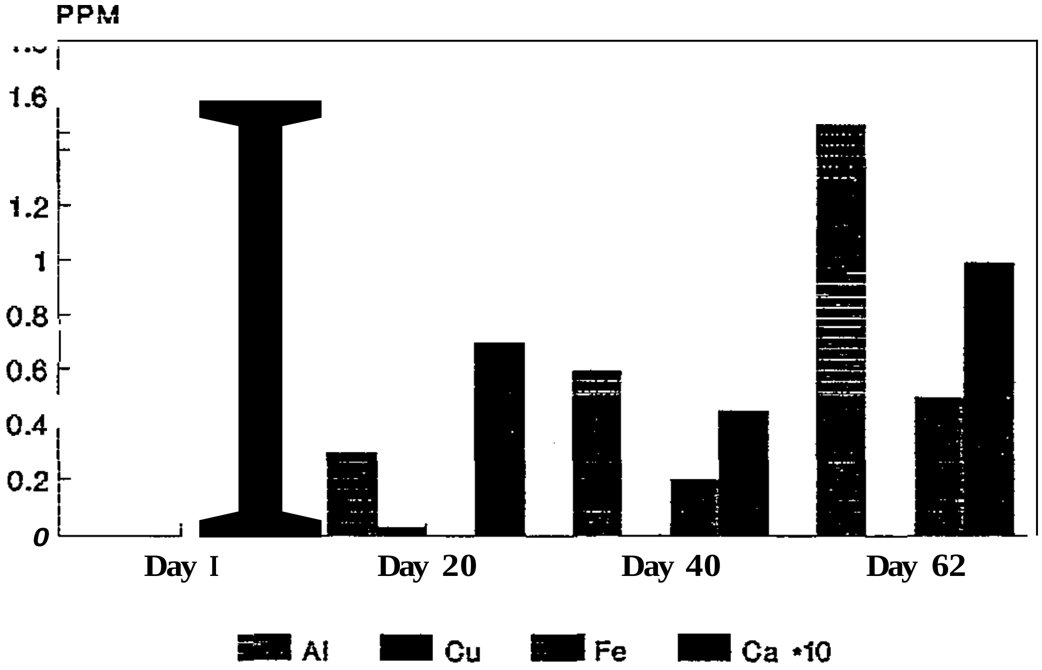


FIGURE 7B : Backfill leach with Backfill spring concentrations of Zn, Si, Na and K

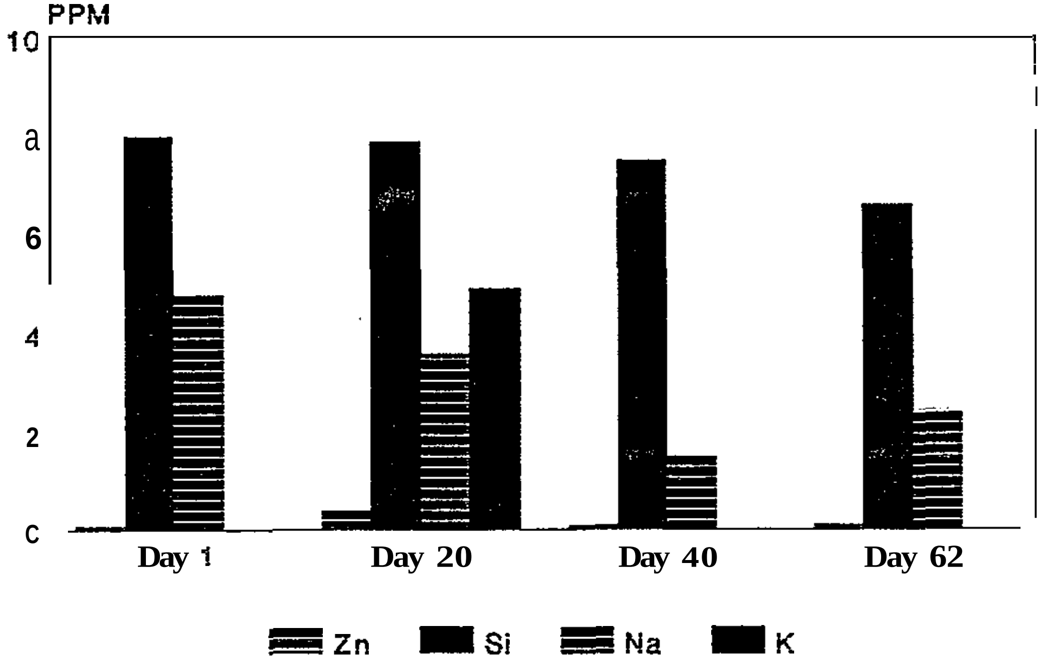


FIGURE 8A : Backfill leach with Forebay water concentrations of Al, Cu, Fe and Ca

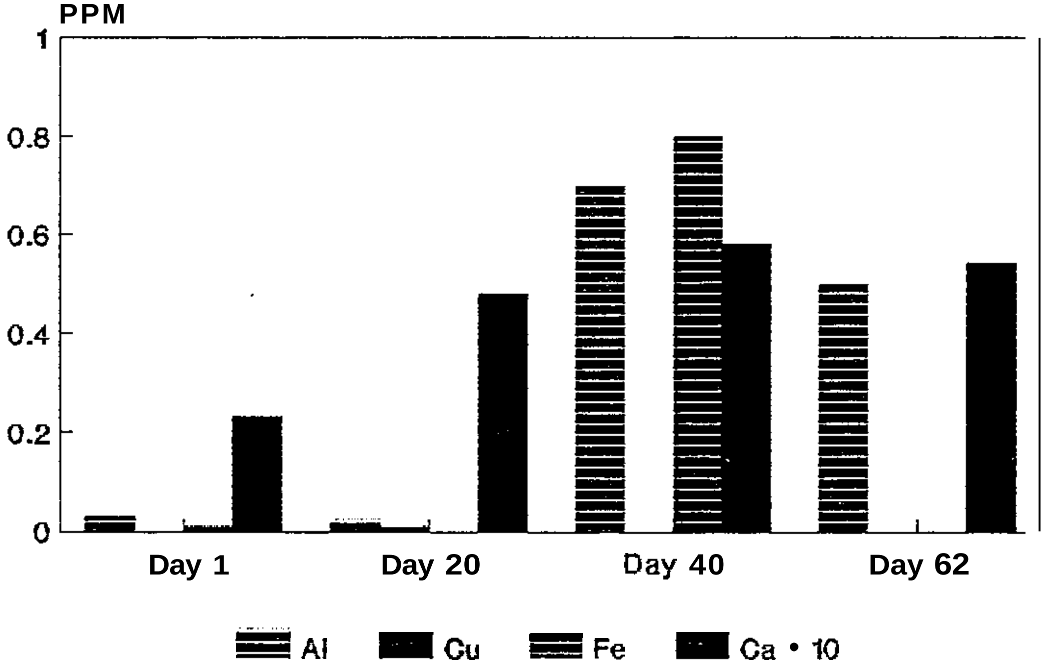


FIGURE 8B : Backfill leach with Forebay water concentrations of Zn, Si, Na and K

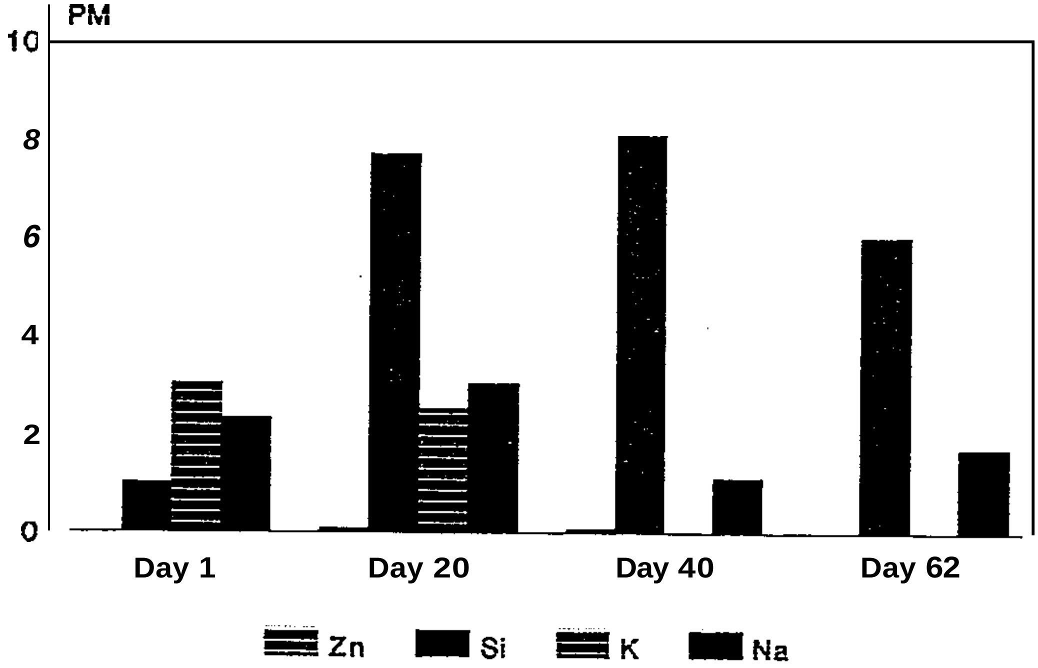


FIGURE 9A Backfill leach with Oriental East water concentrations of Al, Cu, Fe and Ca

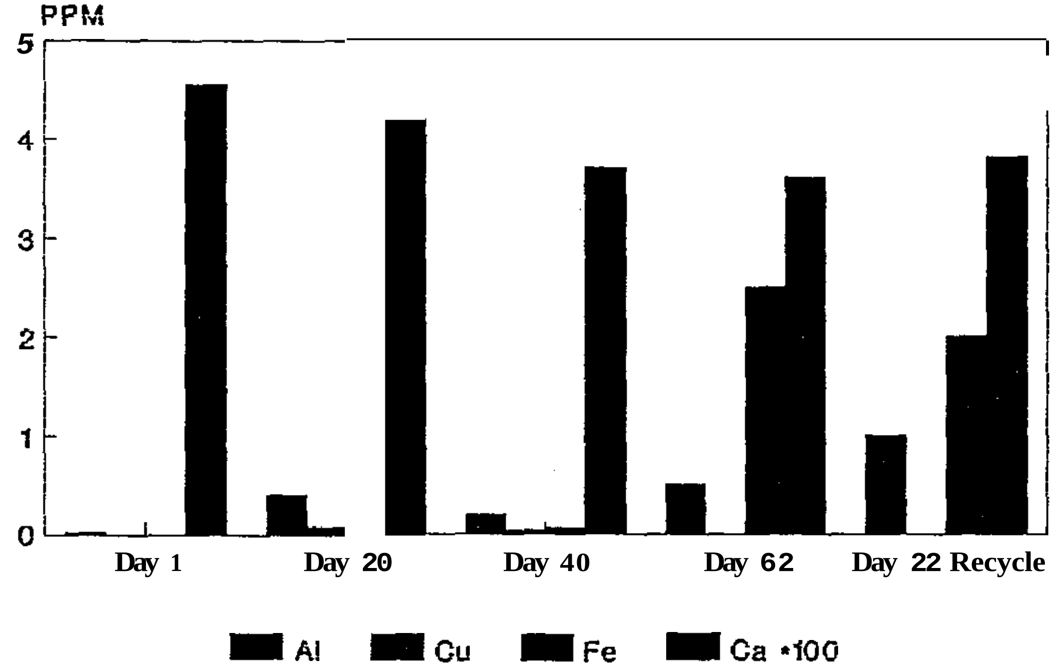


FIGURE 9B Backfill leach with Oriental East water concentrations of Zn, Si, Na and K

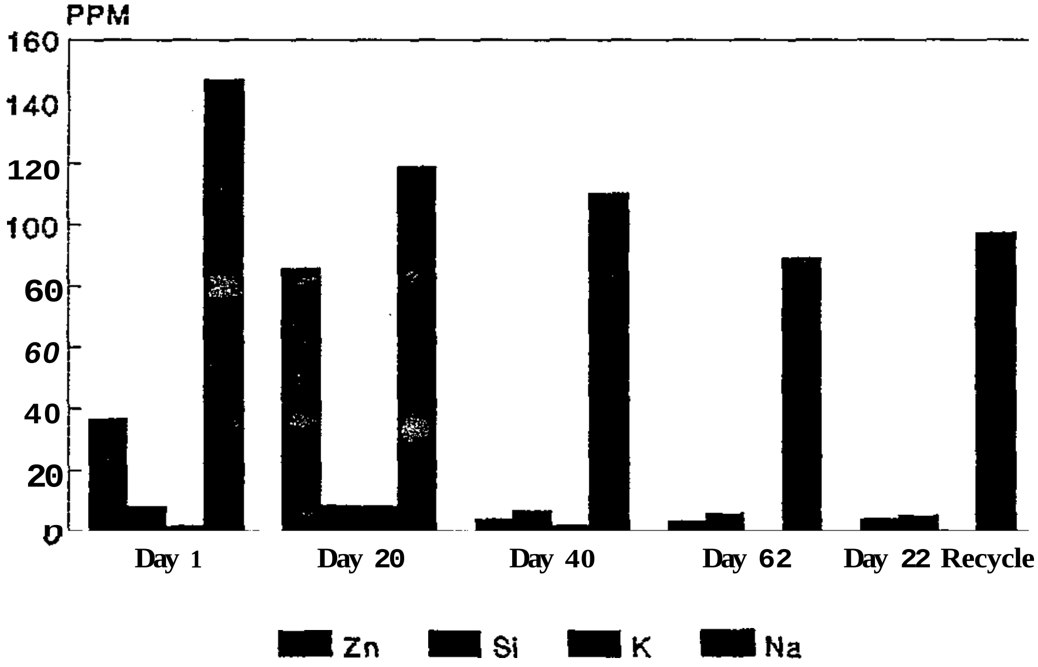


FIGURE 10A : Backfill leach with Oriental West water concentrations of Al, Cu , Fe and CA.

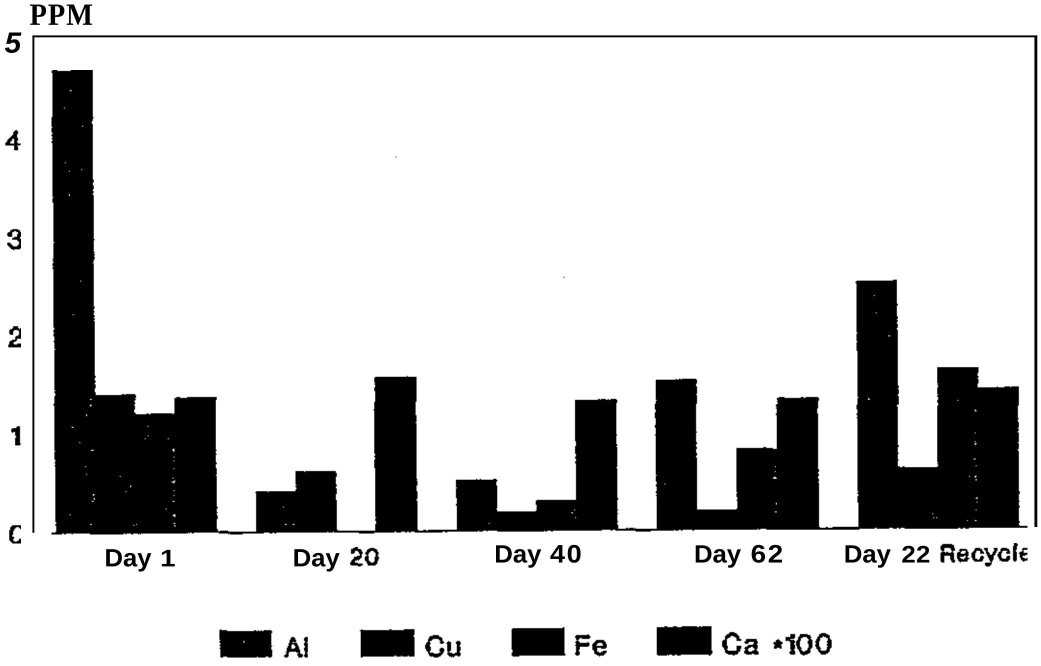
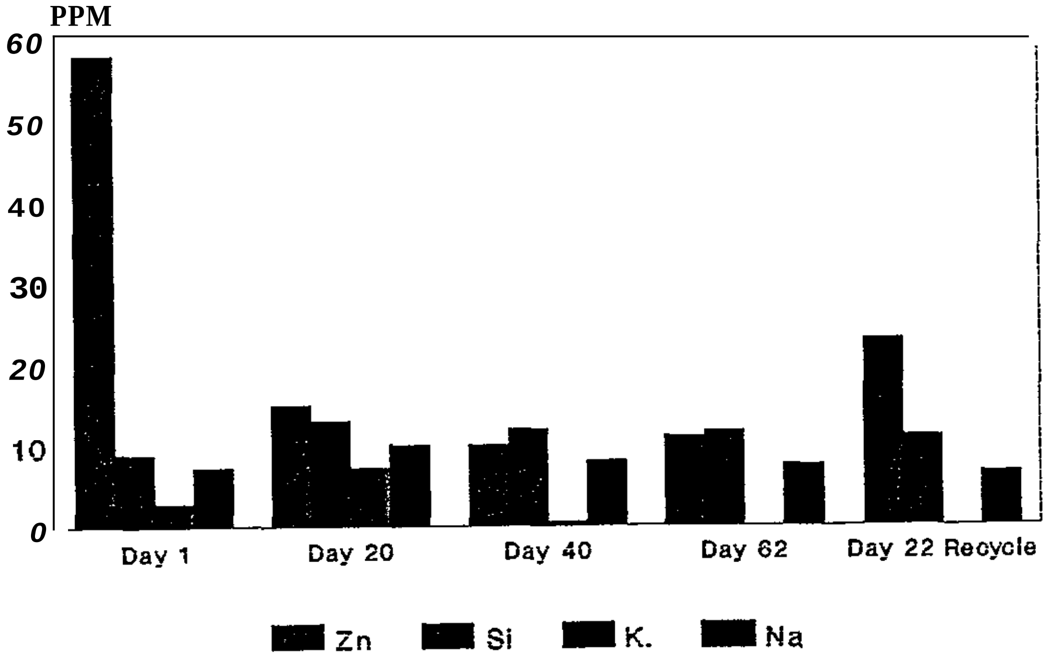


FIGURE 10B: Backfill leach with Oriental West water conentration of Zn, Si, Na and K.



As the leaching time increases, a slight increase in Al and Cu is noted when leaching with Oriental East water. Iron concentrations increase somewhat more as the contact time with the Oriental East water is increased to 62 days. These results suggest that possibly Ca silicates are dissolving and generate some alkalinity.

In Table 7, the pH and the conductivity values, together with the concentrations of acidities, sulphate and sulphur values, are given at the start of the experiments, i.e. prior to exposure with the backfill and at the termination of the experiments after 62 days. The changes in concentrations are significant, in that in absolute terms, the acidities of both Oriental East and West are not that different in the beginning of the experiment, with 167 mg/$CaCO_3$ and 141 mg/$CaCO_3$, respectively. However, at the end of the experiment, after 62 days of contact between water from the two pits and backfill, although a 42 fold reduction of acidity was experienced in the leachate from the Oriental East, in the case of Oriental West water, there was only a 7 fold reduction in acidity.

TABLE 7 : pH, conductivity, acidity, sulphate and sulphur values of day 0 and after *62* days of the backfill leach experiment

SANDFILL **STATIC** LEACH TEST

Location	Oriental West		Oriental East		Forbay		Sandfill Spring	
Time days	0	62	0	62	0	62	0	62
pH	3.2	6.8	6.6	5.9	6.8	6.7	7.4	6.8
Conductivity micromhos/cm	830	650	2190	1950	19	32	83	60
Acidity ppm CaCo3	141	20.4	167	4	14.2	3.9	19.5	2
Sulphate ppm	7.0	.457	91.0	1188	8.0	11.7	6.0	18.6
Sulphur ppm	362	150	825	388	1.5	3.8	4.5	5.9

The material which had been exposed to the waters for 22 days and drained, was re-exposed to more of the same water. Without more detailed data analysis, it is clear that the leachate experiment demonstrates the factors which occur as water contacts bedrock and thereby affects the effluent characteristics.

The acid consumption capacity of the backfill material was determined. In Table 8, the results are given for three grain sizes, coarse "as is", backfill and ground to 1 mm mesh and powdered. As the grain size decreases, the acid consumption is increased from 0.35 kg/tonne of backfill to about 1 kg/tonne of backfill. The acid production of solid material from various sources in the Buchans area was tested by Energy Laboratories in 1988. All of the tailings had some neutralizing potential which appears to be in the same range as that indicated for the backfill. It is therefore suggested that both tailings and backfill are the active materials producing neutralizing capacity. Both backfill and tailings are part of and originate from the natural bedrock (host) environment, and therefore are important contributing components to the effluent chemistry.

TABLE *8* : Acid consumption of backfill

Sandfill Grade.	Coarse	1 mm	Powdered
Weight of Fill.	50 g	50 g	50 g
Volume of water for slurry preparation.	200 ml	200 ml	200 ml
Volume of Sulphuric acid consumed.	35 ml	80 ml	100 ml
Normality of acid.	0.01	0.01	0.01
Weight of acid consumed per 50 g.	0.017 g	0.039 g	0.049 g
Weight of acid consumed per m/tonne of sandfill.	0.34 Kg.	0.78 Kg.	0.98 Kg.
Acid consuming potential meq/100 grm.	0.7	1.6	2.0

3.3 Predictions of long term changes in metal loadings

From the evaluation of the metal loadings from the various sources (Table 1), it was indicated that loadings of copper and zinc do not, in general, correlate in their trends by either increasing or decreasing concurrently. The flow path between the pits, the source of the water and metals to the pits and the geochemical interactions with the bedrock or backfill all indicate that potentially different chemical environments (Ground water or acid mine drainage water) are responsible for dissolution of copper and for zinc. The trends of concentrations of copper and zinc in the Oriental pits suggest similar differential sources or processes.

The findings indicate that, for the long term, changes in the loading are to be expected. These interactions are particularly expressed by the differences between the Oriental East and West pits. As discussed above, the concentrations of zinc in the Oriental East pit have been decreasing steadily since 1987. Further evaluation of the data set, together with the identification of carbonate sources in the bedrock (based on an assessment of existing drill hole information) may yield some insight into the direction of the anticipated change. It is certain that present conditions will not prevail.

4 PRECIPITATION AND FILTRATION

Soon after spring run-off, the water in the Oriental East pit turns to a brown colour, while the Oriental West pit remains clear throughout the year. This change in colour is associated with the formation of a precipitate. If the precipitate is a zinc-carbonate, as suspected, it could be used as a process for reducing the zinc loading to the environment.

Experiments were carried out in the laboratory to determine the factors controlling the precipitation process (Section 4.1). In the field, in ponds constructed in the first meadow, and in the pit, it was determined whether the same factors govern precipitate formation (Section 4.2). Finally, it was determined whether a biological filtration system removes the precipitate from the water column (Section 4.3).

4.1 Precipitate formation by ponding/aeration

The precipitate collected in the first meadow in 1988 contained high concentrations of zinc, and it was therefore important to determine the factors which would enhance its formation. Once dissolved zinc is converted to a suspended form, it can be removed by biological filtration. This appears to be occurring on a small scale on branches suspended in both the Oriental East and West pits.

An experiment was carried out in the laboratory (precipitation experiment No. **4** **,** SEE Methods, Section 2). The objective of the experiment was to determine if ponding or aeration of Oriental water could affect precipitate formation. The key findings are highlighted below.

The water was treated by bubbling air **(O+ ,** kept under Nitrogen to provide an oxygen free environment (O-), a control was kept with air space and, as a final treatment, phosphate was added at concentrations required for algal growth.

The addition of K_2PO_4 to the Oriental West water caused an increase in pH of 2 units. From all the waters tested, only the Oriental West water produced such a pH increase with phosphate addition. Although the exact mechanism is not known, the following explanation is given. The dissolved phosphate species from the addition of the phosphate salt is $HPO4^{-}$. This species is unstable for the pH range of the Oriental West water. It would form phosphoric acid or hypophosphoric acid, a more stable form, and thereby consume hydrogen ions. This change in ionic form would result in a pH increase.

form, and thereby consume hydrogen ions. This change in ionic form would result in a pH increase.

Phosphate was added to produce concentrations equivalent of 1.72 mM. For each litre of water, 0.29 g of Potassium diphosphate was added. To obtain the same concentration range for the Oriental West pit, about 20 tonnes of Potassium diphosphate should be added. This concentration of phosphate was expected to stimulate algal growth. In all treatments, only Ulothrix, Euglena and diatoms were present and there was no difference in the algal population density. Due to the formation of extensive precipitate in the phosphate treatment, it was not possible to identify the algal content, as cellular fragments were attached to the precipitate.

It can be suggested that the addition of potassium diphosphate is beneficial with respect to the pH increase and the associated decreases in metal concentrations. It is unlikely that a single addition of phosphate to the West pit would suffice in promoting sufficient biological activity to sustain a long term improvement in water quality. This is particularly the case, as through the addition of phosphate, the sparse indigenous phytoplankton community appears to be co-precipitated.

In addition to the results obtained for the Oriental West water, the oxidation experiments suggest that other important factors affect the precipitate formation. An elemental mass balance of the water used in the experiment was carried out, accounting for the total elemental concentrations as filtrate plus precipitate. It was indicated that a general good agreement could be obtained for those elements which are present at concentrations above the detection limits of the analytical methods used. Cocentrations of elements present at less then -3 logmmoles were in agreement. Therefore, the experimental procedures can be considered sufficiently reliable for an assessment of the solid and dissolved fractions of the elements with respect to the different treatments used in the experiments.

The distribution of elements in precipitate form is shown in Figure 11A for the Oriental West pit and in Figure 11B for the Oriental East pit. The percentage differences in the elemental composition in the precipitate formed is dependent on pH. The pH and the conductivity remained relatively constant throughout the experiment for both the Oriental East and West.

The different treatments of the water did not seem to have a significant effect on the elemental distribution in general in the Oriental West water, with the possible exception of iron. However,

FIGURE 11A Elemental Distribution in Precipitate - Oriental West

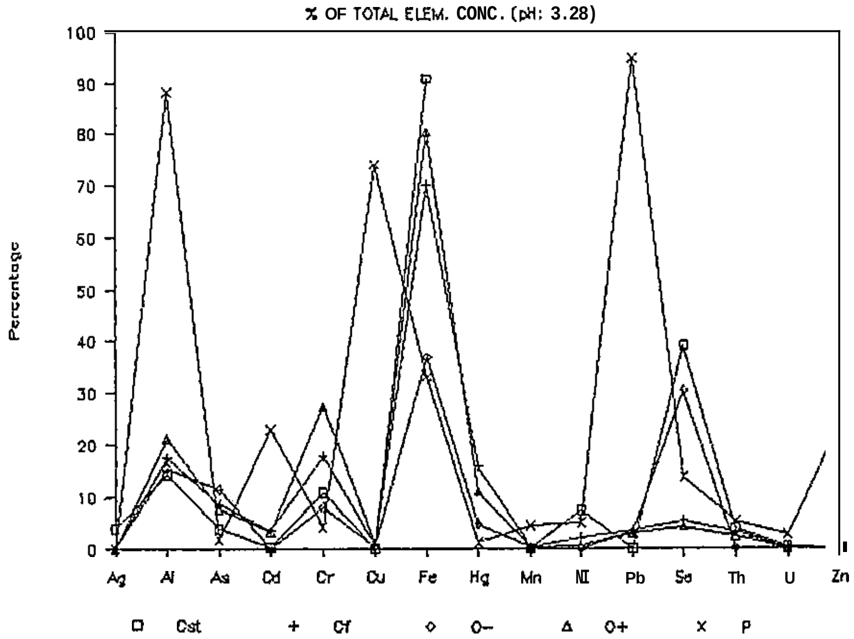
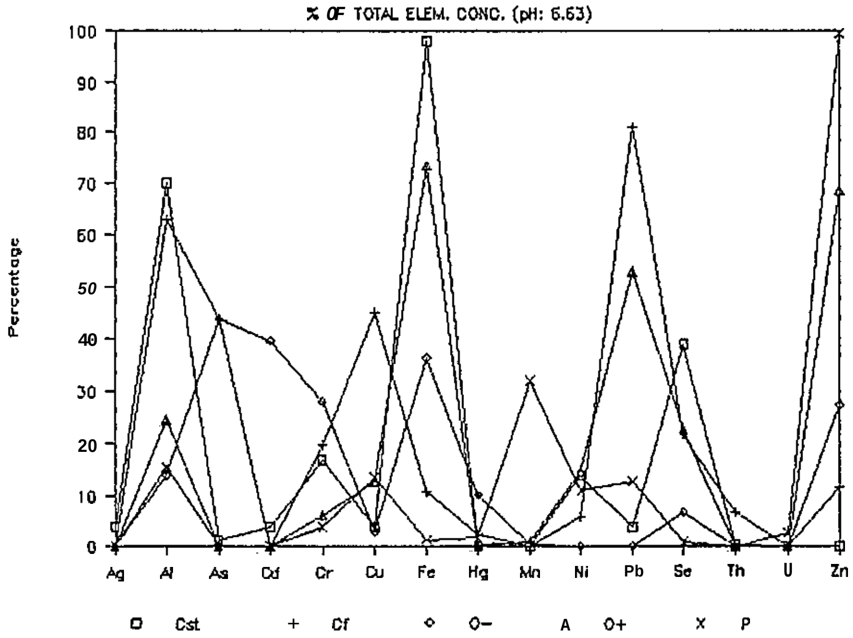


FIGURE 11B Elemental Distribution in Precipitate - Oriental East



OE: MAJOR ION DISTRIBUTION IN PRECIP.

a distinct effect of the treatments is noticeable in the Oriental East water. With aeration (O+), about 65% of the zinc is contained in the precipitate, which fraction reduces to 30% in the oxygen free treatment and further decreases to 15% in the water with the control treatment. A difference in solids fractionation is evident in the control treatment at the start (Cst) and the end of the experiment (Cf), whereby about 10% of the zinc is converted to the precipitate at the end of the experiment. Some changes in the form of copper can also be noted by the end of the experiment in the control treatment, as 40% of the total concentration is found in the precipitate.

It is concluded from these findings that for the Oriental East water, ponding of the water promotes the conversion of zinc and copper from the dissolved form to a precipitate.

4.2 Ponding of the Oriental East water in the first meadow

Although the oxidation experiment yielded encouraging results, it remains to be determined if similar processes occur in the field. In the first meadow receiving the Oriental East effluent, 6 ponds were constructed through which water was diverted from the main flow channel.. Into these ponds, cut brush was placed on August 17, 1989 to serve as a precipitation/collection surface and as growth substrate for biological polishing agents.

In Figure 12A, the dissolved zinc concentrations are plotted with increasing time of placement of the brush for both Pond 1 (the first pond receiving the effluent from the Oriental East pit) and Pond 6 (the final pond from which the water returns to the meadow).

In the first 86 days after placement of the brush, the concentrations of zinc entering the system and those leaving the system are the same. However, after about 100 days, the concentrations in Pond 1 axe lower and further reduced as the water leaves Pond 6, representing a reduction from 39 mg/l entering Pond 1, to 37 mg/l leaving Pond 6 in July, which decreases in October to values entering Pond 1 at 29 mg/l leaving pond 6 at 21 mg/l. However, concurrently with the decrease in dissolved Zn in the final pond after the filtration process has been initiated, an increase in copper concentrations is noted (Figure 12B). The increase occurred after about 100 days of placement of the amendment, and ranged from 0.04 mg/l entering Pond 1, to 0.12 mg/l leaving Pond 6. At present, no explanation can be given for the increase in copper concentrations.

FIGURE 12A Dissolved zinc concentrations in Ponds 1 and 6 in relation to time amendment

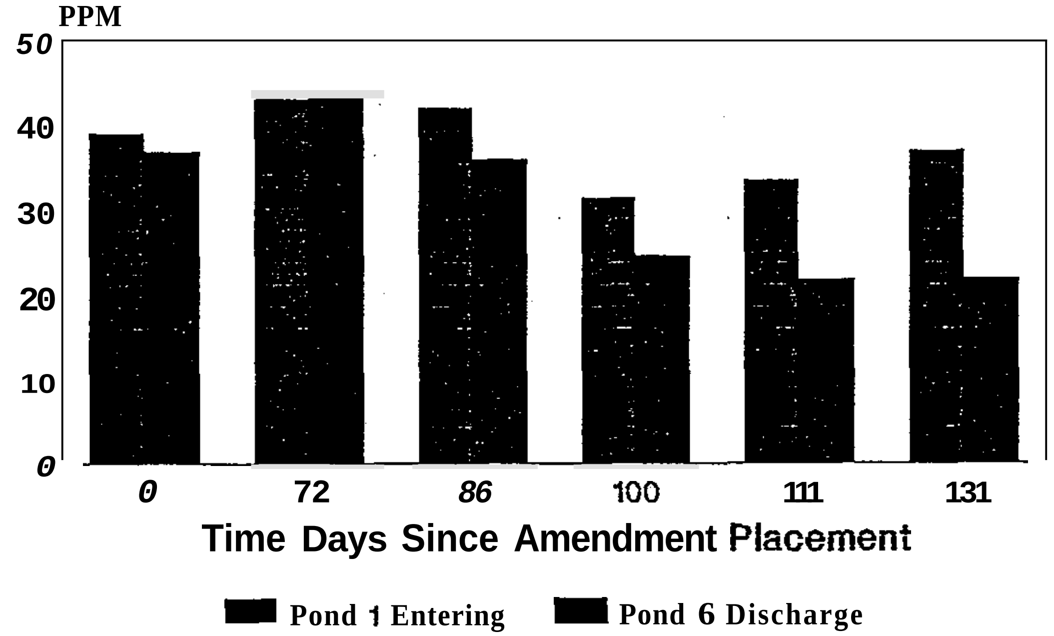
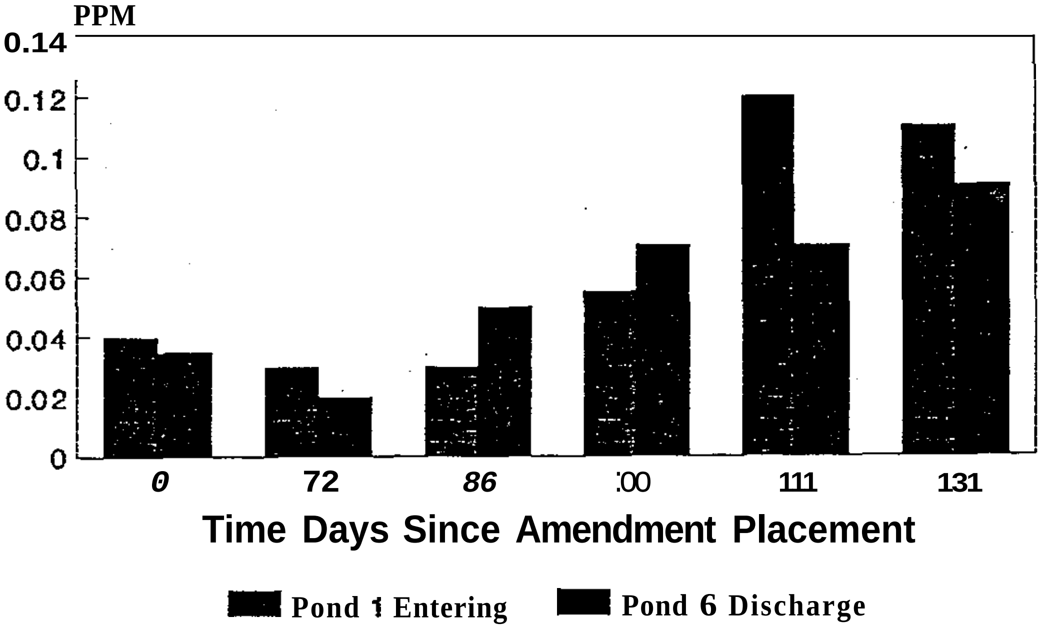


FIGURE 12B Dissolved copper concentrations in Ponds 1 and 6 in relation to time of amendment



As it is proposed that the precipitation process is occurring in the Oriental East pit and is enhanced in the ponds, then in principle, waters collected at different depths in the Oriental East pit should reflect a change in the dissolved elemental composition of the water. In Table 9, the composition of water collected at the surface and at 2m, 7m and 14m depths is presented. Differences can be noted with respect to the concentrations of aluminum and iron. Although the dissolved concentrations of zinc do not display a significant difference with respect to depth, an assessment of the concentrations on the filter papers may yield some insight.

TABLE 9 Characteristics of dissolved solids in Oriental East Pit

SAMPLE DATE		04-Oct-89	04-Oct-89	04-Oct-89	04-Oct-89
SAMPLE VOLUME		250 ml	250 ml	250 ml	250 ml
ASSAYERS CODE		1380	1381	1382	1383
SAMPLING LOCATION		OE PIT	OE PIT	OE PIT	OE PIT
		B/CURTAIN	MIDDLE 2M.	MIDDLE 7M.	MIDDLE 14M
PROCESSING CODE		FA	FA	FA	FA
ELEMENTS mg/l	Al	0.20	0.30	0.30	0.10
	Ca	460.00	465.00	449.00	467.00
	Fe	1.70	2.80	8.70	0.30
	K	3.90	4.90	4.90	3.30
	Mg	43.00	44.00	42.00	44.00
	Na	138.00	139.00	135.00	140.00
	S	359.00	366.00	373.00	386.00
	Zn	36.00	37.00	36.00	38.00

In Table 10, the concentrations of those elements present above the detection limit as suspended solids are summarized. Increases in concentrations of iron in water of the Oriental East pit with depth are evident. With respect to differences in time, i.e. June with warmer water temperatures as compared to October, a higher zinc concentration (0.34 mg/l) in the suspended solid, compared to 0.24 mg/l in October on the surface, is evident. Based on these results, it can be concluded that the fractionation of zinc from a dissolved form to the precipitate is initiated in the pit.

The most distinct difference is evident for iron concentrations in the solids in Ponds 1 and 6, with higher values in October than in July. Overall, comparing the elemental concentrations on the filter papers from Pond 1 and Pond 6 to those determined in the laboratory oxidation experiment, similar trends in elemental composition of the precipitate are evident. This suggests that processes which have been noted to occur under the experimental conditions also occur in the ponds.

The retention time of the ponds was gradually reduced while the brush had been placed. By October, the flow rates to the ponds allowed for about 35 h of retention. Although it is not possible to establish a causal relationship between retention time and precipitate formation along with placement of the brush,

TABLE 10 Characteristics of filtered solids from Oriental East pit, Pond 1, Pond 6 - Oxidation Experiment

		Elements mg/l							
Site Location		Al	Ca	Fe	K	Na	S	Zn	Cu
O E PIT	June 2m	0.02	0.49	1.67	0.00	0.09	0.24	0.34	0.00
	Oct 2m	0.93	0.26	2.80	0.55	0.20	0.24	0.24	0.00
	Oct 7m	0.05	0.25	3.50	0.54	0.18	0.25	0.28	0.00
	Oct 14m	0.06	0.26	3.50	0.45	0.16	0.20	0.25	0.00
POND 1	July	0.00	0.26	0.78	0.00	0.11	0.45	0.40	0.00
	Oct	0.37	0.26	2.80	0.49	0.24	0.26	0.50	0.00
POND 6	July	0.01	0.19	0.42	0.00	0.10	0.64	0.49	0.00
	Oct	0.25	0.21	1.38	0.55	1.54	0.20	0.43	0.00
LABORATORY OXIDATION EXP.									
OE C	March	0.02	0.06	0.46	0.00	0.07	0.10	0.07	0.00
OE C	April	1.30	0.32	2.52	0.03	0.12	0.40	6.72	0.00
OE O-		0.12	0.15	0.35	0.08	0.10	0.39	10.20	0.00
OE O+		2.67	0.40	5.40	1.16	1.12	0.39	0.08	0.02
OE P		0.21	16.00	0.73	0.20	0.33	1.30	28.00	0.01
OW C		0.60	0.11	0.96	0.08	0.30	0.17	0.02	0.00
OW O+		2.60	0.40	5.40	1.20	1.10	0.39	0.09	0.02
OW O-		1.59	0.24	3.20	0.52	1.00	0.23	0.04	0.02
OW P		8.20	5.20	6.40	1.56	1.10	0.33	17.53	1.60

C Control O- Nitrogen Blanket O+ Air Bubbling P Phosohate Addition increasing retention time would likely further result in a reduction of the zinc concentration.

The only process which can be envisaged to result in zinc precipitation in these conditions is the formation of zinc carbonate, along with co-precipitation of iron and aluminium. Zinc carbonate precipitation is known to be governed by temperature. Some indirect evidence of temperature control on precipitate formation was obtained from the observation that the curtains, suspended in the Oriental East outflow, had a precipitate coating only to a depth of 4 m. The curtain at a lower depth was clear of precipitate. The depth of the coating corresponds to that depth at which the stratification of temperature and oxygen occurs in the Oriental East pit. These observations, together with the colour change after spring run-off in the pit, support the proposition that precipitation formation is temperature dependent. The factors controlling the precipitation formation therefore, are temperature and oxygen diffusion, i.e. ponding or retention time.

4.3 Precipitate accumulation: Biological Polishing

As the precipitation process converts the metals from a dissolved form to a suspended form, it is possible to filter them and thereby effect removal from the water column. Precipitate collected in

1988 in the first meadow, attached to either algae or brush, consisted of two types - whitish and brown precipitate. The concentrations of zinc and copper in these materials ranged between 8.3 and 22% and 0.6 to 0.8%, respectively.

It is likely that two different mechanisms are involved, as the respective concentrations of copper and zinc differed significantly in the end product, the white being higher in copper concentration than in zinc. In 1988, as only small isolated pockets were found with white precipitate, it was not considered a significant process. However, in October 1989, a large area of the first meadow close to the waste rock pile was covered in white precipitate. Here, water from the Oriental East pit mixed with seepage from the waste rock pile.

Samples of both types of precipitate were collected together with the periphytic algae. It was suspectedthat purple sulphur forming bacteria are at work, resulting in the formation of the whitish precipitate. Although the white precipitate has higher concentrations of sulphur (Table 11) carbon tetrachloride extraction of the precipitate produced negative results on the presence of elemental sulphur. At present, the formation of the white precipitate is being investigated through computer simulation.

TABLE 11 Characteristics of precipitates collected at various locations

SAMPLE DATE		10-Aug-88	10-Aug-88	12-Feb-89	12-Feb-89	04-Oct-89	04-Oct-89
ASSAYERS CODE		587	588	918	919	1489	1490
SAMPLING LOCATION		BROWN P/CIP FIRST MEADOW	WHITE P/CIP FIRST MEADOW	D TUNNEL DISCHARGE ALGAE/SED	WHITE P/CIP OE PIT OVERFLOW	WHITE P/CIP AT WRP	BROWN P/CIP AT WRP
PROCESSING CODE		SS	SS	SS	SS	SS	SS
ELEMENTS mg/l	Ag	< 0.1	< 0.1	27	2.2	< 0.1	5
	Al	1.8	1.64	4	0.8	70490	26500
	As	< 10	14	16	15	< 10	510
	B	700	200	0.05	0.03	200	400
	Ba	1018	921	6720	220	141	1547
	Be	< 10	< 10	< 0.1	< 0.1	< 10	< 10
	Bi	< 10	< 10	10	< 0.1	11	16
	Ca	1	0.8	0.5	0.14	2480	14200
	Cd	40	38	59	47	15	78
	Ce	< 10	< 10	21	< 0.1	< 10	< 10
	Co	49	64	20	< 0.1	< 10	41
	Cr	29	36	45	13	45	72
	Cu	665	813	2930	55	2632	429
	Fe	14.6	4.7	7	1.32	30100	244300
	K	0.5	0.83	1.5	1.6	249	6640
	La	42	52	97	22	27	50
	Mg	0.18	0.12	0.5	0.06	600	3000
	Mn	< 0.1	< 0.1	0.03	< 0.1	231	770
	Mo	16	37	15	< 0.1	57	151
	Na	0.81	0.7	1.1	0.6	3700	10360
	Ni	51	37	26	< 0.1	15	72
	P	0.14	0.2	0.08	< 0.1	440	880
	Pb	1005	806	9340	265	620	1359
	S	9000	16000	0.67	0.08	56000	7000
	Sb	< 10	< 10	55	< 0.1	< 10	< 10
	Se	< 10	< 10	18	< 0.1	< 10	< 10
	Sn	< 10	< 10	< 0.1	< 0.1	< 10	< 10
	Sr	101	64	128	18	10	75
	Te	< 10	< 10	22	< 0.1	19	< 10
	Th	< 10	< 10	12	< 0.1	< 10	20
	Ti	< 0.1	< 0.1	0.34	0.17	86	860
	U	< 10	< 10	49	< 0.1	< 10	12
	V	22	20	65	39	30	35
	W	2500	7980	30	< 0.1	25	17
	Y	23	34	86	48	40	26
	Zn	82800	222000	7500	696	2292	74000
	Zr	58	43	154	162	11	96

Insight into the formation of this precipitate, may yield some understanding of the copper concentrations which increase in the ponds.

Both precipitates have one important component in common, in that they accumulate in association with biological agents, the brown precipitate with an aquatic moss growth in both Oriental East and West pits and with the periphytic algae, Ulothrix, in the meadows. Through placement of brush into the Ponds 1 to 6 in the first meadow, it is hoped that the biological filtration can be initiated. The brush is intended to serve as growth substrate for the algae and the moss. In the first year of placement of the brush, biological polishing is not expected to occur, as the colonization of the substrate has not yet taken place.

However, the importance of biological agents lies in their provision of new filtration areas on an annual basis, due to continued growth. Non-biological filters would ultimately cease to function as the quantity of accumulated precipitate increases.

In the first year, therefore, the quantification of precipitate accumulation does not reflect the expected capacity of the system. Significant improvement should take place in the coming year.

In Table 12 the quantities of precipitate collected on the brush after 22 days and 92 days are presented, along with quantities on brush for which the time of accumulation was not known. If the precipitate accumulation occurs continuously, concentrating increasingly larger quantities with time, then the quantity of precipitate on the brush suspended for an unknown length of time should be higher than on brush suspended for **a** shorter period.

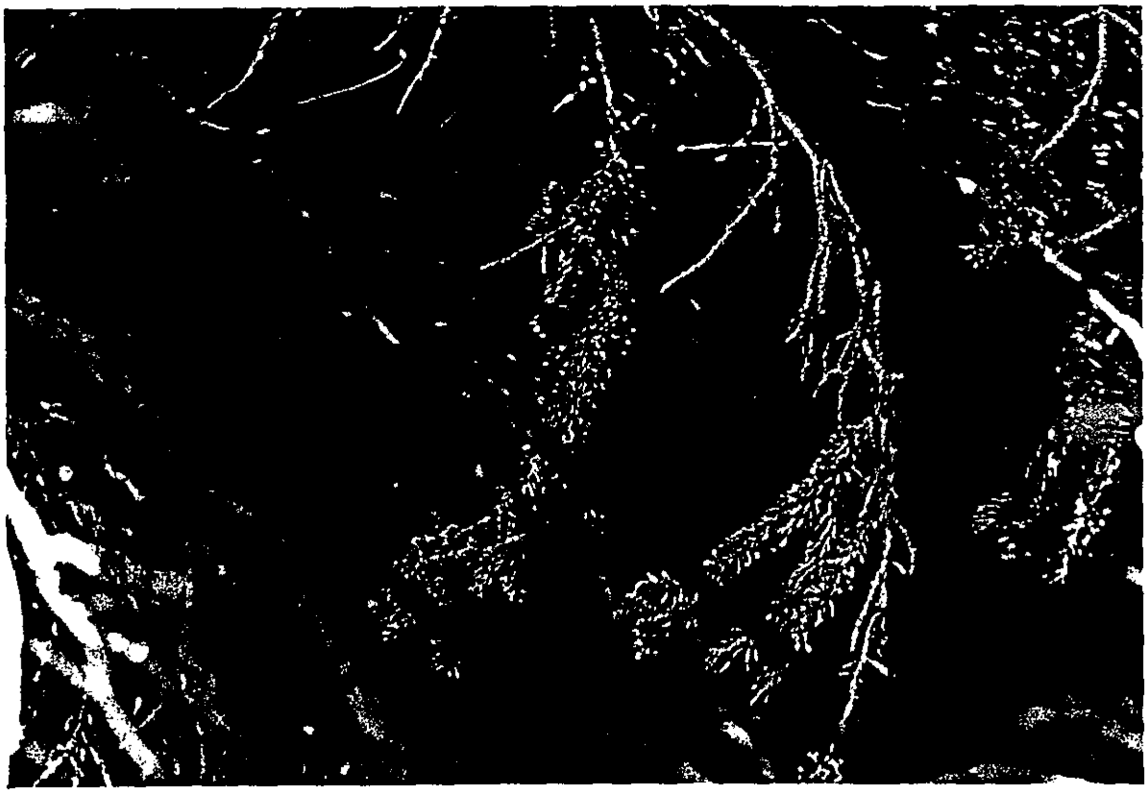
TABLE 12 Precipitate/ jelly accumulation in the Oriental West pit

Sample Date	OW 30-Jun-89	OW 26-Jul-89	OW 04-Oct-89
Date brush placed in pit.	?	?	04-Jul-89
Number of seasons in pit.	?	?	1st
Days of exposure	?	?	92
Branch biomass (g)	52	251	45
Jelly weight (g)	85	111	31
Kg. of jelly per Kg. of substrate.	1.6	0.4	0.7

? -- Old Brush, unknown exposure time

However, the quantities of precipitate collected on brush suspended for an unknown time do not indicate a continuous accumulation process, but rather suggest large differences in accumulated quantities. It is possible that the differences are due to a shortcoming in the method of precipitate collection. The precipitate is lightly attached, and given the instability of the boat, together with bringing the branches out from the water, loss of precipitate occurs to differing degrees. In Plate 1, a branch is depicted with "jelly" accumulation. The large differences of 2.8 kg of "jelly" per kg of substrate in June, compared to 0.4 kg/kg of substrate in July, could therefore be a result of sampling methodology, or sloughing off of precipitate due to wave action.

PLATE 1 Precipitate / jelly accumulation on brush



The accumulation of precipitate on the brush suspended for an unknown length of time in the Oriental West pit shows similar differences in quantities of "jelly" collected in June and in July than those noted in the Oriental East pit (Table 13). It is possible that the differences are not only due to the method of collection and sloughing off, given that in both pits, the July accumulation is lower than that in June.

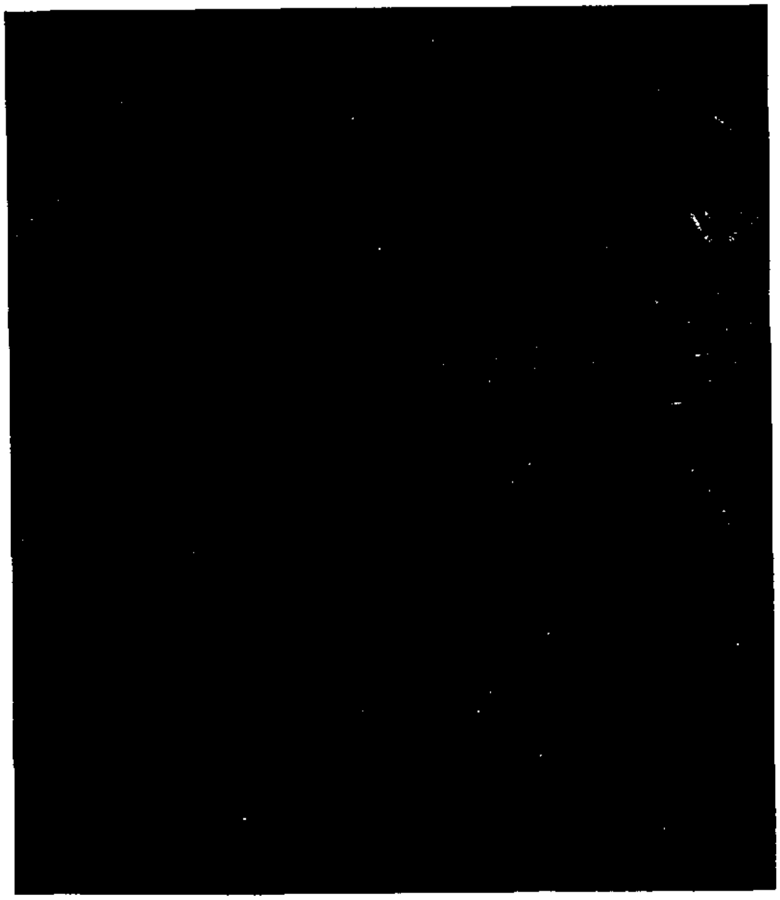
TABLE 13 Precipitate/jelly accumulation in the Oriental East pit

	OE	OE	OE	OE
	30-Jun-89	26-Jul-89	26-Jul-89	04-Oct-89
Date brush placed in pit.	?	?	04-Jul-89	04-Jul-89
Number of seasons in pit.	?	?	1st	1st
Days of exposure	?	?	22	92
Branch biomass (g)	34	379	217	161
Jelly weight (g)	95	145	4	42
Kg. of jelly per Kg. of substrate.	2.8	0.4	0.02	0.26

? -- Old Brush, unknown exposure time

The timed accumulation of "jelly" on brush however, indicates that more material has accumulated with longer exposure to the water. In the Oriental West pit, precipitate had not accumulated on the brush by the end of July, but was present by October. In the acidic conditions of this pit, the accumulation is clearly related to the initiation of growth on the substrate. A haze of periphytic growth can be noted on the curtain (Plate 2). It is anticipated that in both pits, the filtration process will be more effective in 1990 on the brush, as growth of moss and periphytic algae is expected to occur.

PLATE 2 The initiation of periphytic algal growth on the curtain in the Oriental West pit



The accumulation of precipitate in Ponds 1 to 6 however, appears to support an active filtration process, as the quantities of biomass are decreasing from 0.27 kg/kg of substrate in the first pond to 0.07 kg/kg of substrate in the last pond (Table 14). These data suggest that indeed the precipitate formed can be filtered in a pond system.

In Table 15 the concentrations are presented of the major elements determined in the precipitate jelly, as well as those in the leaves and wood which comprise the brush used as substrate. The fresh cut brush will initially absorb some of the metals. Compared to the control leaves and wood, a significant increase of concentrations of Al ,Fe, Na and Zn is evident in brush collected from both Pond 1 and Pond 6. However, the concentrations in the "jelly" of Al, Fe, K, Na and Zn are one order of magnitude higher. It can therefore be concluded that the precipitate is indeed filtered out.

The obtaining of values for suspended solids in this system is complicated by the shallow nature of the ponds. As a water sampling bottle is submerged, the precipitate is disturbed, and thus the suspended solids value is affected. Some estimates were obtained based on filter paper weights. Suspended solids in the Oriental East pit and the ponds range between 11.0 and 4.0 mg/l. Calculating the expected concentrations of zinc on the filter paper

TABLE Accumulation *of* precipitate in ponds 1 to 6

Sample date Oct.4 1989	POND 1	POND 2	POND 3	POND 4	POND 5	POND 6
Date brush placed in ponds.	27/8/09					
Number of seasons in pit.	1st	1st	1st	1st	1st	1st
Days of exposure.	30	30	30	30	30	38
Branch biomass (g)	51	90	145	110	117	210
Jelly weight (g)	14	12.5	23	17	21	14.5
Kg of jelly per Kg. *of* substrate.	0.27	0.14	0.16	0.15	0.18	*0.07*

Jelly g/100. Branch 1989 27 14 16 15 18 7
→ 1990 103 85 25 79 45 23

TABLE 15 Concentrations of major elements in precipitates in Ponds 1 to 6

SAMPLE DATE		24-Jul-89	04-Oct-89	04-Oct-89	24-Jul-89	04-Oct-89	04-Oct-89	04-Oct-89	04-Oct-89
ASSAYERS CODE		1559	1481	1483	1558	1482	1484	1495	1496
SAMPLING LOCATION		CONTROL LEAVES	POND 1 LEAVES	POND 6 LEAVES	CONTROL WOOD	POND 1 WOOD	POND 6 WOOD	POND 1 JELLY	POND 6 JELLY
PROCESSING CODE		SS	SS	SS	SS	SS	SS	SS	SS
ELEMENTS mg/l	Al	265	10070	9010	53	1590	1590	23320	24380
	As	< 10	200	151	< 10	195	289	< 10	< 10
	B	< 10	100	100	< 10	100	400	300	200
	Ba	277	385	308	167	315	270	649	661
	Ca	9285	12070	13490	6428	7810	9230	5680	7100
	Cr	10	47	44	< 10	35	44	58	54
	Cu	< 10	85	24	< 10	11	15	721	85
	Fe	629	22400	7700	279	2100	1400	58800	27300
	K	5833	4150	4980	2500	830	1660	12450	11620
	Mg	2400	1200	1800	602	540	600	1800	1800
	Mn	7751	539	616	465	462	231	308	385
	Na	74	5920	5920	74	740	740	20720	19240
	Ni	< 10	56	26	< 10	21	50	14	10
	P	272	880	1320	136	*440*	880	*440*	*4400*
	Pb	18	154	68	51	44	21	409	165
	S	2000	2000	2000	2000	1000	1000	1000	1000
	Sr	18	39	38	20	26	21	24	27
	Ti	87	602	602	87	86	86	1720	2580
	Zn	966	9869	9080	789	2582	1938	11000	13000
	Zr	< 10	46	40	< 10	< 10	< 10	124	157

(0.06 mg/1) and the mass accumulated on the paper (2.36 mg), the precipitate on the branches is expected to contain 2.2% Zn. In Table 15, Pond 1 jelly and Pond 6 jelly have zinc concentrations of 1.1% and 1.3% respectively, in the same order of magnitude as the above-calculated zinc content for suspended solids in the Oriental East pit. It can be concluded that the precipitate formed in the pit and in the pools is indeed filtered by the brush.

Although the pond system in the first meadow provides evidence that ponding alters the contaminant concentration and that filtration of the suspended solids takes place, the question of whether a similar reduction could be obtained without ponding should be addressed.

A survey of the water quality of natural pools in the first meadow has been carried out. It was intended to compare the water quality changes in the ponds to those which occur when water is diverted into the meadow without the construction of ponds. However, it was not possible to develop a methodology to obtain quantifiable data. In Table 16, the characteristics of the water in pools, collected several times over the summer season are presented. In general, the concentrations of Zn are somewhat lower then those leaving the Oriental East pit, ranging between 19 and 36 mg/1. This is within the same range of reduction noted between Pond 1 and Pond 6, and

TABLE 16: Water characteristics in pools in the first meadow

SAMPLE DATE		30-Jun-89	26-Jul-89	18-May-89	26-Jul-89
SAMPLE VOLUME		250 ml	150 ml	175 ml	250 ml
ASSAYERS CODE		1176	1250	1060	1251
SAMPLING LOCATION		POOL 10	POOL 10	POOL 11	POOL 11
PROCESSING CODE		FA	FA	FA	FA
Temp.		19	25	20	23
pH		5.35	5.67	6.3	5.64
Cond. (umhos)		1750	2300	1700	1925
ELEMENTS mg/l					
	Al	< 0.01	< 0.01	0.1	< 0.01
	Ba	0.06	0.01	0.03	0.01
	Ca	388	402	360	4L6
	Cu	< 0.01	< 0.01	0.01	< 0.01
	Fe	2.1	0.8	0.5	0.01
	K	< 0.01	< 0.01	2.3	< 0.01
	Mg	40	42	38	43
	Mn	9.6	9.9	8.8	10
	Na	130	130	124	133
	P	0.4	< 0.01	< 0.01	< 0.01
	S	402	379	354	385
	Si	7.8	8.5	7.7	8.6
	Sr	0.9	2.3	1.9	2.4
	Zn	23	19	23	24

SAMPLE DATE		30-Jun-89	26-Jul-89	04-Oct-89	04-Oct-89
SAMPLE VOLUME		250 ml	100 ml	250 ml	250 ml
ASSAYERS CODE		1175	1245	1387	1388
SAMPLING LOCATION		POOL 6	POOL 6	POOL 6	POOL 8
PROCESSING CODE		FA	FA	FA	FA
Temp.		21	22		
pH		5.6	5.45	5.2	5.44
Cond. (umhos)		1850	2100		
ELEMENTS mg/l					
	Al	< 0.01	< 0.01	0.7	0.1
	Ba	0.05	0.03	0.04	0.05
	Ca	702	366	230	189
	Cu	< 0.01	< 0.01	0.04	0.02
	Fe	< 0.01	0.7	8.9	5.4
	K	< 0.01	< 0.01	6.8	6
	Mg	42	43	27	23
	Mn	10	9	5.4	4.6
	Na	135	138	90	81
	P	< 0.01	< 0.01	0.3	0.2
	S	413	375	216	176
	Si	8.3	9.9	8	7
	Sr	1	2	0.4	0.4
	Zn	36	15	3.7	2.8

PROCESSING CODE		FA	FA	FA	FA
Temp.		21	21	-	20
pH		5.4	4.67	6.4	3.68
Cond. (umhos)		2000	600	-	600
ELEMENTS mg/l					
	Al	< 0.01	3.5	0.1	2.8
	Ba	0.04	0.04	0.04	0.04
	Ca	583	107	260	97
	Cu	< 0.01	0.01	0.02	< 0.01
	Fe	< 0.01	0.4	1.9	1
	K	< 0.01	0.1	4.1	< 0.01
	Mg	42	13	27	12
	Mn	10	2.8	6.4	2.6
	Na	135	42	91	39
	P	< 0.01	< 0.01	0.4	< 0.01
	S	409	123	230	111
	Si	8.3	6.4	6.8	6.3
	Sr	1	0.4	0.5	0.3
	Zn	37	5.9	6.9	4.3

SAMPLE DATE		04-Oct-89	26-Jul-89	04-Oct-89	26-Jul-89
SAMPLE VOLUME		250 ml	200 ml	250 ml	250 ml
ASSAYERS CODE		1389	1252	1390	1260
SAMPLING LOCATION		POOL 12	POOL 13	POOL 15	TRACKS BY POND 6
PROCESSING CODE		FA	FA	FA	FA
Temp.		11	26	10	26
pH		6.2	5.8	6	3.58
Cond. (umhos)		1475	2800	1500	1450
ELEMENTS mg/l					
	Al	0.3	< 0.01	0.07	1.7
	Ba	0.03	0.02	0.03	0.02
	Ca	434	427	440	330
	Cu	0.04	< 0.01	0.01	< 0.01
	Fe	< 0.01	0.1	0.1	4.9
	K	4.8	< 0.01	3.9	< 0.01
	Mg	42	45	42	41
	Mn	10.6	10	10.9	8.2
	Na	134	133	133	131
	P	0.3	< 0.01	0.3	< 0.01
	S	396	391	343	348
	Si	7.3	8.4	7.8	10
	Sr	1	2.4	1	1.7
	Zn	26	21	32	8.7

suggests that the same processes occur in the first meadow as in the ponds.

The Pools 6 and *8*, located close to Ponds 5 and 6, have low concentrations of zinc. Should these pools be contributing significant volumes of water to the Ponds 5 and 6, decreases in zinc concentrations in these ponds could be due to dilution. However, this is not likely as water movement from the ponds with regulated water levels to the peripheral ponds experiencing evapotransportation, is more likely.

Overall, the concentrations of zinc in the pools in the meadow are similar to those in the ponds. Therefore, the only purpose of the ponding of the Oriental East water is to optimize the process.

5 MICROBIAL ALKALINITY GENERATION

The treatment of acid mine drainage through the utilization of alkaline generating microbes has potential as an alternate approach to the conventional lime treatment. Within the framework of the ongoing research to develop Ecological Engineering methods, a process, referred to as ARUM (Acid Reduction using Microbiology) is seeking conditions which will optimize wetland sediment biogeochemistry with the microbial ecology which enhances sulphate reduction. The required supply of organic matter to drive a self-sustaining system is intended to be provided by a vegetative cover of cattails over the active microbial alkalinity generating and sulphate reducing sediment layer.

To date, alkalinity generation has been observed in various test plots in the field, i.e on site and after over-wintering, resulting in pH increases from 3.2 to 6.5. Concentrations of Al, Fe and Zn in acid mine drainage water have been decreased in the test situations (Kalin, Cairns and McCready, 1989). The ARUM process is in the first year of a 5 year pilot field test program for the treatment of seepages from tailings dams.

Acid mine drainage in the form of a seepage represents a quite different situation to that encountered in pits. In seepage streams, the difficulty is the establishment of a zone of oxygen-free and oxygenated sediment which is required for the microbial system and through which the water has to flow in order to be treated. If the process could be initiated in a pit, the overlaying water column has to be penetrated by the end product of the sulphate reduction, namely the hydrogen sulphide which precipitates the metals. In essence, the biological water treatment system has to be located at the bottom of the pit, above the water column to be treated. The production of hydrogen shulphide gas from the alkalinitygenerating microbes has to travel through the water to the surface in order to provide a mechanism for water treatment.

Organic material has to be used *as* sources of fixed carbon for cellulose degradation which (a) could be obtained in large quantities, and (b) provide a long lasting supply of cellulose as the time required to establish a self-sustaining supply of cattail vegetation will take several years. Sawdust and peat were selected as organic matter supplies which are quite recalcitrant. These materials were tested in limnocorrals (Plate 3) in the Oriental East and West pits.

Plate 3: **Limnocorrals in the Oriental West pit**

The concentrations of zinc are presented in Figure 13A for the surface water and in Figure 13B for the bottom of the Limnocorrals in the Oriental West pit. During the first 73 days after placement of the amendment, monitoring was carried out only with water collected on the surface, i.e. just below the surface. An initial slight decrease in concentration of zinc in both the peat and sawdust amended limnocorrals is due to adsorption of the metals. Essentially, no effects were noted in the concentrations of zinc until 95 days after placement of the amendments.

The concentrations of copper in the same limnocorrals are depicted in Figure 13C for the surface and in Figure 13D for the bottom. It appears that copper is adsorbed quite readily by peat as indicated by the copper concentrations of the surface. The bottom sample indicates less of a difference in adsorbency of the two materials. However, for copper, similar to zinc, no effects of the amendment is noted for the first 95 days after placement.

Although in all previous tests carried out by Boojum in other sites, amendments of sawdust and peat did not produce encouraging results, these should be useable on a theoretical basis to initiate the ARUM process. Samples of both peat and sawdust were collected on the 24th of July 1989 for a determination of some of the aspects of the microbial community.

FIGURE 13A Concentrations of Zinc in limnocorral surface water in the Oriental West pit

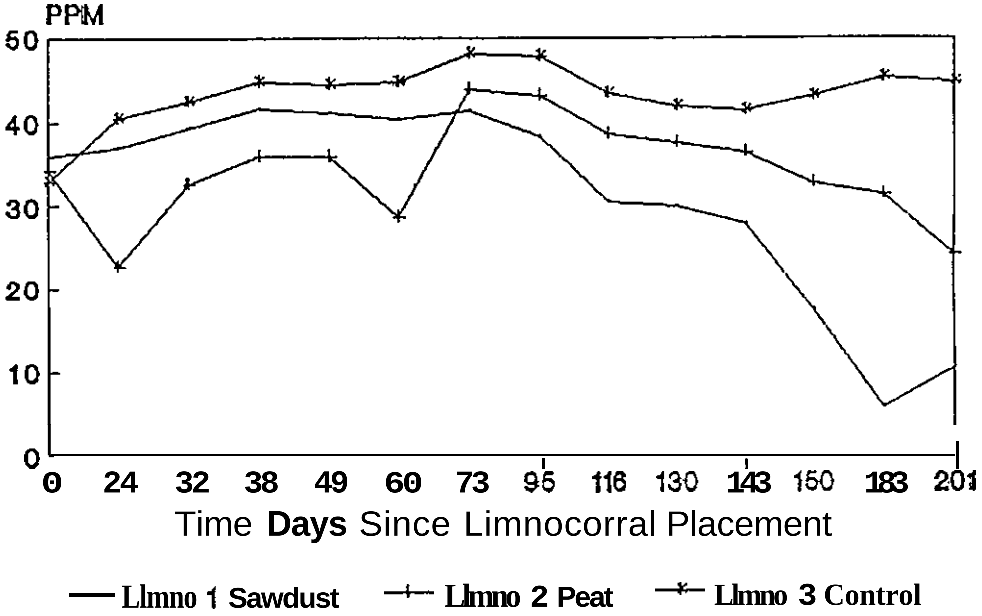


FIGURE 13B Concentrations of Zinc in limnocorral bottom water in the Oriental West pit.

~~85~~

85

79

44

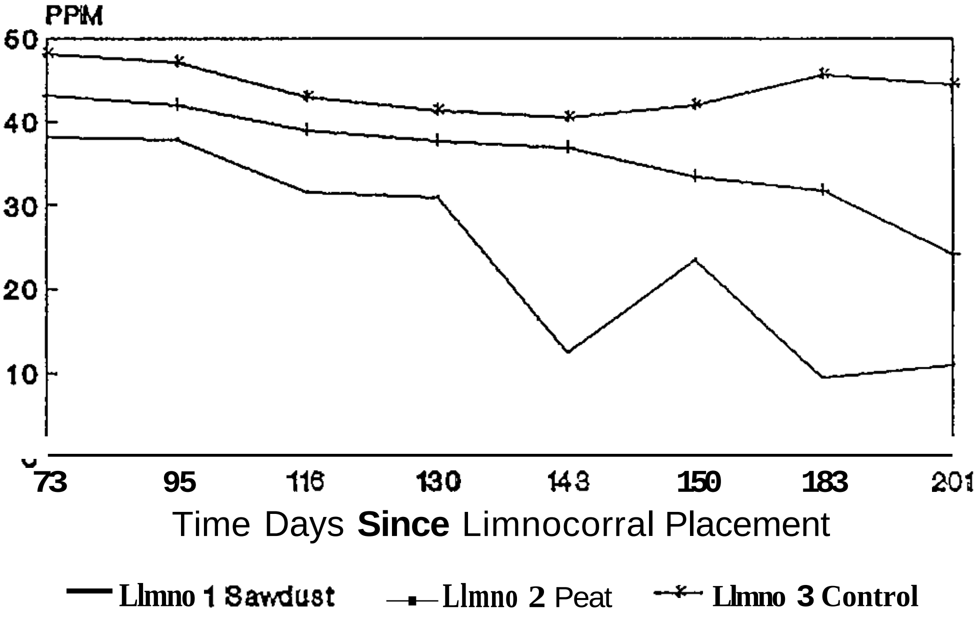


FIGURE 13C Concentrations of copper in limnocorral surface water in the Oriental West pit

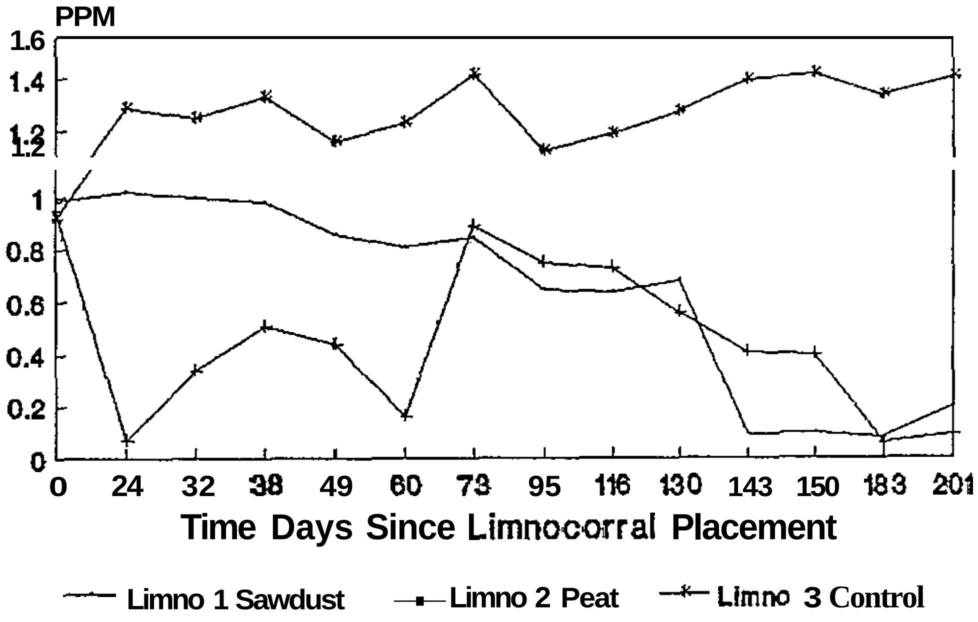
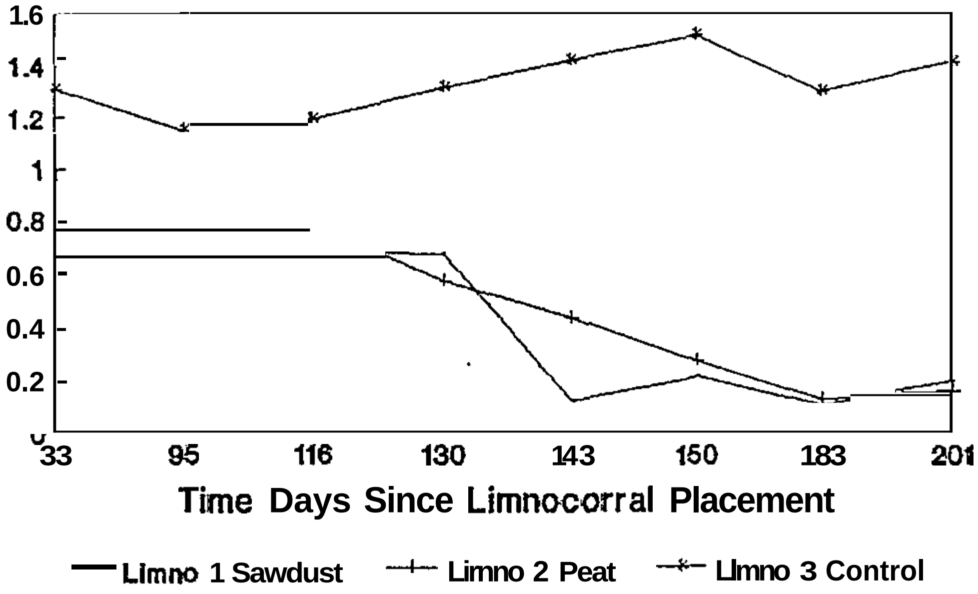


FIGURE 13D Concentrations of copper in limnocorral bottom water in the Oriental West pit.



The results of the microbiological survey indicate that iron reducing bacteria are absent from all amendments with the exception of the peat in the Oriental West pit. Ammonifiers and sulphate reducers on the other hand, are present in all amendments, with the exception of the peat in the Oriental West pit. This suggests that peat is less suitable as an amendment in the Oriental West pit orcontains more recalcitrant cellulose.

It was postulated, that the recalcitrant nature of sawdust and peat might be overcome or reduced if it is used together with a bio-augmentation product such as Dearborn Biolyte CX-70.

Dearborn Biolyte CX-70 is a specially formulated microbial product containing 17 species of micro-organisms selected for their ability to degrade complex carbohydrates, such as cellulose. In addition, the product contains free enzymes, including cellulose which will promote the initial stages of wood biodegradation. This product has the potential to assist the conversion of cellulosic amendments directly through the action of its enzymes and micro-organisms or indirectly by initiating an attack on the amendment and thus improving the accessibility of the indigenous micro-organisms to the substrate.

An experiment as outlined in Section 2 was conducted in the Dearborn laboratory. The objective was to examine the potential of this product to stimulate alkalinity generation in the amended limnocorrals in the Oriental East and West water.

The effect on water pH due to addition of the amendments and alkalinity generating micro-organisms is summarized in Table 17.

Table 17: pH changes in the Biolyte laboratory experiment

AMENDMENT *	Sept.5	Sept.14	Sept.25	Sept.29	Oct.12
1. Sawdust: pretreated with Biolyte CX-70 (0.4 kg per m3 of sawdust)	4	4	4.4	5	6.2
2. Sawdust: pretreated with Biolyte CX-70 (1.2 kg per m3 of sawdust)	4.1	4.2	5.4	6.2	6.5
3. Sawdust: obtained from Oriental West pretreated with BOD diluent only	3.4	3.7	3.7	3.7	3.8
4. Sawdust: obtained from Oriental West and not pretreated	3.3	3.6	3.6	3.7	3.8
5. Peat: obtained from Oriental West and not pretreated	3	3.1	3.2	3.3	3.3

* Oriental West water was added to Amendment (3:1, v/v) on August 29, 1989

The initial pH of the Oriental West water was pH 3.6. It is evident that the greatest pH rises were noted in fleakers which received sawdust pre-treated with Dearborn Biolyte CX-70.
The results further indicate that the peat amendment remains problematic. It was indicated, that cellulolytic activity of the product resulted ultimately in the production of nutrients for the alkalinity generating bacteria. Without the bio-stimulation caused by Dearborn Biolyte CX-70, pH rises were negligible. The laboratory experiment gave sufficient indication that amendment of the limnocorrals with biolyte appeared a reasonable option and this was accordingly tested.

Thus, by October 5th 1989. a mixture of alfalfa and biolyte (outlined in Section 2 in detail) was added to all limnocorrals with treatment in both pits. The result of the initiation of cellulolytic activity is evident in the significant reductions of copper and zinc concentrations after 130 days of placement of amendment, or after 11 days of addition of the biolyte to the limnocorrals (Figures 13A to 13D).

The changes in pH associated with the reduction of the metals are moderate of only about one pH unit from 3.5 to 4.5, and with time, the pH will continue to rise. In the laboratory, pH values generated by microbial systems have been as high as 7.5.

In general, the performance of both materials as amendments with respect to reducing the zinc concentrations is similar, as after about 180 days, the concentrations are reduced to very similar ranges, from 50 mg/l to 10 mg/l or less (Figures 13A, 13B, 14A, and 14B). The rates at which that reduction occurs may be slightly different, which would be a reflection of the differences in recalcitrance of cellulose degradation.

For the reduction of copper concentrations, the performance of both types of amendment after biolyte addition is effective in the limnocorrals in the Oriental West pit, where copper is reduced from 1.4 mg/l to 0.2 mg/l. In the Oriental East pit, where the copper concentrations are significantly lower, the control limnocorral Number 6, with no addition of amendment, displays the same concentrations and trends over time as is seen for the limnocorrals with amendment (Figure 14C and 14D). This is likely due to the fact that these concentrations are prone to error introduced by sampling and analytical uncertainty.

The results obtained after addition of biolyte to the limnocorrals clearly indicate that the ARUM process can be applied, and in principal, a significant reduction of zinc can be achieved in both pits and also for copper in the Oriental West pit.

FIGURE 14A Concentrations of zinc in limnocorrals surface water in the Oriental East pit

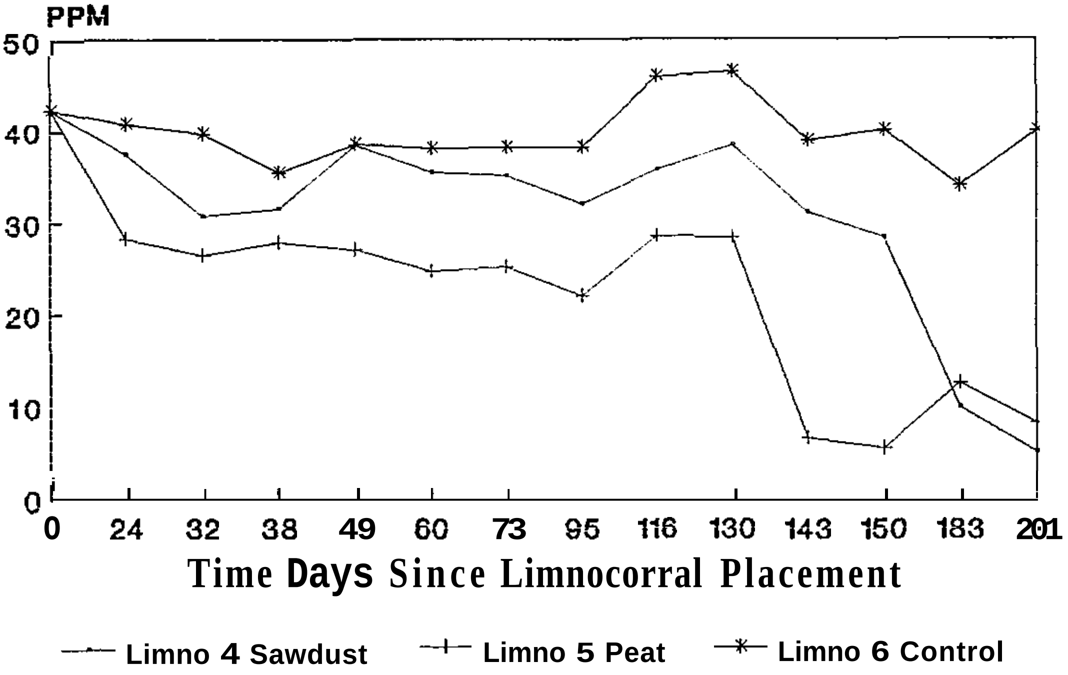


FIGURE 14B Concentations of zinc in limnocorrals bottom water in the Oriental East pit

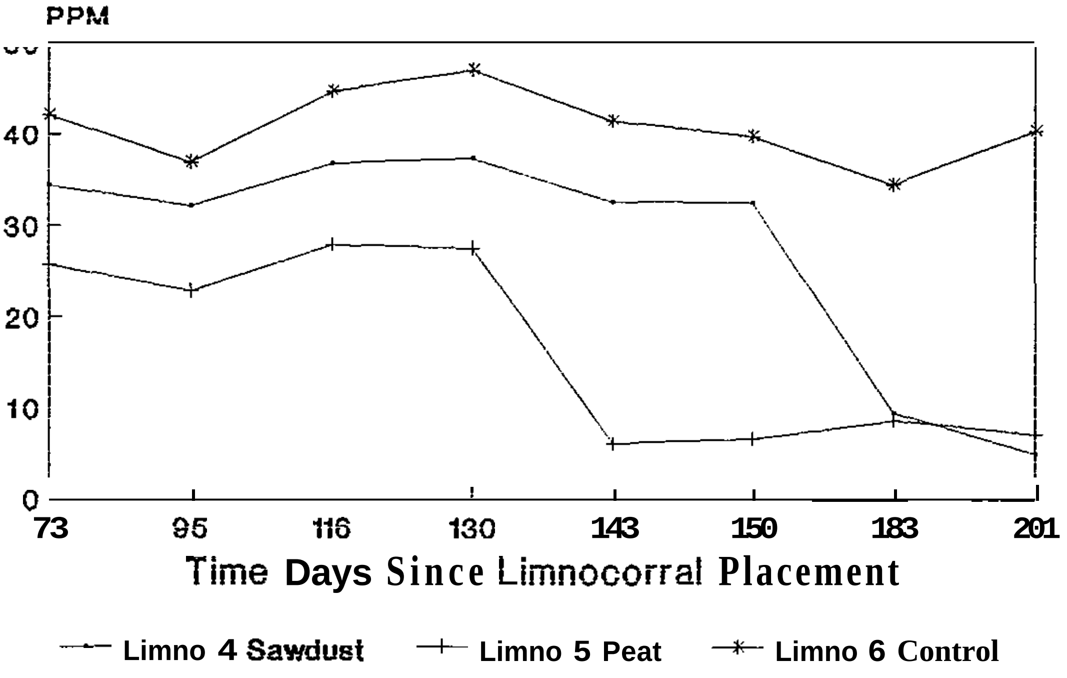


FIGURE 14C Concentrations of copper in limnocorrals surface water in the Oriental East pit

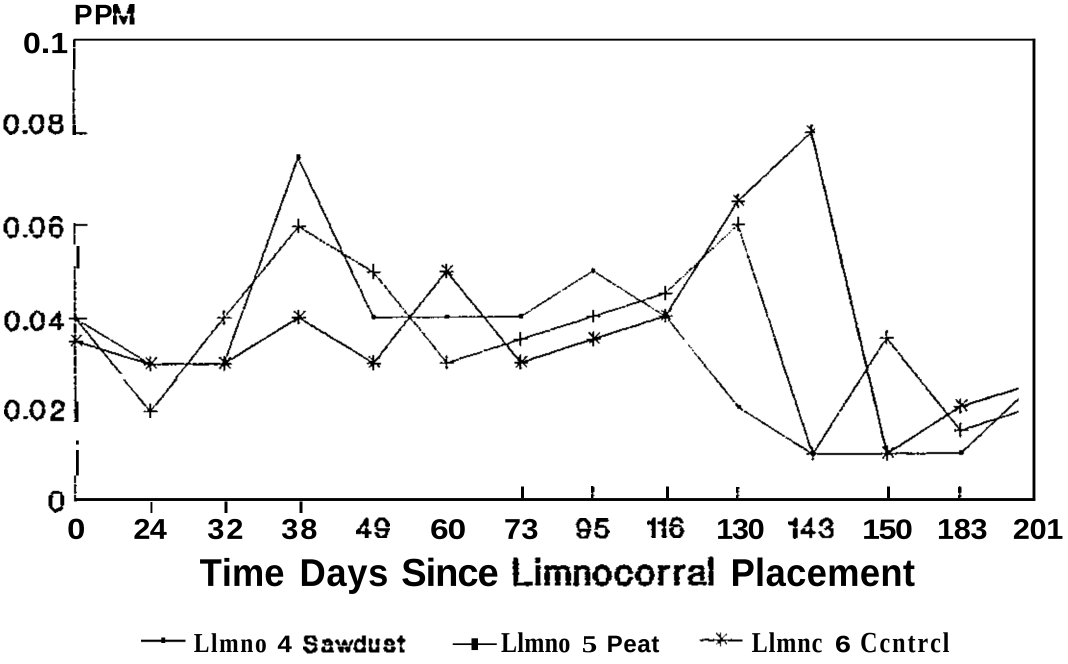
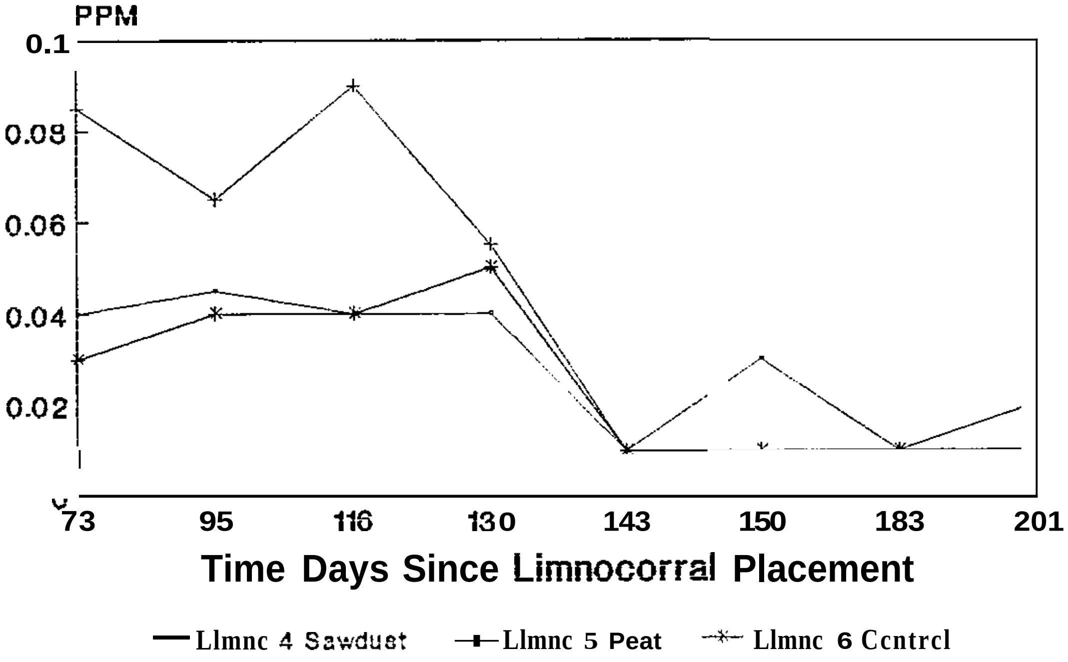


FIGURE 14D Concentrations of copper in limnocorrals bottom water in the Oriental East pit



6 SUMMARY AND CONCLUSIONS

The overall objectives of the **1989** program were to carry out an experimental program which would either produce evidence or refute conjectures made in the **1988** feasibility study. It was postulated that given the chemical and physical conditions of the Buchans mining area, Ecological Engineering methods could potentially provide a self-sustaining environmentally acceptable solution to the abandonment of the mining wastes. The applicability of these more natural methods was principally dependant on:

- the hydrological and geochemical characteristics of the area
- the utilization of natural precipitation processes which occur in the Oriental East pit and in the meadow
- the ability to provide a biological filter for the precipitate formed
- the determination of a suitable amendment for the pits to initiate microbial alkalinity generation.

The hydrological geochemical assessment indicated, with respect to the implementation of a natural system, that zinc concentrations leaving the Oriental pits are on a decreasing trend. If this trend continues, an implemented biological/natural system should perform better with time. The concentrations of copper are either diluted by water entering the Oriental East pit or removed from the water column due to the less acidic nature of the water in this pit. The Oriental East pit is discharging more water than can be accounted for by the precipitation/evaporation from the drainage basin. This suggests that any treatment system has to be designed to accommodate the flows, ranging around 10 1 /sec in the long term.

The source of neutralization is likely a combination of sand used as backfill and bedrock. Acid generation is occurring in the abandoned underground workings and provides a continuous source of copper. It was not possible during the 1989 program to determine if in the long term the balance between acid consumption and acid production can be maintained.

At present, a natural precipitation process results in conversion of dissolved zinc to suspended zinc concentrations, tentatively identified as zinc carbonate. The process is controlled by temperature and retention time, and it occurs both in the Oriental East pit and continues to occur in the experimental ponds as evidenced by the reduction in dissolved concentrations of zinc leaving the experimental pond system. The biological filtration capacity was not established by the end of the growing season in 1989, but is expected to increase by 1990.

The experiments with amending the Oriental East and West water with sawdust or peat indicated that, due to the presence of alkalinity generating micro-organisms, the concentrations of zinc and copper are significantly reduced in the Oriental West pit. In the Oriental East pit, a reduction in zinc is obtained to the same level as in the West pit, but copper concentrations remain at the same low level with or without amendment. The alkalinity generation was initiated by the use of a biolyte mixture. The differences between peat and sawdust as amendment materials for the ARUM process are likely a reflection of the type of cellulose contained.

7 RECOMMENDATIONS

From the data summary and discussion presented in the previous sections, the overriding conclusion has to be that indeed for the Buchans mining area, the implementation of an Ecological Engineering solution to produce a self-maintaining natural treatment system is possible. Although not all the experiments are completed and not all questions which require answers are available at this stage, an overall concept of the walkaway condition for the Oriental pits can be presented for discussion.

It must be emphasized that it is a conceptual close-out scenario for these water bodies which requires detailed evaluation. However, given that the results of the 1989 study are extremely promising, it is felt that through the presentation of the overall concept, a defined implementation plan can be developed.

The close-out concept for Oriental is envisaged as follows.

7. 1 Oriental Pits

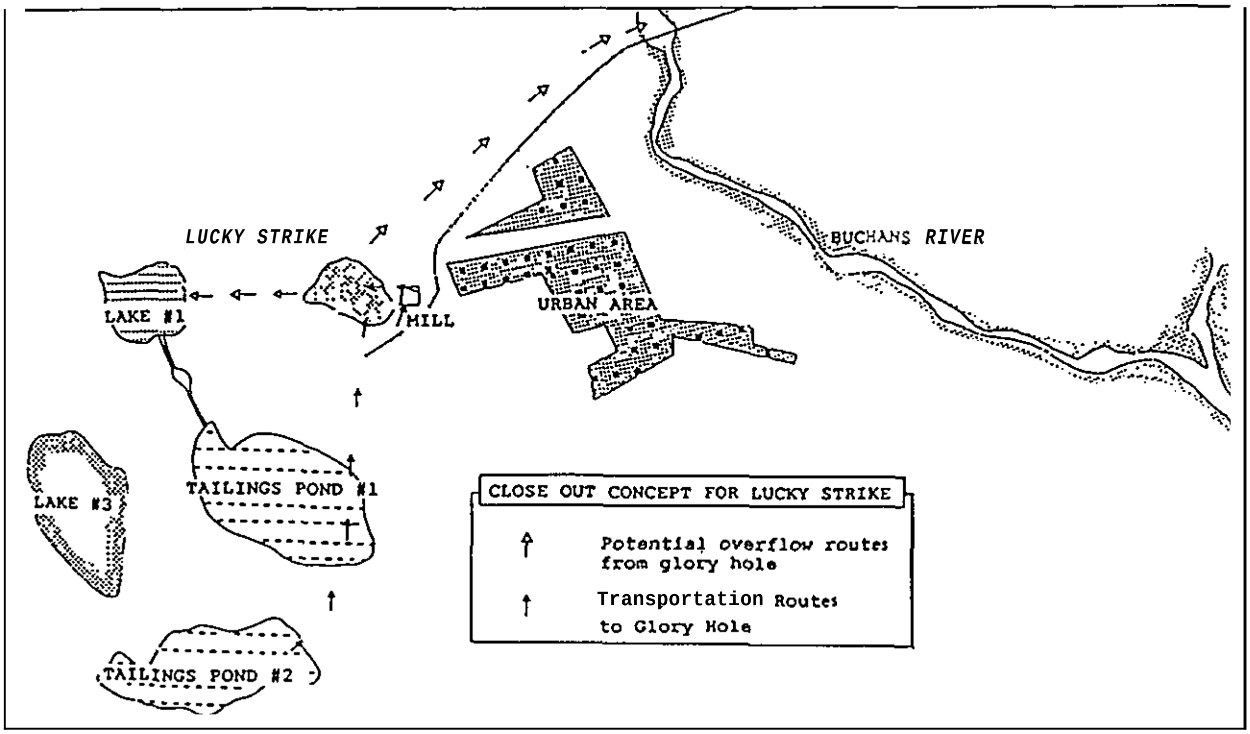
The question of whether the Buchans mining area has sufficient resources of alkalinity generation for production on a long term basis of those conditions which presently prevail in the Oriental East pit may never be answerable. It is reasonable, therefore, and environmentally responsible to assume that, in the long term, the acidic conditions would prevail. Given the indicated general trend in reduction of zinc concentration however, and the rather persistent concentrations of copper, alkalinity generation has to be implemented. The best location for the initiation of these measures is the Oriental West pit.

created from which clean water leaves to the Buchans river. In order to achieve this, the following options have to be considered: The glory hole should be filled to a level yet to be determined (Schematic 2, Question Area 1) with either backfill or tailings material. Both these materials generate a moderate amount of alkalinity which will counteract to some degree the existing acidity.

To determine which material, backfill or tailings, is most effectively used for filling of the Lucky Strike glory hole, the static leach test with both types of material and Lucky Strike water should be carried out. Filling the pit would also prevent or curtail further acidification due to water cover. To determine the level of filling, it is necessary to ascertain the ground water level surrounding the glory hole, in comparison to the water level in the glory hole (Schematic 2, Question Area 2).

Finally, the direction in which the water should or will leave the Lucky Strike should be determined (Question Area 3, Schematic 2). In Schematic 3, two alternatives for the movement of the tailings to the pit are envisaged, one directly slurried to the pit and the second option would involve some processing. This assumes of course, that tailings are the more effective material to be used. They could be slurried and possibly considered for reprocessing which might include the flotation of sulphides. This would allow for separate disposal of the sulphides if needed to reduce AMD, or if the use of backfill is neither economic nor effective in providing neutralizing capacity. The feasibility of extracting precious metals and barite should be evaluated. Some considerations of this possiblity are presented in the Appendix 3. Recovery of precious metals and barite could possibly offset the cost of the reclamation program. Two routes by which the clean water would leave the Lucky Strike are envisaged, either along the railroad to the Buchans river or to Lake 1, as indicated on Schematic 3.

SCHEMATIC 3: Proposed transportation routes of tailings and overflow from Lucky Strike



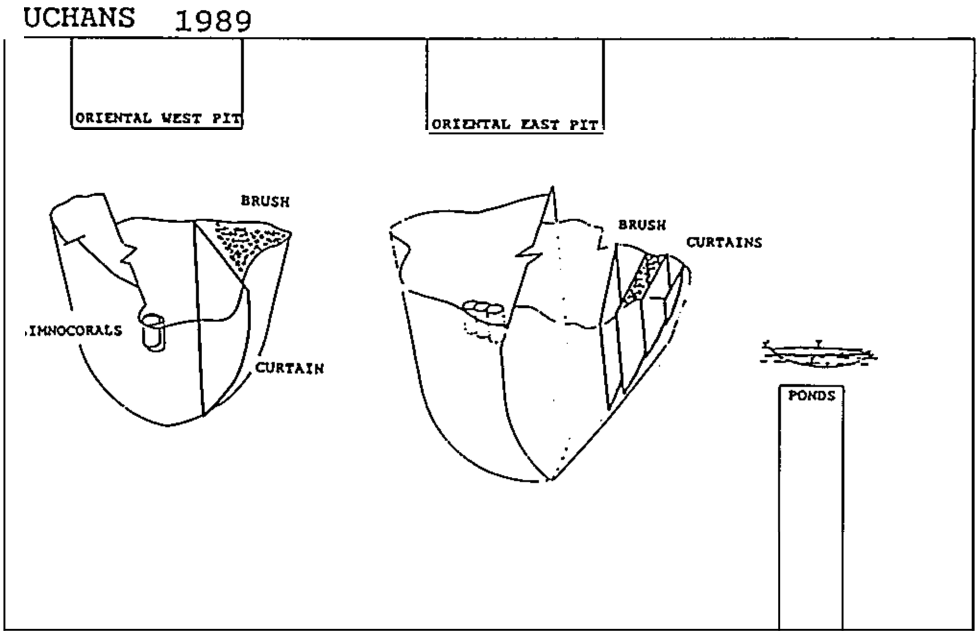
7.4 Oriental Pits

The question of whether the Buchans mining area has sufficient resources of alkalinity generation for production on a long term basis of those conditions which presently prevail in the Oriental East pit may never be answerable. It is reasonable, therefore, and environmentally responsible to assume that, in the long term, the acidic conditions would prevail. Given the indicated general trend in reduction of zinc concentration however, and the rather persistent concentrations of copper, alkalinity generation has to be implemented. The best location for the initiation of these measures is the Oriental West pit.

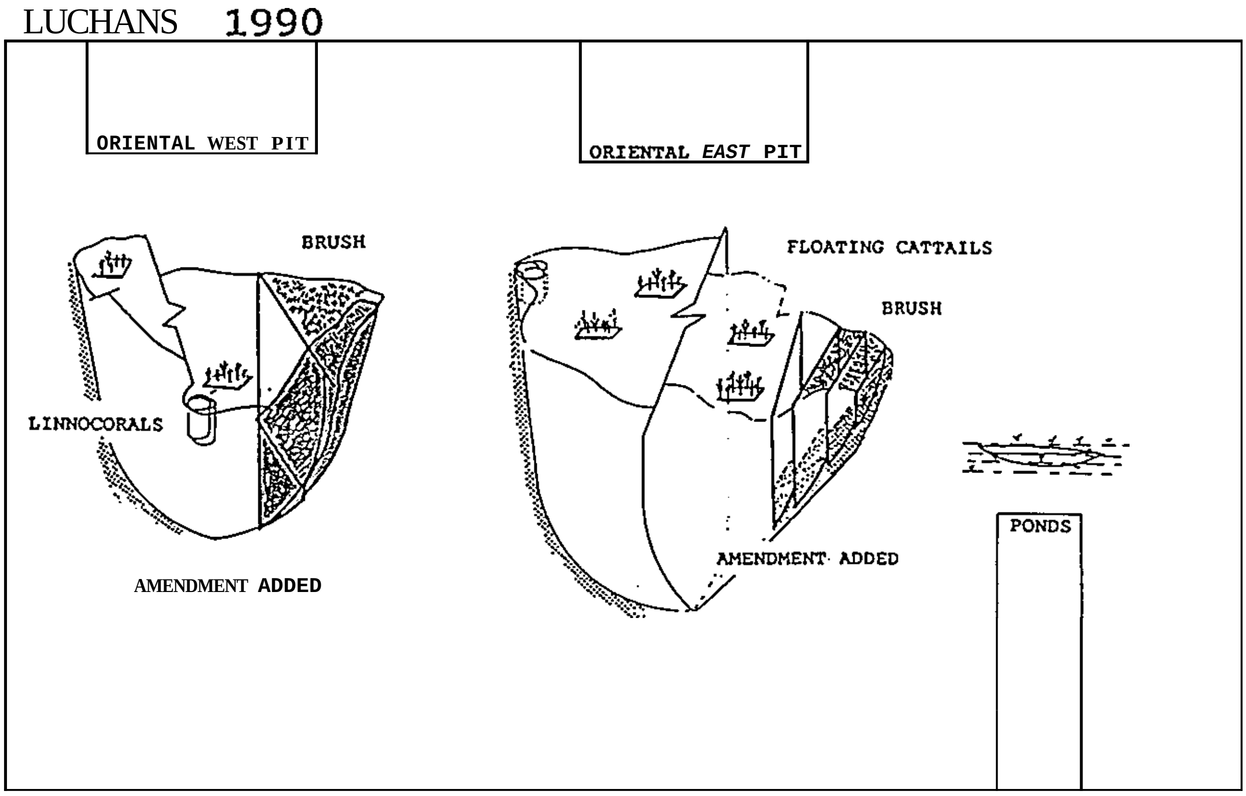
Given that the limnocorrals are producing good results with microbial alkalinity generation following the biolyte alfalfa amendment, it would follow that for these glory holes, organic amendments should be considered which would reduce the metal loading to the meadows.

The close-out scenario for the Oriental is represented in Schematics 4a and 4b and 5. In Schematic 4a the conditions are presented in which the pits are at the end of 1989 or beginning of 1990. The scale up from the limnocorrals has to be tested on an intermediate level before full implementation in the pit. These

SCHEMATIC 4A: Experimental status in the Oriental Pits



SCHEMATIC 4B: Proposed scale up for 1990 for the Oriental pits

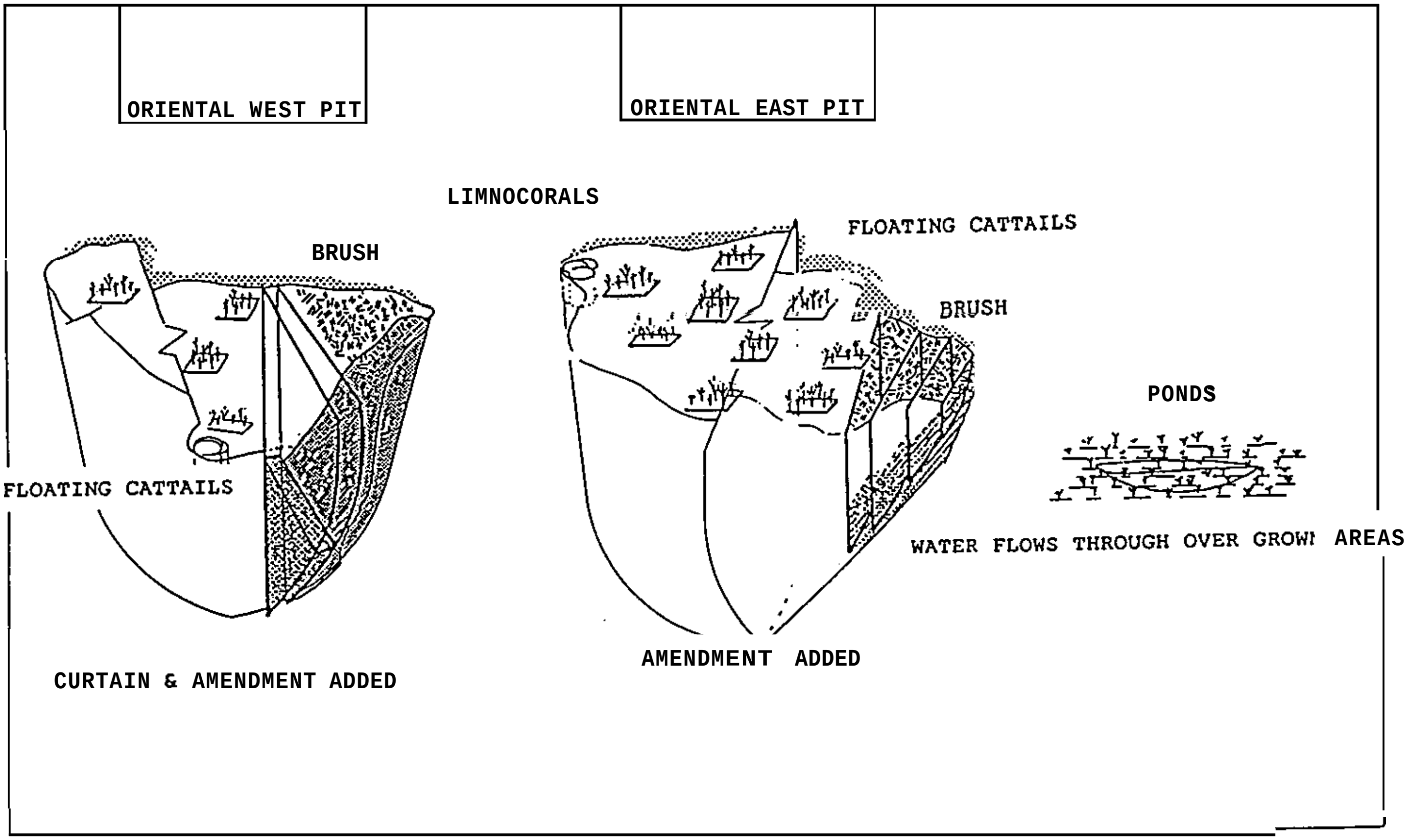


measures are depicted in Schematic 4b. It is proposed that the existing curtains are used for test areas, and at the same time, hydroponic cattail floats will be introduced to both pits. Some reduction of contaminants could be achieved in the Oriental West pit and at the outflow of the Oriental East pit if alkalinity generation is initiated similarly to the limnocorrals. The year 1990 would in essence, be the year in which the final confirmation of the system would be obtained.

After this year, in 1991 and the years to **follow**, the requirements on extending the system will be known and the floating cattails will provide a surface cover and through decomposition of the leaves, cellulose is provided to the alkalinity generating bottom sediment as depicted in Schematic 5.

From a biological point of view, the effectiveness of the system will improve with time. The final close out scenario for the Oriental pits would therefore consist of a floating wetland/cattail cover with a alkalinity generating bottom sediment. Thus should, in the long term the acid generation exceed the neutralization noted in the Oriental East pit at present, both pits together should be able to handle the reduction **of** copper an zinc. The ponds in the first meadow could be enlarged and considered as a backup polishing system.

SCHEMATIC 5: Final close - out concept for the Oriental pits



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APPENDIX 1 TO DECEMBER 1989 REPORT

4 JANUARY 1990

APPENDIX 2 lists the chemical analyses for filtrates from the leach experiment, for original waters from the Oriental West Pit, Oriental East Pit, Forebay, and Sandfill spring, and for samples collected 20, 40 and 62 days after the start of the experiment (data for samples collected at the end of the experiment, after 120 days, will be added later). Because of the inhomogeneous nature of the Sandfill material, and the low concentrations of many of the elements in the original waters, possible trends can be indicated only for some of the parameters.

Oriental West Pit water increased in pH, and decreased in conductivity, and in [Cu], [S], and [Zn] (the sulfate value in the analysis of the original water is probably wrong).

Oriental East Pit water decreased somewhat in pH and conductivity, and in [Ca], [Mn], [Na], [S], and [Zn] (the sulfate value in the analysis of the original water is probably wrong).

Forebay water showed small decreases in pH, and in [K] and **[Na],** and small increases in conductivity and in [Al], [Ba], [Ca], [Mg], [S], and [Si].

Sandfill spring water showed small decreases in pH, conductivity, [Ca], [Mg], **[Na],** and [Si], and small increases in [Al], [Ba], [Fe], [Mn], and [S].

The results suggest that geochemical effects of the presence of Sandfill material in the workings of the Oriental Mine are likely to be relatively minor. They probably include neutralization of some of the available acidity (increase in pH), small decreases in conductivity and in Cu and Zn concentrations.

DRILLHOLE DATA AND ANALYSES OF DRILLHOLE SAMPLES

APPENDIX 3 lists data for drillholes, in the vicinity of the Oriental Pits, in which the presence of calcite was mentioned in the core descriptions, indicating some acid-neutralizing potential.

The third page of Appendix 3 lists drillholes in the same area that have been found to be still accessible. Conductivity and pH measured in small samples collected from the top of the water column in these drillholes are listed in the same table. One-litre samples for chemical analysis were collected from DH# 209, 292, 300 and 1080 on 15 November 1989.

APPENDIX 4 lists the analytical results for the drillhole samples together with earlier analyses of surface waters, groundwater, and pit waters, for comparison. For convenience, Figure A4-1

ASARCO-BUCHANS

PROBLEMS FOUND IN AVAILABLE DATA (4 January 1990)

1. Drillhole Data:

In the listing provided by Mr. Neary, nineteen of the 'selected' drillholes with numbers above 1000 show elevations >3000 ft. I presume that the prefix 3 was added to make nominal elevations for the mining operation positive. This requires confirmation.

2. CHEMEX data of 20 July 1989:

The SO, values for the Oriental East Pit water are too low to make sense; I suspect that they have not been corrected for dilution in the laboratory. This should be checked.

3. Weather Data:

We still do not have daily precipitation and temperature data for March 1989 and April 1989. In addition, only partly legible Xerox copies of data sheets are available for: July 1985; March and July 1986; March, August and September 1987; May and June 1988. **Also**, the 1989 data sheets transmitted by FAX miss some lines, and on most the dates do not show. The degree of correlation of the various discharges with precipitation cannot be determined until the record is complete.

In future it would be better to make LEGIBLE 8+ x 14 Xerox copies, and have them sent by mail direct from Buchans to Calgary. This would save both FAX and courier charges.

4. Monitoring Data for 1989:

The LEVEL for the Oriental West Pit for 1 October 1989 (822.6') can't be right.

The pH for the Oriental East Pit for 15 July 1989 (4.8) is too low to be reasonable, unless the pit was limed again.

The pH values for Simms Brook for 3 June and 29 July 1989 (9.5 and 8.3) are questionable.

The pH data for Buchans River show a number of values exceeding 9.0; is there any explanation for this?

Buchans Sandfill Leach Experiment 1989

FILTRATES, conc. in mg/L

WATER SOURCE	O.West	O.West	O.West	O.West	O.West	O.West
Elapsed, clays	0	20	40	62	120	22-R
Sample Date	03-Sep	27-Sep	17-0ct	08-Nov		08-Nov
Assayers #	wh 1360	1397	1485	1501		1529
pH	3.20	5.00	5.00	5.00		4.80
Cond. (urnhos)	830	690	745	650		720
Cu, mg/L-ASARCO	1.35	0.42	0.34	0.38		0.81
Zn, mg/L-ASARCO	43.505	11.95	9.65	11.6		23.85
Ag	<0.01	0.01	(0.01	<0.01		(0.01
Al	4.7	0.4	0.5	1.5		2.5
As	0.8	0.3	(0.01	<0.01		(0.01
8	(0.01	0.04	0.2	<0.01		<0.01
Ba	0.05	0.1	0.2	0.4		0.4
Be	(0.01	0.01	<0.01	(0.01		<0.01
Bi	0.02	0.08	0.06	<0.01		<0.01
C	<0.01	38	718	89		29
Ca	135	155	130	131		139
Cd	0.3	0.4	0.04	<0.01		<0.01
Ce	0.02	0.02	(0.01	(0.01		<0.01
Co	0.09	0.2	0.1	<0.01		(0.01
Cr	0.01	0.07	0.03	(0.01		(0.01
cu	1.4	0.6	0.2	0.2		0.6
Fe	1.2	(0.01	(0.3	0.8		1.6
Hg	0.03	0.01	(0.01	(0.01		(0.01
K	2.9	7.3	0.5	<0.01		(0.01
La	0.05	0.1	0.07	0.1		0.1
Mg	14	20	17	15		14
Mn	2.9	2.9	2.6	3		3.2
Mo	0.3	0.9	0.08	<0.01		(0.01
Na	7.3	10	8	7.5		6.6
Nb	0.1	0.03	0.01	<0.01		<0.01
Ni	(0.01	0.07	<0.01	<0.01		(0.01
P	2.9	0.2	7.6	(0.01		<0.01
*** Ph	1.4	0.2	0.06	(0.01		<0.01
S	362	160	116	1SO		163
Sb	(0.01	0.07	0.02	<0.01		(0.01
Se	0.01	0.1	0.09	<0.01		(0.01
Si	8.9	13	12	11.7		11.1
Sn	(0.01	0.03	0.01	(0.01		(0.01
Sr	0.4	0.2	0.2	0.2		0.7
Te	0.1	0.2	0.1	(0.01		0.1
Th	(0.01	0.02	(0.01	(0.01		(0.01
Ti	(0.01	0.01	0.01	<0.01		(0.01
U	0.1	0.02	0.07	(0.01		(0.01
V	<0.01	0.03	<0.01	<0.01		<0.01
W	0.1	0.1	0.07	<0.01		(0.01
Y	0.03	0.07	0.05	(0.01		0.1
Zn	58	15	10	11		23
Zr	0.01	0.03	(0.01	(0.01		(0.01
Chloride	1086	-	-	-		-
Acidity ??	141	26	-	20.4		-
*** Sulphate	7	-	-	457		-
Cu (Asarco/Lab)	0.96	0.70	1.70	1.90		
Zn (Asarco/Lab)	0.75	0.80	0.97	1.05		

Buchans Sandfill Leach Experiment

FILTRATES, conc. in mg/L

WATER SOURCE	Forebay	Forebay	Forebay	Forebay	Forebay
Elapsed, days	0	20	40	62	120
Sample Date	03-Sep	27-Sep	17-Oct	08-Nov	
Assayers #	wh 1359	1399	1488	1503	
pH	6.80	5.60	5.80	6.60	
Cond. (umhos)	19	40	31	32	
Cu, mg/L-ASARCO	0.01	0.04	0.07	0.04	
Zn, mg/L-ASARCO	1.005	0.14	0.02	0.02	
Ag	(0.01	<0.01	(0.01	(0.01	
Al	0.03	0.02	0.7	0.5	
As	(0.01	(0.01	(0.01	<0.01	
B	<0.01	0.01	0.06	(0.01	
Ba	0.02	0.1	0.09	0.1	
Be	<0.01	(0.01	(0.01	<0.01	
Bi	(0.01	(0.01	(0.01	<0.01	
C	(0.01	55	110	60	
Ca	2.3	4.8	5.8	5.4	
Cd	(0.01	(0.01	<0.01	(0.01	
Ce	0.01	(0.01	(0.01	(0.01	
Co	(0.01	<0.01	<0.01	<0.01	
Cr	(0.01	(0.01	(0.01	(0.01	
Cu	(0.01	0.01	(0.01	<0.01	
Fe	0.01	(0.01	0.8	(0.01	
Hg	<0.01	(0.01	<0.01	(0.01	
K	3	2.5	(0.01	(0.01	
La	0.02	(0.01	(0.01	(0.01	
Mg	0.4	0.7	0.8	0.5	
Mn	<0.01	0.1	0.08	<0.01	
Mo	(0.01	(0.01	(0.01	<0.01	
Na	2.3	3	1.1	1.7	
Nb	(0.01	(0.01	<0.01	(0.01	
Ni	(0.01	(0.01	(0.01	<0.01	
P	<0.01	0.1	(0.01	(0.01	
Pb	<0.01	0.01	(0.01	(0.01	
*** S	1.5	3.2	2.8	3.8	
Sb	(0.01	<0.01	(0.01	<0.01	
Se	<0.01	(0.01	(0.01	<0.01	
Si	1.0	7.7	8.1	6	
Sn	(0.01	(0.01	(0.01	(0.01	
Sr	<0.01	0.01	0.01	(0.01	
Te	(0.01	<0.01	(0.01	(0.01	
Th	<0.01	(0.01	(0.01	(0.01	
Ti	(0.01	<0.01	0.01	(0.01	
U	0.04	<0.01	(0.01	(0.01	
V	(0.01	0.01	(0.01	(0.01	
W	<0.01	(0.01	<0.01	(0.01	
Y	<0.01	(0.01	<0.01	(0.01	
Zn	<0.01	0.09	0.08	<0.01	
Zr	(0.01	(0.01	<0.01	<0.01	
Chloride	4.7	-	-	-	
Acidity ??	14.2	10	-	3.9	
*** Sulphate	8	-	-	11.7	
Cu (Asarco/Lab)	ERR	4.00	ERR	ERR	
Zn (Asarco/Lab)	ERR	1.56	0.25	ERR	

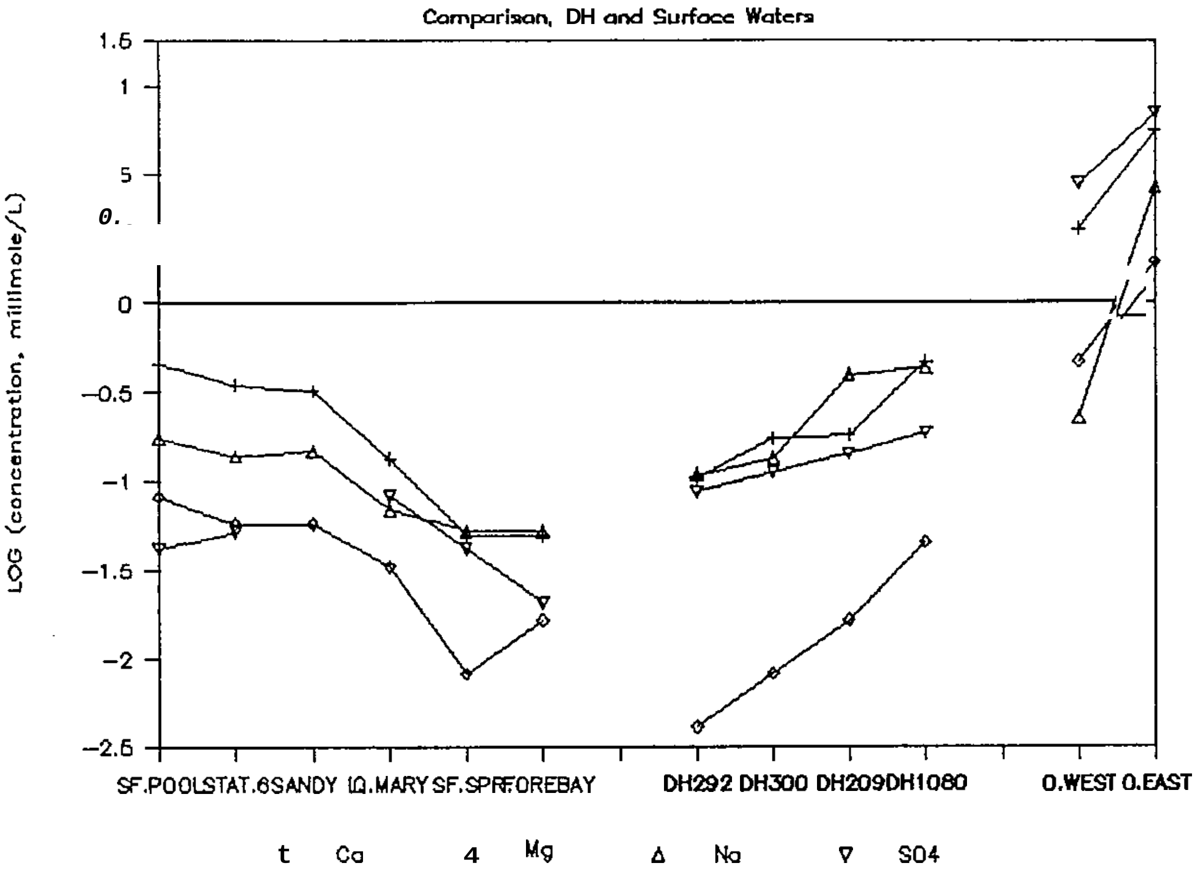
DRILLHOLES showing CALCITE (data in feet)

DH #	Northing	Easting	Collar	T.O.	CALCITE interval		Average CALCITE	
	ft	ft	Elev.	ft	from	to	depth	elev.
124	6600	11402	798		326	336	331	467.0
125	6601	12099	767		189	407	298	469.0
130	6402	12099	761		143	166	155	606.5
133	6322	9686	796		416	464	440	356.0
137	6401	12504	752		122	167	145	607.5
140	6201	12900	741		93	146	120	621.5
142	6204	9851	786		26	34	30	756.0
145	6501	9298	814		435	442	439	375.5
153	6747	11411	805		23	56	40	765.5
158	7443	11420	802		1554	1630	1592	-790.0
170	7568	10901	822		410	486	448	374.0
170			822		970	997	984	-161.5
206	6797	11801	779		126	130	128	651.0
216	7102	12703	762		114	278	196	566.0
216			762		243	277	260	502.0
280	6730	12800	752		99	285	192	560.0
292	7400	12630	772		627	717	672	100.0
295	8500	11000	826		1091	1167	1129	-303.0
296	6880	12850	761		502	539	521	240.5
303	7080	11100	820		310	345	328	492.5
981	7250	13000	765		121	144	133	632.5
981			765		851	892	872	-106.5
1022	7000	13000	759		265	287	276	483.0
1027	7000	11750	781		430	455	443	338.5
1031	7000	11575	791		619	633	626	165.0
1031			791		651	661	656	135.0
1147	6550	10441	813		266	269	268	545.5
1149	6700	10591	818		216	232	224	594.0
1149			818		298	300	299	519.0
1149			818		389	399	394	424.0
1154	6850	10741	822		240	248	244	578.0
1294	7150	10000	825		720	723	722	103.5
1311	6700	9300	816		249	254	252	564.5
1311			816		286	296	291	525.0
1343	6625	9850	822		175	196	186	636.5
1435	6625	9775	825		258	256	257	568.0
1442	5300	4000	968		3	147	75	893.0
1442			968		156	173	165	803.5
1442			968		185	194	190	778.5
1442			968		290	498	394	574.0
1442			968		532	533	533	435.5
1442			968		545	586	566	402.5
1442			968		740	798	769	199.0
1442			968		1197	1299	1248	-280.0
1450	7000	10200	821		159	180	170	651.5
1461	6500	9925	821		214	225	220	601.5
1872	7125	11500	795		60	629	345	450.5
1872			795		644	647	646	149.5
1876	7275	11500	795		61	446	254	541.5
1876			795		476	735	606	189.5

ASARCD - BUCHANS UNIT

DRILLHOLE DATA (in feet)

					DEPTH		ELEVATION				
DH #	Northing ft	Easting ft	Collar Elev.	T.D. ft	Bedrock	Water	Bedrock	Water	TEMP. degree C	pH units	COND. microS/cm
O.E.P.	6023	11727						759	6	6.7	1420
SFS	9500	12000						760	6	7.9	70
209	7005	11997	785		59	15	726	770	6.5	7.1	100
292	7400	12630	772		123	18	649	754	7.1	8.2	21
295	8500	10994	827		30	3	797	824	5.8	7.7	328
300	8759	10544	851		20	5	831	846	6.1	8.2	205
1062	7999	11499	804		68	14	736	790	7.0	9.5	85
1080	7992	11816	816		44	0	772	816	6.0	7.6	98
1084	7999	10501	829		40	9	789	820	7.1	8.7	53
1579	10048	10437	856		140	56	716	800		7.9	
1606	10166	13441	806		79	42	727	764	5.2	9.2	128
2353	7130	11999	777		83	31	694	746	5.1	6.8	53
2367	6899	11509	797		27	27	770	770	5.2	7.1	44


Comparison, DH and Surface Waters
LOG (concentration, millimole/L)
1.5
1
5
0.
0
-0.5
-1
-1.5
-2
-2.5
SF.POOLSTAT.6SANDY 1Q.MARY SF.SPRFOREBAY
DH292 DH300 DH209DH1080
O.WEST O.EAST
t Ca
4 Mg
Δ Na
∇ S04

SELMINCO. Two water samples were collected on February 13, **1989.** One sample was purged with N_2 and used for sub-samples (O^-) and (O^+). The other sample was used for sub-samples (Cs), (Cf), and (P).

DENISON. Two samples were collected on March 26, 1989. No special preservation was used. The samples were processed on March **28,1989.** All sub-samples were obtained from these two bulk samples.

Whenever two samples collected on different dates were mixed neither the proportions of the two original samples nor the chemical analyses of the two waters were known.

Data collection:

At twenty-four hour intervals, the ph, conductivity and temperature were measured in'each of the sub-samples. Chemical analyses were performed on the samples at the start and at the end of the experiment. After the various sub-samples were created and the suspended material had settled, a 250 ml aliquot was taken of the supernatant liquid and filtered through a 0.45 micron filter under the standard conditions. The filtrate was acidified and the filter residue dried and weighted. Both filter residue and filtrate were analyzed (Cs). In addition an unacidified sample was submitted for analysis of nitrate, ammonium, chloride and sulphate. At the end of the experiment a 250 ml sample was again obtained of the clear water portion of the sub-samples. This sample was filtered, acidified and submitted for analysis. Following the sampling of the clear water portion the remaining water and precipitate were homogenized. Care was taken to ensure that all solids adhering to the wall of the jar were also removed and suspended. While continually mixing, a 250 ml sample was withdrawn. This sample was then filtered through a pre-weighted and conditioned filter paper under standard laboratory conditions. Subsequently the filter residue was submitted for analysis. Following the removal of all the samples the remaining volume in the jars was measured using calibrated beakers.

Two blank filter papers were also analyzed to obtain background data on the elemental concentration within the filter papers.

RESULTS

The results of the pH, conductivity and temperature measurements are listed in Table 1, the analytical results of the various samples are shown in Table **2,** and the weight of the precipitates is listed in Table 3. Tables 1,2 and 3 are not included in the appendix for brevity.

for and 12). A comparison of these figumilarity between the variability of tfour different waters, especially if td is considered. This strongly suggbility of the pH measurements with timesurement procedure.

he Oriental West water caused a cons(approx. 2 units). None of the watd a similar change. Although the exae following explanation is given forlved phosphate species from the add HPO4-. This species is unstable forThe stable form would be $H_2PO_4^{-2}$. Theuld result in an increase in the pH.e oxide/hydroxide complexes this cha by the acid buffering capacity of has the lowest concentration of Fe account for the lack of any sig

ELEments considered for the four dife listed as inorganic parameters intion of freshwater aquatic life (Enpecific to the mine site. The totfiltrate plus precipitate) are sh6, the elemental concentrations in Figures 17 and 18, and the pe precipitate versus the total cogures 19, 20, 21 and 22.

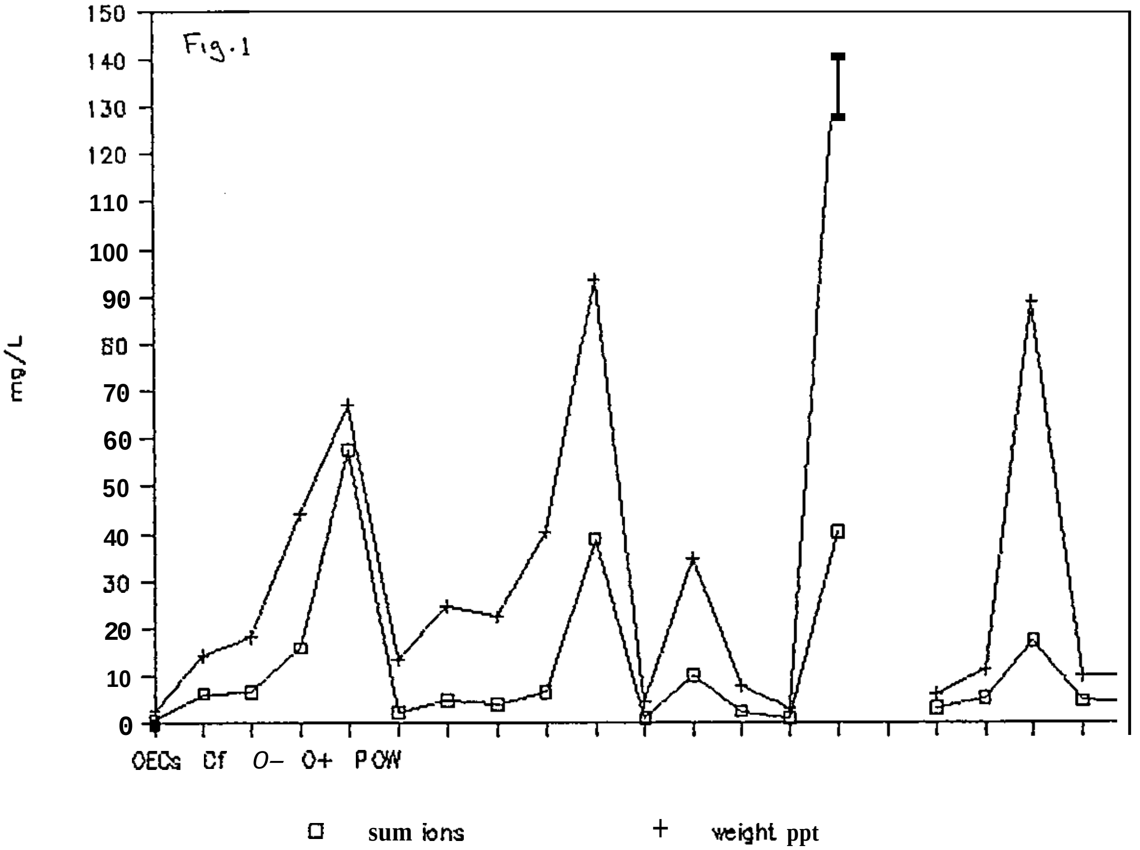
on sample volume, amount of prs of both the filtrate and the pres it possible to do a material baes with P-amendment, the total ehe other samples from one site station of the total elemental ces (Figs. 13 thru 16) shows gation for most of the elements bcant differences, however, are pa lesser extent for Cr, Cu, and P-3 logmmoles. Similarly the cd less than ideal for K. Since to certain elements only for all the analytic method for these accurate enough.

istribution in the precipitate (tal concentration) between the shows that it is strongly pH don takes place in the Denison a higher pH show not only more it is not known why the conductivity changed so significantly in this sample.

SUMMARY

1. The pH and conductivity remain more or less constant for the sub-samples and appear to be independent of the amendments to the waters from the various sites. An exception is the P-amendment.
2. Observed minor fluctuations in the pH are primarily due to the procedural errors in the measurement of the pH.
3. The amount of the precipitate and the type of elements incorporated in the precipitate are strongly affected by the magnitude of the pH of the water.
4. The analytical method used to measure the concentration of As, Cd, Se, C and P, and to a lesser extent Cr, Cu, K and Mg, appears to be insensitive.
5. No single amendment is superior in accelerating precipitation of most of the elements in the waters of the four sites. It appears that the precipitation of elements or groups of elements is specific to a particular amendment and different for each site.

SUM IONS & WEIGHT PRECIPITATE



Cond. & ion conc.; filtrate

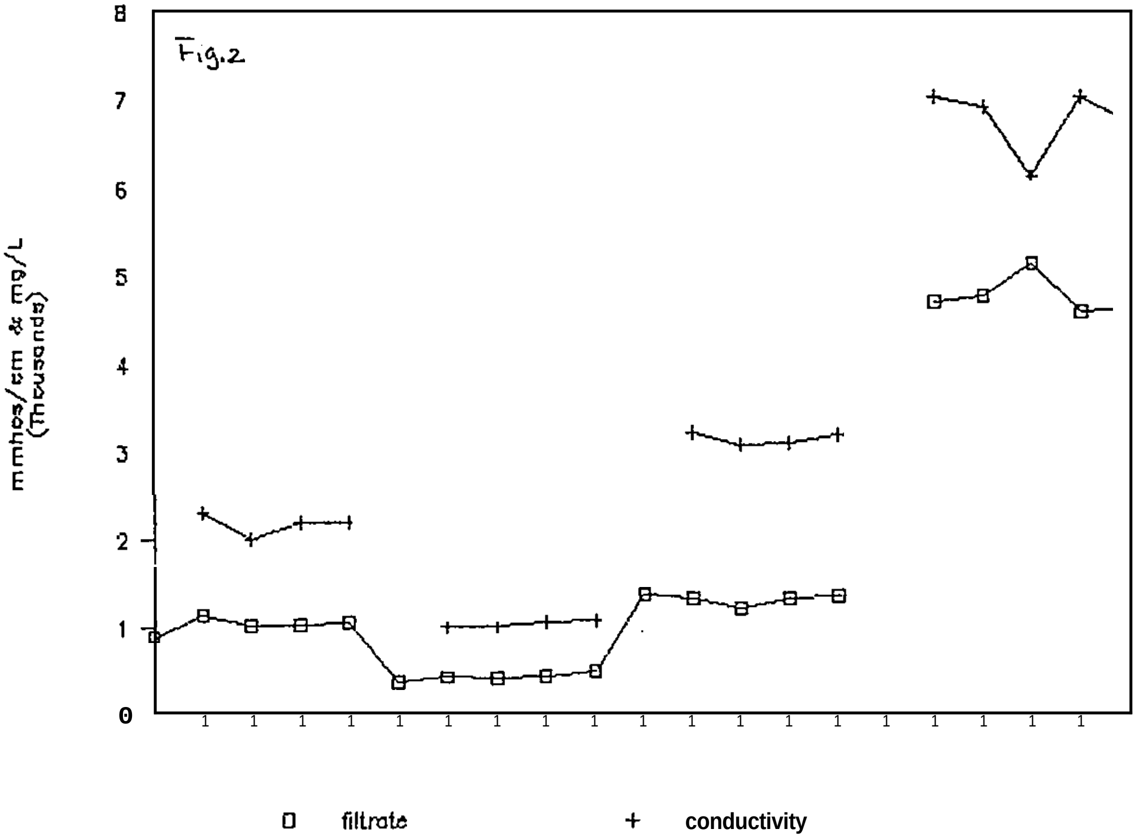
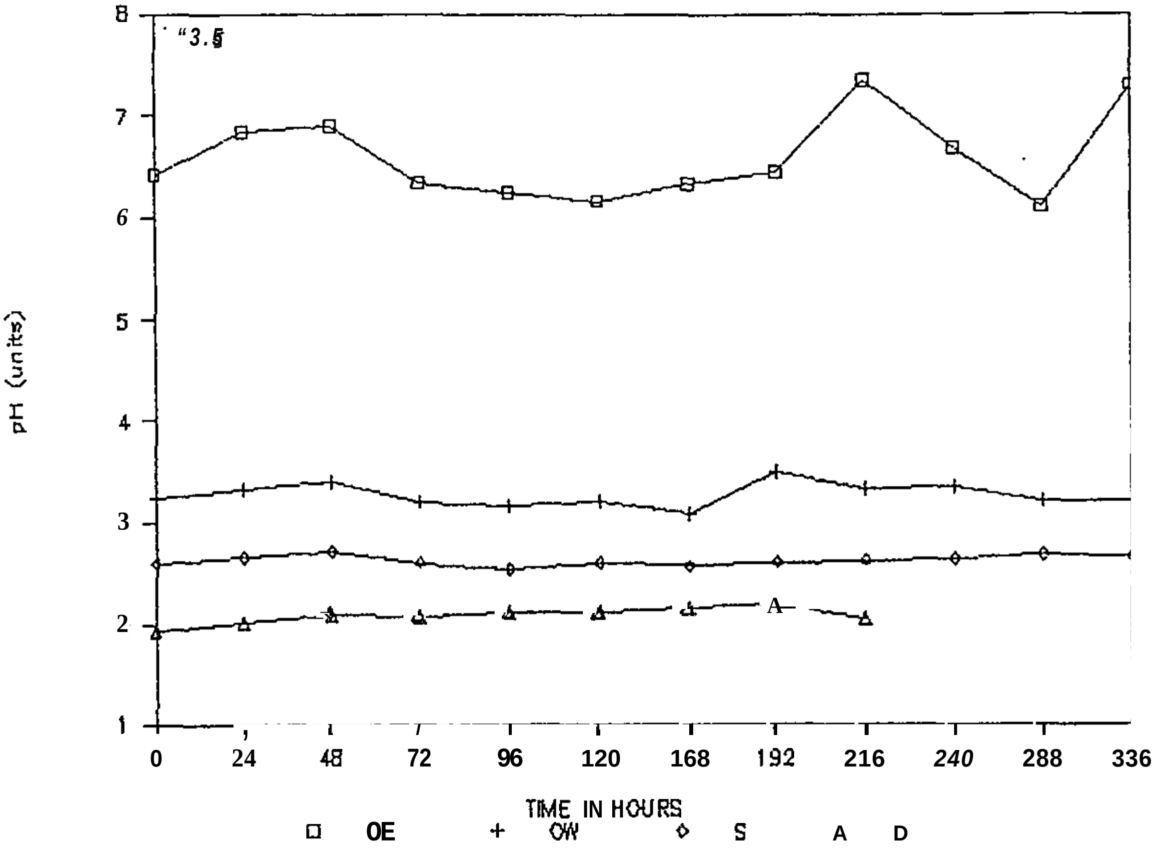


Fig. 1 & 2

pH versus time; Ox+



pH versus time; P

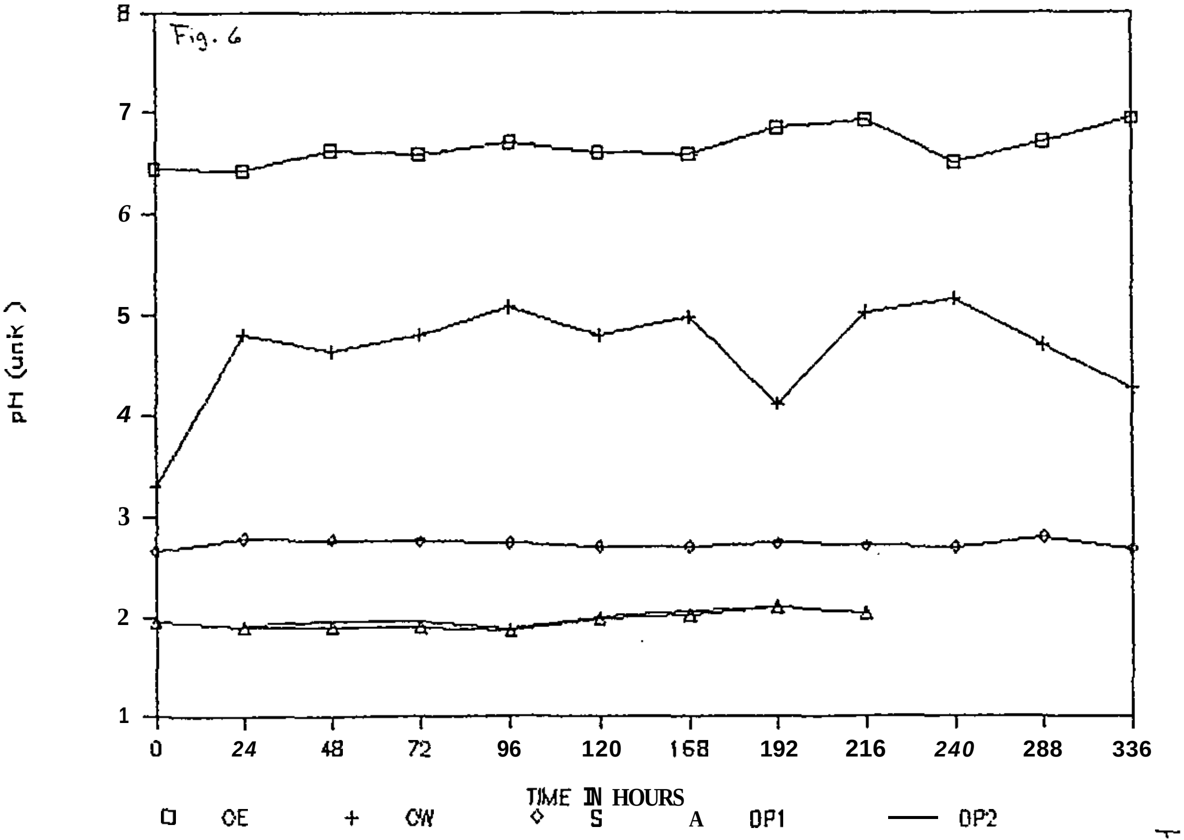
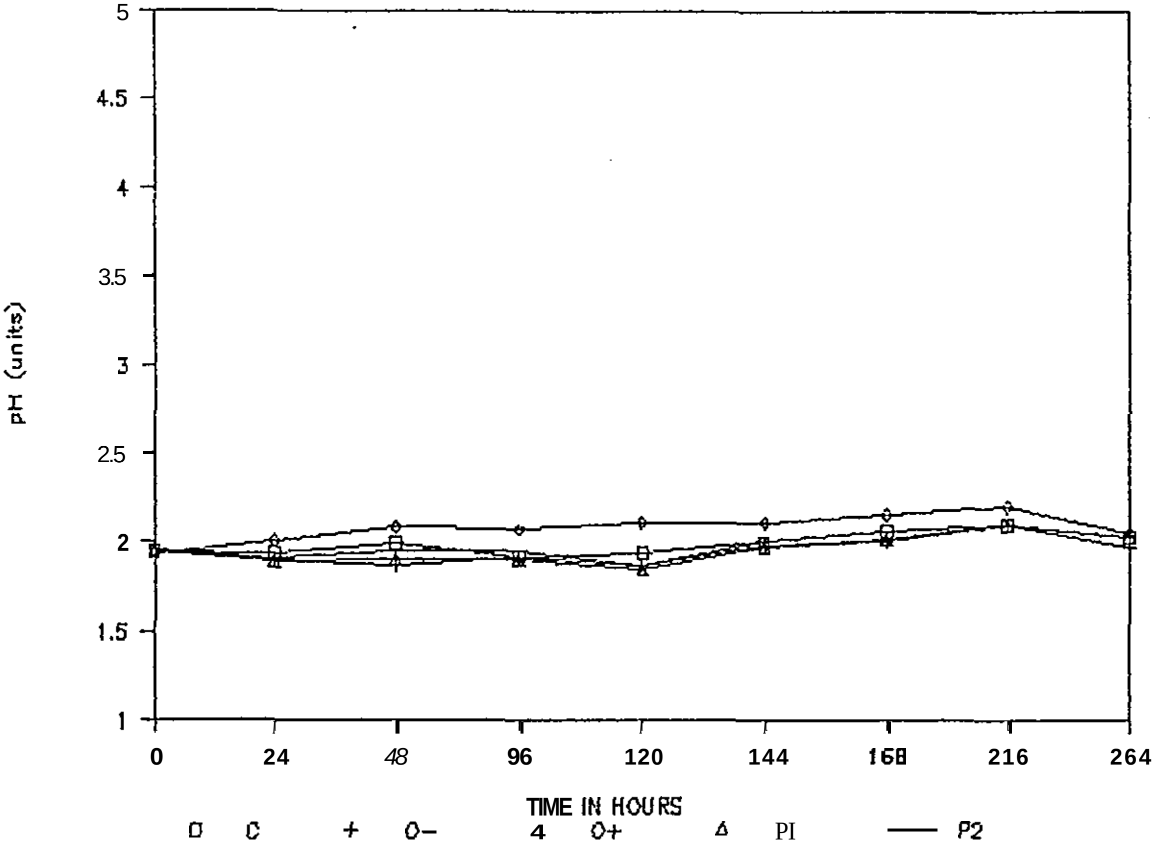


Fig. 5 & 6

pH versus time; D



pH versus time; S

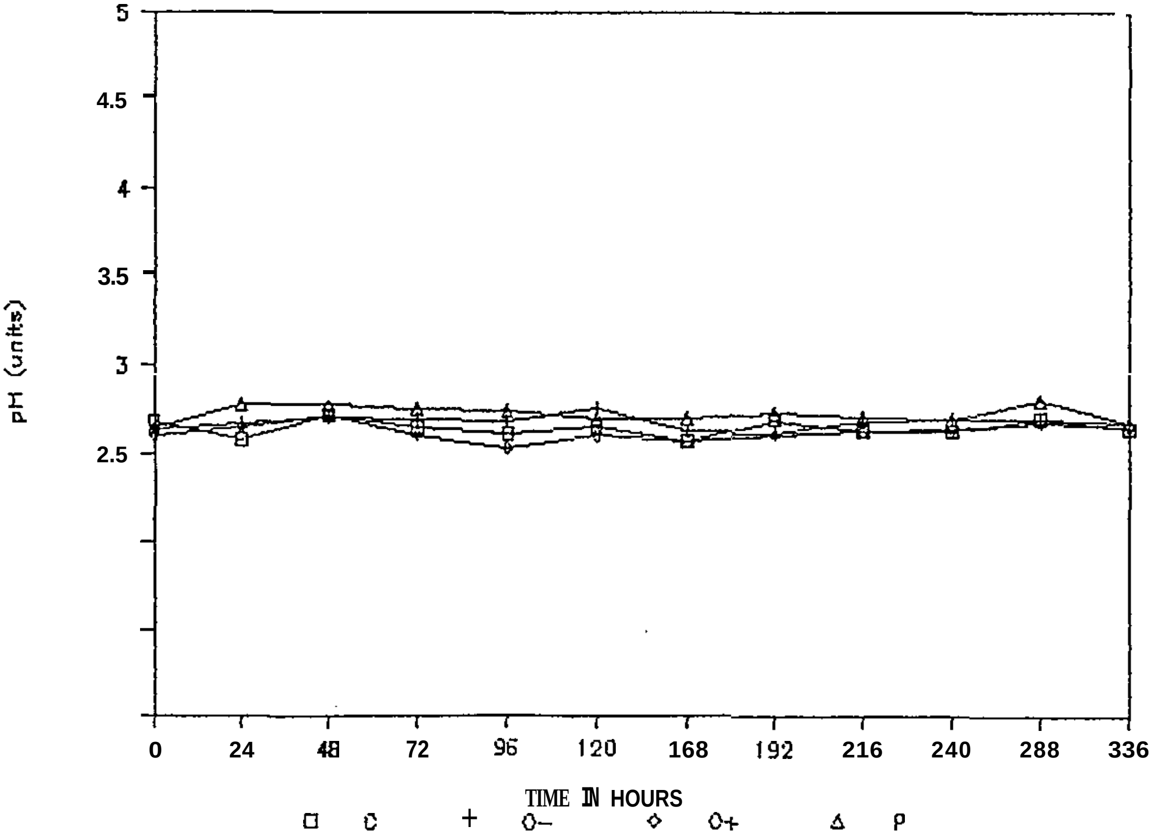
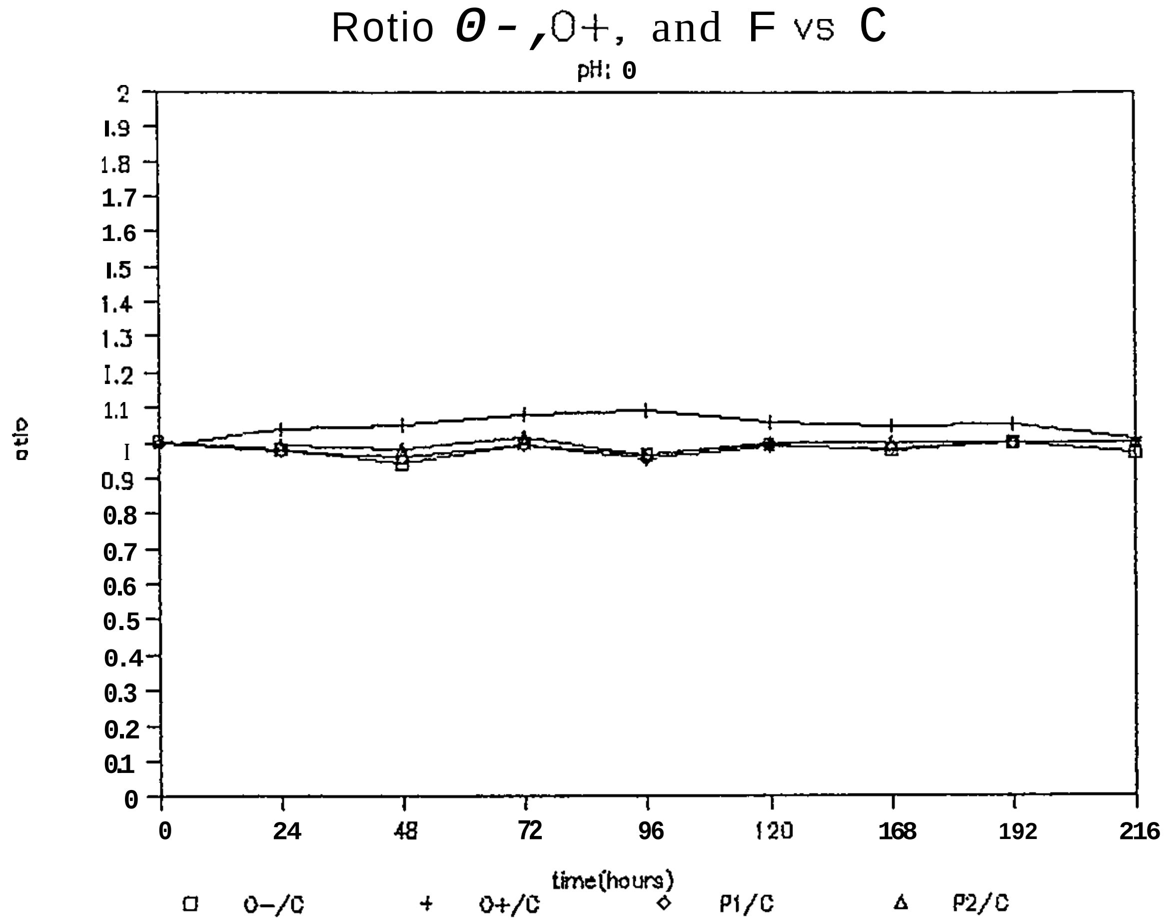


Fig 8


Rotio O-,O+, and F vs C
pH: 0
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
ratio
0
24
48
72
96
120
168
192
216
time(hours)
□ O-/C
+ O+/C
◇ P1/C
△ P2/C

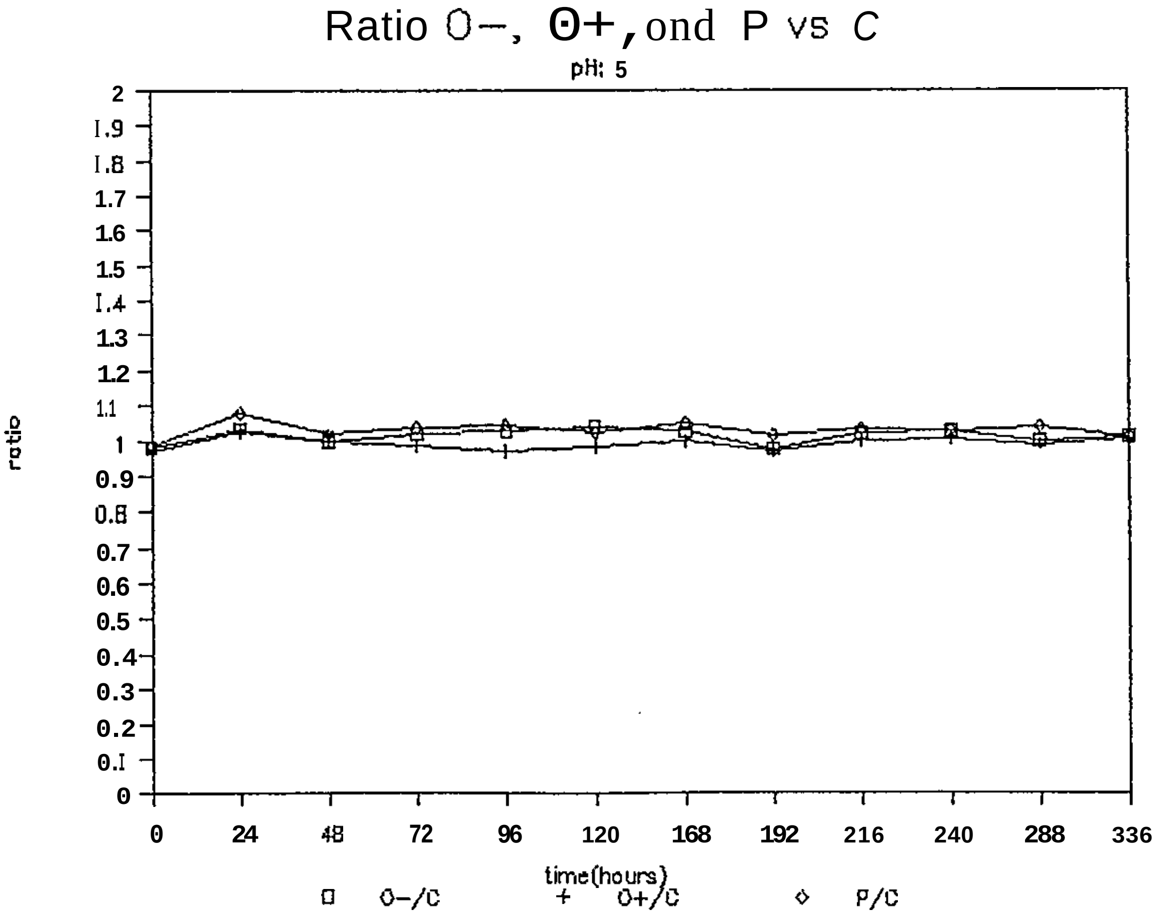
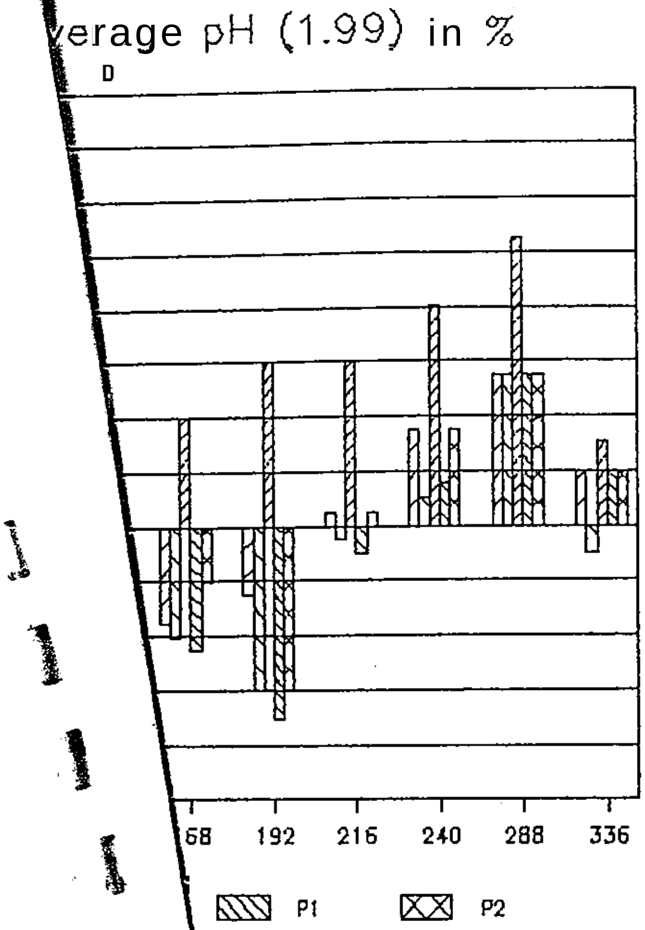

Ratio O-, O+, ond P vs C
pH: 5
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
ratio
0
24
48
72
96
120
168
192
216
240
288
336
time(hours)
□ O-/C
+ O+/C
◇ P/C

Fig. 10


verage pH (1.99) in %

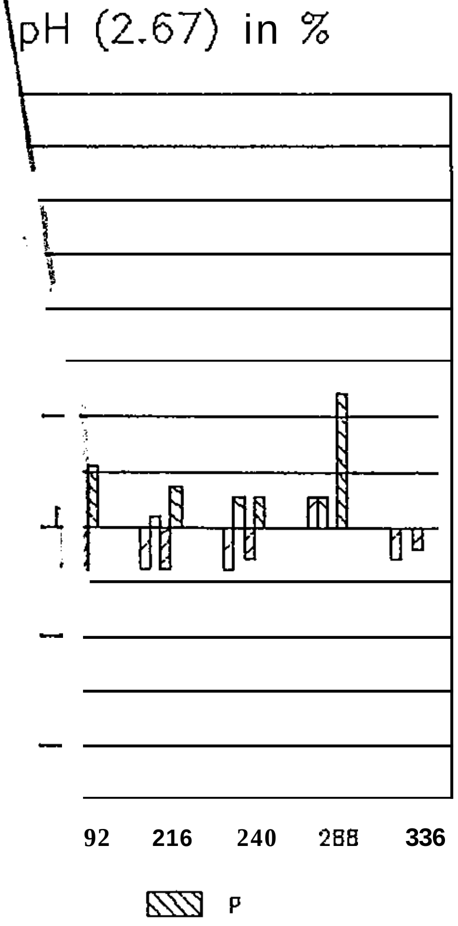
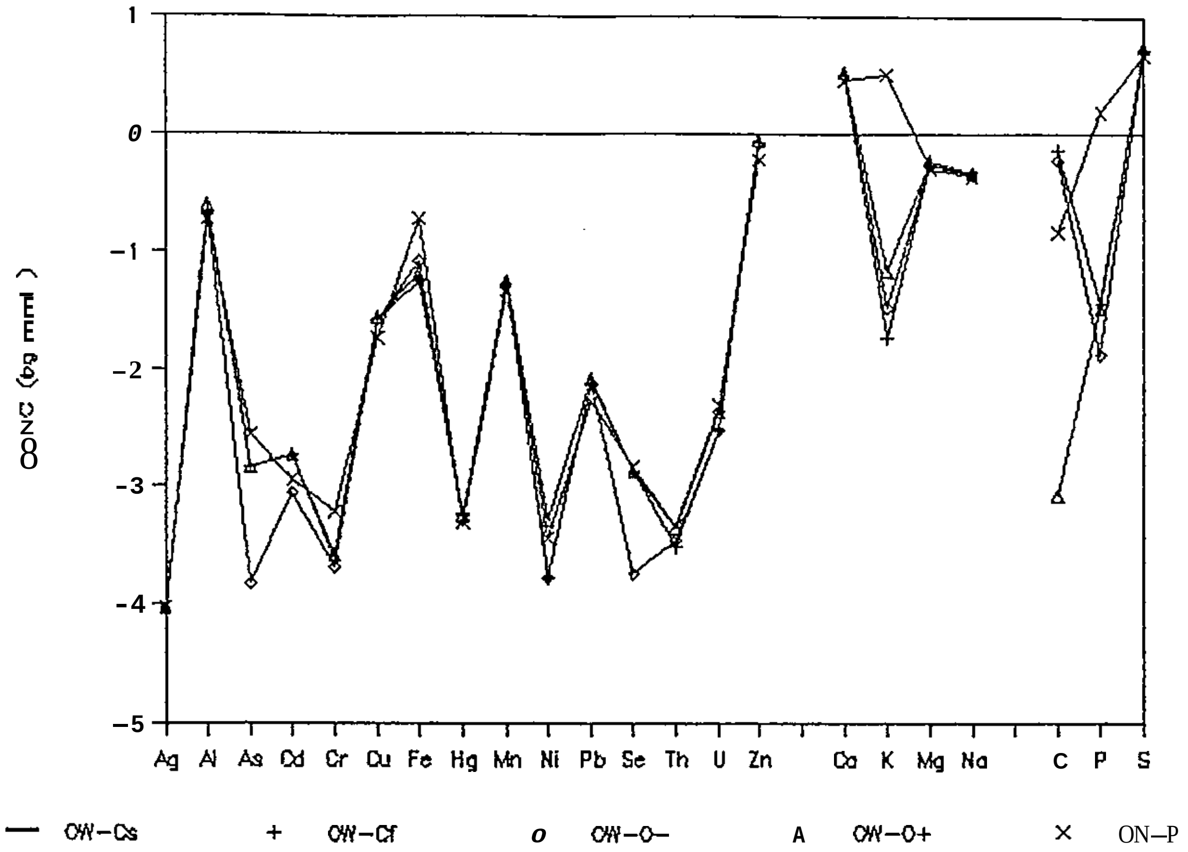

pH (2.67) in %

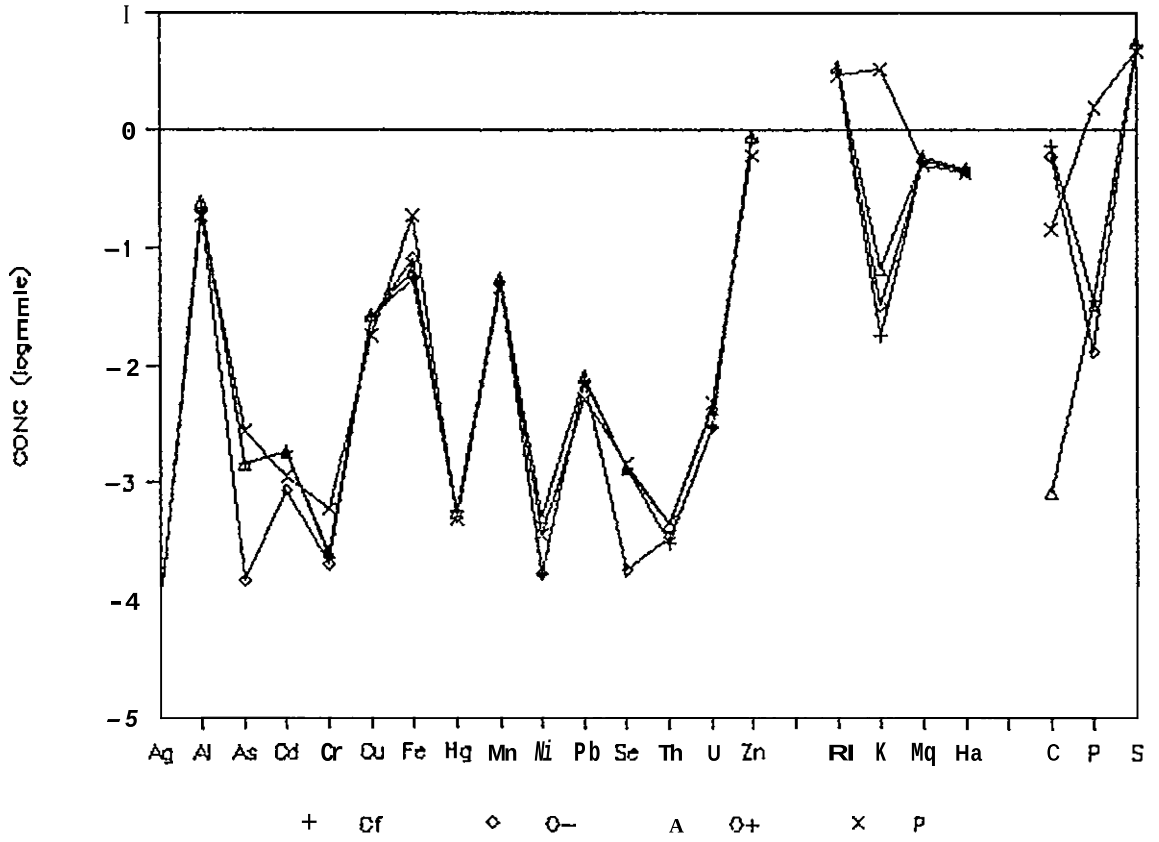
Fig. 12

OW: TOTAL ELEM. CONC. VS AMENDMENTS



OW: TOTAL ELEM. CONC. VS AMENDMENTS

Final takedown



D: TOTAL ELEM. CONC. VS AMENDMENTS

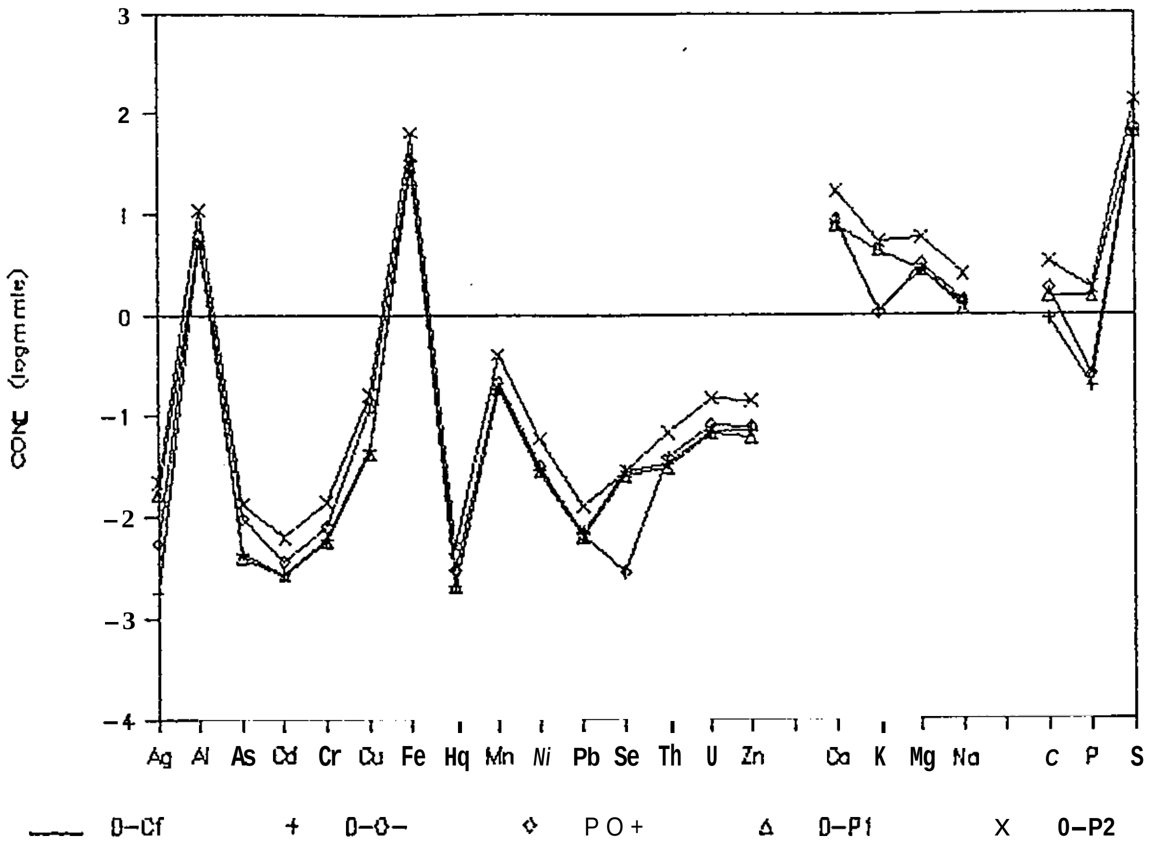
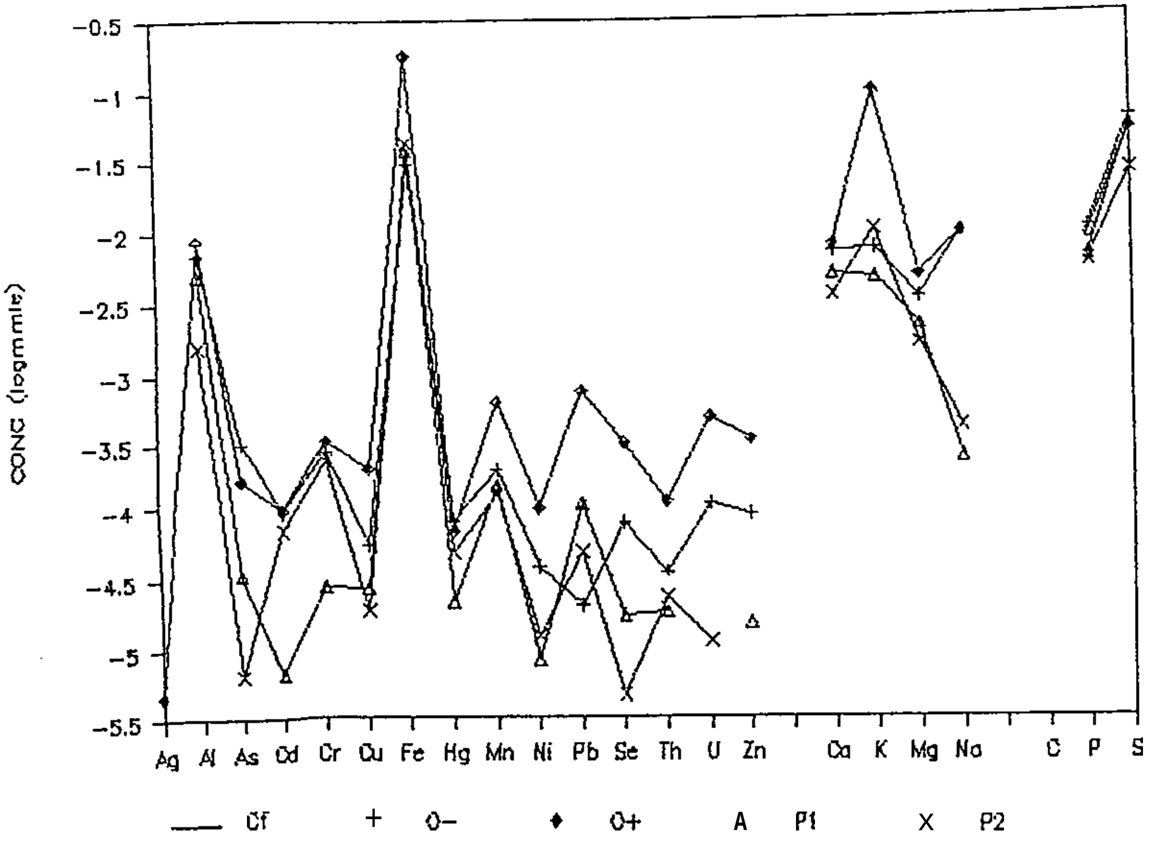


Fig. 16

E: MOLAR CONC.,FRECIPITATE



S: MOLAR CONC.,PRECIPITATE

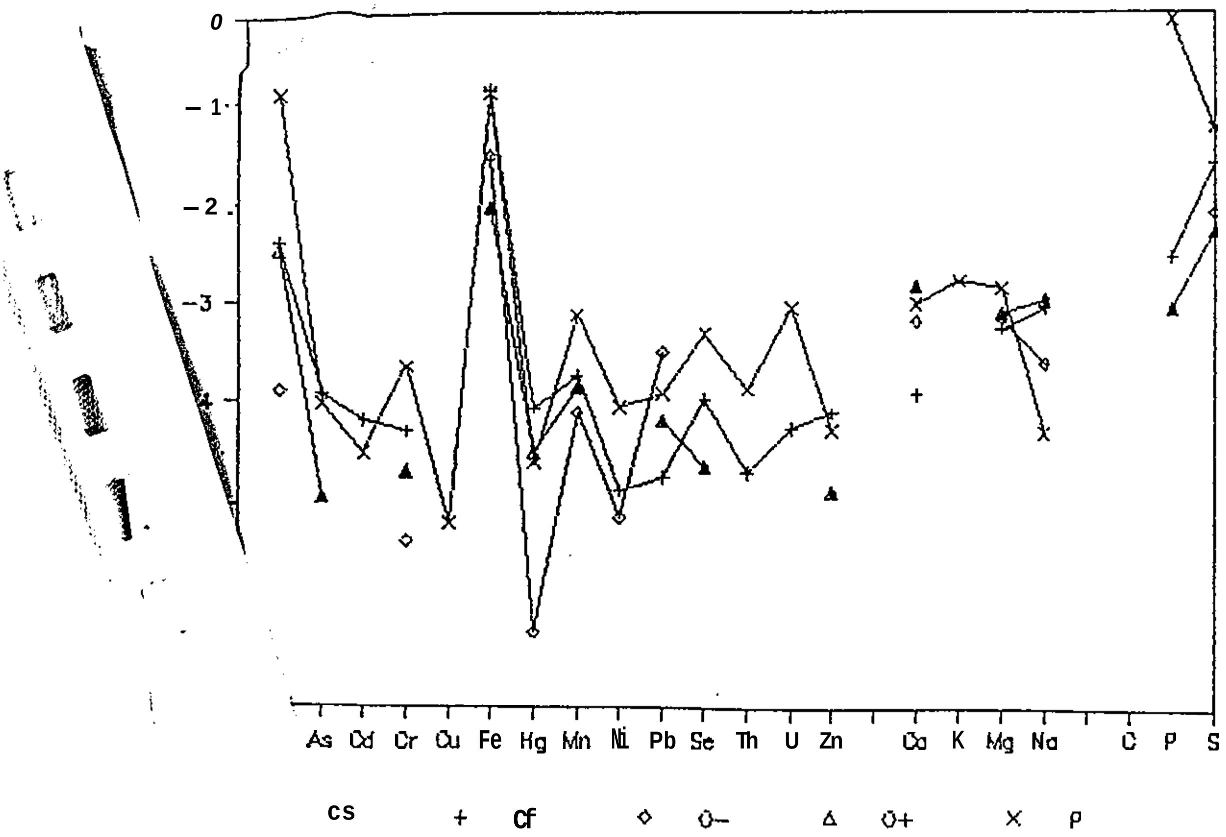
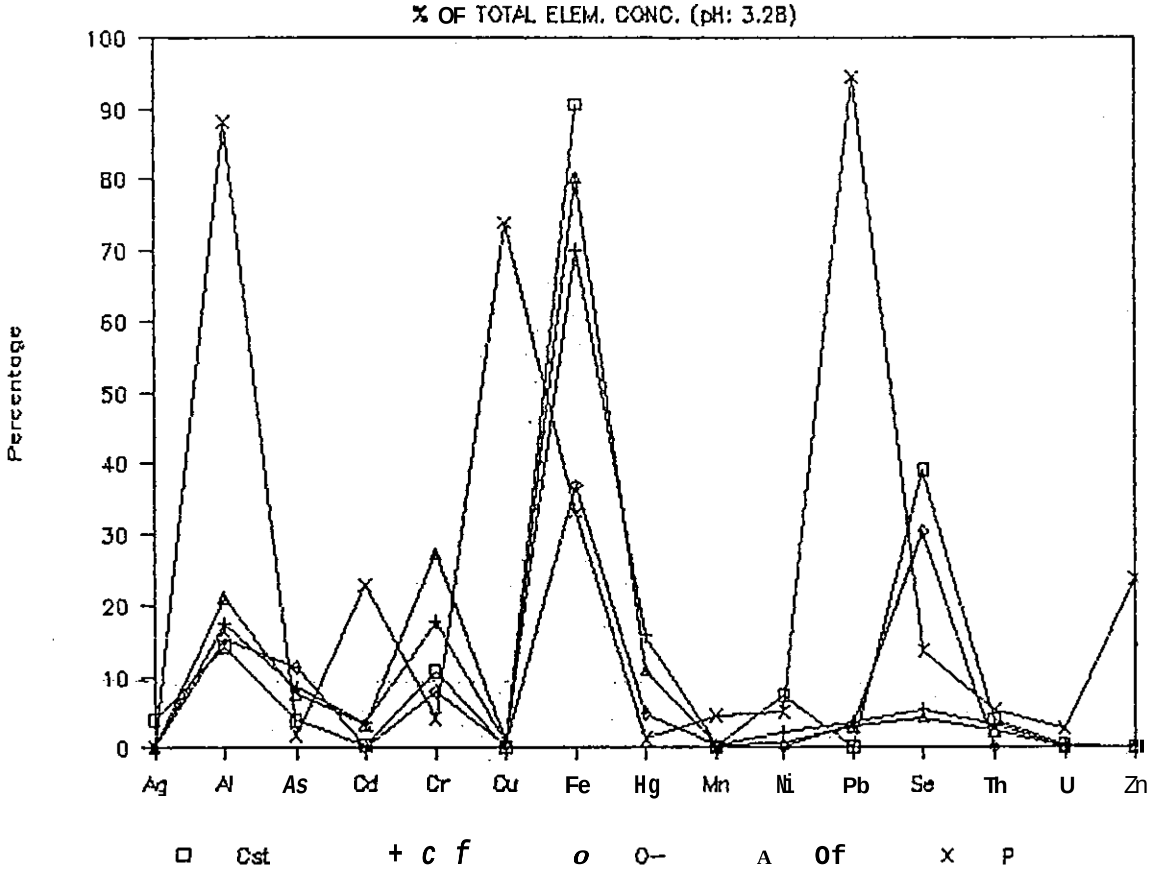


Fig. 18

OW: ELEMENT DISTRIBUTION IN PRECIPITATE



OW: MAJOR ION DISTRIBUTION IN PRECIP.

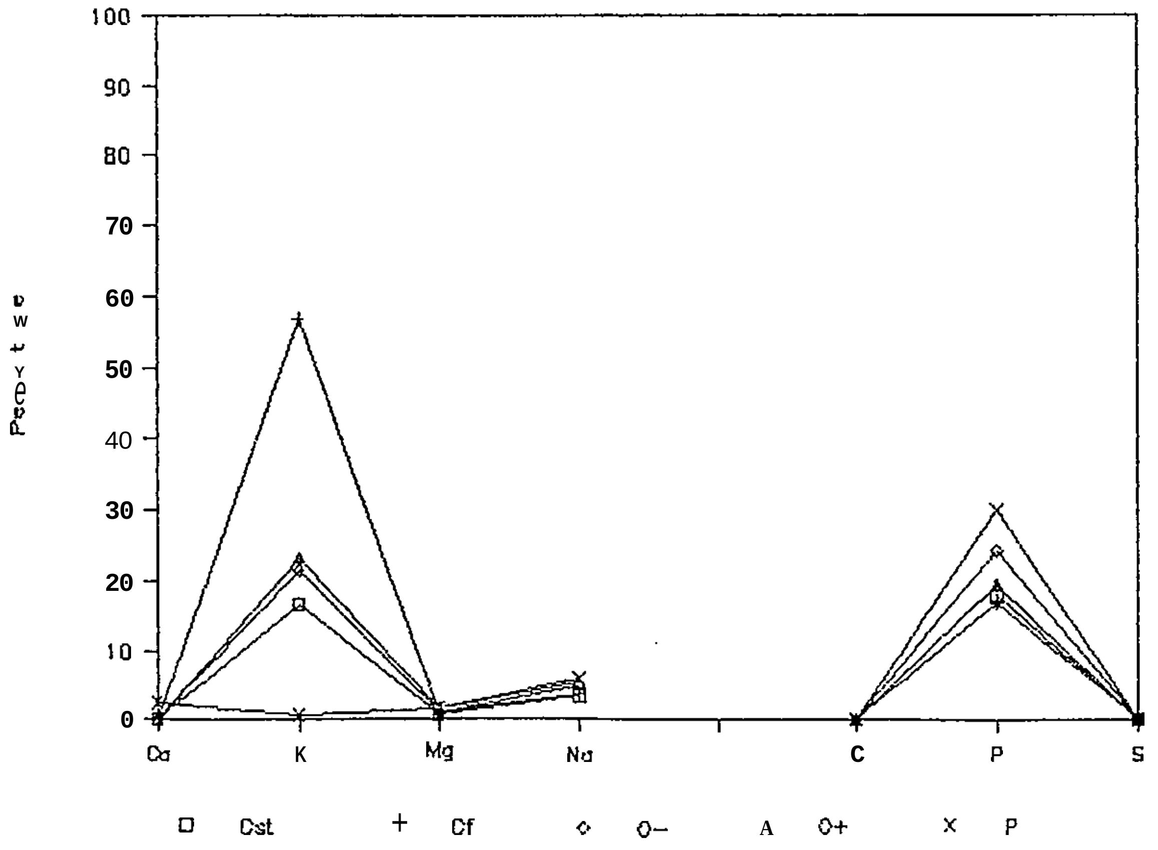
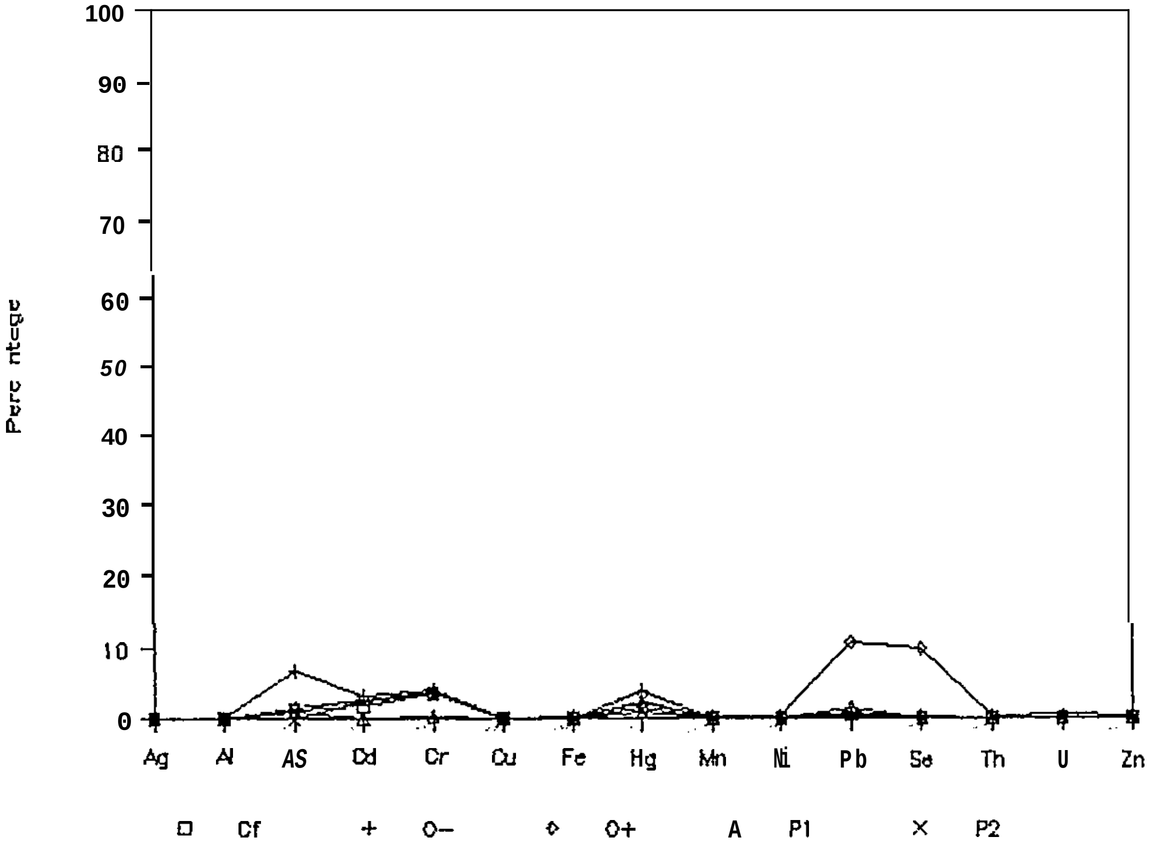


Fig. 20



D: MAJOR ION DISTRIBUTION IN PRECIP.

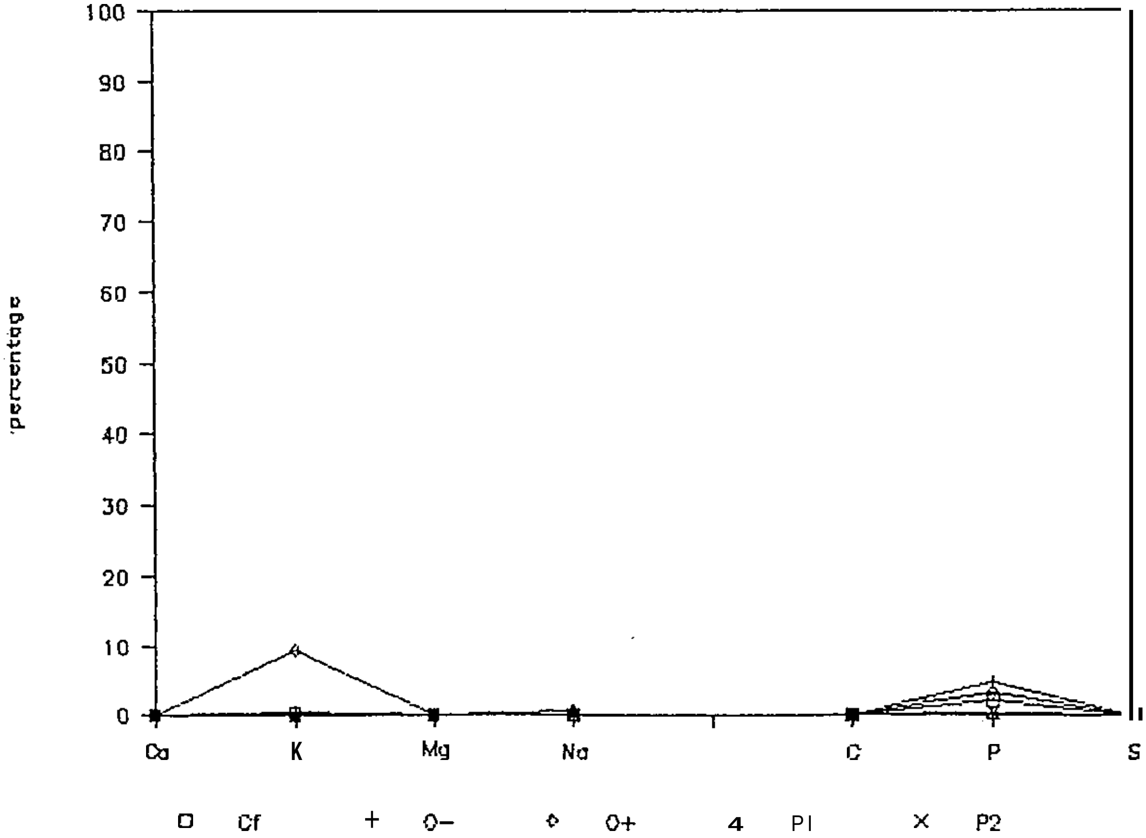
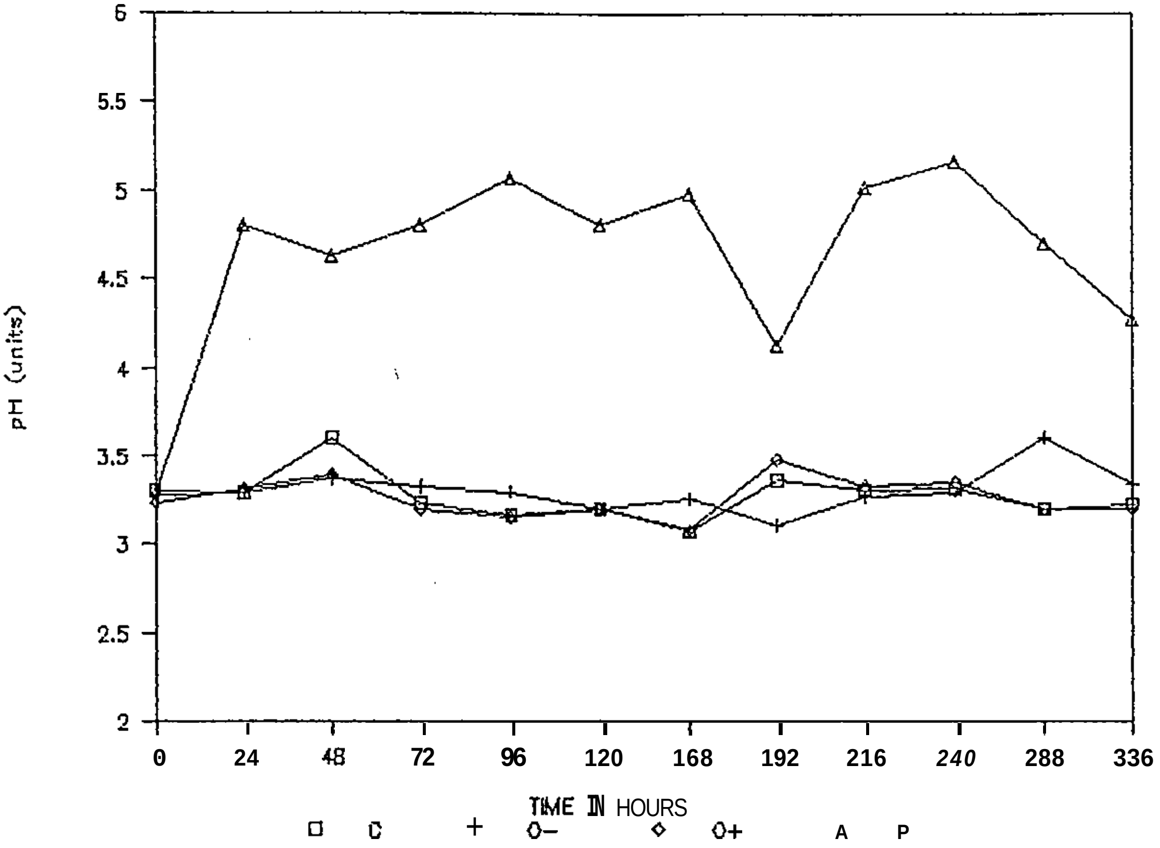
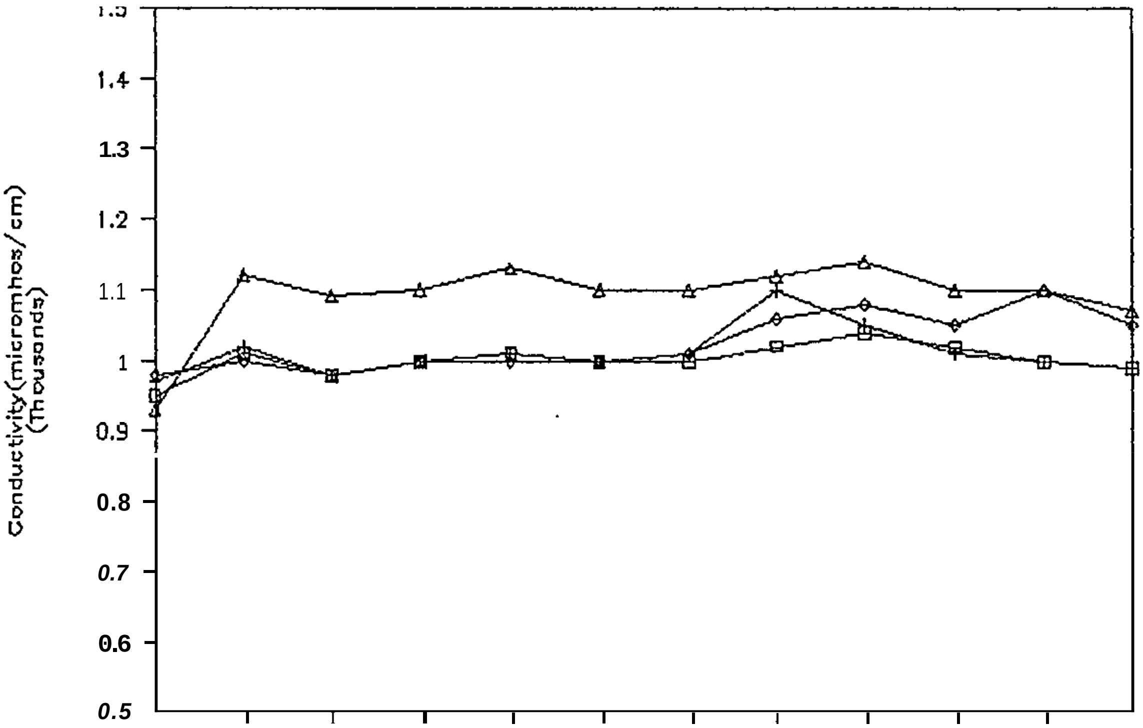


Fig. 22

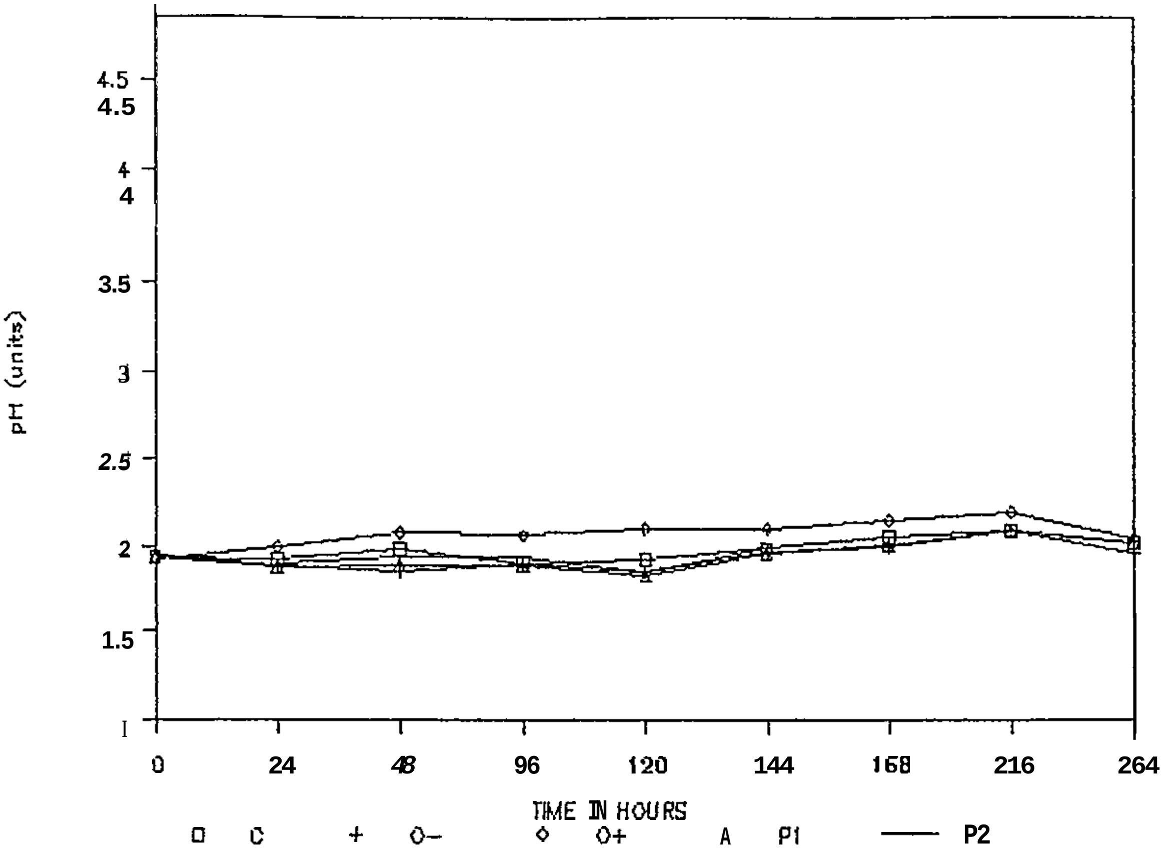
pH versus time; OW



Conductivity versus time; OW



pH versus time; D



Conductivity vet-sus time; D

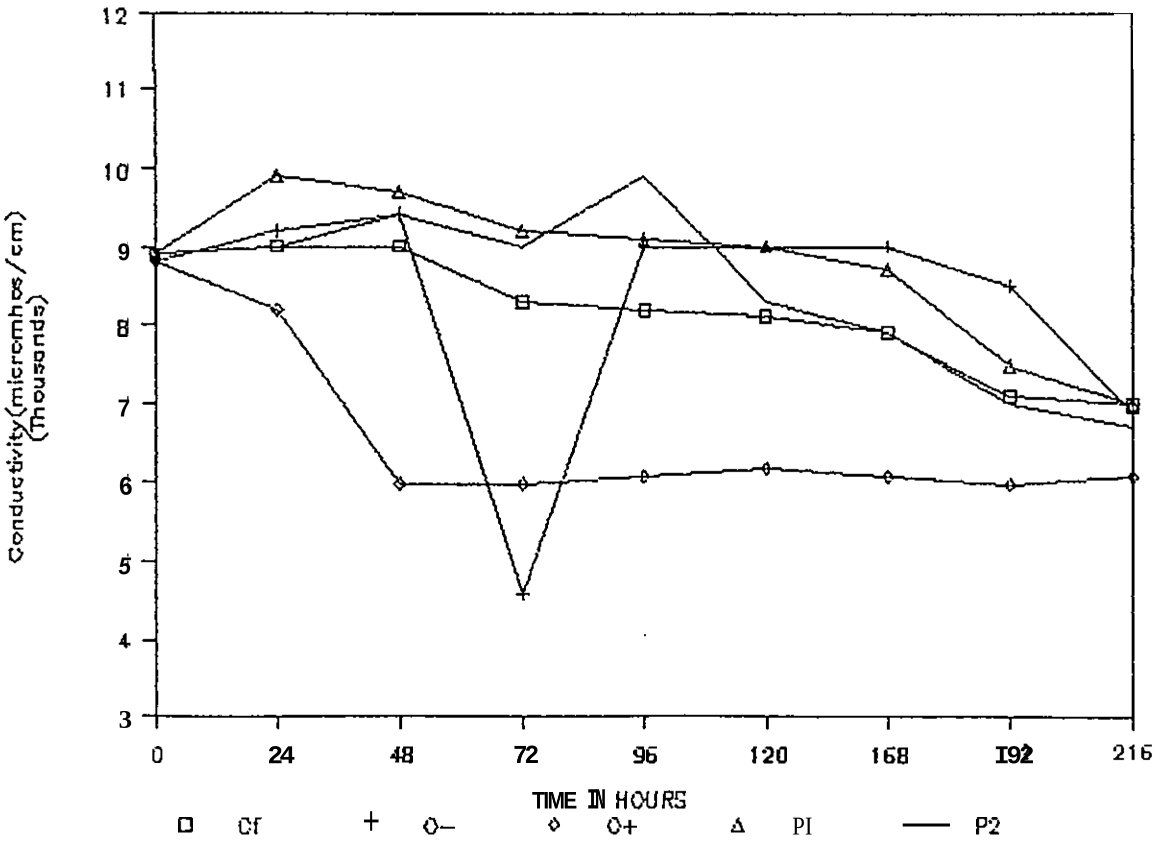


Fig. 26

APPENDIX 3:

PROPOSAL FOR PRE-FEASIBILITY STUDY ON RECLAMATION OF BUCHANS TAILINGS

Introduction:

This proposal has been prepared at the request of M. Kalin of Boojum Research.

Due to the low grades of precious metals in the Buchans tailings and the relatively small tonnage in the deposits close to the mill site, it is unlikely that the tailings could be reprocessed for gold and silver alone at a profit. Mean gold and silver values in Pond No.2 were reported by Collins and LeGrow, May 1947 to be 230 ppb. (0.0067 oz/t) and 21 ppm (0.61 oz/t) respectively. Assuming Can $500 for gold and Can $6.00 for silver, the gross metal values in this pond are $3.35/short ton for gold and $3.661 for silver for a total of $7.01/ton. Assuming 60% expectation of gold and silver in leaching, recovered metals would be worth $4.20/ton.

Mining and milling costs for precious metals alone would probably exceed the value of recovered metals in a relatively small operation although mineralogical information suggests that cyanide consumption would be low and disposal of retreated tailings in a mine pit would cost very little. It may be economic to recover the precious metals if barite were recovered at the same time, and the retreated tailings were reutilized to alleviate environmental problems with acid mine drainage.

It is proposed to determine the technical and economic viability of a plant to recover precious metals and barite in this study..

Scope of Study

The scope of the study would include the following:

1. Review of available information on barite processing at Buchans and on marketing of the product.
2. Estimate the average grades of gold and silver tailings in

Ponds No. 1 and No. 2 based on Department of mines drilling results. In this connection, a fraction of the samples would be re-assayed for gold using the most accurate practical method available to confirm the original assays.

3. Carry out a limited program of laboratory investigations on composite samples from each dam including the following routes:
    a. Direct cyanidation of the tailings with no barite recovery

    b. Recover barite by flotation and cyanide the barite rougher tailings

    c. Recover sulphides by flotation. Recover barite by flotation of the sulphide tailings. Cyanide the sulphide concentrate and barite flotation tailings separately and dispose of the two cyanide tailings separately for maximum effectiveness in the environment.

4. Select the most economic processing method and processing rate.

5. Prepare a schematic flowsheet of the process and an overall mass balance.

6. Prepare a major equipment list for mining and processing including existing equipment and equipment that would have to be purchased.

7. Prepare estimates of capital and operating costs for the project based on quotations from suppliers and recent information from files.

8. Make conclusions on the technical and economic feasibility of the project.