

THE APPLICATION OF ECOLOGICAL ENGINEERING FOR CLOSE-OUT AT BUCHANS

ERRATA SHEET

GENERAL: Throughout the 1991 report, the abbreviation (T) indicates metric tonnage.

SUMMARY

Page iv: Third bullet should read: "...ultimate rise in water level of the Lucky Strike pond would increase the Drainage Tunnel discharge rate by less than 10 percent, if the tunnel plug installed in 1988 is effective in sealing the Tunnel.

Page iv: Sixth bullet should read: "The major aquifers are likely the faults...."

Page viii: Fourth bullet should be changed from "OEW" to "OWP".

Page x: Add a third point: "The discharge rate of the Drainage Tunnel should be monitored during filling of the Lucky Strike."

SECTION 2

Page 2-106 Replace table with insert.

Page 2-113: Ignore, as table 3-1 is now complete on page 2-106.

Page 2-180: Paragraph 1, fourth line should read "The hydrological and geochemical conditions in Buchans are such, that changes in the long-term trends of effluent characteristics are not likely."

Paragraph 2, third line should read " --during the investigation on the Buchans effluents and the ground water geochemistry, interpretation.."

Paragraph 3: All references to averages should read annual averages.

Page 2-182 Paragraph 2, fourth sentence should read "...both copper and zinc concentrations have remained relatively constant."

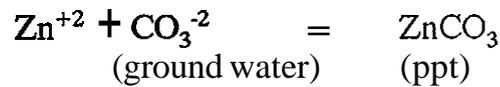
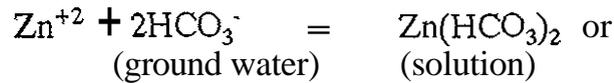
Page 2-183: Last paragraph, **first** sentence: Replace "Oriental effluents" with "various effluents".

Last paragraph, point 1, should read "1 AMD generation ongoing - Drainage Tunnel and tailings beach #1, waste rock pile."

SECTION 3:

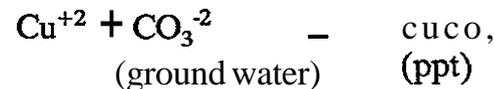
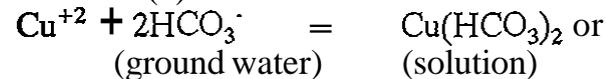
Page 3-4: Paragraph 1, last line should read "...represents AMD with ground water."

Page 3-5: Formula (2) at bottom of page should read



Page 3-6 First line should read: "(3) The carbonate precipitates, but it later may dissolve in water rich in carbonate."

Formula (2) should read



Line nine should read "(3) The carbonate precipitates later may dissolve in water rich in carbonate."

Page 3-7: Paragraph 2, first sentence:
Change "At pH 7 to 8..." to "At pH 6.5 to 10.."

Page 3-8 At top of page, first sentence should read: "When samples are stored for different periods of time in the laboratory, changes in zinc concentrations should be measured."

At top of page, line 7 should read "... observations is that the zinc concentrations in Lucky Strike,"

Last paragraph at bottom of page **should** read "The aeration probably could function in two ways, depending on pH and the degree of saturation of the water with respect to CO₂."

- Page 3-9 First sentence of page should read "(2) When the water is stirred or bubbled, zinc bicarbonate releases CO₂ and precipitates as zinc carbonate."
- Last paragraph at bottom of page should read:
"Therefore, natural precipitation of zinc carbonate can reduce zinc concentration to a level no lower than 1 mg/l; this concentration cannot be reduced other than by...."
- Page 3-10 First sentence of Section 3.3: Replace "hydrogen" with "zinc".
- Page 3-11: Paragraph 1, first sentence, should read
"It follows that, if acidity is low and pH is neutral, dissolution of the phosphate rock..."
- Paragraph 2, second sentence should read "... (slow-release phosphate) was added to the water."
- Page 3-12: Paragraph 2, ninth line should read:
"Traps placed and retrieved in autumn collected significantly less precipitate than those traps placed during the following spring and summer."
- Page 3-13: Last paragraph, second sentence should read: "At the surface of the pit, however, hydrolyzed ferrous ions will be gradually oxidized by air to hydrolyzed ferric ions, which then...."
- Page 3-14 Delete third paragraph and replace with "In order to confirm the presence of ferric hydroxide, precipitate samples were collected from the Junction between the First and Second Meadow which receives the main precipitate loading. Samples were also collected in the First Meadow in the vicinity of the polishing ponds, where precipitate has accumulated longer, is older, and represents a potential source of dissolved zinc, if the meadows are flooded by a new polishing pond. During the 1990 investigation, sediments in the meadows were sampled for concentrations of metals. In the upper portions of soil profiles in the First Meadow, very high zinc concentrations were determined."
- Page 3-15: Sentence at top of page should read:
"The changes in the slope of the curves between pH 2.5 and 3.5 indicate the presence of ferric iron."
- Paragraph one, line 5 should read "oxygenated water (meadow) will contain ferric iron."

Paragraph one, line 6 should read: "...directly in the main flow path (junction) will contain some ferrous iron..."

Page 3-16 Paragraph 2, second sentence:
Change "pH 2 to 3" to "pH 6 to 7".

Page 3-18: Table 3-3. For rows OWP, LS, and OEP, the units are zinc concentration, mg/l.

SECTION 4:

Page 4-16 Last paragraph, third sentence should read
"There is a slight increase in pH and a reduction in conductivity and acidity within the amendment."

Page 4-22 Last paragraph, second line: Change "acidity" to "pH".

Page 4-26 Last paragraph, second sentence should read
"There were no detectable levels of VFA producers in test conditions 4 and 5."

Page 4-32 Paragraph 3, second sentence: I.G. stands for Imperial gallons.

Page 4-35: Last paragraph, first sentence should read
"Potato waste initially decreased acidity slightly (Figure 4.1-18), whereafter acidity rose to a peak of **1850 mg/l** CaCO₃ equivalents by day **35**."

Page 4-36 Replace 2nd paragraph (After **75** days.....) with the following: "After **75** days, when all detectable Zn had been removed from the jars with new peat and potato waste, the mean acidity of these jars was **110 mg/l** equiv. CaCO₃, (TABLE 4.1-4). The **OWP** water used in this experiment had an acidity of **170 mg/l** equiv. CaCO₃, (based on titration with NaOH to pH **8.3**). **This** reduction in acidity of **60 mg/l** equiv. CaCO₃, is probably due to microbial alkalinity generation including sulphate reduction.

Page 4-37: Replace 3rd paragraph (The volume of....) with the following: "In this experiment, 1 g of potato waste removed all the Zn (about **65 mg/l**; Taylor colourimetric test) from 1 l of West Pit water in **75** days. From this result it can be estimated that **32** tonnes of potato waste would remove the approximately **2.0** tonnes of Zn in the West Pit in **75** days. The **65 mg/l** Zn used for this estimate is very high for the West Pit. **An** ICP determined Zn concentration for a sample collected from the

same site and time as that used in the potato waste experiment gave a Zn concentration of **47 mg/l**. Using this figure, it can be estimated that **42** tonnes of potato waste would be required to remove **2.0** tonnes of Zn from the West Pit in **75** days. It can be expected that the amount of potato waste required would be in the range of **32** to **42** tonnes given by these two estimates.

Page 4-38 Paragraph 2, line 4, should read: "**62.7** mg zinc from OWP water." should read "**65** mg of zinc from 1 litre of OWP water."

Page 4-39 Last sentence on page: Replace "decompose" with "proceed"

Page 4-103: Last paragraph, fourth sentence should read: "Biological polishing performance represented as growth in the ponds is discussed in section **4.2.6...**"

Page 4-104: Section **4.2.2.1** title should be: "Flow and residence times" (also change Table of contents)

Page 4-106 Paragraph 1, last sentence: Change "...1.5 to almost **5%**..." to "**3.7** to **9.3 %**..."

Page 4-108: Paragraph 1, seventh sentence should read "This weight loss is due to combustion of organic carbon, carbonates, and hydroxides in the sample."

Page 4-119: Replace this page with insert.

Page 4-120 Replace this page with insert.

SECTION 5:

Page 5-3: Paragraph 2, third sentence should read "Simulation of OEP water as a mixture of pure water (i.e. rain, snowmelt, Sandfill Spring) with OWP water generally resulted in unrealistic mixing ratios."

Page 5-4 Fourth line should read "... through the ground and workings."

Delete last sentence of paragraph.

Page 5-5: Paragraph 3, second sentence should read "The climatic (precipitation) records should account for the recharge-driven water levels in the ground overlying the Drainage Tunnel. The required recharge rates represented **50%** of the mine's estimated precipitation/evaporation regime."

Paragraph 3, last sentence: Insert "**an** estimated" before "hydraulic conductivity".

Page 5-8: Paragraph 1, first sentence should read: "**As** the raising of the Lucky Strike water level is expected to take place during **1992**, the Drainage Tunnel discharge rate may increase, and new discharge points may become evident ..."

Page 5-9 Paragraph 1, 4th line: Replace "copper" with "heavy metals".

Page 5-9 Paragraph 1, last sentence should read "The mixing simulations using samples of **TP-1** and **TP-2** collected in **July 1991** (discussed in Section 2.4), indicate that the waters are undersaturated and could dissolve Smithsonite if present (from previous deposition)."

Page 5-10 Paragraph 2, first sentence: Replace "can be" with "was".

Paragraph 2, third to last line: Replace "beach #4" with "beach #1".

Page 5-11: Third line: Replace "**56 mg/l**" with "**63 mg/l**". Third sentence: Replace "pit #'s 3 to 11 ..." with "pit #'s 11 to 3 ...".

Paragraph 1, first sentence should read "In Table **5.3-2**, descriptions of the test pits are given, along with pH, conductivity, and acidity determinations."

Page 5-13: Paragraph at bottom of page: Replace "**755 m³/d**" with "**659 m³/d**".

Page 5-14: Replace page with insert.

Page 5-16 Replace table with insert.

Page 5-27: Replace with map with insert.

**THE APPLICATION OF
ECOLOGICAL ENGINEERING
FOR CLOSE-OUT AT BUCHANS**

Final Report

For

ASARCO INCORPORATED
Buchans Unit

and

ABITIBI-PRICE INCORPORATED

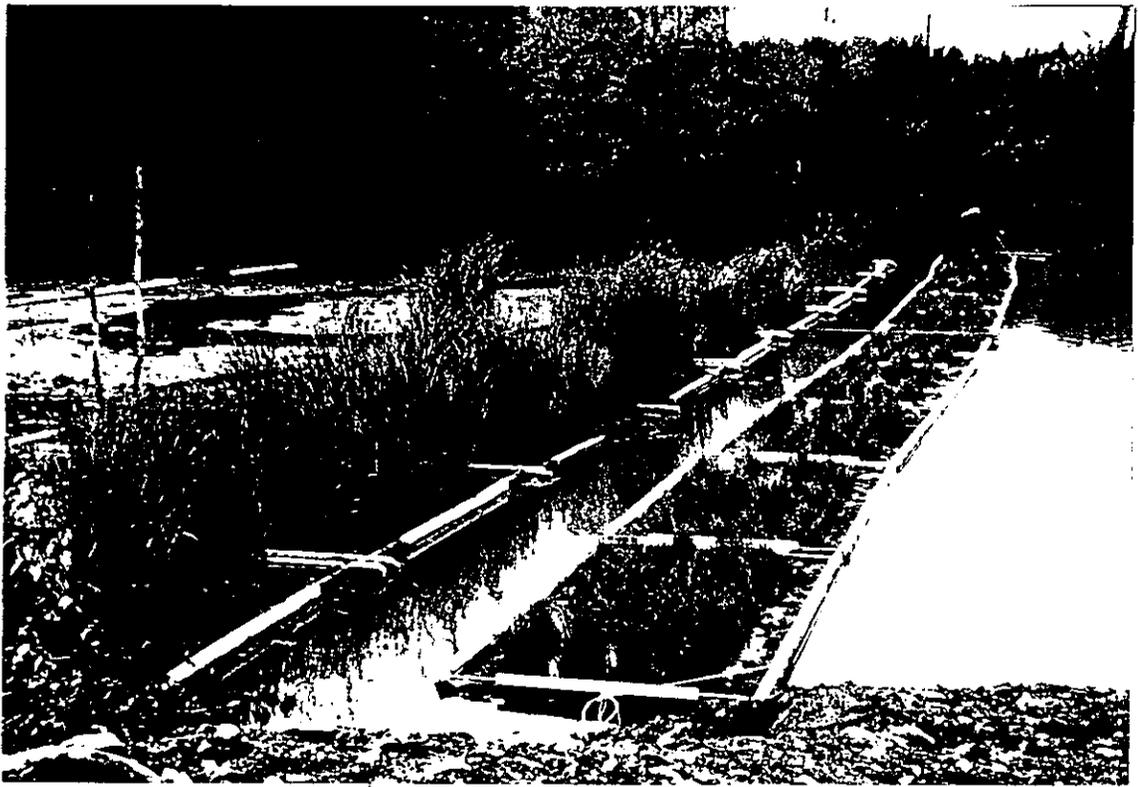
P.O.#'s 91-3,91-3a,91-6

Prepared by

Boojum Research Limited

December, 1991

REVISION #1 - JANUARY 23,1992



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SUMMARY

After three years of investigation with the objective of finding an environmentally acceptable decommission approach to the mining operations at the Buchans Unit of ASARCO INCORPORATED, three treatments have been identified:

1. Biological Polishing, which utilizes algae to remove zinc.
2. Natural phosphate rock treatment, which represents a chemical approach to handling of the effluents.
3. ARUM (Acid Reduction Using Microbiology) a microbiological process which can be used in Buchans effluents.

Each treatment can function on its own but it **is** recommended that they be used in combination .

This report brings together hydrological, geological, geochemical, biological and chemical information. A summary in point form presents the essential facts which were used to determine the Ecological Engineering treatment options.

Hydrology, Geology, Geochemistry and Chemistry:

- Water from the Lucky Strike pit and/or the mine workings can contribute only to a portion of the Drainage Tunnel discharge.

- Discharge from the Drainage Tunnel is not "driven" by the water level in the Lucky Strike pond, but by the generally higher water level in the surrounding ground.
- Results of preliminary, simplified, model simulations suggest that the water level of the Lucky Strike pond will not be able to rise much above 900 ft. a.s.l.
- Model simulations also suggest that the ultimate rise in the water level of the Lucky Strike pond would increase the Drainage Tunnel discharge rate by less than 10 percent, if the tunnel plug installed in **1988** is effective in sealing the Tunnel.
- The ultimate water level in the Lucky Strike pit could be reached in about **14** years.
- The Buchans area has a ground water setting consisting of a thin discontinuous glacial **till** over faulted bedrock, with locally thick drift of sand and gravel.
- The major aquifers are likely the faults which transmit large volumes of ground water.
- The active portion of the flow system has a depth of **150** to 300 ft.
- The Buchans tailings possess net acid-generation potential.
- Leaching experiment results indicate that up to **5.6%** of the metal sulphides estimated to be available in tailings were dissolved over the course of the experiment.

- The Buchans effluent water chemistry is dominated by a bicarbonate buffering system.
- The CO₂ solubility will determine the lower boundaries of zinc concentration in these waters, which is 1 - 2 mg/L of zinc.
- Precipitate formation in the OEP is a function of ferrous oxidation to ferric carbonate or ferric hydroxide.
- The acidity in the OWP is mainly the result of hydrolysis of aluminum salts.
- The use of phosphate rock or slow release calcium phosphate fertilizer will replace the zinc carbonate by zinc phosphate precipitate, which has a lower solubility than zinc carbonate.
- Phosphate rock is applicable to all Buchans effluents.
- The acidity in TP2 is generated mainly on the exposed beach and the result of ferrous iron hydrolysis.

Ecological Engineering Measures:

- All amended limnocorrals stimulated the development of ARUM, but peat, compared to sawdust, was responsible for higher sustained rates of ARUM.
- Limnocorrals amended with peat (**LC2, LC5**) effectively reduced acidity and precipitated zinc as sulphides. Low microbial activities are maintaining reducing conditions in the amendment, and zinc remains immobilized as zinc sulphide.
- Limnocorrals amended with sawdust did not support high rates of ARUM microbial activity, and zinc was only partially precipitated as sulphides.
- ARUM microbial activity currently prevails in all amended limnocorrals, but at rates sufficient to maintain low redox (only in the **LC2** and **LC5**) for 900 days.
- In Waste rock seepage, zinc concentrations are reduced generally from **80 mg/L** by **50 %** or more in Ponds **7 - 9** due to ARUM supported by the natural peat.
- Laboratory tests suggest that the addition of 19 g of peat and 1 g of potato waste removes all the Zn from 1 L of OWP in 80 days.

- A second curtain enclosing **770 m³** of water (1.2 % volume of pit) has been set up in the Oriental West Pit with peat (21.2 T) and potato waste (**0.77 T**).
- Weight losses of organic substrates were as great or greater in the ARUM-active limnocorrals (LC2 and LC5) as in those which are failing (LC1 and LC4). Therefore through leaching or decomposition organic carbon is released for sulphate reduction and the rates can be quantified.
- Sequential extractions of alfalfa gave results which were similar to those for cattails and peat. Therefore cattails are useful to ARUM as sources of carbon.
- Floating cattails on the rafts successfully overwintered in the Orientals.
- Cattails grow better on the OEP than on the OWP. Nutrients are required in OWP.
- Seedlings can be established by seed germination directly on rafts.
- Biomass of cattails are **555 g/m²** in OWP and **2260 g/m²** in OEP were measured in the second year rafts. When the populations are mature **1.35 T** of litter/OWP/year, and **22.4 T** litter/OEP/year may be expected.
- Periphyton on alder branches and netting grew at rates from **0.8 to 35 grams** dry weight per square meter of substrate per day.

- In June, 30 mg Zn was removed per m² (substrate)/day in fertilized ponds. In July and August, 220 mg Zn was removed. In September and October the rates dropped to about 75 mg Zn/m² (substrate)/day.
- In August, with a **16** day residence time, 88% of the dissolved zinc was removed. In July over **93%** was removed with a residence time of 80 days.
- The effluents from the Oriental West do not contribute to the characteristics of the Oriental East pit. The acidic conditions are not derived from acid generation of the exposed massive sulphide.
- Copper and zinc in the OWP is derived from precipitates previously formed in the underground workings.
- The zinc concentration in the OEP also originates from precipitates underground, but copper concentrations are likely constituents of the ground water.
- Lucky Strike water will decrease to a minimum zinc concentration of 1 to 2 mg/L zinc which **is** the same as that in TP-2.

Recommendations:

- ARUM has increased the rate at which the concentrations of zinc and copper decrease in the OWP. Further improvements are expected from the second curtain installed in **1991**.
- ARUM and phosphate rock should be used in combination for the effluents at the OEP.
- Scale up of biological polishing in the first meadow would provide further backup to the treatment.
- A holding pond in the First Meadow with a volume of **29,000 m³** receiving OEP outflow of about 1000 m³/day could have an average residence time of about 30 days, similar to the experimental polishing ponds (18-80 days). Therefore biological polishing can be expected to occur at similar rates after scale up.
- The zinc loading to the first meadow is about **14.6 tonnes** (1 tonne/yr from WRP). of which about 5.8 tonnes of zinc can be removed annually.
- **In TP2**, biological polishing should remove zinc to a concentration below 1 mg/L. In addition it should reduce the zinc loading from tailings beach # 1.

- Further investigation of the hydrology of the Drainage Tunnel is required and experimental meander using phosphate rock and biological polishing will define a reduced retention time.
- Lucky Strike should be flooded in a controlled manner and treated with phosphate rock.

•

- The discharge rate of the Drainage Tunnel should be monitored during filling of the Lucky Strike.

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Schematic 1-1: Schematical Composite Vertical Section . . . , 1- 8

10 INTRODUCTION

In 1988, Boojum Research was retained by the Buchans Joint Venture (Asarco Inc. and Abitibi-Price Inc.) to evaluate options for decommissioning the various effluents from the old Buchans mining operations. Buchans is located approximately in the center of Newfoundland (Map 1-1).

The conventional approach to waste water rehabilitation is represented by lime treatment, which requires perpetual maintenance, and is often accompanied by sludge disposal problems. In Map 1-2 an overview of the Buchans area is presented. Effluents which require treatment emerge at the Orientals and reach the Buchans River via the 1st and 2nd Meadow. Additional treatment at the site is needed at the effluents of the tailings ponds (TP-1 and TP-2). Further water reclamation is required at a third group of old mine workings, called **Lucky Strike** and Drainage Tunnel.

Given the site layout, to arrive at treatment options either conventional or novel requires a multidisciplinary approach. Furthermore, the recent emergence of environmental requirements and their associated economic costs warrant the consideration of novel, yet unproven, approaches to waste water treatment at this site. Ecological Engineering - a soft technology based on natural water cleansing processes - was considered by the Joint Venture as a potential solution to the decommissioning of Buchans' effluents. A commitment was made to carry out research and development on these natural processes, mainly focusing on the effluents of the two Oriental gloryholes.

The 1991 report on Ecological Engineering summarizes three years of experimentation, and scale-up steps in the gloryholes. The Ecological Engineering approach, which has emerged from the investigations carried out, utilizes phosphate rock to remove zinc at low concentrations and biological polishing processes to relegate zinc, in either the suspended or dissolved form, to sediments in polishing ponds. Where acid is generated, a microbial process known as **ARUM** (Acid Reduction Utilizing Microbiology) will be applied.

In the previous years, experiments to demonstrate the feasibility of Ecological Engineering were carried out. **As** the results obtained were very encouraging, albeit experimental in nature, Boojum Research was requested during 1991 to broaden the scope of its work to include an assessment of Ecological Engineering for the Lucky Strike - Drainage Tunnel system. In Schematic 1-1, the relationships between the Lucky Strike, the Drainage Tunnel, and the Orientals are outlined. It is evident, when the mine workings are considered together with the effluent points, that a hydrological connection exists between the underground and the discharge. The mine workings below sea level up to the present water level in Lucky Strike have already been flooded for some years. However, Lucky Strike still continues to fill, and when it reaches its final water level the characteristics **of** the Drainage Tunnel effluents may change.

In general, for all effluents it is important to ascertain whether the existing characteristics of the water will improve naturally or become worse in the long term. Natural improvement can be expected, as the underground workings cease to generate acid in the absence of air and oxygen. Furthermore, given that the Buchans mine utilized wood in the underground

workings, when low oxygen conditions are established, microbial reduction of either iron or sulphate will occur naturally. Therefore, during the Ecological Engineering study, extensive efforts have been made to arrive at an understanding of the sources of zinc in the effluents.

The Ecological Engineering approach was also extended to the treatment of Tailings Pond-2, and it was concluded that an overall broader data base on all Buchans effluents, their chemistry, and the mine's groundwater and geochemical regimes should be developed. This technical report, therefore, contains great amounts of detailed information, which can easily cloud the overall picture. However, this detail is necessary since Ecological Engineering is a novel technology, based on the understanding of natural chemical and biological water cleansing processes.

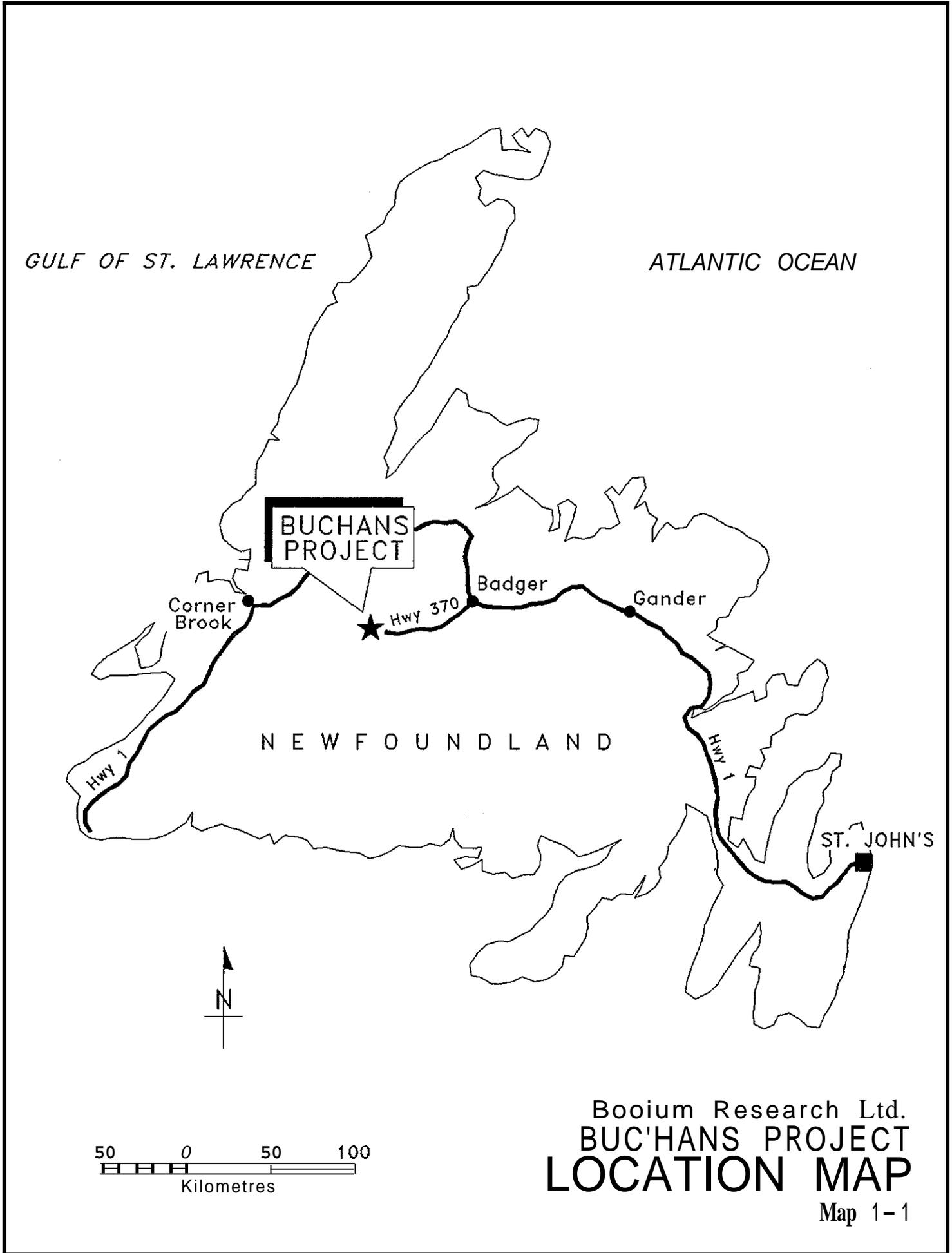
When the transition is made from experimental results to full-scale application of a biological system, the input parameters for the design are different from those required for conventional engineering. Ecological Engineering initiatives provide the foundations for the development of new ecosystems in the Orientals, Lucky Strike, and **TP-2** in the long term. Until these systems are stable, some maintenance will be required in the form of nutrient addition, either to the microbial community reducing the acidity in the sediments, or to the algal populations which polish the water.

This nutrient supply could potentially be phosphate rock or slow-release fertilizer, which in itself removes zinc from the water. From the results presented in this report, it is evident that close-out decisions can be made based on a threefold approach to treatment: (1)

biological, (2) chemical; and (3), microbiological. Each is considered as a sole means to address the existing loadings from the effluents. Therefore, it follows that if all three approaches work together, an environmentally-acceptable, low-maintenance decommissioning approach can be (and has been) identified.

This report presents the foundation of the design criteria necessary for the components within each system. The hydrology and geochemistry of the Buchans effluents which discharge into the Buchans River are presented in Section 2.1. A conceptual model of the ground water flow fields, based on geological structures and the topography of the area, is put forth in Section 2.2. The relationship between Lucky Strike gloryhole and the Drainage Tunnel, which drains Lucky Strike into the Buchans Rver, is described in Section 2.3. Section 2.4 summarizes the tailings effluents and their geochemistry. In Section 2.5, the hydrological and geochemical information is incorporated with long term trends in contaminant concentrations in the effluents to predict possible contaminant sources.

In Section 3, the fundamental chemical processes relevant to the Buchans effluents are described. This section is followed by a description of all the Ecological Engineering experiments carried out to date. Finally, descriptions of the close-out measures required for the Orientals, the Drainage Tunnel and Lucky Strike, and the tailings are presented as conclusions in Section 5. A comprehensive list of all major conclusions is provided at the beginning of the report.



GULF OF ST. LAWRENCE

ATLANTIC OCEAN

**BUCHANS
PROJECT**

Corner
Brook

Badger

Gander

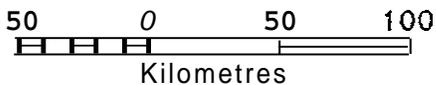
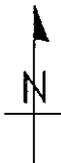
Hwy 370

Hwy 1

N E W F O U N D L A N D

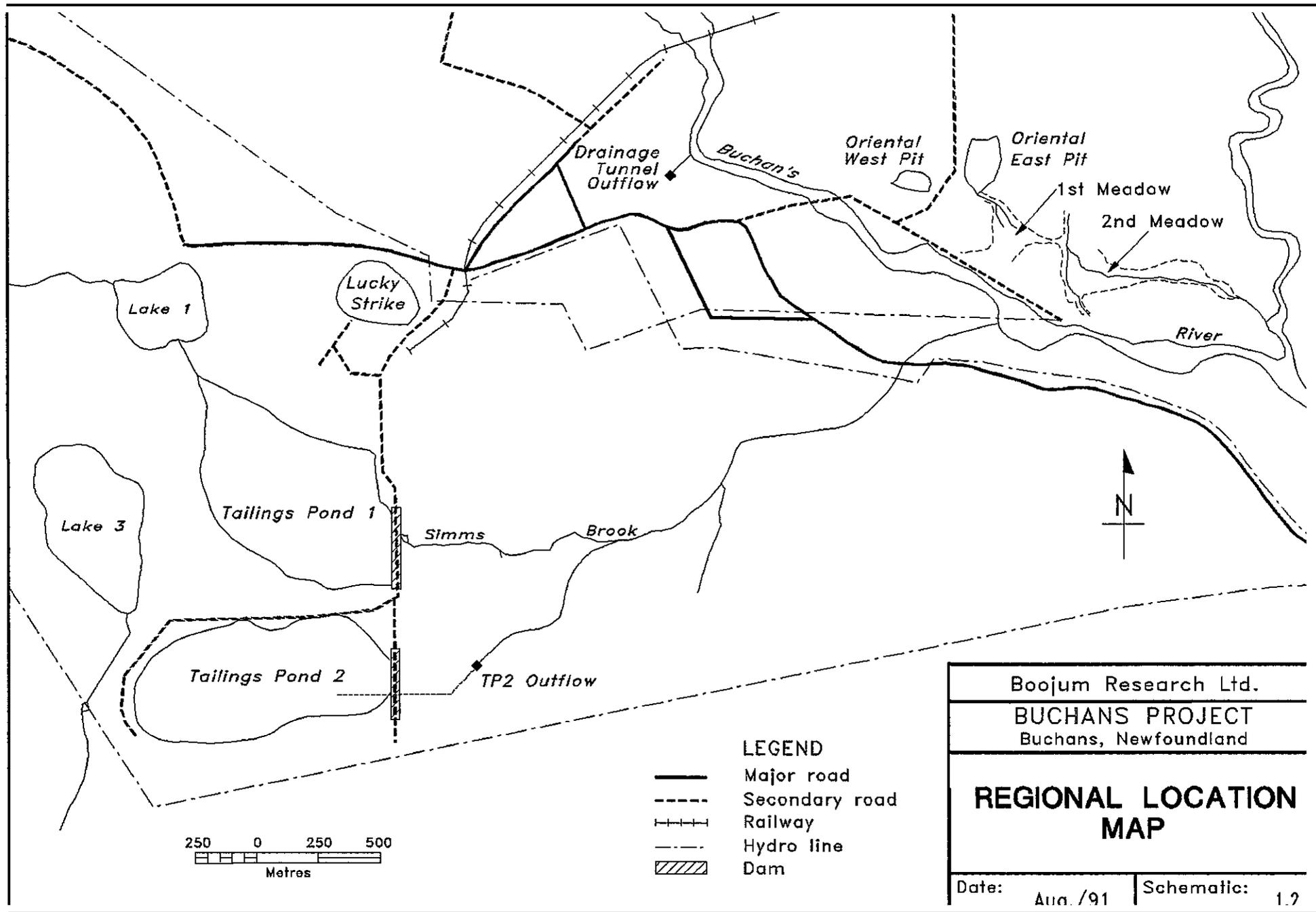
Hwy 1

ST. JOHN'S



Booium Research Ltd.
**BUC'HANS PROJECT
LOCATION MAP**

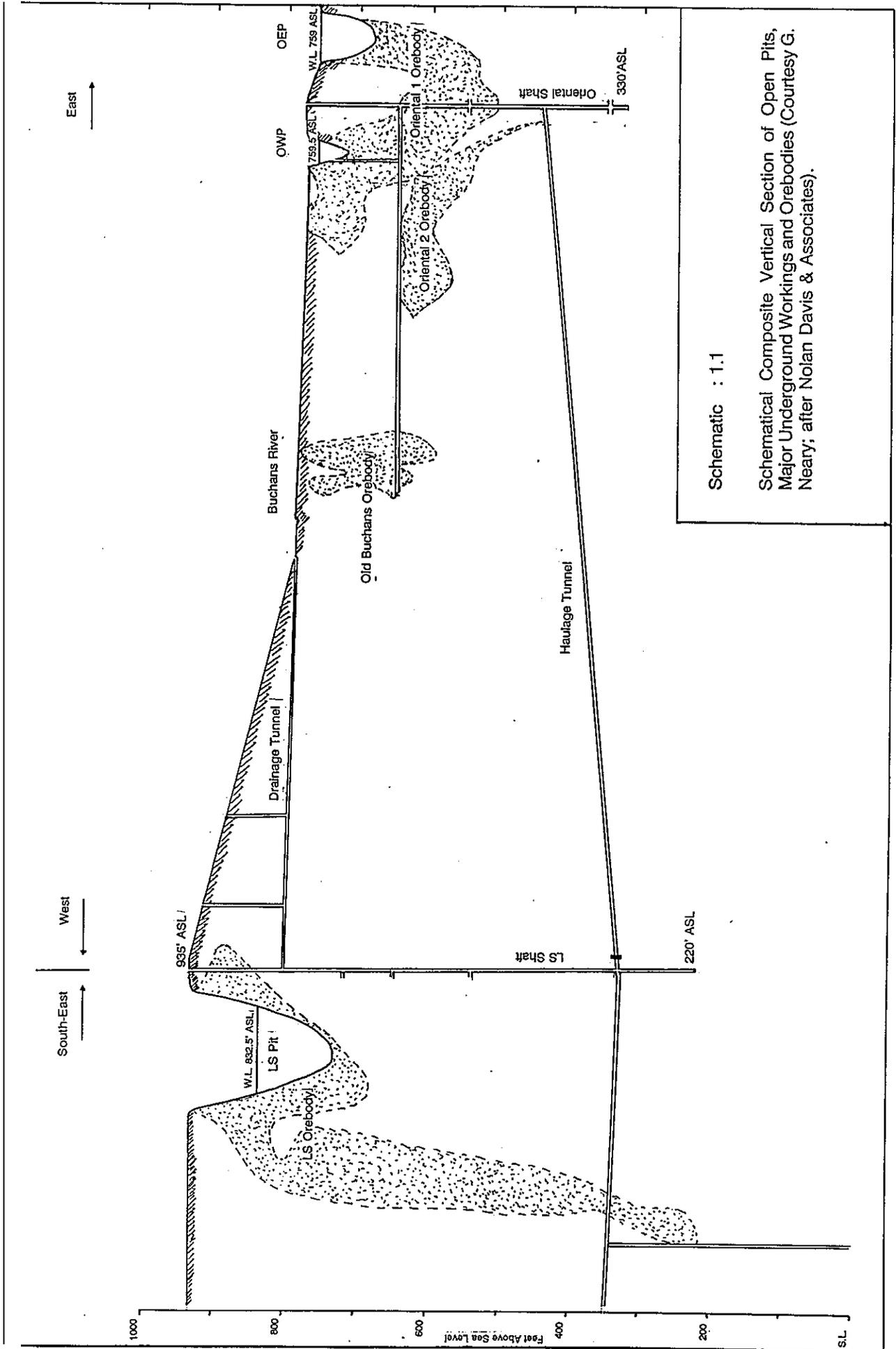
Map 1-1



Boojum Research Ltd.
BUCHAN'S PROJECT
 Buchans, Newfoundland

**REGIONAL LOCATION
 MAP**

Date: Aug. /91 | Schematic: 1.7



Schematic : 1.1

Schematic Composite Vertical Section of Open Pits, Major Underground Workings and Orebodies (Courtesy G. Neary; after Nolan Davis & Associates).

20 HYDROLOGY AND GEOCHEMISTRY

Effluent characteristics from the Buchans mining operations display an unusual complexity. Long-term trends in monitoring data indicate significant changes with time. The causes of these long-term changes have been the focus of work towards decommissioning.

A precise definition of the drainage basin for the gloryholes and the tailings basins is difficult, due to the nature of the terrain. After the initial assessment was carried out in 1988, it was concluded that existing effluent characteristics would certainly continue to change (based on evaluations of the precipitation records and geochemical results).

In 1989/90, investigations mainly addressed Ecological Engineering measures, and only a limited amount of geochemical work was carried out. The results of initial experiments in Ecological Engineering were promising, providing a feasible, low-cost, and possibly maintenance-free decommissioning scenario. Based on this work, questions about the long-term stability of contaminants in the effluents received further investigation.

The hydrological and geochemical investigations utilized existing data and information that could be obtained cost-effectively, such as that recovered from existing drill holes. The general assumption was made that a full-scale hydrological investigation would not produce more useable information, given the complexity of the geology and hydrogeology at Buchans.

Therefore, groundwater sources for the Orientals were addressed using geochemical

simulations, such as PHREEQE. This computer program uses chemical analysis of effluents as input, and essentially matches water characteristics from different sources, taking mineral precipitation and dissolution processes into account. This approach was used as extensively as possible, and supplemented with water analyses from accessible drill holes in the vicinity of the Orientals and the Lucky Strike.

The exploration holes were opened and groundwater samples obtained for chemical analysis. A conceptual framework for the hydrology in the Orientals and Lucky strike area was constructed, based on key geological features of the areas. This work was carried out under subcontract to Nolan Davis.

During the course of the 1991 project, the scope was broadened to formulate overall measures required to achieve environmental regulatory compliance. Therefore, monitoring data on Lucky Strike, Drainage Tunnel, and the tailings drainage was included in the geochemical and hydrological assessment.

The hydrological and geochemical conditions are those which determine the plan of action. All effluents to the Buchans River are discussed in Section 2.1. In Section 2.2, the physical groundwater flow field is presented, which is followed in Section 2.3 with details for the Lucky strike and Drainage Tunnel. Finally, the conditions of the tailings ponds are presented in Section 2.4. The last subsection on hydrology and geochemistry (Section 2.5) attempts to discuss the long-term trends in all effluents in contact with mine workings. The result is a prediction of potential changes in long-term effluent characteristics.

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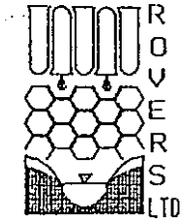
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ASARCO - BUCHANS UNIT

EFFLUENTS TO BUCHANS RIVER

DECEMBER 1991

ASARCO - BUCHANS UNIT

EFFLUENTS TO BUCHANS RIVER

1. INTRODUCTION

since the start of mining in the Buchans area, Buchans River has received a variety of heavy-metal contaminated discharges from the mining operations. Between 1928 and 1965, about 8.5 million SD tons of mill tailings were reportedly sent down the river to a growing tailings delta in Red Indian Lake. Mine water from the Lucky Strike mine was discharged into Buchans River via a Drainage Tunnel completed in July 1928. The river has been receiving drainage from Tailings Pond #1 since 1965, and from Tailings Pond #2 since 1972, via Simms Brook.

Upon termination of the mining operations in 1984, the mine workings were flooded, which resulted in rising waterlevels in the Oriental East and West Pits and in the Lucky Strike Pit. The waterlevel in the Lucky Strike Pit is still rising and not expected to stabilize for another 15 years or so. The waterlevel in the Oriental West pit stabilized in 1986, when the Oriental East Pit started overflowing, suggesting subsurface drainage from the West Pit to the East Pit. The discharge from the Oriental East Pit flows to Buchans River via a marshy area known locally as the First and Second Meadows. Heavy-metal contaminated water also seeps from the Oriental mine waste-rock dump into Buchans River a short distance below the Oriental mine road.

A routing chart (Figure 1-1), representing Buchans River from the dam at Sandy Lake (or Buchans Lake) to the highway bridge near Red Indian Lake, shows all significant additions to stream flow in this reach of Buchans River. Water samples for determination of pH, [Cu] and [Zn] are collected at more or less regular intervals at monitoring stations established to measure discharge rates from the Drainage Tunnel (DT), the Oriental East Pit (OEP), and Simms Brook (SB). No detailed data exist for the seepage from the Oriental waste-rock dump. Data from the monitoring stations are available in tabulated form for the period from January 1987 to September 1991, but in this report they are presented only in the form of graphs.

In this report, available data are used to characterize the effluents discharged into Buchans River, to evaluate apparent changes in heavy-metal concentrations in the effluents with time, and to discuss the possible effects of various perceived treatment options.

Every effort has been made to make sure that the data used in the interpretations presented in this report are the best available. Any errors found, and significant new information that could affect the interpretations should be brought to the attention of the author as soon as possible to enable correction and, where necessary, re-interpretation.

2. MONITOR DATA

A. Discharge Rates

The rate of discharge from the Drainage Tunnel (Figure 2-1) is relatively stable, but it shows a slow long-term increase related to the rise in groundwater levels in the area surrounding the slowly filling Lucky Strike Pit. The average discharge rates in 1988, 1989 and 1990 were 121, 108 and 114 USgpm (7.6, 6.8, and 7.2 L/s), respectively. The discharge rate dropped in mid-1988 after the completion of a concrete 'plug' in the tunnel at the first intermediate shaft, about 1500 ft from the tunnel portal.

The discharge from Simms Brook (Figure 2-2) shows highs during the snowmelt and the rainy period in the fall, with lows during the summer months. Average discharge rates in 1988, 1989, and 1990 were 1403, 1010, and 1660 USgpm (88.5, 63.7, and 104.7 L/s), respectively. In an earlier report, comparison of the SB monitor data with those for the TP#1 and TP#2 discharges suggested the existence of an additional (probably diffuse) heavy-metal source in the Simms Brook drainage basin; the reportedly poor quality of the SB gauging station still prevents a more definite conclusion.

The rate of discharge from the Oriental East Pit (Figure 2-3) peaks during the snowmelt period and is relatively low during the summer months. The average discharge rates in 1988, 1989 and 1990 were 160, 151 and 170 USgpm (10.1, 9.5, and 10.7 L/s), respectively.

Streamflow rates in Buchans River (Figure 2-4) are recorded only in a relative sense, as High, Med-High, Medium, Low, or Very Low.

B. pH

The pH of the DT discharge (Figure 2-5) shows relatively small variations around annual averages of about 6.6. The pH of the SB discharge (Figure 2-6) shows seasonal highs and lows around annual averages near 7.2, with occasional unexplained extreme values (e.g. 8.1 and 8.4 in 1991). The pH of the OEP discharge shows seasonal highs and lows, with some indication of long-term increase; recent annual averages were between 6.8 and 7.0.

The pH of Buchans River water also shows seasonal highs and lows around annual averages of 7.3 or 7.4, but no obvious long-term trend.

C. Copper

All three discharges show some seasonal variations in [Cu]. The DT and SB discharges (Figures 2-9 and 2-10) show minor long-term increases in [Cu], but the OEP discharge does not. The [Cu] values for the DT discharge (Figure 2-9) all exceed the guideline of 30 ppb, with at least some values being five times the guideline value. The data for both the SB and OEP discharges (Figures 2-10 and 2-11) show some values below the guideline, but most exceed the guideline by up to 30 ppb.

The [Cu] values for Buchans River (Figure 2-12) appear to reflect a small long-term decrease; they have been well below the guideline value for most of the period since late 1989. Only one sample exceeded the guideline value in 1991.

D. zinc

The DT discharge (Figure 2-13) shows some slow fluctuations, with minor highs in late winter, followed by a low during snowmelt and spring rains, and a second high in mid- to late-summer; no long-term trend is visible. The SB discharge (Figure 2-14) shows high [Zn] values during snowmelt and in fall and early-winter; a long-term decreasing trend likely reflects a long-term decrease in [Zn] values in the discharge from the Tailings Ponds. The OEP discharge (Figure 2-15) shows seasonal low [Zn] values during snowmelt, and a significant long-term decrease in [Zn] since 1987.

The [Zn] values for Buchans River (Figure 2-16) show decreasing seasonal variations, and a long-term decreasing trend that reflects the decreases in [Zn] values in both the SB and OEP discharges; they all exceed the guideline value, in some instances by as much as an order of magnitude.

E. Loadings

Copper loadings from the DT, SB and OEP discharges are shown in Figures 2-17 to 2-19, respectively; zinc loadings for the three discharges are shown in Figures 2-20 to 2-22. The largest Cu-loading is delivered by the SB discharge, followed in order of decreasing magnitude by the DT and OEP discharges. The largest Zn-loading is still being delivered by the OEP discharge, followed by the DT and SB discharges.

Actual heavy-metal loadings in Buchans River cannot be determined, although analyses of Buchans River water are available, because no streamflow data exist for the river. Therefore a plot of the combined known Cu and Zn loadings to Buchans River from the three discharges is presented in Figure 2-23. The major Cu-loading in Buchans River is contributed by SB discharge (mostly from Tailings Pond #1). The major Zn-loading in Buchans River is contributed by the OEP discharge, which shows a slow long-term decrease; it may eventually be equalled by the very slowly rising Zn loading from the Drainage Tunnel. Additional loading may be contributed by seepage from the waste-rock dump, and from possible discharge of contaminated groundwater elsewhere.

Figure 2-23 shows a slow long-term increase in combined known Cu-loading for Buchans River, due to increasing loadings from the DT and SB discharges, and a slow long-term decrease in combined known Zn-loading, due to decreasing loadings from the SB and OEP discharges that are partially offset by increasing loading from the DT discharge.

3. WATER CHEMISTRY

The analyses for water samples collected in July 1991 from Buchans River and from the effluent streams it receives are listed in Table 3-1. The points sampled include the Forebay, Drainage Tunnel, Simms Brook, Oriental East Pit, and Buchans River, as well as the Sandfill Spring and Oriental Pond. These and earlier analyses made on samples from some of those points all represent the mid-summer situation. No

repeat analyses are available for the seepage from the waste-rock dump, for the powerhouse discharge, or for the Middle and East Branches of Buchans River.

The data in Table 3-1 include field measurements of water temperature, conductivity, Eh and pH. Laboratory analyses included determination of the concentrations of Cl, Br, F, NO₃, SO₄, and HCO₃. Unfortunately, the samples were analyzed for concentrations >1 mg/L only, which resulted in rather large ion-balance errors, ranging from +34.2 to +76.6% for the dilute "natural" waters, and from from t4.4 to +15.8% for the more concentrated effluents.

Three analyses for Buchans River samples, collected from the Forebay, at the Powerhouse, and at the highway bridge, are illustrated by Figure 3-1. The absence of points for several of the elements of interest, which makes useful interpretation impossible, reflect the 1 mg/L analytical precision cut-off.

The variations in the elemental concentrations in surface waters and effluent discharges that were sampled along Buchans River between the Forebay and the highway bridge are illustrated by Figure 3-2 for Ca, Mg, Na, Cl, SO₄, and HCO₃, and by Figure 3-3 for Al, Cu, Fe, Mn, Pb, and Zn. The increases in the major-ion concentrations in BR water between the Forebay and the powerhouse reflect effluent additions: the decreases between the powerhouse and the highway bridge reflect the addition of presumably uncontaminated water from the Middle and East Branches. No useful interpretation is possible for the metal concentrations, because of the analytical precision cut-off.

The variations in the concentrations of Ca, Mg, Na, SO₄, Cu, and Zn *are* shown in the proper station sequence in Figure 3-4, which contains blanks for suggested additional sampling stations above the Drainage Tunnel (BR/DT), at the Oriental mine road (BR/MR), the Oriental waste-rock seepage (WRS), above the Powerhouse (BR/PO), the Powerhouse outfall (PO), and the Middle and East Branches of Buchans River (MBR and EBR).

In the absence of discharge data for Buchans River, no reliable metal balance can be established for the reach between the dam and the highway bridge. It would be necessary to obtain streamflow measurements for Buchans River at the dam and at the highway bridge, and for the discharges from the Powerhouse, and from the

Middle and East Branches of Buchans River. Water samples for analysis should be obtained at the same places, at the same time.

4. POTENTIAL EFFECTS OF TREATMENT OPTIONS

A. Drainage Tunnel

There appears to be insufficient room for the biological treatment of DT discharge, between the tunnel portal and Buchans River. As it is unlikely that the DT discharge will be allowed to continue discharging into Buchans River without treatment, it has been suggested that the DT discharge should be pumped to one of the Oriental Pits, where it would add to, and be treated as part of, the OEP discharge. The relative advantages and disadvantages of the West and East Pits as recipients of the DT discharge have been discussed in an earlier report ("The Drainage Tunnel and the Lucky Strike Pit").

Pumping of the DT discharge to the Oriental Pit(s) will remove this effluent in one place and add it indirectly, after treatment, farther downstream. As a result, the water quality in Buchans River downstream of the DT outfall point should improve; this could be checked by establishing a monitoring station where the Oriental mine road crosses the river. This should be done early enough, so that periodic sample collection could be started well before diversion of the DT discharge takes place, to establish the present water quality at that point.

B. Oriental East Pit

Ecological Engineering measures for treatment of the OEP discharge are currently being tested. A potential doubling of discharge from the OEP, through the addition of DT discharge, will affect both the hydraulic performance and the biological performance of the scaled-up treatment system to be established in the Meadows. These potentially serious drawbacks should be taken into account during the scale-up design. In addition, increased ice formation in and downstream of the system could affect the efficiency of the system during the winter.

C. Simms Brook

A combination of Ecological Engineering measures is now being evaluated for application to the discharges from the two tailings ponds for the reduction of the Cu and Zn concentrations in SB discharge to below the guideline value of 30 ppb. In an earlier report ("Weather and Monitoring Data, 1987-1990", dated 16 April

1991) it was suggested that the drainage basin of Simms Brook downstream from the discharge points of the two tailings ponds contributes additional heavy-metal contaminated water; the somewhat questionable nature of the discharge data for Simms Brook make it impossible to confirm this. The possibility should, however, be investigated and, if confirmed, the ecological engineering measures would have to be designed to also deal with this potential source of dissolved heavy metals.

D. Other Heavy-Metal Sources

As there are no discharge data for Buchans River, an attempt was made to determine the magnitude of BR discharge indirectly. For that purpose, the monitoring data were used to determine combined discharge rates, Cu-loadings and Zn-loadings from the known effluent sources, for each observation date. Each of the combined Cu-loading and Zn-loading values was divided by the corresponding [Cu] and [Zn] values for Buchans River for the same date. The results of these calculations are shown in Figure 4-1 as curves for: (1) the combined discharge rate of the three known effluent sources (unmarked curve); (2) Buchans River flowrates calculated from combined Cu-loadings from the three sources, and [Cu] values for the BR monitoring station (curve marked 'Cu'); and (3) Buchans River flowrates calculated from combined Zn-loadings from the three sources, and [Zn] values from the BR monitoring station (curve marked 'Zn').

The streamflow rate in Buchans River at the highway bridge should, of course, be higher than the sum of the flowrates for the three effluent sources, because discharge from the Forebay, the Powerhouse, and the Middle and East Branches are added. The curve marked 'Cu' indicates flowrates between 0.73 and 9.5 times (average 2.6 times) the combined rate indicated by the unmarked curve; the curve marked 'Zn' indicates flowrates between 2.3 and 439 times (average 77.6 times) the combined rate indicated by the unmarked curve. The discrepancy between the rates based on Cu and those based on Zn could be explained either by assuming that an additional (unmonitored) source is adding to the Cu-loading in Buchans River, or by assuming that some of the original Zn-loading is lost by precipitation. Which of these two possible processes is actually taking place, and at what rate, cannot be determined without accurate streamflow data for Buchans River.

5. CONCLUSIONS

- a. Transferring Drainage Tunnel discharge to one of the Oriental Pits will improve water quality in the reach of Buchans River between the tunnel outfall and the Oriental mine road.
- b. Addition of Drainage Tunnel discharge to the Oriental discharge will affect the hydraulic stability and the treatment efficiency of the scaled-up Ecological Engineering treatment system planned for the Meadows. It may also lead to icing build-up in or downstream from the system in winter.
- c. Simms Brook likely receives some heavy-metal contaminated drainage from its drainage basin downstream of the tailings ponds. This can, however, not be confirmed without more reliable streamflow data for Simms Brook.
- d. Buchans River appears to receive Cu-contaminated discharge from a source or sources other than the three documented ones; or it is losing Zn by precipitation. Neither possibility can be confirmed without reliable streamflow data for Buchans River.

6. RECOMMENDATIONS

- a. A gauging station (Water Survey of Canada standard) should be established on Buchans River, far enough below the outfalls from the Oriental East Pit and Simms Brook to allow complete mixing of river water and effluents; a location at or near the highway bridge would provide for ease of access.
- b. Monitor stations for periodic collection of monitor samples and measurement of temperature, conductivity, and pH should be established at the Forebay, on Buchans River at the Oriental mine road and the Powerhouse, and on the Middle and East Branches of Buchans River.
- c. Water samples for complete analysis should be collected from the Forebay, from Buchans River at the Oriental mine road, and from the Middle and East Branches of Buchans River, for comparison with Buchans River water at the highway bridge, and possible establishment of "background" heavy-metal concentrations. Such samples should be collected at least once shortly after

break-up, once during the summer low-flow period, and once during the **fall** high-flow period.

- d. The gauging station on Simms Brook should be improved to provide more reliable streamflow data; location near the highway crossing should provide for ease of access.
- e. Attempts should be made to determine the quantity and **heavy-metal** content of seepage that reaches Buchans River directly from the waste-rock dump.
- f. The possibility that Buchans River water is losing Zn by precipitation should be checked.

5 December 1991

R.O. van Everdingen

FIGURE 1-1. BUCHANS RIVER: additions between the Forebay and the highway bridge.

	1	2
	=====	=====
FB - FOREBAY	S	S
BR/DT - BUCHANS RIVER above Drainage Tunnel		Q
DT - DRAINAGE TUNNEL*****>	Q	Q
BR/MR - BUCHANS RIVER at mine road bridge		S
<*****WRS - WASTE-ROCK SEEPS	S	Q
SB/HW &		
SB/BR - SIMMS BROOK*****>	Q	Q
(tailings drainage)		
BR/PO - BUCHANS RIVER above powerhouse		S
<-----PO - POWERHOUSE DISCHARGE		S
<*****OEP - ORIENTAL DRAINAGE	Q	Q
<-----MBR - MIDDLE BRANCH R.		S
<-----EBR - EAST BRANCH R.		S
BR/HW - BUCHANS RIVER at highway bridge	S	Q

NOTES:

***** indicates effluent discharge.

Column 1 at right indicates CURRENT data collection.

Column 2 at right suggests FUTURE data collection.

S indicates HIGH-FLOW and LOW-FLOW samples should be collected.

QS indicates FLOWRATES should be measured and SAMPLES collected on a WEEKLY or BI-WEEKLY schedule.

Figure 2-1
DRAINAGE TUNNEL: DISCHARGE

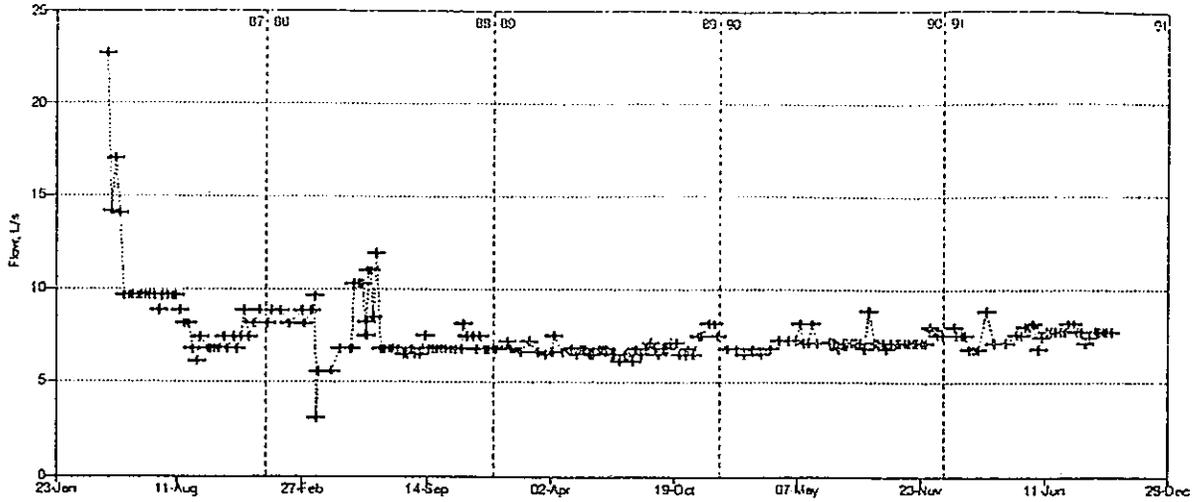


Figure 2-2
SIMMS BROOK DISCHARGE

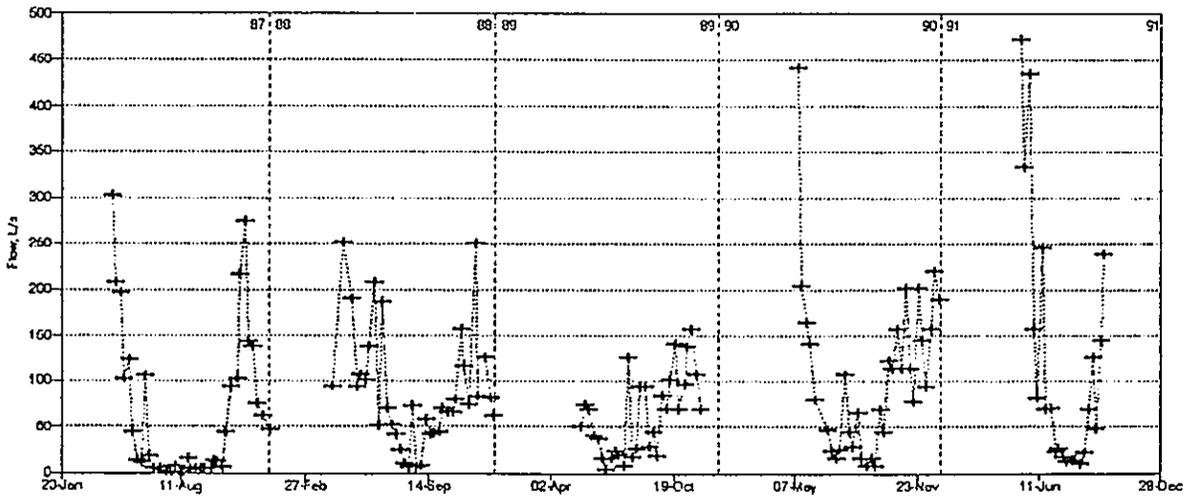


Figure 2-3
ORIENTAL EAST PIT: DISCHARGE

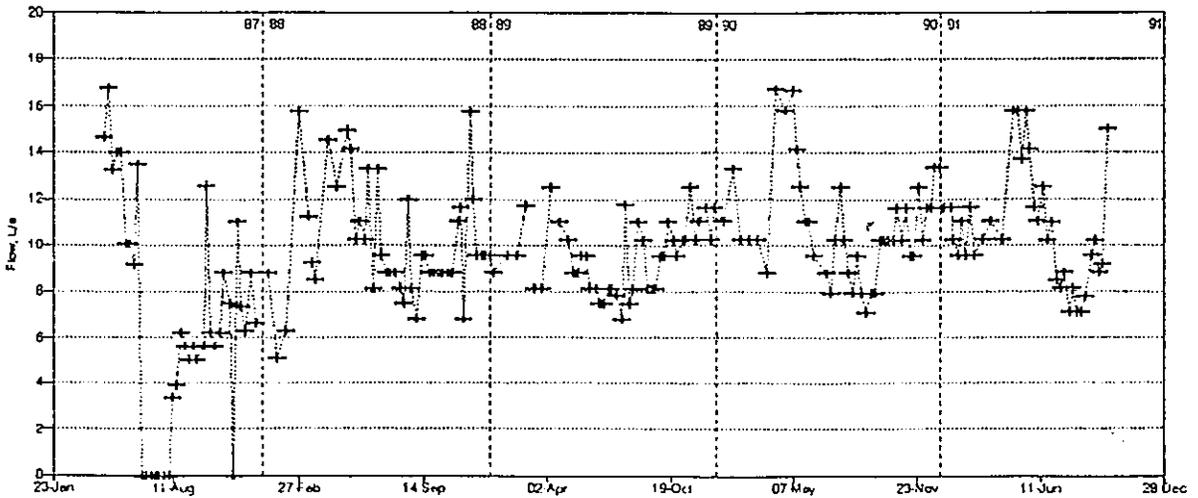


Figure 2-4
BUCHANS RIVER: DISCHARGE

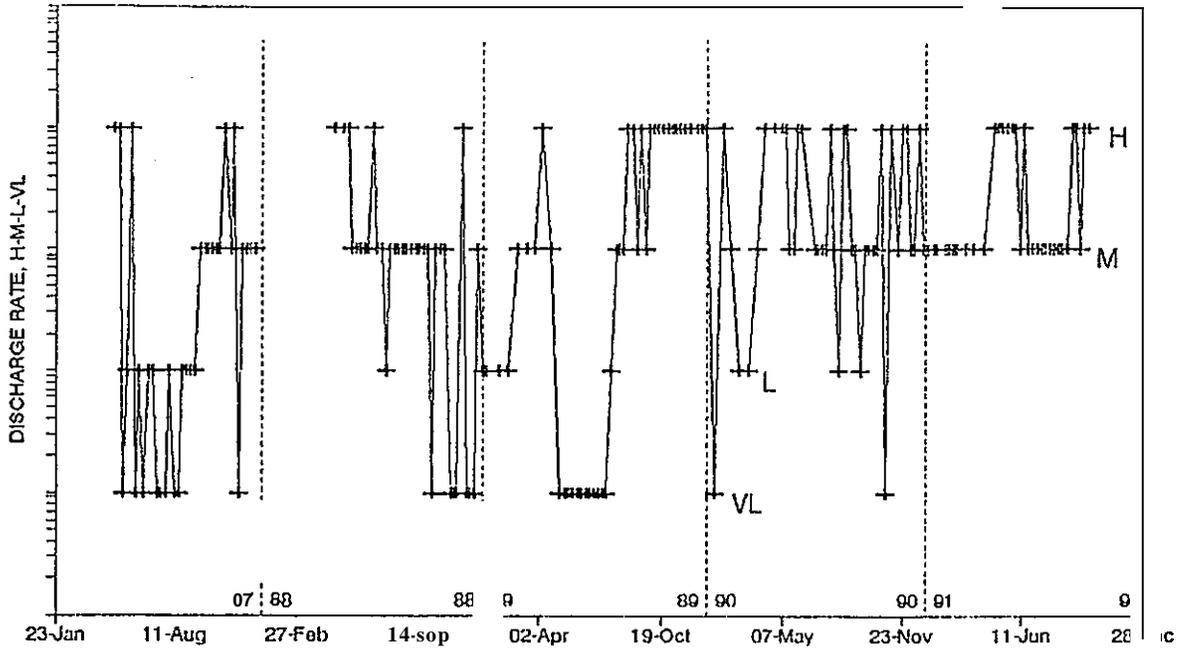


Figure 2-5
DRAINAGE TUNNEL EFFLUENT: pH

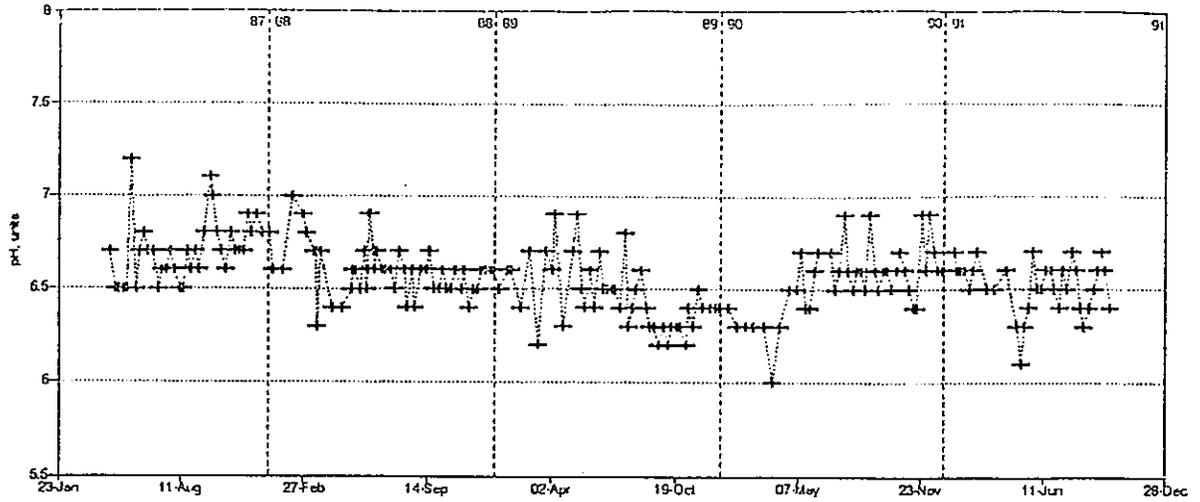


Figure 2-6
SIMMS BROOK WATER: pH

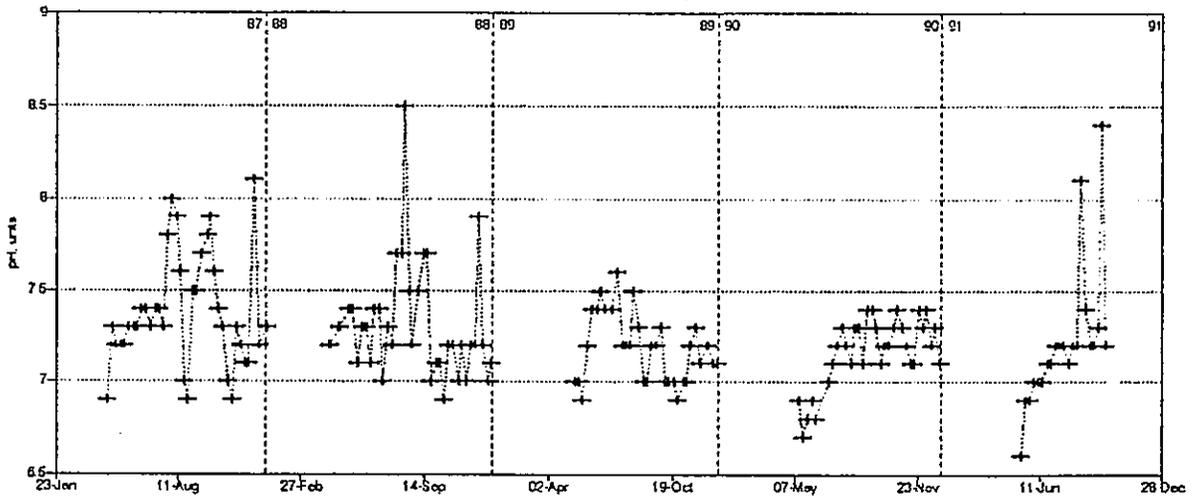


Figure 2-7
ORIENTAL EAST PIT EFFLUENT: pH

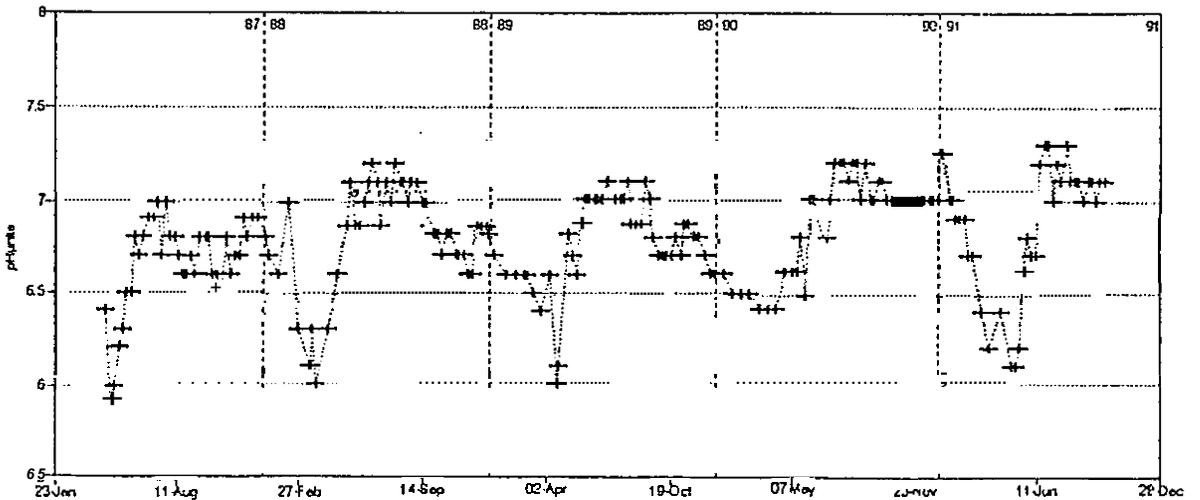
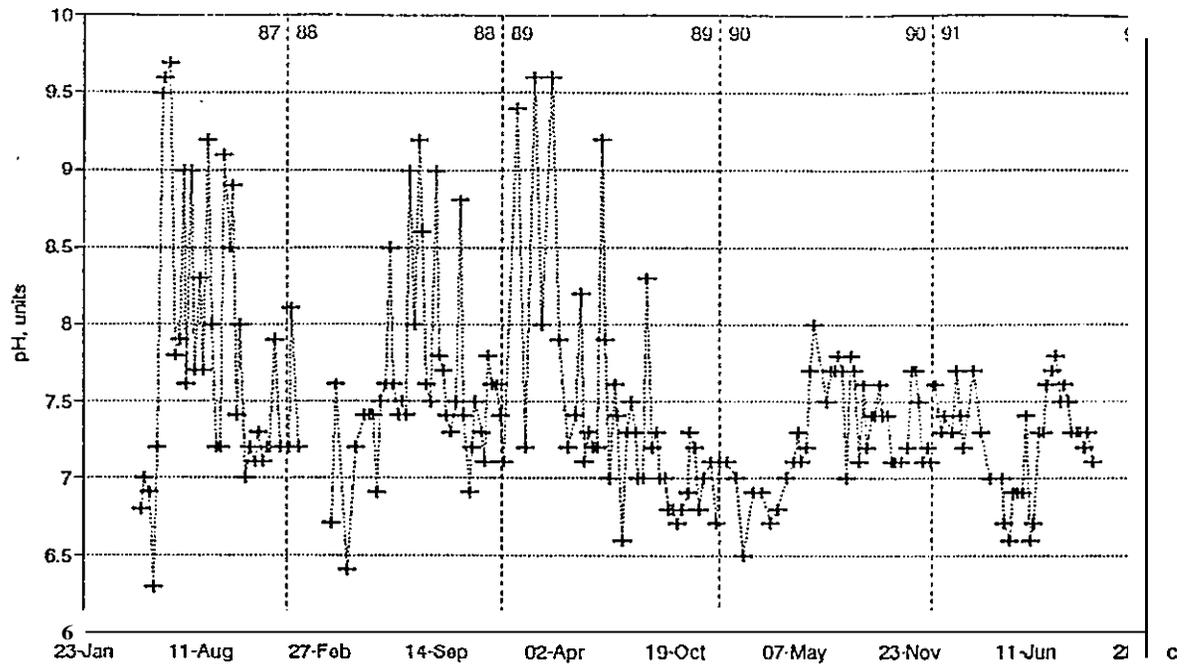


Figure 2-8
BUCHANAN RIVER WATER: pH



2 - 20
 Figure 2-9
 DRAINAGE TUNNEL EFFLUENT COPPER

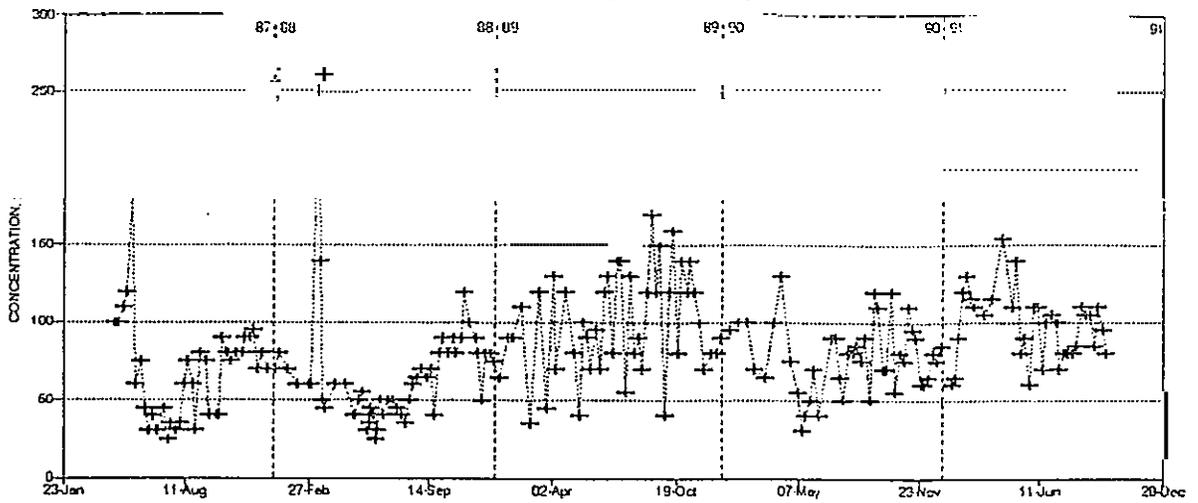


Figure 2-10
 SIMMS BROOK WATER: COPPER

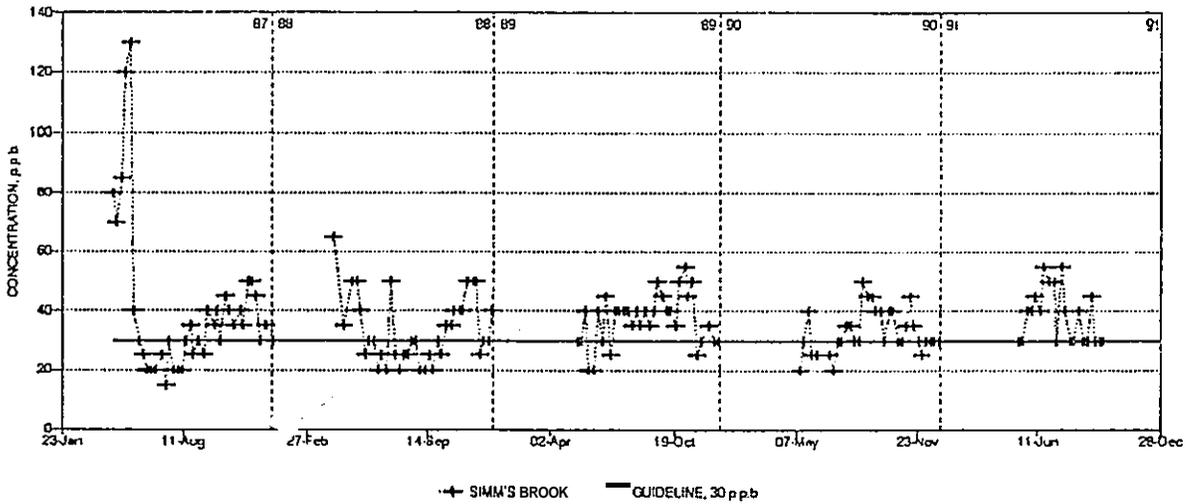


Figure 2-11
 ORIENTAL EAST PIT EFFLUENT: COPPER

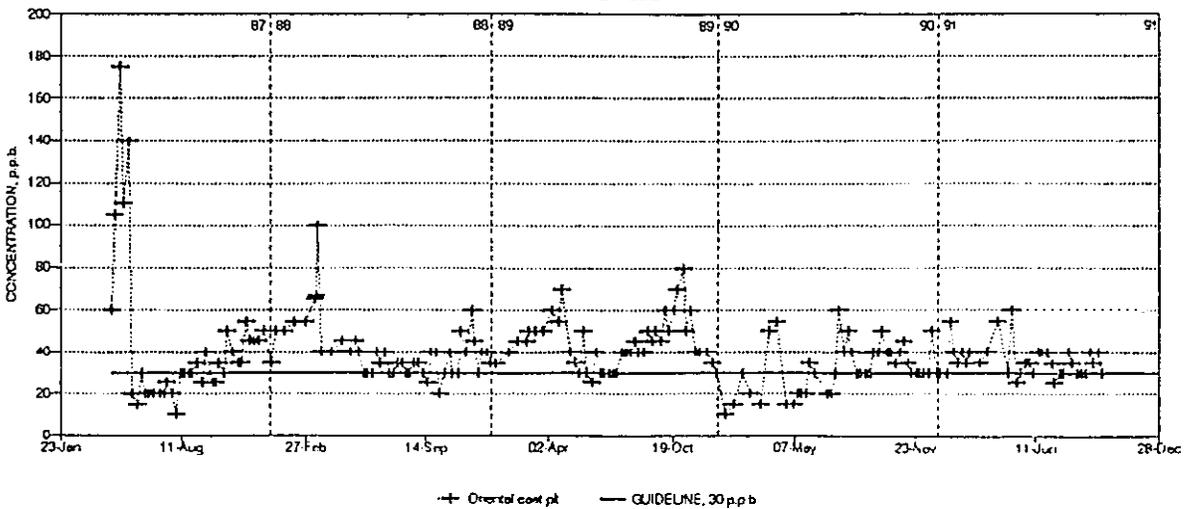


Figure 2-12
BUCHANS RIVER WATER: COPPER

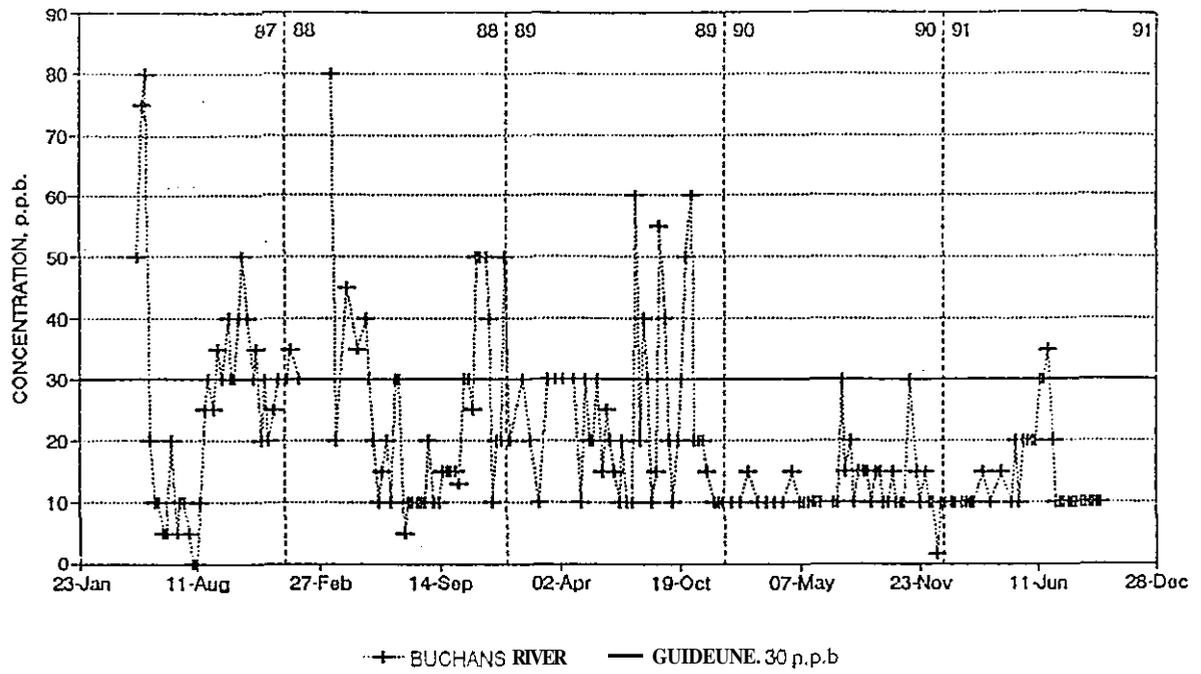


Figure 2-13
DRAINAGE TUNNEL EFFLUENT: ZINC

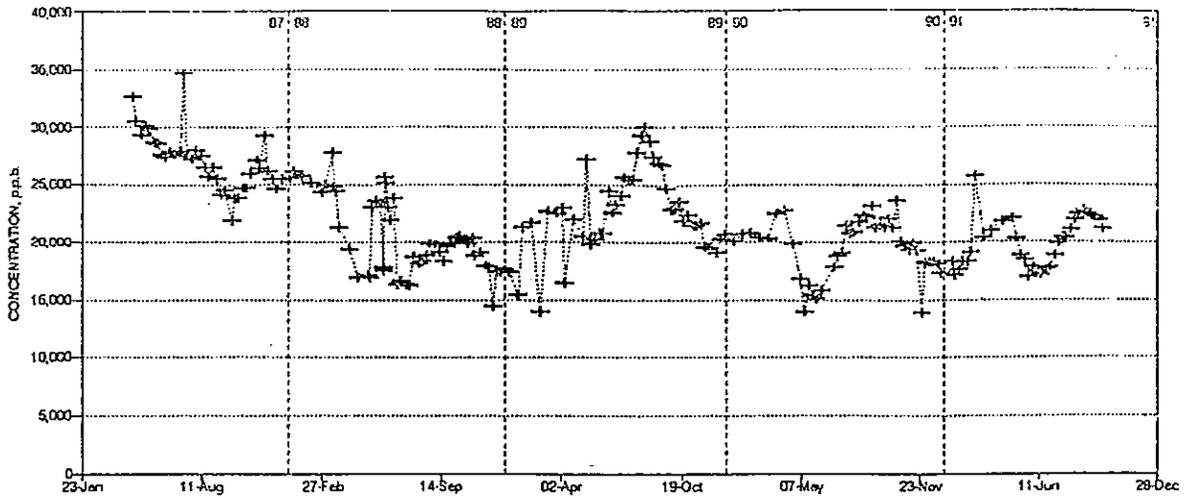
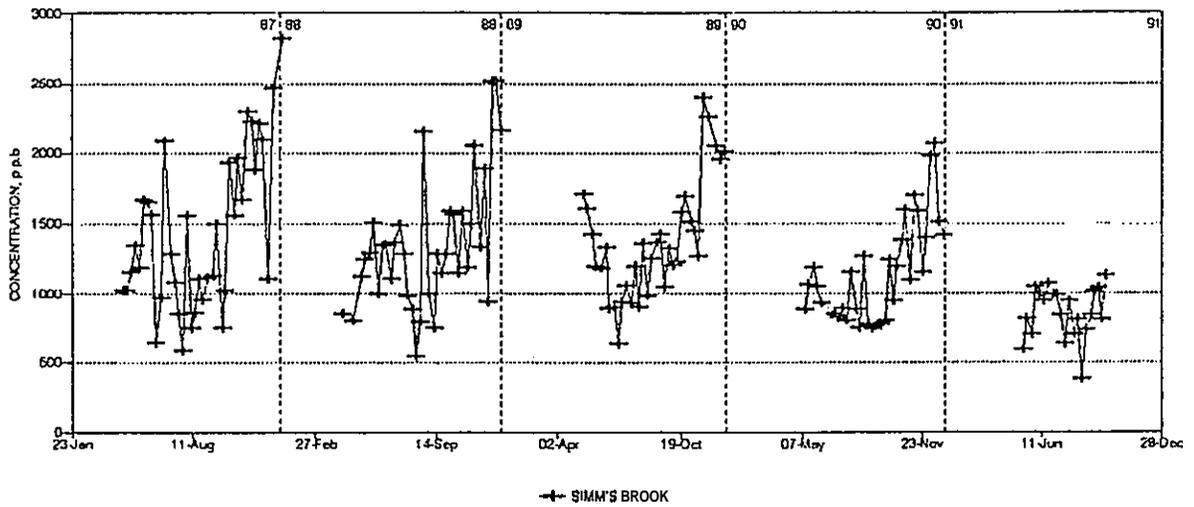


Figure 2-14
SIMMS BROOKWATER: BNC



← SIMM'S BROOK

Figure 2-15
ORIENTAL EAST III EFFLUENT: ZINC

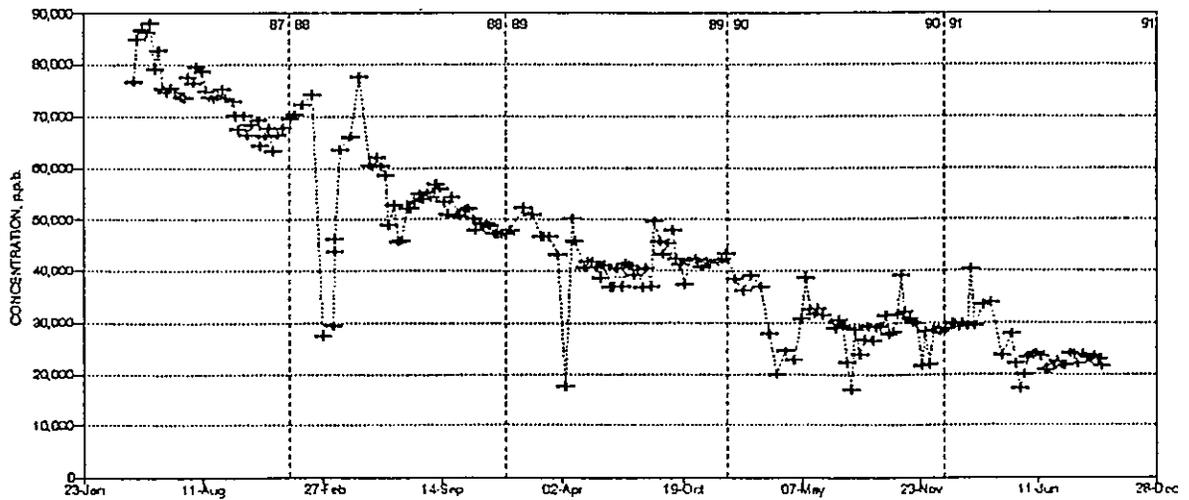


Figure 2-16
BUCHANS RIVER WATER: ZINC

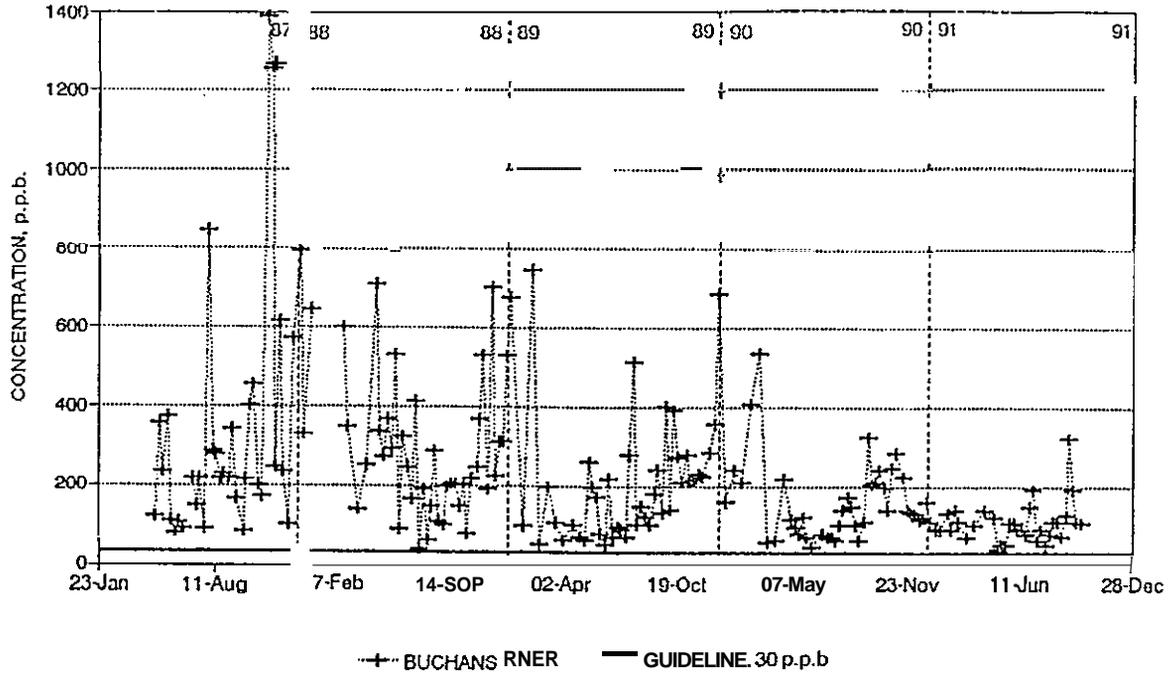


Figure 2.17
DRAINAGE TUNNEL EFFLUENT: Cu LOMING

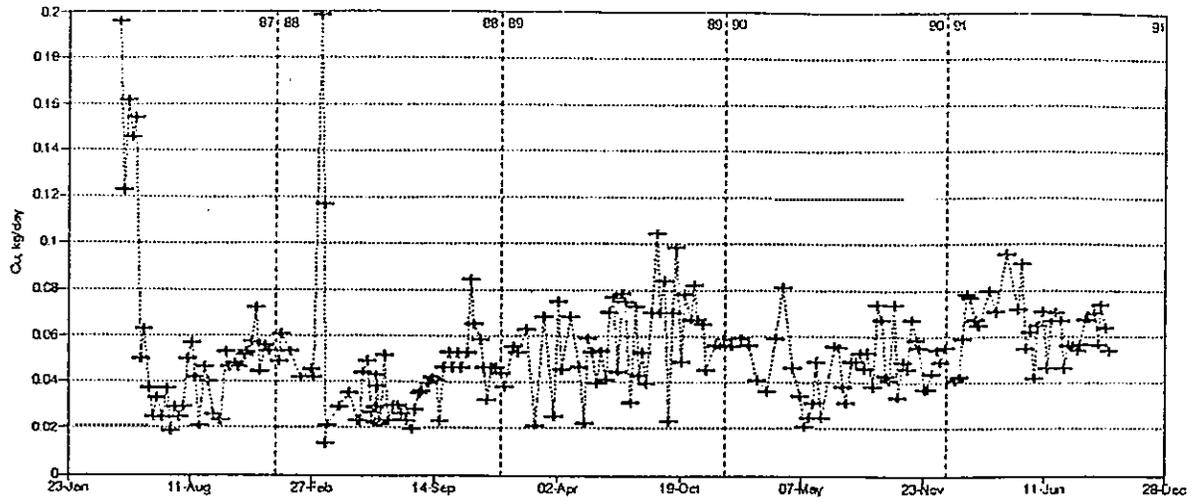


Figure 2-18
SIMMS BROOK: Cu LOADING

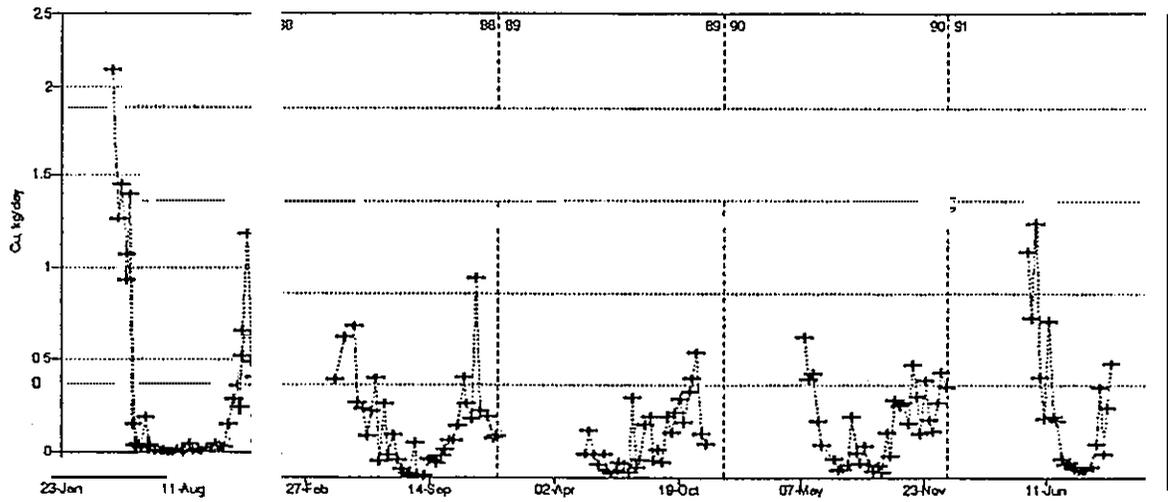


Figure 2.19
ORIENTAL EAST PIT: Cu LOADING

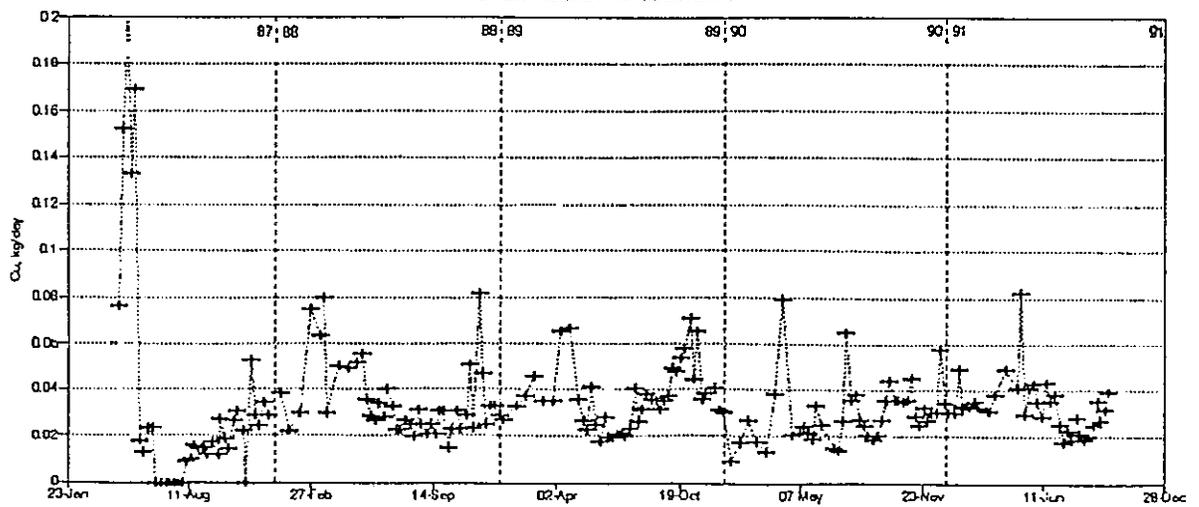


Figure 2-20
DRAINAGE TUNNEL EFFLUENT: Zn LOADING

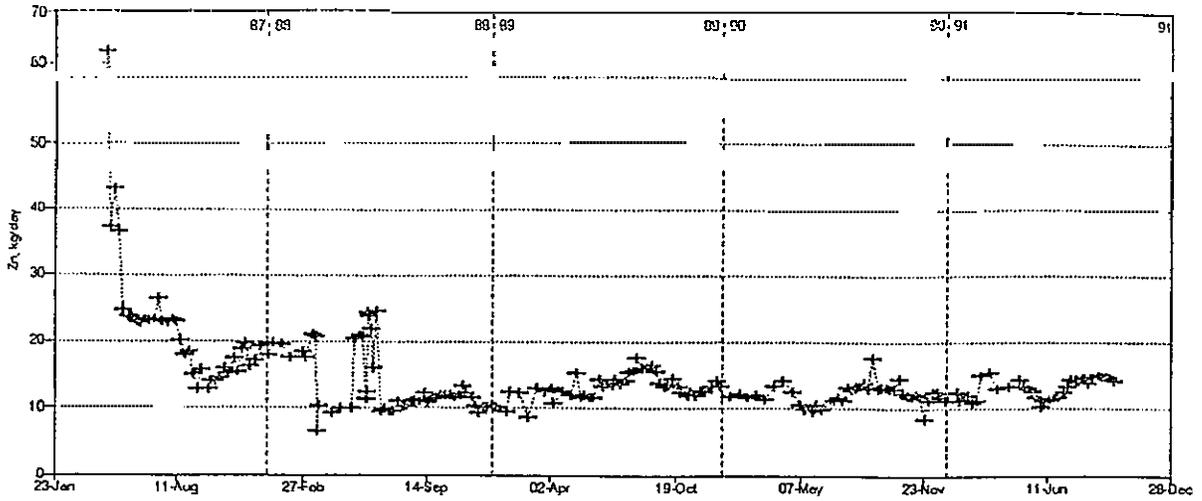


Figure 2-21
SIMMS BROOK: Zn LOADING

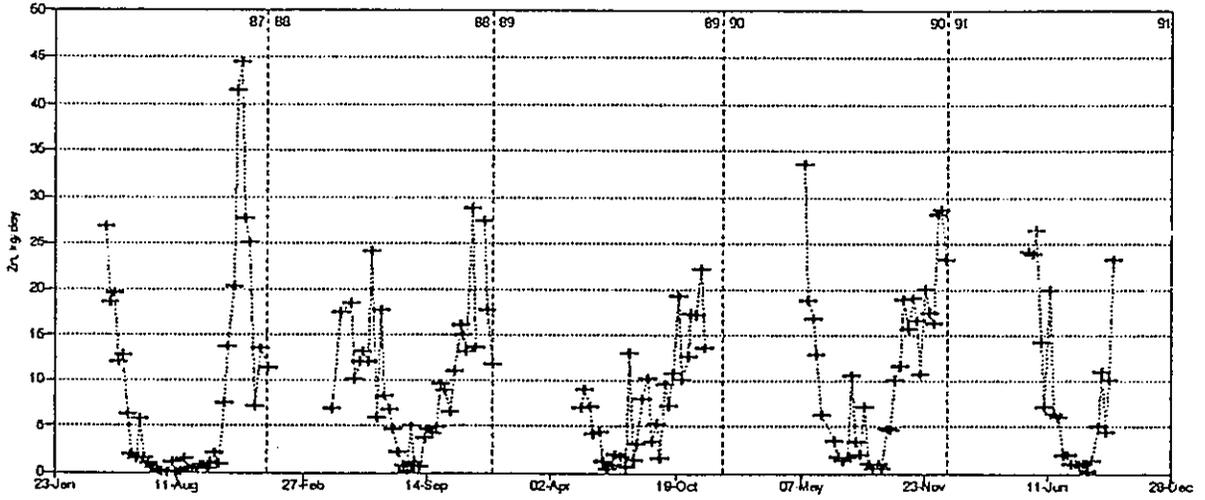


Figure 2-22
ORIENTAL EAST PIT: Zn LOADING

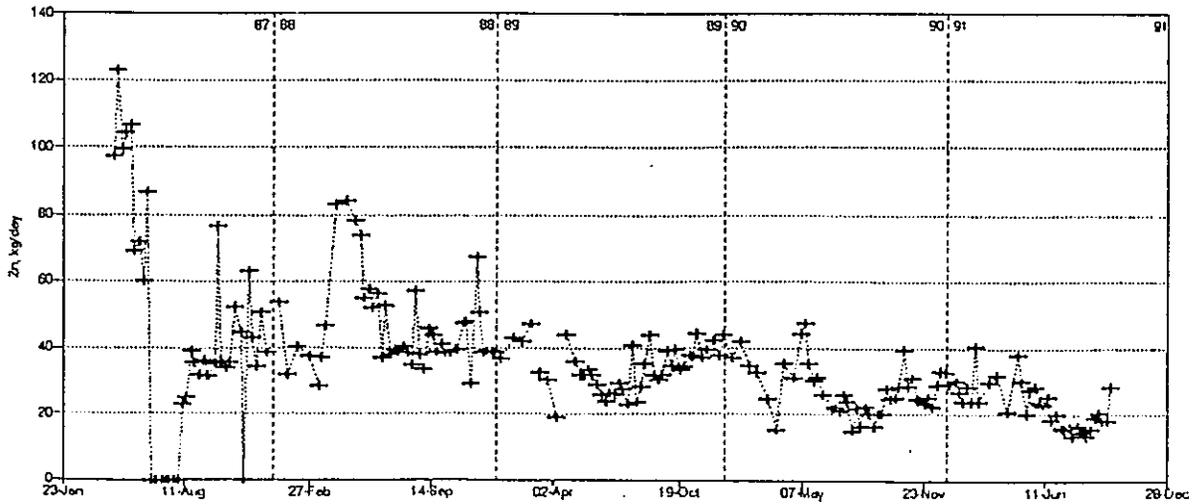
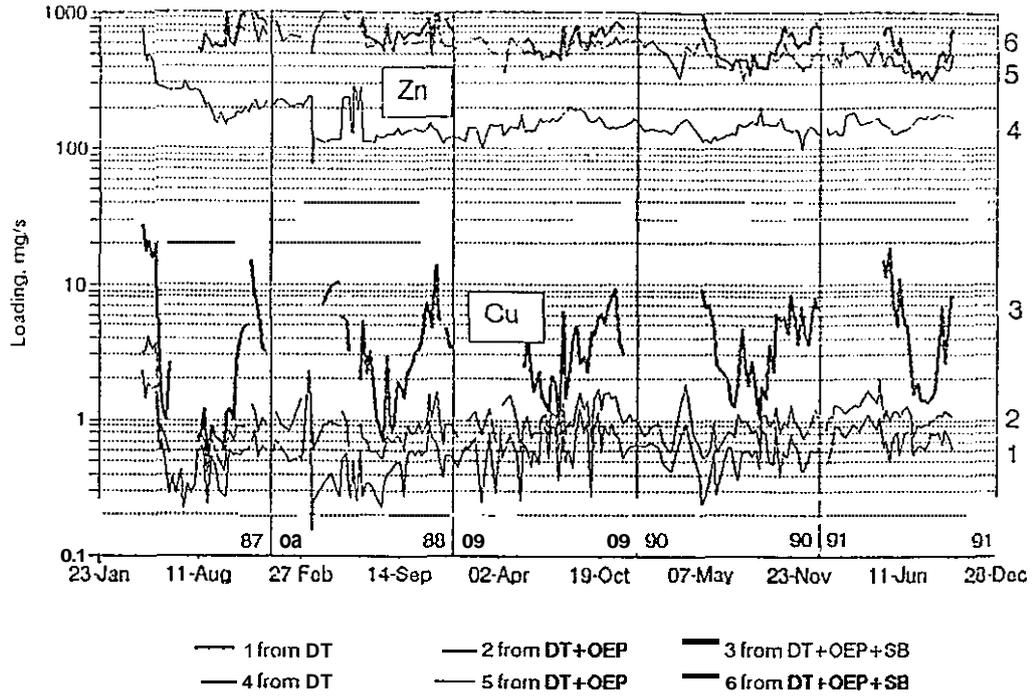


Figure 2-23
BUCHANS RIVER: LOADINGS



2 - 27
TABLE 3-1. CHEMICAL ANALYSES - SURFACE WATERS (mg/L)

SAMPLE DATE	5-Jul-91	5-Jul-91	5-Jul-91	5-Jul-91	5-Jul-91	5-Jul-91	5-Jul-91	5-Jul-91	5-Jul-91	5-Jul-91	5-Jul-91		
SAMPLE VOLUME	100	100	100	100	100	100	100	100	100	100	100		
ASSAYERS CODE	2912	2915	2907	2906	2911	2910	2914	2905	2913	2908	2909		
SAMPLING LOCATION	BUCHANS Sandfill Spring	BUCHANS Oriental Pond	BUCHANS Forebay Spillway	BUCHANS R.above power hou	BUCHANS R.at Bridge	BUCHANS OEP Outflow	BUCHANS Drainage Tunnel	BUCHANS SimmsBroo at HWY	BUCHANS SimmsBrook at B.R.	BUCHANS Lucky Strike	BUCHANS OWP Centre		
Processing code	SFS FA	O.POND FA	FOREBAY FA	BR/PH FA	BR/HW FA	OEP FA	DT FA	SB/HW FA	SB/BR FA	LS FA	OWP FA		
** F I E L D **													
Temp. (C)	5.4	22.8	12.9	13.9	13.6	13	6.1	16.2	14.3	12.2	14.8		
pH	5.85	6.23	5.24	5.2	4.38	6.47	5.61	5.98	6.89	6.84	3.9		
Cond. (umhos/cm)	123	67	20.8	46.8	33	2410	483	100	115.8	1291	733		
Eh (mV)	65	63	85	74	76	50	150	90	65	82	277		
ELEMENTS At.weightDet.lim.													
RI	26.9815	1	2			I	10	2		1	3	6	
8	10.8100	I										I	
Ca	40.0800		17	2	2	7	3	389	37	16	12	102	85
cu	63.5460						0.02	0.035	0.1	0.05		0.07	0.67
Fe	55.8470	1											2
K	39.0983	I	15	2		24		2	2			14	
Mg	24.3050	1	3	I	I	I		40	5	2	2	11	11
Mn	54.9380	1						11					2
Na	22.9898		5	2	3	3	3	98	13	3	4	11	4
P	30.9738	I											2
Pb	207.2000	1											I
s	32.0600	1	3	1		2		316	31	6	6	84	105
si	28.0855	I	8		2	2	3	8	8			4	6
Sr	87.6200	1						2					
Ti	47.9000	I	2	I	I	1		2	4			2	
Zn	65.3800	I					0.19	23	17	I		13	35
Br	79.904	0.2						1.09					
Cl	35.453		2	0.7	0.8	3	1.2	123	16	2	0.1	5.8	1.5
F	18.9984	0.1	0.2			0.3		1.9		0.3			
NO3	62.0049	0.2	0.8	0.6	0.7		0.7		10		0.7	12	
so4	96.06		3.6	7.2	I	9	3.5	907	106	23	19	240	316
HCO3	61.01		6.1	4.58	13.05		2.75	25.93	4.88		4.27	8.51	1.22
CATION SUM, e.p.m.		1.92	0.32 *	0.31	1.18	0.40 *	29.23	3.62	1.12	1.05 *	7.56	7.25	
ANION SUM, e.p.m.		0.25	0.25 *	0.10	0.29	0.16 *	22.88	2.90	0.55	0.48 *	5.49	6.64	
RATIO		7.53	1.26 *	2.99	4.09	2.44 *	1.28	1.25	2.04	2.19 *	1.38	1.09	
ERROR %		76.56%	11.46%*	49.83%	60.68%	41.78%*	12.19%	11.01%	34.21%	37.22%*	15.84%	4.37%	

Figure 3-1
EUCHANS RIVER: CHEMISTRY

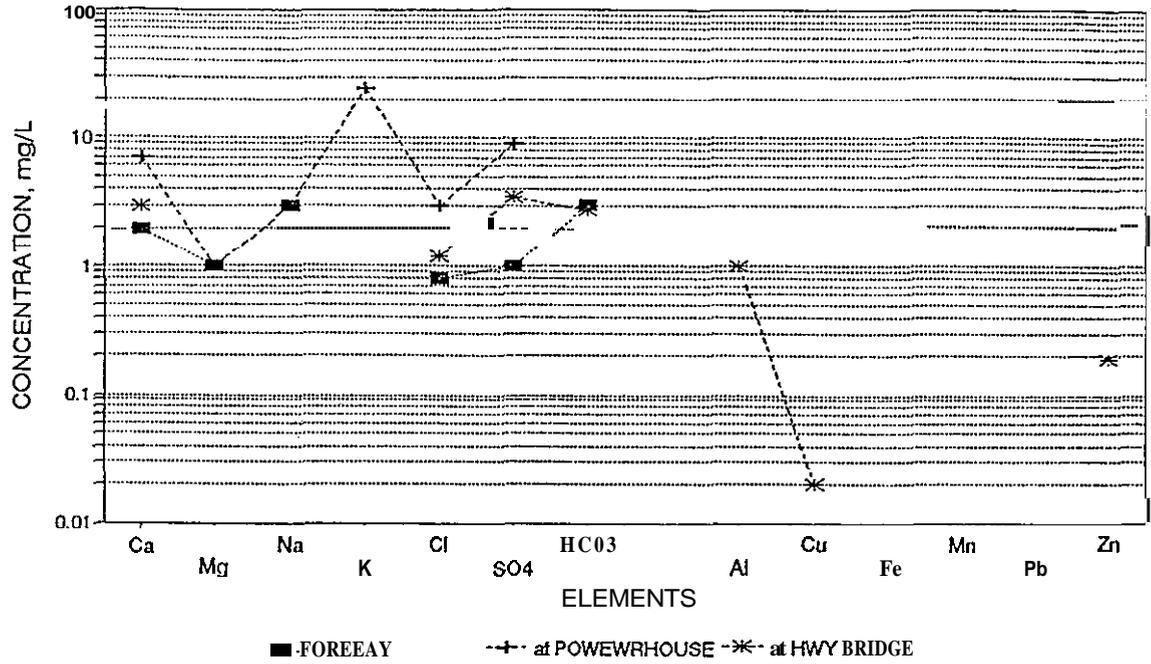


Figure 3-2
EFFLUENTS: CHEMISTRY

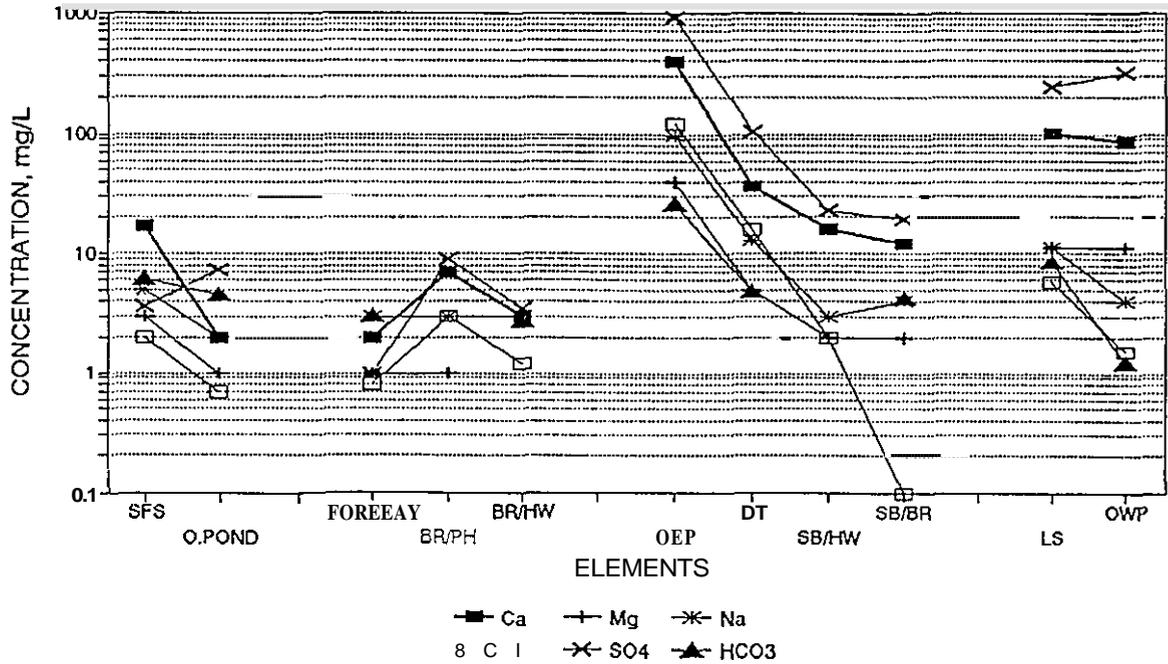


Figure 4-1
BUCHANS RIVER CALCULATED DISCHARGES

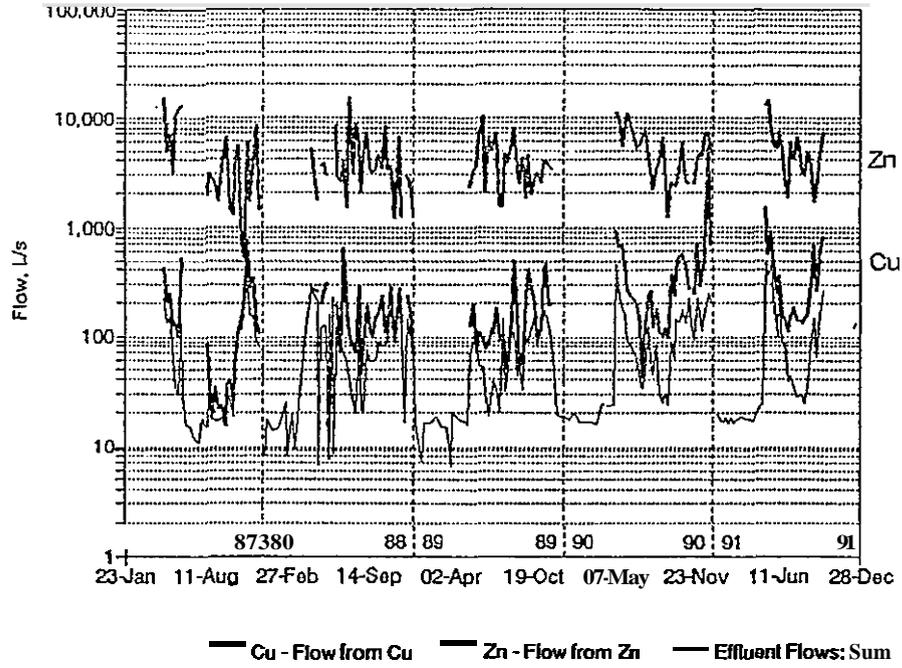


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EXECUTIVE SUMMARY

As part of the Ecological Engineered Closure Program for Asarco's Buchans Mine, a preliminary groundwater flow model was developed, using primarily existing information, for an area encompassing the Oriental and Lucky Strike Pits. The model was developed as an aid in understanding the quantity and quality of groundwater inflowing to the pits and drainage tunnel.

The geology within the study area is extremely complex; due primarily to the structure, which has created the permeable fractures in the rock. This fracturing has been created by eight different processes over the last 600 million years; but predominately by thrust faulting which occurred approximately 450 million years ago. The large scale faults are shown on Figure A, as well as drill holes which were sampled for water chemistry and permeability during this study. Each of the inter-fault blocks are also faulted by a series of lesser faults. A cross-section of the major faulting associated with the Oriental Orebodies is also presented in Figure A.

This structure implies a similar complexity in the groundwater flow system. The natural complexity is further enhanced by intensive underground/surface mining, and the large number of deep (> 1000 feet), open, vertical exploration boreholes.

As a result of this complexity, and absence of detailed groundwater investigations, the model developed for this study should be considered as a "first approximation" only; to be used as a basis for guiding subsequent studies, and to be constantly refined as new data becomes available.

The Buchans area can be classified, in terms of a groundwater setting, as having a thin, discontinuous glacial till over crystalline, faulted bedrock. In localized areas thick drift, encompassing sand and gravel, can be found.

The climatic regime of the area results in relatively large annual volumes of water infiltrating into the ground. This groundwater recharge occurs primarily in the spring and fall. Climatic data gathered at Buchans since 1929 indicated a major decline in total annual precipitation during the late 1950s to 35"/yr, followed by a rise in the early 1970s to 46"/yr. There is also a rising trend commencing in the early 1980s (43"/yr) which continues through to the present 10 year mean of 46"/yr.

The major aquifers which transmit relatively large volumes of groundwater flow are the faults, and the sand and gravel sequences.

The active portion of the flow system, in which most of the present day groundwater flow is occurring, is expected to be relatively shallow i.e. 150-300 feet in depth. Gravity is expected to be the dominant mechanism generating flow.

Therefore, on a first approximation, topographic highs are considered to be groundwater recharge zones, with flow directed generally toward rivers and lakes in the lowlands. However, the fault zones are expected to exert significant control over the actual direction and rate of flow.

The deep seated faults and open diamond drill holes could provide for an intermixing of near surface ground waters, with deep waters of differing chemistry.

The model has indicated that the next phase of the groundwater investigation should encompass:

- 1) A detailed study should be undertaken into the position, attitude, thickness and opening of regional and intermediate scale faults that intersect, or are in close proximity to the pits and tunnel. The major faults should include **Ski Hill**, **Old Buchans**, **Buchans River** and **Airport** faults.
- 2) A surficial mapping of sands and gravel units in proximity to the areas of concern would aid in assessing the potential for groundwater inflow from the units.

2.2.1. Introduction

Nolan, Davis and Associates (N.S.) Limited (NDAL) was contracted by Boojum Research Ltd, in the Spring of 1991, to form part of the groundwater team involved in the development of an Ecological Engineered Closure Program for Asarco's Buchans Mine, Newfoundland.

Numerous studies related to the Closure Program have been carried out to date. This text assumes the reader is familiar with all previous reports.

The study area is located within the Exploits River Watershed in central Newfoundland (Figure 1-1); being positioned around the Town of Buchans (Figure 1-2).

2.2.2. Terms of Reference

The primary goal of the hydrogeological program, at this stage of the investigation, was to aid the Boojum team in assessing the groundwater flow system which interacts with the Oriental Pits. Such a study was to key in on specifically the physical flow field, to augment the groundwater chemistry data already obtained.

This was necessitated as a result of three anomalous conditions being encountered at the Oriental Site, namely:

The surface outflow from the Oriental East Pit is larger than can be accounted for by water balance analysis over its surface water watershed.
Zinc concentrations in the Oriental East and West Pits are gradually declining, primarily in the former.

There is no known source (i.e. calcite veins) for the alkalinity which is present in the water chemistry of the Oriental East Pit.

At a later date, it was requested by Mr. G. Neary that two other components should also be kept in mind, namely identifying the source (s) of groundwater inflow to the:

Lucky Strike Pit, and
the drainage tunnel which links the Lucky Strike Mine and the Buchans River.

2.2.3. Philosophy of Approach

Given the scope of the evaluation, geological complexity, and time/budgetary constraints, conceptual models were utilized to understand the unsaturated and saturated groundwater flow field. The modelling was to serve as a basis to understand the available groundwater chemistry, as well as to form a logical approach to delineate a drilling/ piezometer installation program, if required.

In undertaking any groundwater modelling of a fractured rock system, three points must be kept in mind.

- 1) **An** adequate appraisal of the hydrology of fractured rocks must depend on a continual mixture of data collection, observations, and hydrogeological inferences. More particularly, emphasis is placed on reconstructing the geological and hydrological history as an essential start to understanding and modelling fractured rock systems (LeGrand, H. 1979). In this regard, the following discussion of modelling revolves around the data gathered throughout the Boojum field program to date, as well as the considerable historical and ongoing geological assessment of the Buchan's area. The latter was determined through information available in the literature, as well as discussions with Mr. J. Thurlow of BP Selco.

- 2) In fractured rock systems, there is an element of INDETERMINACY, to the extent that it is not possible to be sure of the position and extent of each fracture. Application to this investigation implies that in "Microscopic" terms the actual individual fracture which a water molecule takes in moving through the flow field, and its rate of flow through each fracture, is indeterminate. However, in "Macroscopic" terms, the bulk flow of water in terms of directions and rate of travel can be approximated to the level required for the scope of this evaluation. It is to this level of understanding that the modelling is directed.

- 3) For this type of modelling to be effective, it was necessary to determine where within the flow field the assumption of "equivalent porous medium" flow applied, and therefore Darcy's law was most applicable. In that regard, it was critical to address the connectivity of the discontinuities (fractures) within the rock mass. Therefore, it was initially decided to develop a Conceptual Model of the Discontinuities (Section 5.0) before proceeding with the groundwater flow model.

To date, there is no base of pertinent hydrogeological data (i.e. head levels, hydraulic conductivity, porosity, surface water discharge/heads) to draw upon, to allow progression from conceptual, to analytical, to numerical modelling.

A total of two models were initially developed in order to derive the groundwater flow model; namely, the Geological and Discontinuity models, as discussed in the following sections.

2.2.4. Conceptual Model - Geology

It should be noted that this section only summarizes the large volume of existing geological data. It attempts to highlight those components of specific interest in developing the hydrogeological model. Most of the data was abstracted from Thurlow et. al. 1986, Thurlow 1988, and discussions with the author.

2.2.4.1 History of Events

The Buchans Group underlying the study area forms part of the Dunnage Zone of Central Newfoundland, a deformed volcano - sedimentary terrane which records the opening and subsequent closure of the early Palaeozoic Iapetus Ocean (proto - Atlantic Ocean).

A pictorial view of major events is shown on Figure 41. A brief summary of pertinent points indicates:

• Late Pre-Cambrian •

The initial stage of Ocean opening between the European and North American plates occurs, creating an island are complex.

• Ordovician/Silurian •

Commencement of ocean closure, involving obduction and subduction along the margins; initial formation of island are complexes, and the Buchans Group.

Major thrust faulting event occurs during late Ordovician time, telescoping the Buchans Group Volcanics and forming a significant mountain chain (Taconic Orogeny).

• Silurian/Devonian •

Intrusion of Topsails Granite with associated subaerial volcanism (Acadian Orogeny).

• Carboniferous •

Extensional tectonics, erosion, re-activation of some Buchans Group thrust faults.

• Permo-Triassic •

Rifting, breakup of Pangea, and opening of the modern Atlantic Ocean.

• Erosional Hiatus •

• Quaternary •

Glaciation

2.2.4.2 Bedrock Geology

The initial geological conceptual model was one of complex stratigraphy. The present model is one of considerably simplified stratigraphy, with a corresponding increase in structural complexity.

2.2.4.2.1 Depositional Model

The study area is underlain by the Buchans Group (Figure 4-2), which generally comprises a complex assemblage of rocks. These were emplaced by volcanism in an island arc setting, generated over an eastward dipping subduction zone during lithospheric plate collisions which accompanied closure of the Iapetus Ocean. Local scale assessment around the Buchans orebodies suggests channelling of transported ores in a graben or half graben structure.

Specifically, the unit comprises a complex assemblage of mature, calc-alkaline, shallow submarine, mafic to felsic volcanic/volcano-clastic rocks, and related proximal clastic sediments. It contains galena, sphalerite, chalcopyrite, gold and silver mineral assemblages. The mineral deposit is considered unique in the world among massive volcanogen sulphides, because of their high grade and extensive development of mechanically transported fragmental ores.

This igneous assemblage consists of four felsic and mafic volcanic formations, characterized internally by rapid lithological variations and facies changes (Figure 4-3). The basaltic rocks are generally pillowed (breccia and lava) and amygdaloidal. The felsic rocks range from dacitic to rhyolitic with quartz and plagioclase phenocrysts; they are commonly coarsely fragmental.

Of these four formations, the Buchans River Formation hosts all major volcanogenic sulphide ore bodies. All major ore bodies are bounded in part by thrust faults, which brought older rocks on top of younger rocks. The Buchans River Formation lies within two major thrusts sheets; namely: the Lucky Strike sheet and the structurally higher Oriental sheet (stratigraphically best preserved).

The Lucky Strike stockwork and overlying in-situ orebody mark the main known exhalative vent (Figure 4-4); although Oriental and Old Buchans orebodies are also in-situ deposits formed at vents whose original locations are unknown, due to later dislocation by thrusting.

During volcanism, local grabens developed and talus breccias accumulated along fault scarps. Debris **flows**, set in motion by resurgent volcanism, moved downslope depositing fragmental orebodies in topographic depressions within *six* brecciated ore channels, already partially infilled with sands/gravel.

This configuration resulted in three different types of ore bodies termed, “stockwork”, “in-situ,” and “transported.”

The entire Buchans’s Group conformably overlies greywackes and conglomerates, as well as the Skidder Basalt. The upper contact is both an intrusive contact with the Topsails Granite, or a fault contact with the Hungry Mountain Complex. To the south it is overlain unconformably by Carboniferous clastic sediments. It is expected that uplift and subaerial erosion, since Devonian time, resulted in erosion of the Appalachian Mountain belt, exposing its core.

2.2.4.2.2 Structural Model

This model is discussed in Section 5.0.

22423 Metamorphic Model

Due to the young age of the Buchans Group, the rocks were not affected by the Taconian Orogeny. Due to its northern location, it escaped the main effects of the Acadian Orogeny. The Buchan's Group, therefore, escaped the main imprint of both of the major Appalachian metamorphic episodes.

The Buchans Group is a relatively low metamorphic rank, i.e. prehnite - pumpellyite metamorphic assemblage. This was imposed by relatively shallow burial (2 to 3 miles (3 to 5 km) during the thrust faulting episode. There has been no post-ore imposition of higher rank, due to regional thermal or dynamic metamorphic effects.

2.2.4.3 Overburden Geology

The overburden deposits are primarily due to glaciation during the Pleistocene period; minor Recent sediments (in the form of bogs) are present in the study area.

The general consensus is that Newfoundland possessed its own ice cap, largely independent of the mainland ice sheet during the maximum stage of the Wisconsinan glaciation. During this period, there was strong outward ice flow over the main part of the island. Later, during the waning stages of the island ice cap, a very complex flow pattern developed, as a result of erratic migrating ice centres. It has been suggested that one of these local ice caps was located near Buchans, and persisted in the area up to as recently as 9250 years BP.

No detailed mapping of glacial geology have been undertaken in the Buchans area. The glacial geology is very complex. It is probable that the general area was subject to successive ice movements in very different directions. Evidence to date suggests a dominant ice movement from the northeast, a prominent one from the northwest, and an obscure direction from the west-southwest.

Glacial deposits which blanket the Buchans area comprise basal till and glacio-fluvial sand and gravels. Thickness ranges from 0 - 55 m; with an average of 7 m. The thickest overburden is encountered immediately north of the Oriental Pits, along an extensive, regional, glacio-fluvial channel. These deposits were mined for slope backfill. They overlie and are overlain by till sheets.

In field exposures, the till is primarily a sandy silt to silty sand; with a relatively high clay content in localized areas.

2.2.5. Conceptual Model - Rock Mass Discontinuities

2.2.5.1 Introduction

Site inspection and literature reviews identified that fracture flow would likely exert the main control on the groundwater flow field within the bedrock. Therefore, it was imperative to develop a conceptual model to aid in the understanding the processes which developed the discontinuities (jointing, fracturing, faulting), and their resultant distribution on at least a macroscopic scale.

Visual inspection of the till on-site indicated an absence of jointing within the matrix. Therefore, this section deals only with the bedrock.

In this regard, it was imperative to understand the connectivity of the discontinuities in three dimensions. The density of fractures, between which enough intersections exist for a general flow to be possible, is referred to as the "Percolation Threshold." Below the threshold, fractures are on average not connected. A finite set of fractures can be interconnected, creating what is referred to as a "finite cluster," but many clusters are independent; water cannot flow from one to the next. Above the Percolation Threshold, one cluster becomes infinite, and flow can take place throughout the medium. But local finite clusters may still

exist, independently of the infinite one. As the density of fractures continues to increase, the chances of finding a finite cluster drops steadily to zero.

A total of nine processes are implicated in the development of the discontinuities present within the rock mass. The processes include, in order of decreasing age:

- volcanism with attendant extensional faulting
- Ordovician faulting (the dominant structural event in the Buchans area)
- Devonian- Carboniferous intrusion/faulting
- stress relief due to regional erosion
- stress relief due to valley rebound
- glacial scouring/loading
- stress relief due to glacial unloading
- topographic controls
- mining
- exploration drilling

The structure of the entire Buchans group is therefore extremely complex. The individual processes are discussed further below.

2.2.5.2 Volcanism

Two main trends are recognized at Buchans: 1) SE - NW, marked by the prominent orientation of the Rothermere-McLean orebodies, and controlled debris flow movement that formed the transported ores (Figure 5-1), and 2) **SW** - NE, marked by prominent mineralized fractures in the Lucky Strike footwall stockwork ore, and by the overall distribution of the ore-horizon breccias, particularly northeast of Oriental in the Sandfill and Middle Branch channel occurrences (Figure 5-1).

These inferred conjugate fault - fracture systems were apparently coeval with volcanism, fumarolic activity and sedimentary processes that formed the ores. They are tensional fractures that may have accompanied caldera formation.

It is of note that the major in-situ Lucky Strike deposit is located on one of the main intersections for these conjugate systems.

This system was extensively modified by the subsequent, more important thrust faulting event; to the extent that it is now unlikely to exert control on the present day groundwater flow field.

2253 Ordovician Thrust Faulting

The entire Buchans Group is presently envisaged as a Thrust Belt composed of a series of sheets, separated by significant thrust faults (Figure 5-1), which created the Appalachian mountain chain. The thrusting developed toward the south-southeast during the late Ordovician, prior to the emplacement of the Topsails Granite. Most fault planes dip to the north.

Facies distributions suggest that some thrusts propagated along early, high-angle, normal faults, which were active during volcanism. Lithological contacts were also typically the locus of strain, and indeed most major lithological contacts in drill core are now sheared and/or intruded by late diabase **sills**. The relatively incompetent mineralized and altered pyroclastic rocks of the Buchans River Formation have also served as a focus for strain. All the major orebodies are bounded on at least one side by thrust faults (note cross-sections Figure 5-2).

The study area is dominated by duplex anti-formal stack geometries (Figure 5-3), which are nested at a variety of scales, ranging from orebody scale, to that of the entire Group.

The structural map (Figure 5-4) of the local area is dominated by a structural culmination (historically called the Buchans anticline), manifested by a window of stratigraphic hanging wall rocks which occur structurally below the orebodies. Built directly on this culmination is a small scale, east-west trending, cylindrical, antiformal stack, with a gentle double plunge, which contains the Lucky Strike and Rothermere orebodies. This is called the Lucky Strike

Sheet. Within this stack, the Lucky Strike orebodies were interpreted to form a smaller scale antiformal stack. The Oriental orebodies lie in a structurally higher panel called the Oriental Sheet, and are themselves complexly thrust into a series of antiformal stacks.

The study area lies within and immediately adjacent to this closed elliptical structure (Figure 54). Inside the structure, northeast striking and northwest facing basaltic and arkosic rocks structurally underlie the Oriental and Lucky Strike orebodies. The Old Buchans Fault is a significant thrust. It joins the Ski-Hill and Buchans River faults. Between the old Buchans and Ski-Hill faults occur a series of lesser thrusts with displacements of less than 1000 feet (300 m). The Ski-Hill fault is a significant thrust fault with displacement of 0.6 mile (1 km); it exhibits an anomalously straight planar surface.

Of note is that in the vicinity of the Lucky Strike and Oriental in-situ orebodies, a zone of significant, hydrothermal alteration obscures the contact between the Ski-Hill and Buchan's River formations. This zone, previously called the "Intermediate Footwall", is a complex, poorly understood stratigraphic package, which has been altered extensively and modified significantly by faults.

From the available data it would appear that the study area is positioned in the middle of the thrust belt, since all major thrusts continue outside of the area and locally do not break up in a network of diverging splays and/or blind thrusts. Further, all of the major thrust faults delineated to date, intersect the existing ground surface, due to the extent of geological erosion and subsequent removal of the original overlying roof thrusts. The presence of antiformal stacks further increases the number of tip lines intersecting the present ground surface.

All of the thrusts are interconnected in an anastomosing network (Thurlow, pers. comm.). Other things being equal, "horses" (a pod of rock completely bounded by two or more such fault surfaces) are more common in the internal, older and deeper parts of a Massif; whereas blind thrusts and isolated and diverging splays are more common in the younger,

external and shallower portions (Boyer and Elliott 1982). The study area appears to represent the deeper part of the fold belt which created the Massif (Appalachian Mountain Chain).

The fault zones are represented by narrow zones of brittle shear. The width varies directly with displacement, ranging from a few inches with displacements of less than 100 feet (30 m), to tens of feet with displacements of greater than 0.6 mile (1 km).

The faults can be infilled with sand/clay or lithified, typically by secondary quartz and epidote. Many fault planes are intruded by diabase sills, which emanated from gabbroic bodies associated with emplacement of the Topsails Granite. These were fractured at a later date. Jointing is not well developed around the ore zone due to rock competency; a foliation however is developed.

At present, it is difficult to determine which one(s) of these fault zones are still actively controlling the present day flow field. It is assumed that on a "Megascopic" scale the major thrust fault zones exert a significant control on the local study area. These faults can be expected to extend down to 2.5 miles (4 km) and more. Of note, is the positioning of a basalt with calcite amygdules approximately 1100 feet (350 m) below the Oriental Pits, which may be connected via one or a number of these deep fault systems.

2.2.5.4 Devonian - Carboniferous Intrusion/Faulting

During the Devonian Orogeny, a broad, open, regional folding was created in the Buchans area. It imparted a weak NE striking subvertical fracture cleavage to all existing lithologies, which is axial planar to a broad open syncline within the Buchans Group. The intensity of cleavage varies directly to rock competence. Deformation related to this cleavage is nowhere sufficiently intense to cause visible effects of strain. This activity also included diabase and granitic intrusions.

During the Carboniferous, some reactivation of faulting occurred (Thurlow, pers. comm.).

2.2.5.5 Stress Relief - Regional Erosion

Subaerial exposure of the region since Carboniferous time, has resulted in the removal of **2 to 3 miles (3 to 5 km)** of rock within the original Massif, above the present day erosional surface, due to regional erosional processes. **As** the weight of rock was removed, the resultant stress relief would result in reactivation of the thrust fault network and opening of fractures.

However, such a reactivation would propagate downward only to a depth where the weight of the overlying rock mass created a counterbalancing "sealing" trend. This would be more applicable to horizontally oriented fractures, than the vertical/subvertical orientation. Such a trend would result in reduced hydraulic conductivity with depth.

This was noted by Randall et. al. (1988), who described a die-off within the Appalachian region at approximately 250 feet (**75 m**). Therefore, the base of the most active part of the flow field is expected to be in the **150 to 300 foot (50 to 100m)** depth range within the study area.

2.2.5.6 Stress Relief - Valley Rebound

This process involves the uplift of strata due to the differential erosion, resulting from localized removal of material by stream action within valleys. This differential unloading over a valley results in two processes; namely, a rebound of the valley floor and upwarping of beds in the valley wall. The rebound of the valley floor occurs due to relief of vertical stress, and the compressional stress by the weight of the overlying rock mass in the adjacent valley flanks. The arching also causes minor vertical fracturing near the axis of the arch. The inward movement of the valley walls occurs as a function of lateral stress relief. The unequal horizontal stress along the walls results in vertical tensile flexures. The extent of the development in each case is determined by the modulus of elasticity of the rock mass (**E**).

The process operates on a geological time frame which could be induced in the Buchan's River Valley. This process has been quantified by Matheson and Thompson (1973) for valleys in the 1000 to 5000 foot (300 to 1500 m) wide and 90 to 210 foot (28 - 65 m) deep range. Within the study area, the Buchan's River Valley is 8200 to 9800 feet (2500 to 3000 m) wide (using the 2220 feet (676 m) contour line) and 66 to 130 feet (20 to 40 m) deep. However, such features are more well developed in gently dipping bedrock characterized by a low modulus of elasticity, i.e. in incompetent argillaceous sedimentary rocks. Given the generally more competent nature of the underlying rock in the Buchans area, the extent of such a rebound may be restricted to less than the 3 - 10 percent of valley depth, as noted by Matheson et. al. (1973).

Such relief of confining pressure also creates an exfoliation discontinuity, which is more common in massive rocks. In the study area, such exfoliation is not expected to be due to thermal or chemical processes. The process is generally restricted to shallow depths (less than 200 feet (60 m)). Generally near the surface, such jointing outlines sheets of rock which are parallel to one another, and to the surface of the rock mass; as well they are thin and discontinuous. With increasing depth the sheets become thicker and are more continuous until finally they cease to exist.

2.2.5.7 Glacial Scouring/Loading

The effect of glacial action on joint development is difficult to assess, and not accurately identified or discussed in the literature. The impacts could theoretically include:

- 1) Expansion of existing jointing, created by the aforementioned processes, may occur due to glacial plucking or ice-shove action;
- 2) The development of a basal till cover over the study area would induce glacial smearing of till material into the near surface fractures; thereby sealing them off with unconsolidated material;
- 3) Horizontal to sub-horizontal fractures may be sealed off due to glacial loading.

2.2.5.8 Stress Relief - Glacial Unloading

The removal of the glacier would allow expansion of the fractures previously sealed off. The extent to which the discontinuity patterns (developed prior to the last ice age) have been renewed by this action, is unknown. It is assumed that the extent of discontinuities developed pre-glaciation is still present (within minor surface smearing), that it has re-opened to its original extent, and been augmented by additional exfoliation due to glacial unloading.

In the Atlantic Provinces, bedrock is usually characterized by an intense horizontal fracturing over the top 3 to 10 feet (1 to 3 m) due to exfoliation; in part a result of glacial unloading. How extensive this is in the study area, is unknown. However, it is assumed to be developed to some degree.

2.2.5.9 Topographic Controls

Jointing in a rock mass has been shown in the literature to exert influence on topography; but topography can also influence joint development, if sheeting and exfoliation are present.

The development of such exfoliation along steep slopes results in inclined layers of rock dipping downslope. These layers start to move downhill under gravitational forces, which result in dilation and horizontal extension perpendicular to joint surfaces. Such a process would reinforce the incipient trend of weakness in the rock mass.

With this action comes 1) a higher frequency of jointing along slopes rather than over the high areas, and 2) more jointing over narrow high areas, rather than broad rounded ridges. Better development of such jointing occurs over steeper slopes, where the slumped material at the base of the slope is continuously removed from the base by water actions, such as is the case at this site. This then allows for additional sliding and propagation of jointing to higher and higher levels.

2.2.5.10 Mining

The underground mining (Figure 5-5) within the ore zones, (specifically Lucky Strike and Oriental which were mined out to within 700 feet (210 m) of surface), could theoretically create a local stress field, resulting in collapse and propagation to the surface to form subsidence. However, it is not expected that this has created a significant component of fracturing within the rock mass given:

- general rock competence;
- there were very few rock bursts in the mines;
- a large portion of the workings were backfilled hydraulically with sand. The mining design was to mine 26 feet (8 m) wide slopes and leave 22 feet (7 m) wide pillars. The slopes were infilled with sand and then the pillars were mined and left open;
- there is no evidence identifying significant subsidence in and around Buchan's due to mine collapse.

2.2.5.11 Exploration Drilling

There are 315 diamond drill holes within approximately 3.5 mi² (9 km²) surrounding the Lucky Strike and Oriental Pits. Most are greater than 1000' (300 m) open and vertically oriented; they range in diameter from 1.5 to 6 inches (4 - 15 cm). They were not grouted off after drilling.

2.2.6. CONCEPTUAL MODEL - GROUNDWATER FLOW FIELD

2.2.6.1 Approach

The conceptual model was based upon that developed by Toth (1970). This relies on two systems: the Hydrogeological Environment (geology, topography and climate) and the

Groundwater Regime (hydrostratigraphic units).

The following discussion deals only with the physical (not chemical) characteristics of the flow field, and assumes:

- 1) that water is the fluid medium, with its resultant density, specific gravity and compressibility constants;
- 2) the validity of the Darcy Continuum on at least the Megascopic, if not the Macroscopic scale of interpretation; although discrete fracture flow will have to be superimposed upon this base concept.

2.2.6.2 Regime Parameters

This section identifies the major hydrostratigraphic units (HU) which are believed to be pertinent in the control of the present active portion of the groundwater flow system. HU's are groups of geological units which exhibit similar properties in terms of the characteristics which govern flow of groundwater through them.

Of the three characteristics pertinent to describing a HU, i.e. hydraulic conductivity (K), porosity (n) and compressibility (B); the latter is assumed to be a constant.

A total of five distinct, significant HU's were identified, namely:

- Bedrock HU
- Thrust Fault HU
- Till HU
- Sand/Gravel HU
- Podzol HU

These are discussed, to the extent available, below:

2.2.6.2.1 Bedrock HU

All four bedrock geological formations within the Buchan's Group are presently considered to exhibit similar hydrogeological properties, and therefore are designated as one HU. This unit is considered to represent the rock blocks or "horses" positioned between the major thrust faults. These blocks are expected to be faulted and fractured as well.

No specific field data is available. However, the mine workings were never considered to be wet, even when mining under the Buchan's River. Six deep exploration holes were slug tested for this study to give bulk Ks for the rock mass. The data is summarized in Table 1. It indicates a low bulk K of 10^{-9} to 10^{-10} ft/sec. (10^{-10} to 10^{-11} m/sec.). Matrix and fracture K and n values are unknown. The overall discontinuity pattern is expected to be developed in three dimensions, but quite likely exhibits a strong anisotropy. In local mined areas, pseudo-karst flow could occur.

The unit is thought to be best characterized on a macroscale as a homogeneous, anisotropic, fractured, consolidated medium.

2.2.6.2.2 Thrust Fault HU

The localized zones surrounding all the major thrust faults discussed in Section 5.3 are included within this HU. Those specifically related to this assessment are thought to include:

- Ski Hill Fault
- Old Buchans Fault
- Buchans River Fault
- Airport Fault

A dozen or more intermediate scale faults are probably also important. Both the intermediate and regional faults are expected to be interconnected in three dimensions.

No hydrogeological field data are available for this HU. Given the wide variety of infilling along fault planes, it is expected that K varies widely, i.e. 10^{-2} to 10^{-7} cm/sec.

Where mine workings intersected the major faults, no large-scale water incursion occurred (Thurlow, pers. comm.). However this may be a function of the stress field set up around the tunnel workings which can squeeze fractures off (Gale, pers. comm.)

This unit is thought to be best characterized on a macroscale as a heterogeneous, anisotropic, fractured, consolidated to semi-consolidated medium.

2.2.6.2.3 Till HU

This unit comprises the basal till geological unit. It does not visually exhibit any jointing; flow is expected to be controlled by the primary effective porosity.

A range of 10^{-5} to 10^{-7} ft/sec. (10^{-6} to 10^{-8} m/sec) will be taken as being representative of the bulk K of this HU.

Matrix porosities are expected to range from **0.3 - 0.4**.

The unit can best be described on a macroscale as a homogeneous, isotropic, porous, non-fractured, semi-consolidated medium.

2.2.6.2.4 Sand/Gravel HU

This unit comprises the geological sand/gravel unit found above and below the till.

A bulk K range of 10^{-2} to 10^{-4} ft/sec. (10^{-3} to 10^{-5} m/sec.) will be taken as representing the upper unit. Where this unit is overlain by till, it is expected that glacial overriding will lower these K's, but to an unknown extent.

This unit can best be described on a macroscale as an isotropic, homogeneous, porous, non-fractured, unconsolidated medium.

2.2.6.2.5 Podzol HU

This unit comprises the pedological unit developed over the top of the glacial till and sand/gravel. As such, it encompasses both the A and B horizons as well as the zone of frost penetration down to approximately 3 feet (1 m). It is expected that the soils in the area comprise predominately Podzols.

Based upon data available elsewhere for podzols (Agricultural Canada), K values can be expected to be in the range of 10^{-2} to 10^{-4} ft/sec. (10^{-3} to 10^{-5} m/sec); with the variability predominantly due to layering and development of pans in the B horizon. Pans have been noted locally near Luck Strike (Thurlow, pers comm.)

In macro terms, it can be described as an isotropic, heterogeneous, unconsolidated porous medium. The heterogeneity is layered.

2.2.6.3 Hydrogeological Environment

2.2.6.3.1 Regional Perspective

In terms of spatial perspective, the study area lies within the Northeastern Appalachian Hydrogeological Region of North America (Heath, 1988). Within Newfoundland, it resides within a Lowland setting, best quantified as setting 9D (glacial till over crystalline Bedrock) to 9I (bedrock uplands) within the Northeast and Superior Uplands, as summarized in Figure 6-1 (Aller et. al., 1987).

With respect to temporal perspective, the study zone represents the core of the original Appalachian Massif, created by the closing of the Iapetus Ocean. As noted by Narasimhan (1990), it is convenient to divide a Massif into hydrogeologic zones. The outermost zone

consists of alluvial/colluvial sediments, talus and scree, punctuated by rock outcrops. The rock outcrops and near surface bedrock constitute an intermediate zone, characterized by rock weathering, and augmented fracture apertures due to stress relief. The third zone is the core, characterized by complex folds/faults. The first two zones have been removed by erosional processes, which have reduced the Massif to a flat erosional plane; thus leaving the core exposed. This also results in an absence of relief, and thus the associated highly variable climatic patterns and rapid response hydrological events associated with the young high relief/slope Massif.

2.2.6.3.2 Water Balance

A general water balance diagram felt to be indicative of the study area is shown on Figure 6-2. It was derived from data at Seal Cove near St. John's, but generally represents what is seen throughout the Atlantic Provinces.

The study area receives a relatively large volume of precipitation, with relatively low evapotranspiration, resulting in a large annual surplus. The annual surplus is distributed over eight months in two distinct wet seasons, winter-early spring and late fall. During the initial portion of the winter-spring wet season, air temperatures are below freezing. The moisture surplus goes into storage as snow, and although there are some snow melts during winter, the development of frost probably restricts recharge of the groundwater flow system. **As** a result, this snowmelt is lost to stream flow. Warming trends commencing primarily in April, release the snowpack storage and eliminate frost cover, allowing for a major groundwater "recharge window." The volume of water released at this time is however probably greater than the infiltration rate, and a large portion is lost to streamflow. During the summer months, evapotranspiration rates exceed precipitation, peaking in July. The deficits in soil moisture incurred in June, July and August are quickly replenished in September. During this replenishment, the recession curves bottom out. During October to December, precipitation occurs mostly as rain due to the high air temperatures. The absence of frost allows this to form the second major "recharge window."

Given the large water surplus, water tables/piezometric surfaces are expected to be quite high, thereby resembling the surface topography. This results in a maximum of possible fluid potential differences within the groundwater flow field.

To assess climatic data for any long-term trends, the annual total precipitation data collected at the mine site since **1929** were analyzed utilizing a running decadal means analysis. The results are plotted on Figure **6-3**. The station exhibits a major decline during the late **1950s** to early **1960s**. At that time, a significant increase started, rising through into the early **1970s** to a level exceeding that prior to the **1950s**. Of note is the local rising trend commencing in the early **1980s** and continuing through to the present.

2.2.6.3.3 Unsaturated Zone/Interflow

This portion of the flow field encompasses the unsaturated zone, and the zone of periodic saturation, or Interflow zone. This is the zone which primarily governs the processes related to storm runoff.

Where the Till HU is present at surface, the combination of low topographic slopes, low rainfall intensities, full vegetation cover, highly permeable Podzol HU and low permeable Till HU, necessitates utilizing the Variable Source Model of forest zone hydrology (Dunne and Leopold, **1978**) in explaining the movement of water within this zone. The low permeable Till HU results in the development of a perched water table within the Podzol HU during rainstorms, when infiltration rate and volume exceed the infiltration rate for the former. Saturation therefore only occurs intermittently during rainfall/snowmelt events. This zone usually ranges up to **3 ft (1 m)** thick, and encompasses the Podzol Soil HU.

Where the Sand/Gravel HU is present at surface, its high permeability is expected to create a water table aquifer response to infiltration. In this scenario water infiltrates vertically downward to the saturated zone, which is perched over the underlying Till or Bedrock HUs; then runs laterally to the nearest discharge zone, partially governed by the configuration of

the till or subcrop surface.

Where the Bedrock HU is exposed at surface, it is expected that the Horton Overland Flow model (Dunne and Leopold, **1978**) describes surface runoff; implying sheet flow over the subcrop surface until it either encounters a discontinuity for infiltration, or a surface stream. In this situation the Bedrock HU becomes the water table aquifer for the infiltrating water, creating a response similar to the Sand/Gravel HU.

2.2.6.3.4 Saturated Zone

This portion of the flow field encompasses the zone below the level of continuous saturation; i.e. below the water table.

A summary of the impact of pertinent hydrogeological characteristics on the groundwater flow field is presented below.

2.2.6.3.4.1 Presence/Character of Aquifers and Aquitards

Given the regime characteristics, the Till HU is defined as an aquitard. It therefore serves primarily as a storage reservoir, and/or as a conduit for recharge to the underlying aquifers or discharge into surface waters at relatively low rates.

The Sand/Gravel HU, where positioned above the Till HU, is defined as an aquifer. It serves primarily as a conduit for transmission to surface waters, and the Bedrock or Thrust Fault HUs, where they directly underlie it.

The Thrust Fault HU is considered to be an aquifer. Since there is a high probability that all major intermediate scale faults are interconnected in the local study area, they will be considered as one aquifer. This aquifer however is characterized as being of a linear, thin, "pipe" style configuration, which can extend to depth, and which intersects the subcrop

surface. Where overburden is absent it receives infiltration directly from surface during rainfall/snowmelt events. More commonly the Till HU is present and infiltration would be expected to be continuous and slow.

At the present time it is open to speculation as to what the Bedrock HU should be called. Until more K data become available it will be lumped together with the Thrust Fault HU; due to the intense faulting which the inter-thrust fault blocks ("horses") are expected to exhibit.

At this time it is not expected that a perched water table is developed over the bedrock subcrop surface where overlain by the Till HU. It is expected to occur locally where bedrock is overlain by the Sand/Gravel HU, due to the contrast in K. However due to the expected intense fracturing within the bedrock, it is not expected to be a major influence.

Given the higher expected K values within the top 15 feet (5 m) of bedrock surface and the higher $K_h:K_v$ ratio, flow should be induced down the subcrop topographic gradient. In this case the configuration of the subcrop surface becomes important in controlling this portion of the flow field.

2.2.6.3.4.2 Composition

All Overburden HU's are expected to contain both soluble and insoluble constituents, with the former predominating.

The Bedrock HUs can be regarded as primarily insoluble, except for the mineralized zones, and the unit(s) responsible for the high pHs which were encountered in two drill holes north of the Oriental pits. This would include those lithologies where calcite amygdules are present.

2.2.6.3.4.3 Water Bearing Openings

The Till and Sand/Gravel HUs exhibit primary porosity only. The Bedrock HU's exhibit both primary and secondary porosity; the latter predominating and controlling flow. Given the mineralogical composition of the bedrock forming the matrix through which the flow field operates, no enlargement of fractures by solution processes is expected.

The extensive underground mine workings are expected to have created a major localized zone of large-scale, primarily horizontally oriented, water bearing openings. They would form an indirect vertical connection with the surface through the open pits and shafts at the Lucky Strike and Oriental Mines, which are now plugged with debris. This could be significant enough in the mine areas to create what could be described as a "pseudo-karst" type flow.

In this regard, there are three major individual tunnels which join localized mine working areas that are of note in the study area (note Figure 5-5).

- 1) The Drainage Tunnel is a **3610** foot (**1100** m) long tunnel, which joins the Lucky Strike pit with the Buchans River. At Lucky Strike, it is positioned at the **800** foot (**244** m) level; being **135** feet (**41** m) below ground surface at an elevation of **800** feet (**244** m). It is joined to the surface by three vertical shafts; it drains by gravity at its downstream end, at which point it is sampled periodically. It is sealed off from the surface at the Lucky Strike shaft by a bulk-head seal, which is at present assumed to be water tight. A second bulkhead was installed at one of the intermediate shafts.
- 2) The Main Haulage Level Tunnel is a **6890** feet (**2100** m) long tunnel, which joins the Luck Strike No **3** level workings and the Oriental workings. It was constructed in **1933**. It is positioned at the **350** foot (**107** m) level, placing it **585** feet (**178** m) below ground surface at Lucky Strike. It is believed to be sealed off at the Lucky Strike operations.

- 3) A 1970 foot (600 m) long tunnel was driven from the Oriental Mine to the Old Buchans Mine, where a mineralized zone was mined out under the Buchans River at the 650 foot (198 m) level. This placed it some 299 feet (60 m) below the Buchans River. After cessation of mining a floodgate door was installed within the tunnel east of the river.

The large number of exploration drill holes apparently not collapsed, and are regularly re-used for geophysical tests (Thurlow, pers. comm.). As a result they must be considered as forming a significant set of water bearing openings. Given their orientation and depth they could play a significant role in allowing interconnection between the deep and shallow flow fields.

2.2.6.3.4.4 Mechanisms Generating Flow

Given that the active portion of the flow field is expected to be primarily relatively shallow i.e. 150 to 300 feet (50 - 100 m), it is expected that the dominant mechanism generating flow is fluid potential (gravity).

Gradients imposed by either thermal, and/or electro-osmotic potential are not expected to apply. The former is deduced from temperatures of groundwater (4-2°C) taken in five boreholes tested down to 55 m, which show no sign of thermal gradients, even though the wells are 1200 to 3600 feet (365 - 1100 m) deep.

However, the geological conditions are appropriate such that chemical - osmotic gradients may have some influence. Such a condition was noted when a corrosive calcium-chloride brine was intersected from an exploration hole drilled at the 3500 foot (1066 m) level in the MacLean mine. It was initially under an extreme pressure, which decreased rapidly to a give a lower but continuous flow into the workings.

2.2.6.3.4.5 Storage/Transmission Characteristics of Dominant Aquifers

The two major aquifers are believed to be the Sand/Gravel and the Thrust Fault HUs. No data are available on their Transmissivity or Storage Coefficients.

The Sand/Gravel HU, where present at surface, is considered to be a water-table aquifer. It is expected that the Darcy flow concepts can be utilized to model the transmission flow. Where present under the Till HU it will be confined to some extent, probably exhibiting non-flowing artesian conditions.

Where the Till HU is present at surface, it will represent the water-table aquitard.

Where the Thrust Fault/Bedrock HUs are confined to some extent by overburden deposits, they will be considered as artesian aquifers. Based upon static water levels obtained in boreholes sampled to date, all but one exhibited non-flowing artesian conditions. However, where the overburden deposits are thin or non-existent (the more dominant scenario) it is considered to be the main water-table aquifer.

On a Microscopic scale, transmission flow through the Thrust Fault HU is probably best described as "pipe flow". This may also apply at a Macroscopic scale at which the Darcy Continuum applies; however, for the first approximation level of understanding trying to be achieved for this study it is assumed that the inter-thrust block zones are highly fractured and interconnected sufficiently enough with the thrust faults that the system exceeds the Percolation Threshold, and therefore can be modelled using Darcy flow concepts. The thrusts are expected to provide a major degree of anisotropy, such that a higher K exists in the NE-SW direction.

2.2.6.3.4.6 Recharge/Discharge

The main source of water to the system is meteoric from rainfall and gravity drainage; there are no oceanic, diagenetic or magmatic sources. However, the calcium-chloride brine may be a locally significant factor. Recharge into the bedrock is facilitated by the thin overburden over most of the study area, and the intersection of the massive thrust faults within the surface.

Discharge is from either evapotranspiration, or to surface waters and/or underflow out of the basin.

2.2.6.3.4.7 Hydraulic Head

No detailed piezometer installation is available from which to develop a two or three dimensional equipotential map, indicating vertical and lateral gradients and direction of flow. Static water levels in the deep open boreholes indicate levels ranging within **6.5 to 32 feet (2 to 10 m)** of ground surface, even over the topographic high around the Lucky Strike pit. This suggests that due to the climatic regime, with its large volume of water surplus and therefore relatively large volume of infiltration, water levels resemble surface topography.

2.2.6.3.4.8 Boundary Conditions

The initial approximation of a lower boundary for the active portion of the flow field is 150 to 300 feet (50 to 100 m). However it is expected that flow along the large thrust faults, mine workings and open drill holes will significantly alter this lower boundary. It is suspected that the major faults are open to at least **0.6 mile (1 km)** in depth (Thurlow, pers. comm.). At present it is envisaged that the lower boundary will be placed at the **300 feet (100 m)** level, but will be considered to represent a leaky aquitard system.

The rock discontinuity conceptual model could not quantify the Percolation Threshold. However, it did identify a qualitative probability of where within the flow field it would more likely be found. It indicates that there is a high probability that within the top 15 feet (5 m) of the bedrock surface it is exceeded. Below the 300 foot (100 m) depth there is a high probability that it is not exceeded. In between these two extremes it is expected that the probability dies off as a function of depth.

Therefore, it is expected that this configuration implies that Local flow systems (as defined by Toth, 1962) apply i.e. each topographic high is a recharge zone and the adjacent topographic low is its corresponding discharge zone. However it must be noted that the vertical boreholes and mine workings will alter this to some extent so that there will be some direct interconnection between Toth's Local, Intermediate and perhaps even Regional Flow Systems.

For the present therefore, the Zero flow boundaries are positioned at the topographic surface water divides. Head controlled boundaries are positioned at the elevation of water in the Buchans River.

2.2.6.3.4.9 Anisotropy

Based upon the conceptual model of rock discontinuities there are three trends in the fracturing patterns within the bedrock, which are hypothesized to control the $K_h:K_v$ ratio (or anisotropy) of the flow field within the bedrock.

The top approximately 15 feet (5 m) of the bedrock surface are expected to exhibit a higher degree of fracturing such that $K_h > K_v$; due primarily to glacial erosion and unloading expansion associated with isostatic rebound. Below this 15 foot (5 m) mark the vertical and subvertical fracturing associated with faulting, and vertically oriented boreholes becomes dominant; resulting in $K_v > K_h$. This also occurs as horizontally oriented fracture planes tend to squeeze off faster with depth.

K values are expected to be significantly greater in a direction parallel to the major thrust faults. This generally implies in an east-west direction. It is expected that this forms the dominant anisotropy within the rock mass.

2.2.6.3.4.10 Groundwater Flow Rate/Direction

There is presently insufficient data to determine this. Given the model developed, groundwater watersheds are expected to resemble surface water watersheds. Groundwater flow is therefore expected to be directed toward the Buchans River and then either into it or as underflow beneath the channel toward the south and into Red Indian Lake.

CONCLUSIONS

- 1) The geology within the study area is extremely complex, due primarily to the structure. This implies a similar complexity in the groundwater flow field. The natural complexity is enhanced by intensive underground/surface mining, and the large number of deep (>1000 feet), open boreholes.
- 2) **As** a result of this complexity and lack of previous detailed hydrogeological studies, this report developed a conceptual model of the physical groundwater flow field, based upon existing data and theoretical principles. The model presented herein should be considered as a "first approximation" only; to be used as a basis for guiding subsequent studies, and to be constantly refined *as* new data becomes available.
- 3) The primary control over the transmission and storage of groundwater within the flow field appears to be exerted by the major thrust faults. For the study area these include at least the **Ski Hill**, Old Buchans, Buchans River and Airport Faults. Given that those fault systems may be open to depths of **0.6** mile or more, and their proximity to the Pits, implies that they should be given consideration as a transport mechanism to bring water of different chemistry up from depth.
- 4) Groundwater inflow to the drainage tunnel is expected to result from a) intersection with fault zones, b) the more fractured zone near the bedrock surface, and c) the sand/gravel unit. At this time it is expected that there is a higher probability that the flow in the sand and gravel exerts the more dominant control.

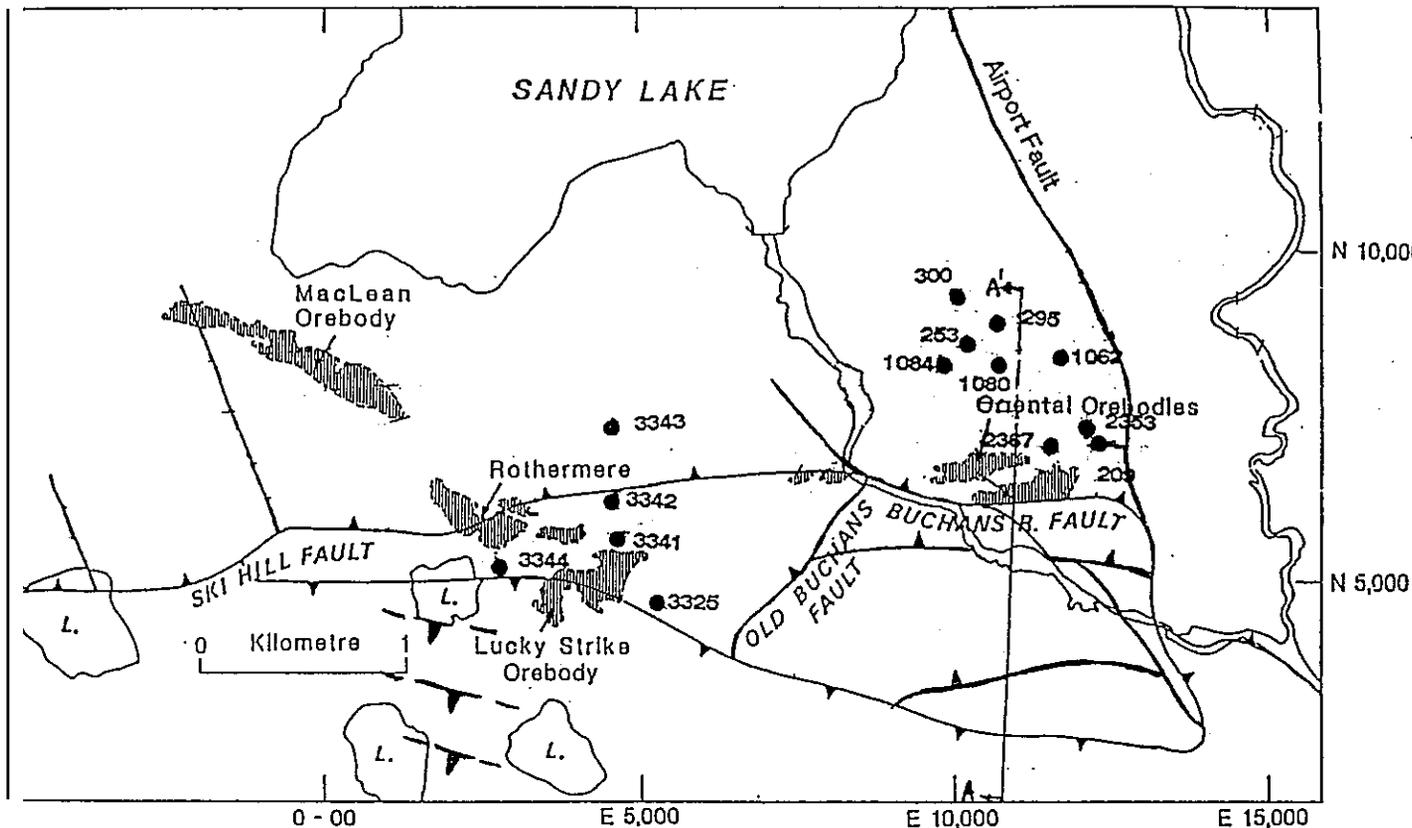
RECOMMENDATIONS

- 1) A more detailed understanding of at least the major thrust faulting within the Lucky Strike - Oriental study area is an absolute necessity. Therefore, it is recommended that:
 - a) discussions be held with Mr. J. Thurlow, to become up to date with the latest data and concepts;
 - b) undertake detailed inspection of the cores of specific holes; for assessment of structural characteristics;
- 2) A surficial mapping program should be undertaken in the area of the Drainage Tunnel. This would require a backhoe/trackhoe for excavating test pits.
- 3) The results of the chemical results from the last borehole sampling, and discussions with Mr. Thurlow in 1) above should be used to augment the flow system developed in this report.
- 4) At this stage it is felt that the next stage of investigation should involve placing piezometers, specifically in the major fault zones which are in direct connection with the Oriental Pits. This may be done by either: a): placing them in existing boreholes (if they intersect the fault in question, are large enough, and are not required for geological purposes in the future) and/or b) undertaking a new drill program specifically for this purpose.

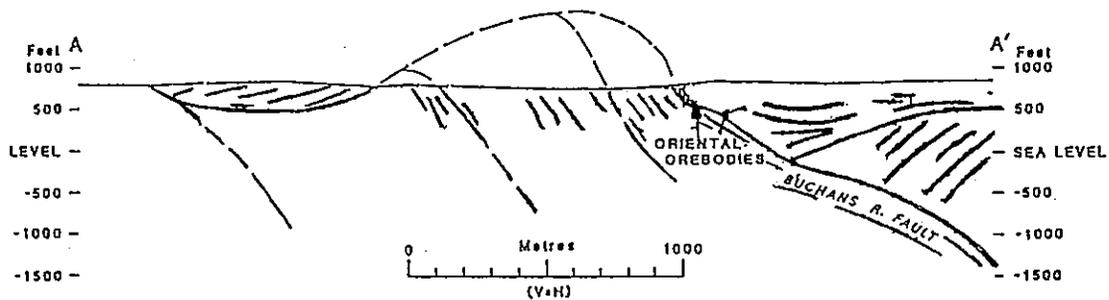
TABLE 1

**Bulk Hydraulic Conductivity
Vallies for the Bedrock HU**

Hole No.	K (ft/sec.)	K (m/sec.)
3325	9.5×10^{-10}	2.9×10^{-10}
3342	1.1×10^{-10}	3.4×10^{-11}
3343	1.4×10^{-10}	4.2×10^{-11}
3344	1.8×10^{-9}	5.5×10^{-10}
2367	2.7×10^{-10}	8.2×10^{-11}
1062	4.3×10^{-9}	1.3×10^{-9}

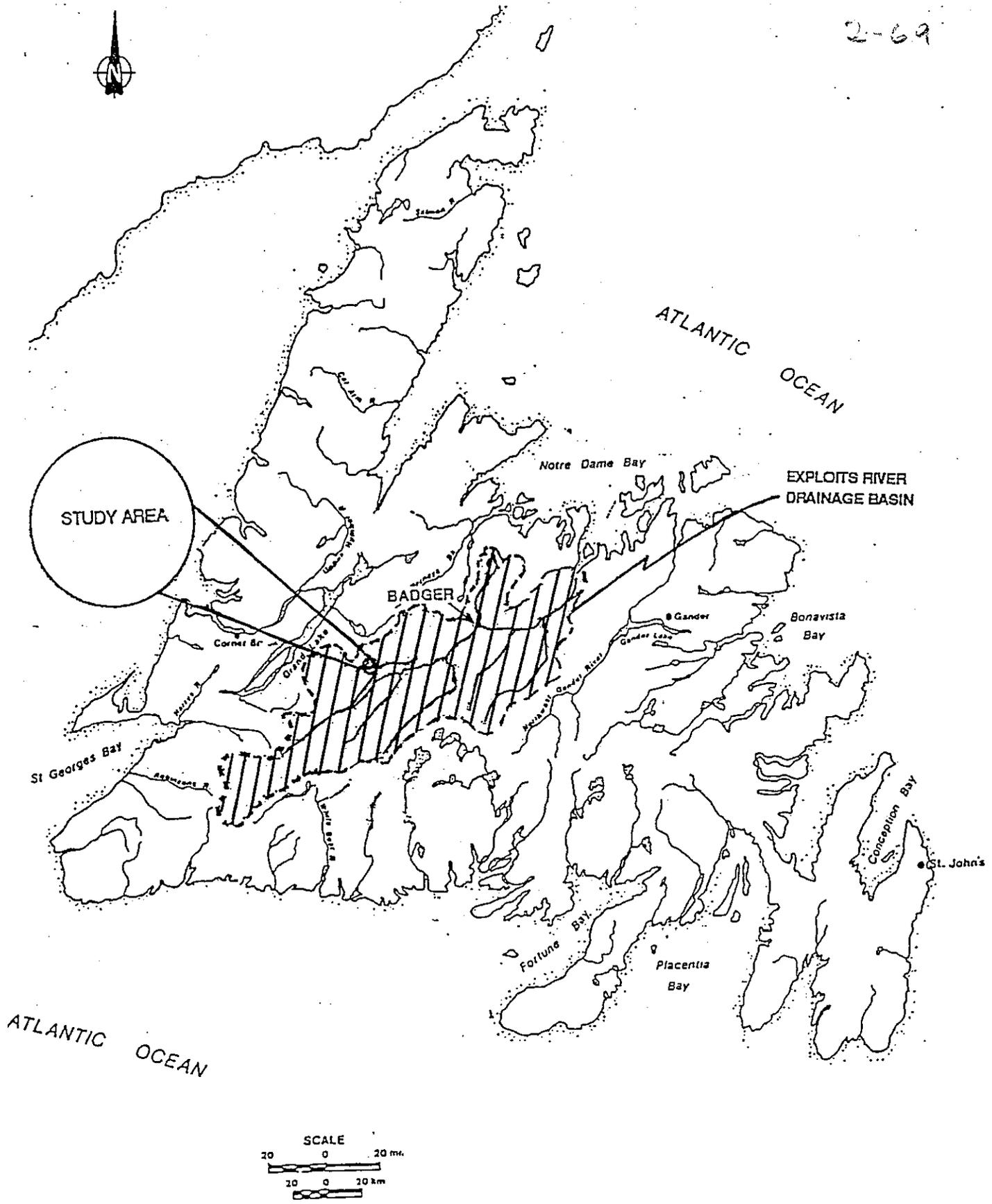


● Position of test holes which were sampled for chemistry and hydraulic conductivity for this study



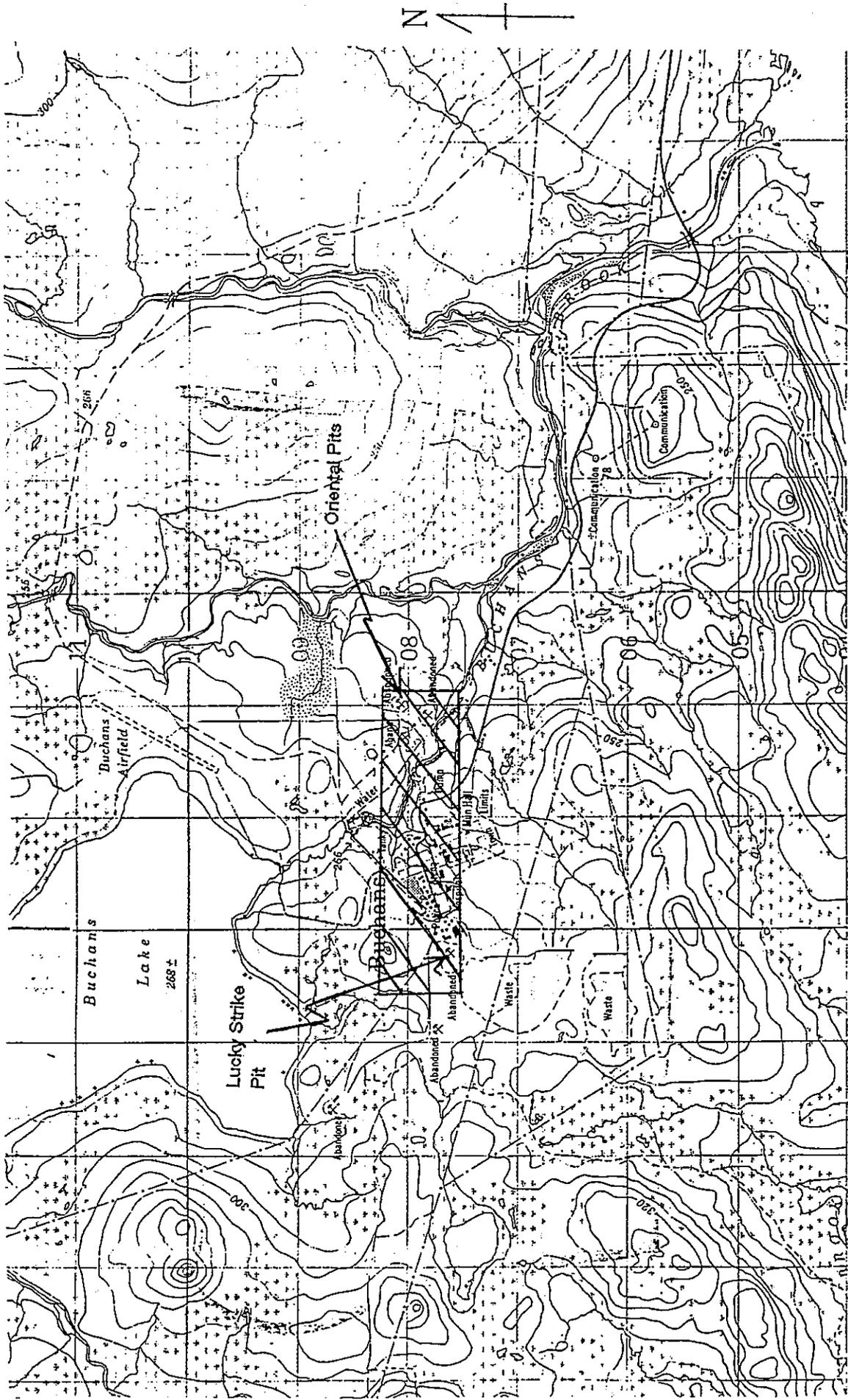
NOLAN, DAVIS & ASSOCIATES

FIGURE A
GENERALIZED STRUCTURAL MAP OF THE STUDY AREA
(after Thurlow, 1988)



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& ASSOCIATES**

**FIGURE 1-1
REGIONAL LOCATION MAP**

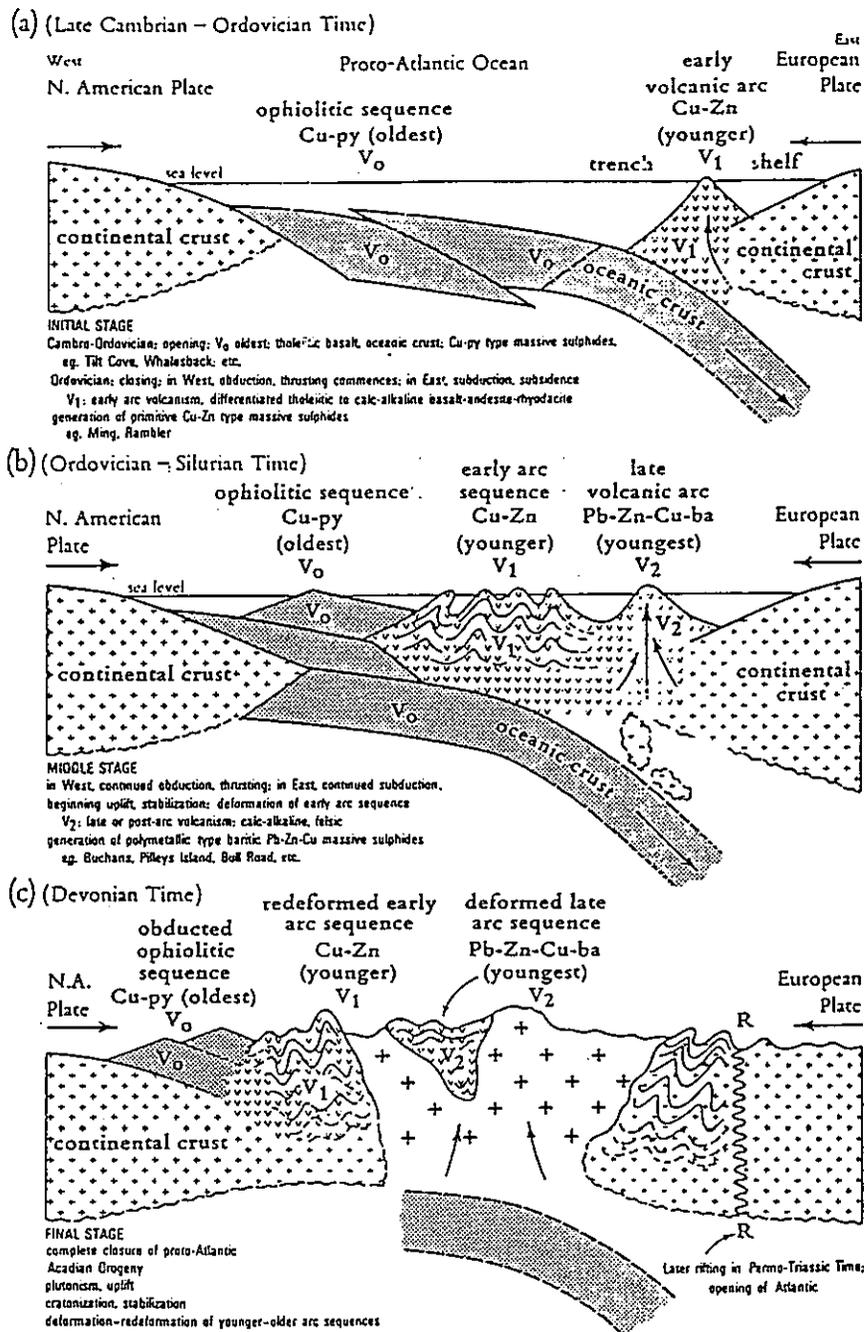


SCALE: 1:50,000

**NOLAN, DAVIS
& ASSOCIATES**



FIGURE 1-2
DETAILED LOCATION MAP



Metallogenic relationships. North Atlantic Margin.



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FIGURE '4-1
 METALLOGENIC RELATIONSHIPS
 • NORTH ATLANTIC MARGIN
 CAMBRIAN - DEVONIAN TIME
 (after Hutchinson, 1982)

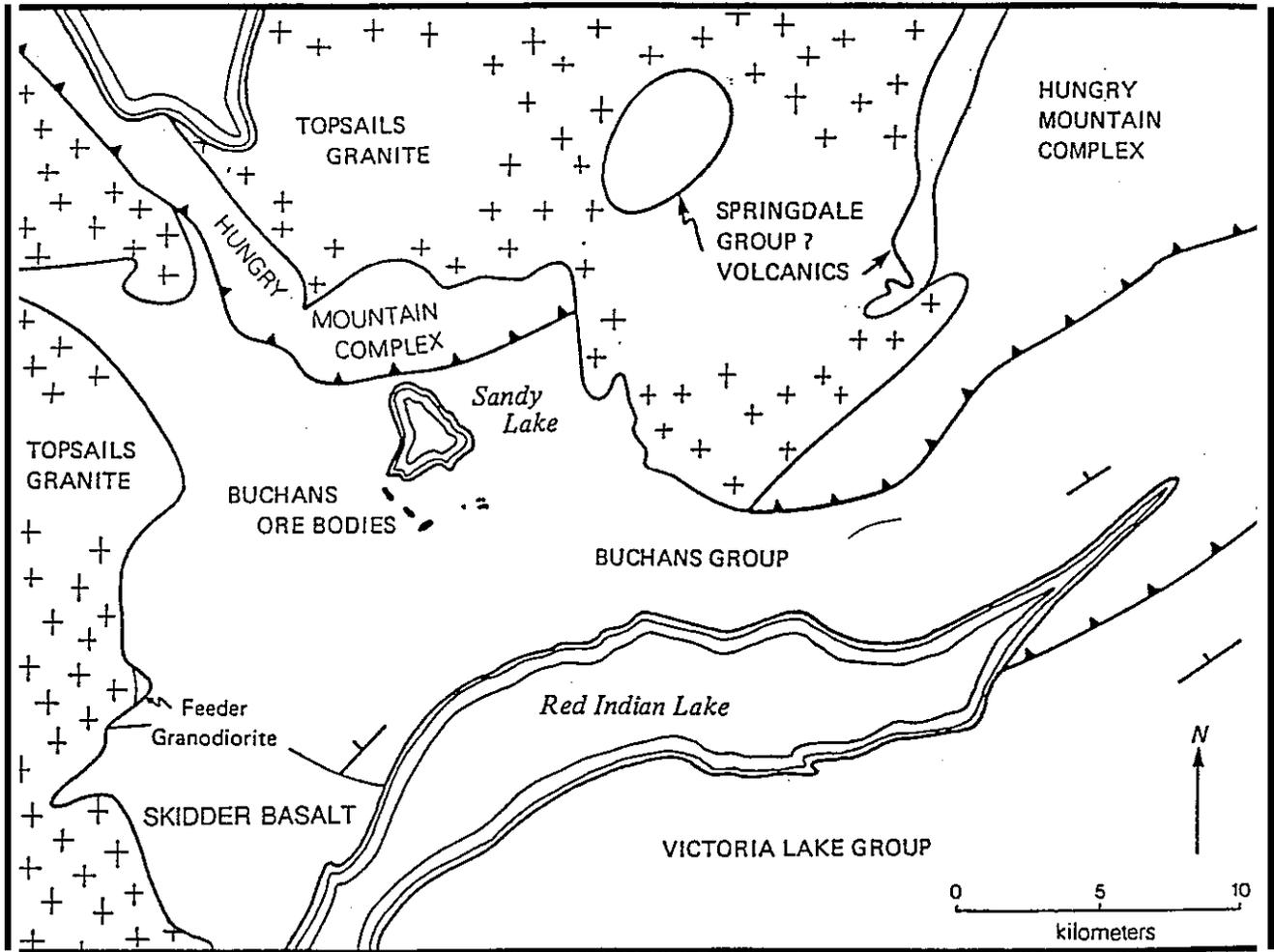


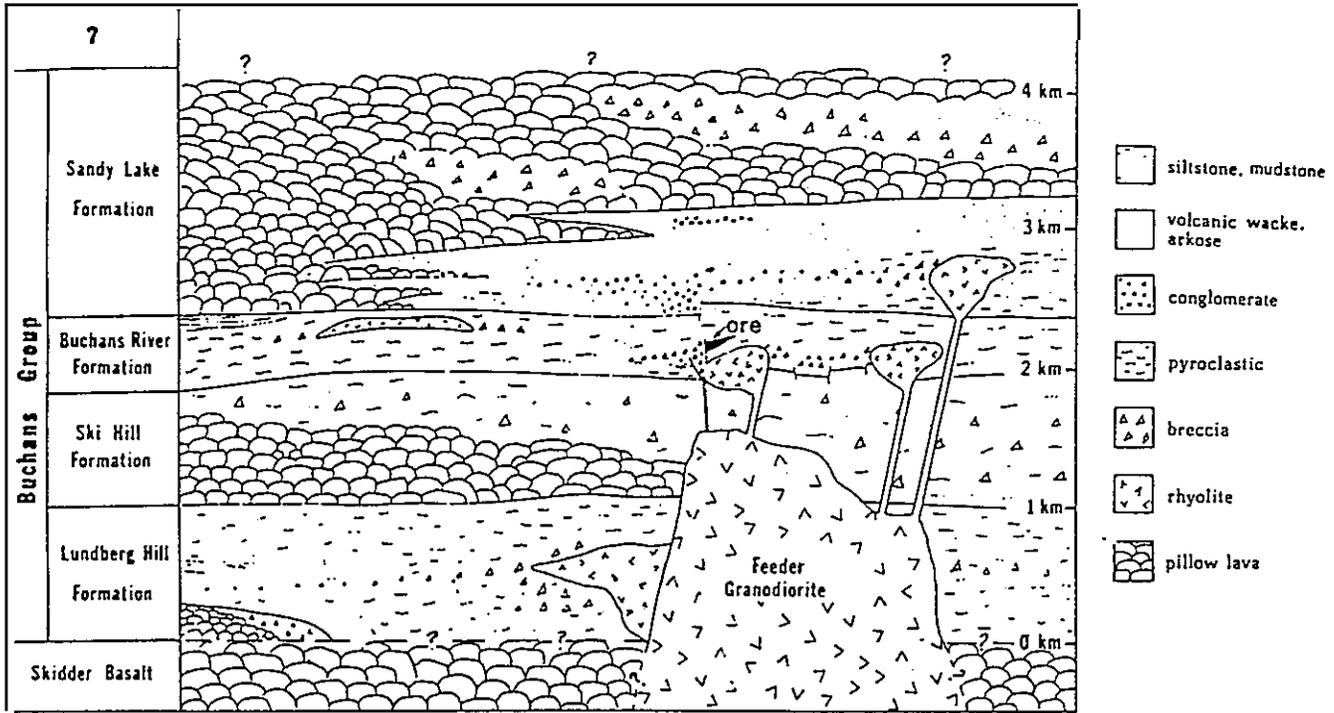
FIGURE 4-2

GENERALIZED GEOLOGY OF THE BUCHANS MINE

(after Thurlow and Swanson, 1987)



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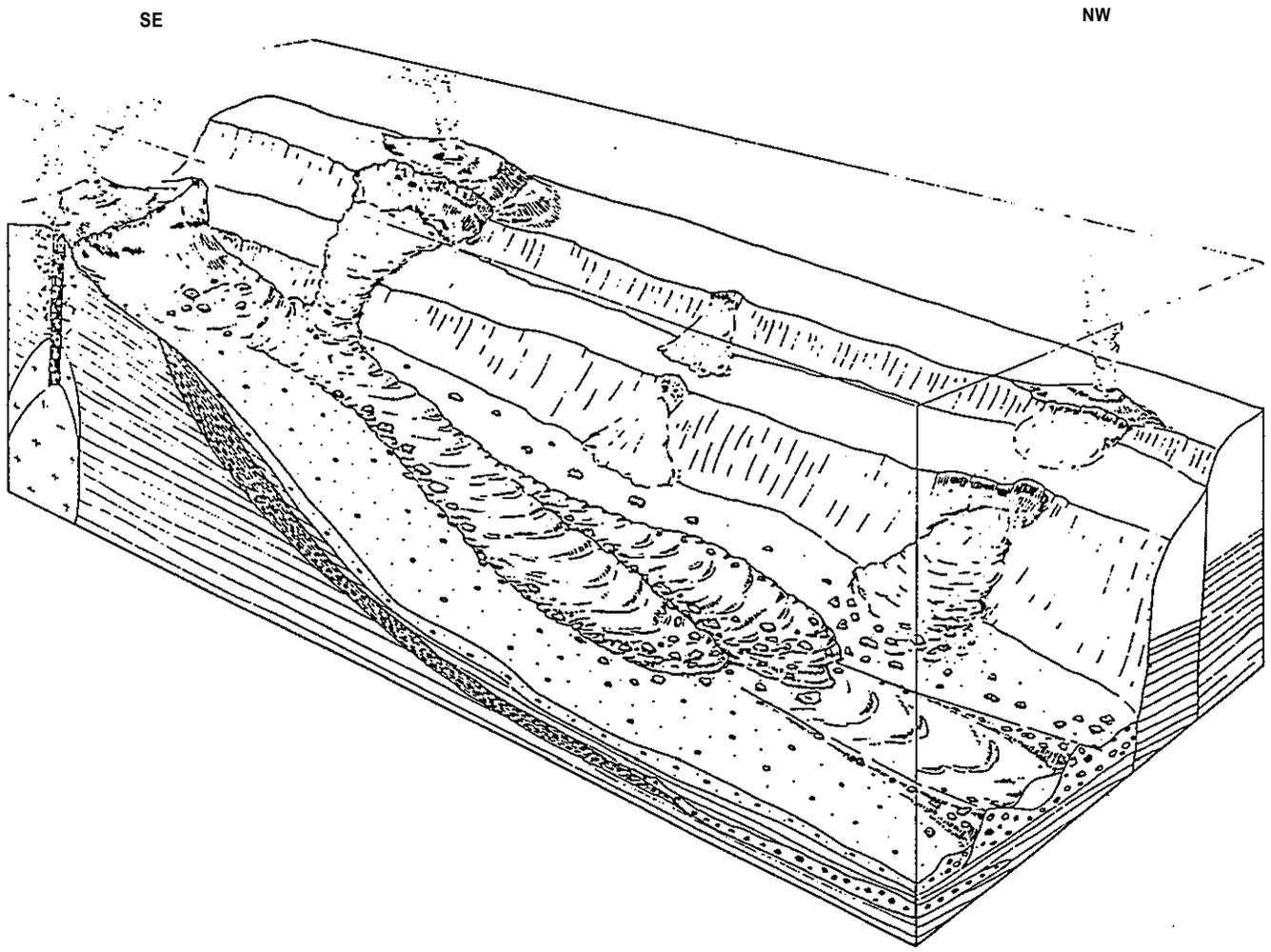
Formation	Maximum Thickness in Oriental Block	Maximum Thickness	Lithologies	Former Stratigraphic Names
Sandy Lake Formation	200m	2000m?	Basaltic pillow lava, pillow breccia intertonguing with coarse grained, redeposited clastic rocks of felsic volcanic derivation (arkosic conglomerate, arkose, wacke, siltstone). Local abundant tuff, breccia, polyolithic pyroclastic breccia and tuffaceous sedimentary rocks.	Sandy Lake Basalt. Upper Arkose, Lake Seven Basalt. Footwall Arkose. Footwall Basalt. part of Prominent Quartz sequence.
Buchans River Formation	200m	400m?	Felsic tuff, rhyolite, rhyolite breccia, pyritic siltstone, wacke, polyolithic breccia-conglomerate, granite boulder conglomerate, high-grade in situ and transported sulphide orebodies.	Lucky Strike Ore Horizon sequence. Oriental Ore Horizon sequence, parts of Intermediate Footwall.
Ski Hill Formation	1000m?	1000m?	Basaltic to andesitic pyroclastic rocks, breccia, pillow lava, massive flows. Minor felsic tuff.	Ski Hill sequence, parts of Intermediate Footwall. Oriental Intermediate.
Lundberg Hill Formation	200m minimum	1000m?	Felsic pyroclastic rocks, coarse pyroclastic breccia, rhyolite, tuffaceous wacke, siltstone, lesser basalt, minor chert and magnetic iron-formation.	Part of Prominent Quartz sequence, Wiley's Prominent Quartz sequence, Little Sandy sequence (?).

FIGURE

SCHEMATIC STRATIGRAPHIC AND LITHOLOGIES OF THE BUCHANS GROUP (after Thurlow and Swanson, 1987)



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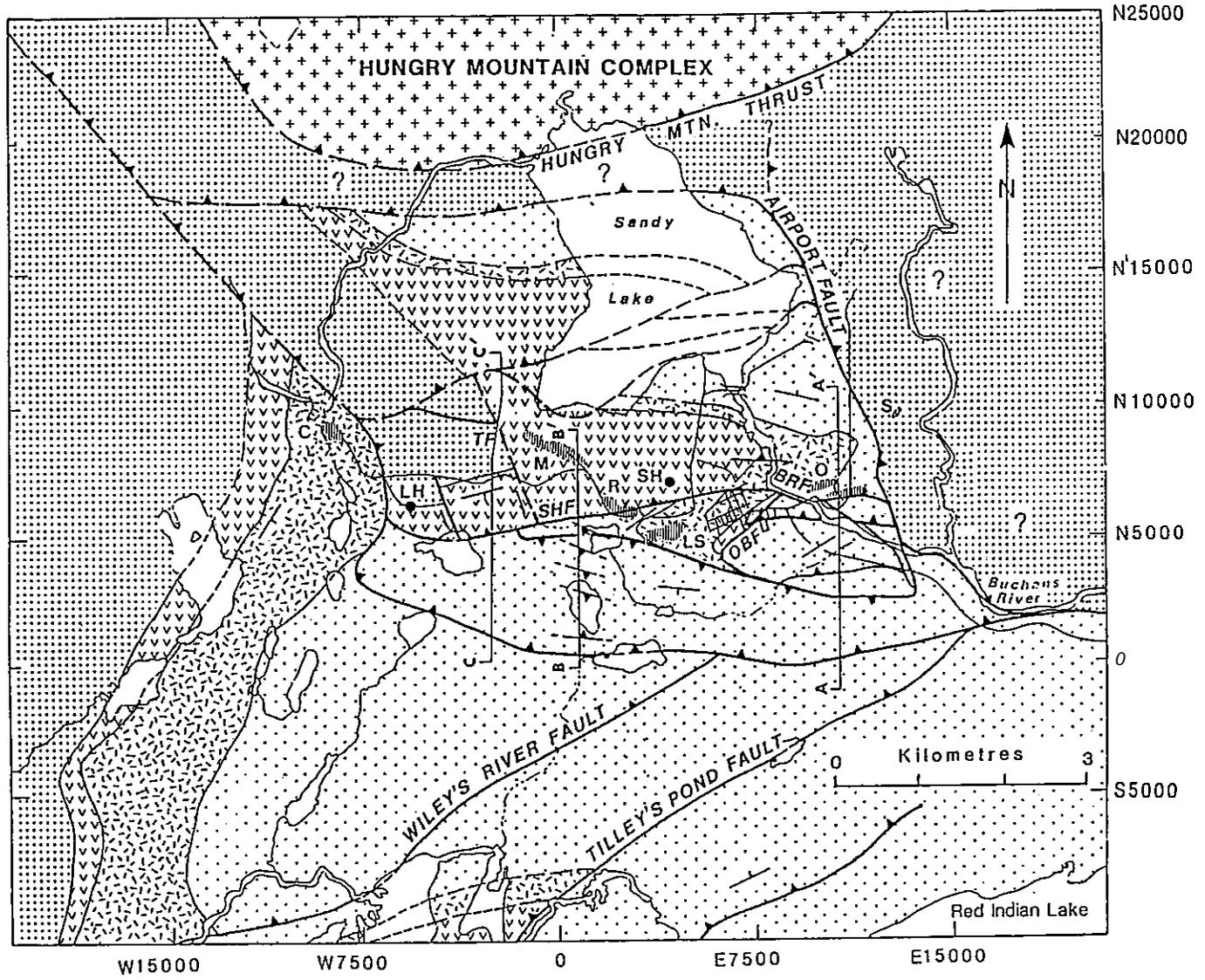


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& ASSOCIATES**

FIGURE 4-4

SCHEMATIC BLOCK DIAGRAM OF THE

**MACLEAN CHANNEL
(after Thurlow and Swanson, 1987)**

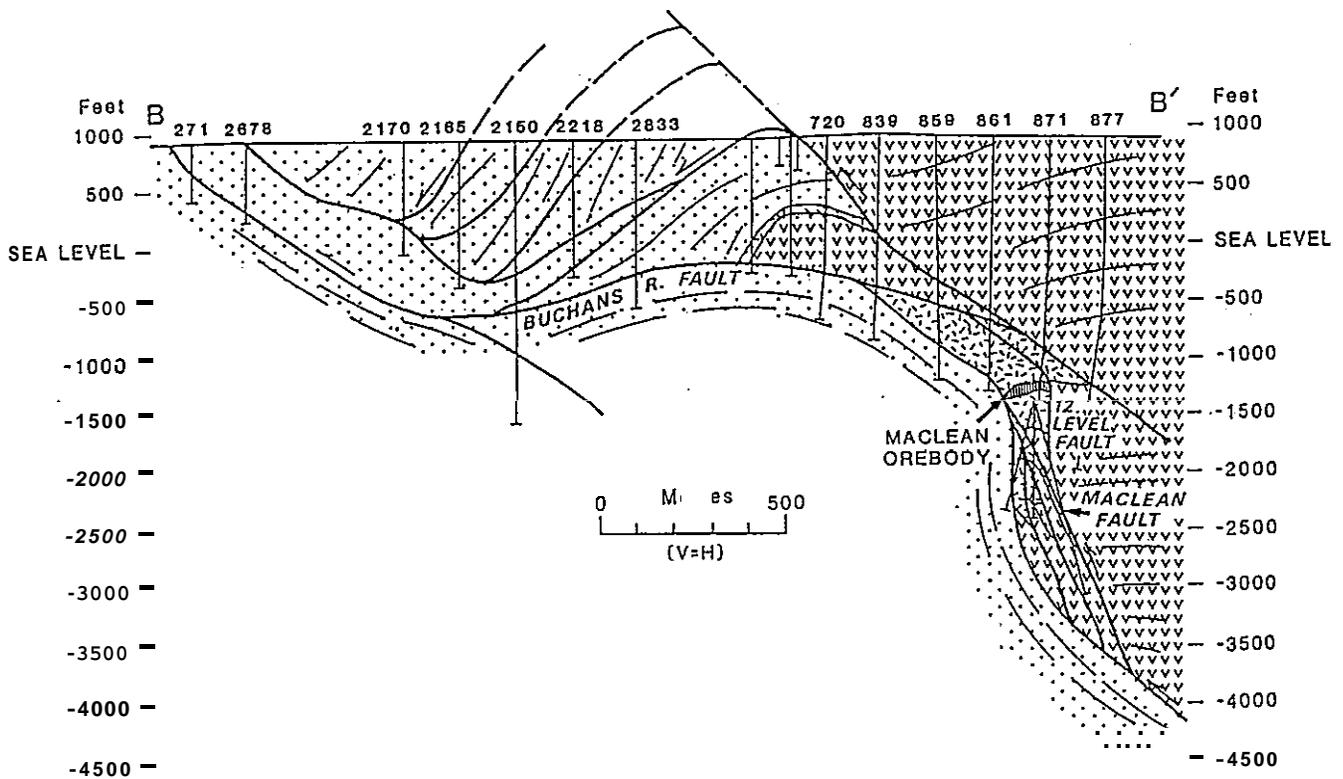
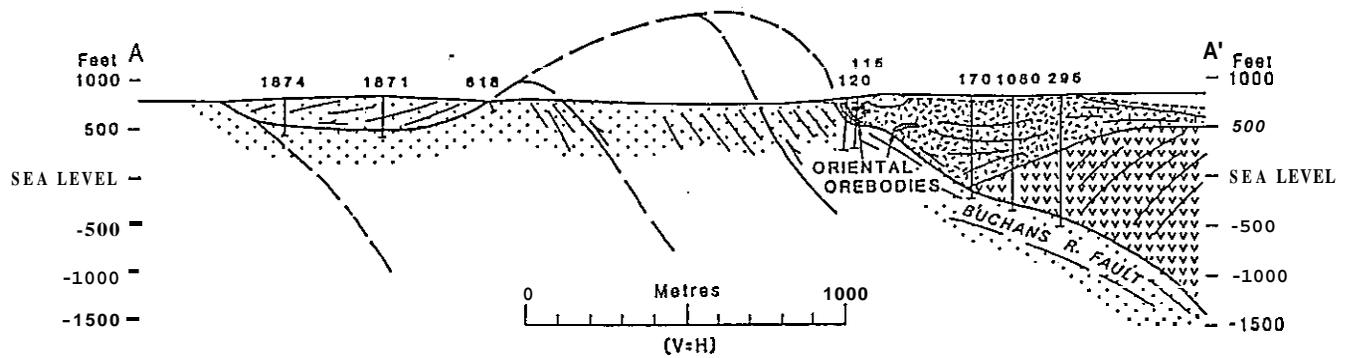


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5-1

BEDROCK LITHOLOGY/STRUCTURAL MAP OF THE

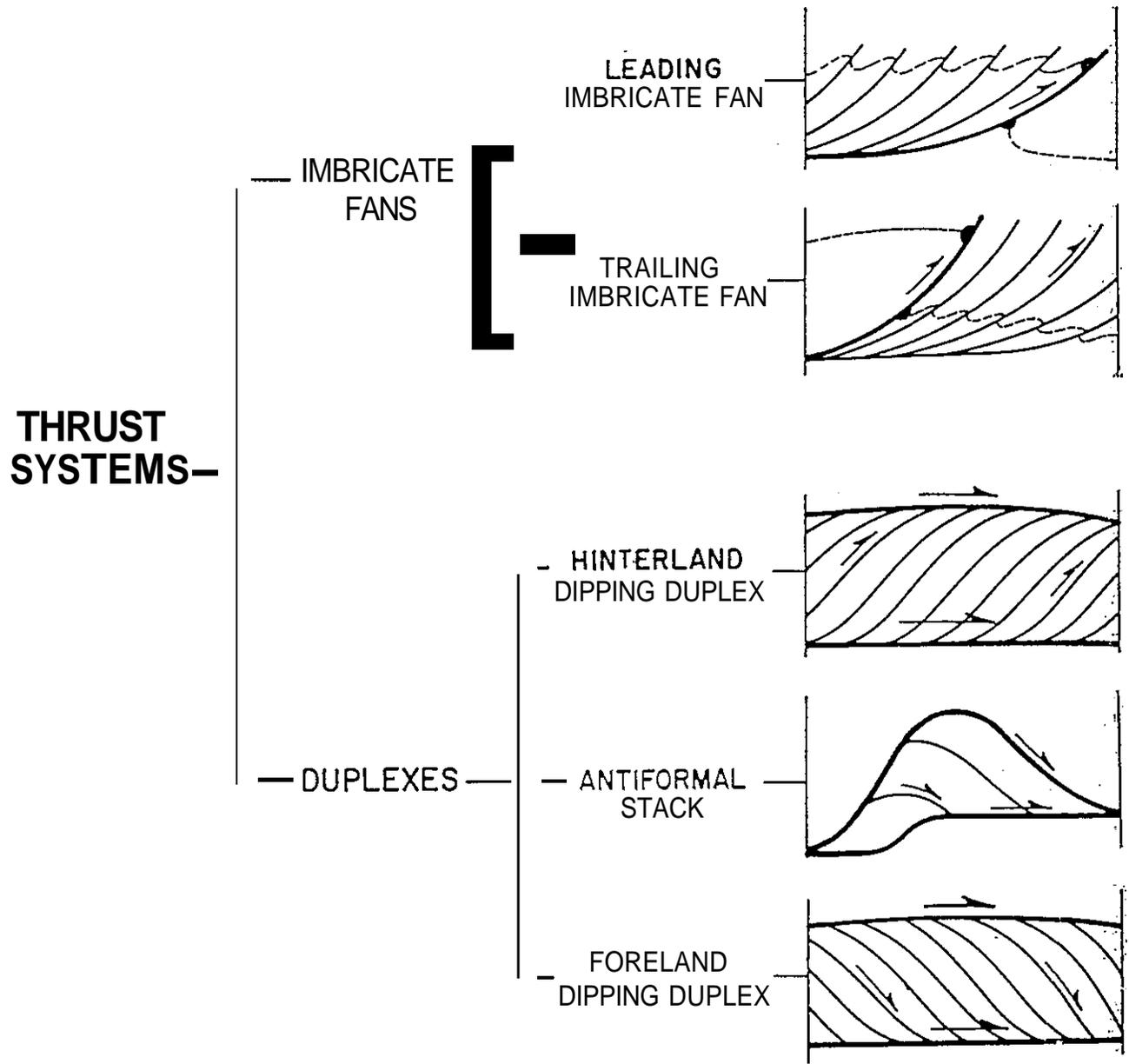
BUCHANS MINE AREA
(after Thurlow and Swanson, 1987)



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FIGURE 5-2
PERTINENT BEDROCK CROSS SECTIONS

(Note: Figure 5-1 for Location and Legend)



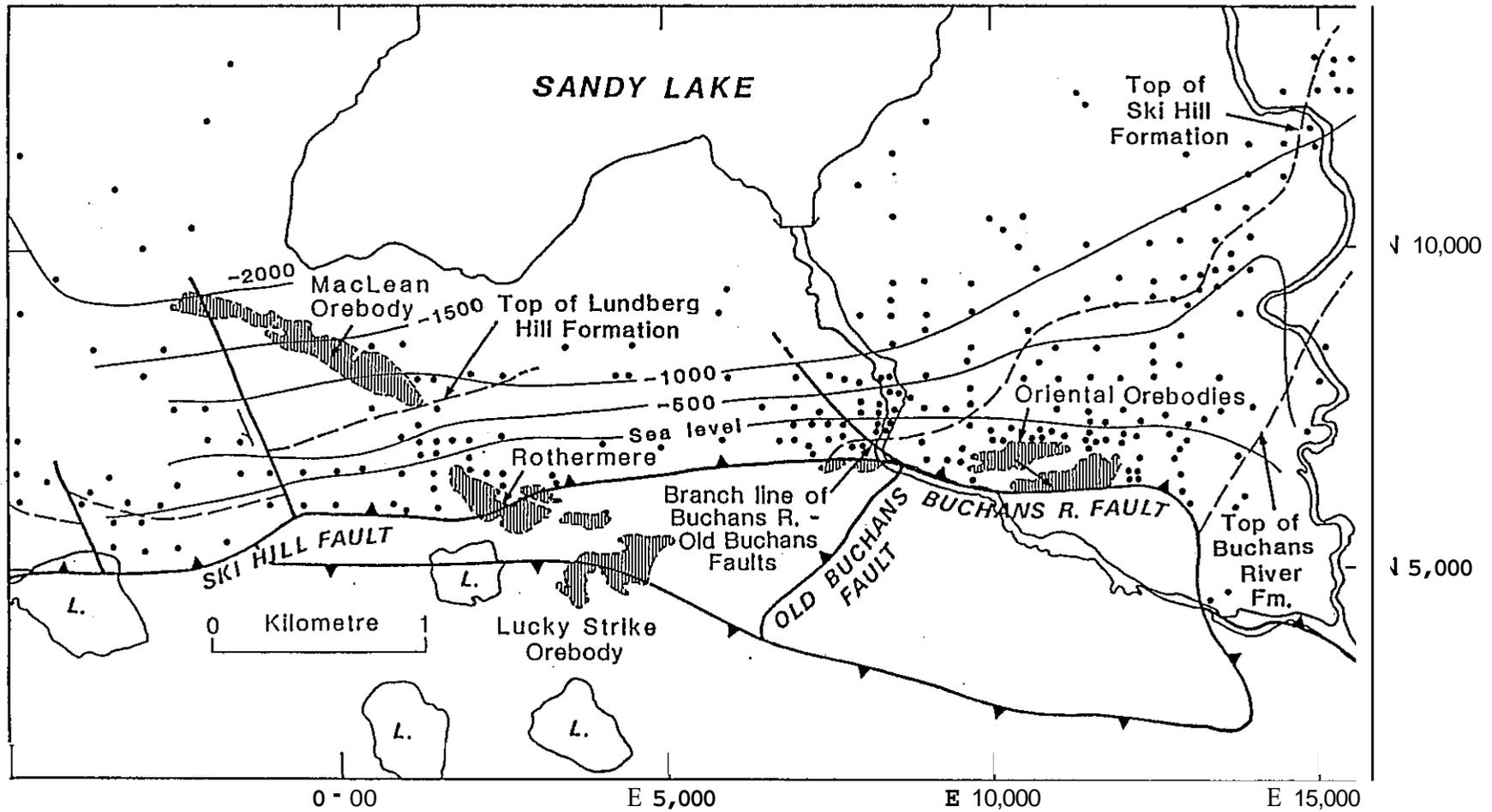


Figure 5d

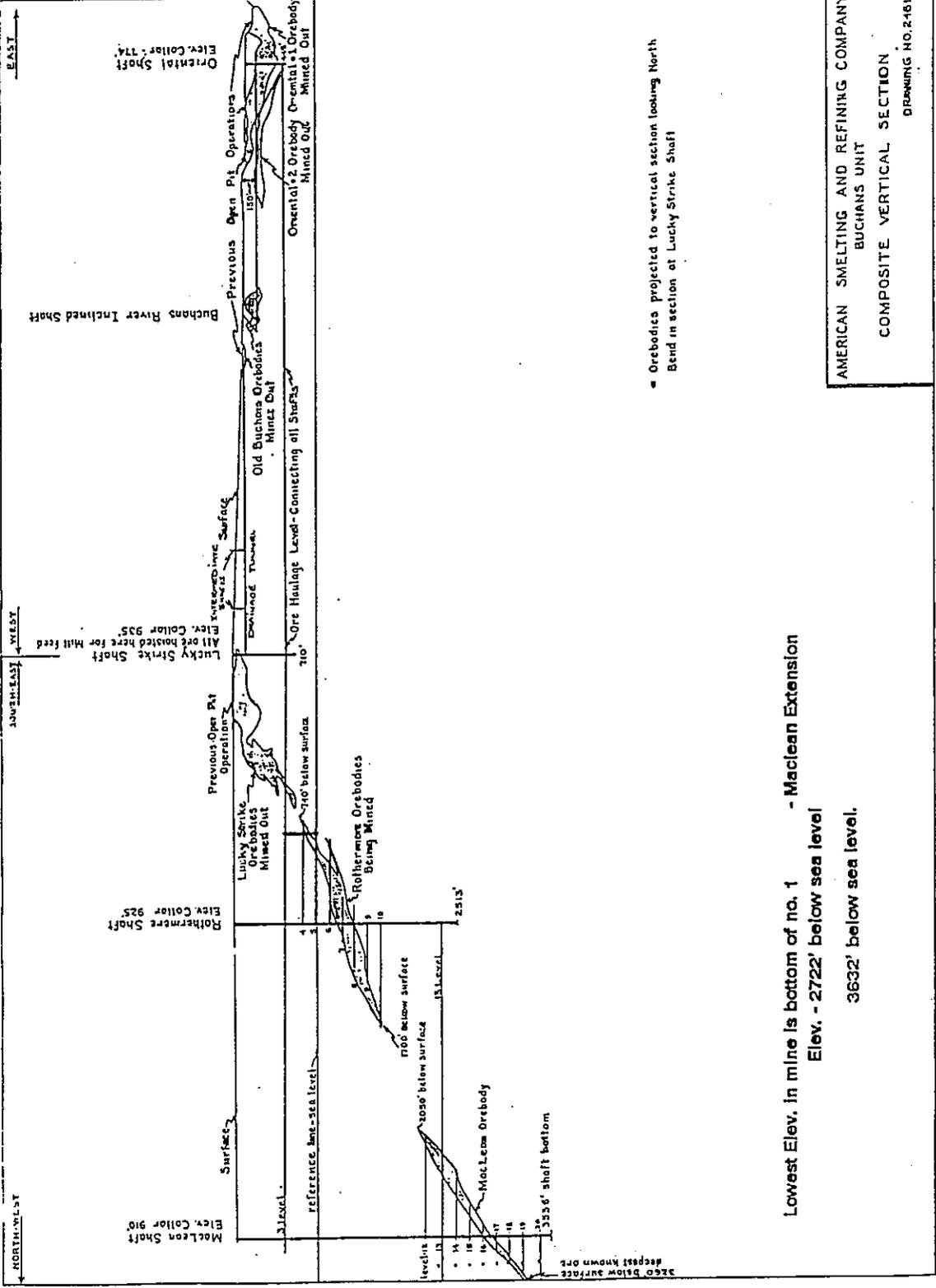
GENERALIZED STRUCTURAL MAP OF THE STUDY AREA

(after Thurlow, 1988)



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2-78



Lowest Elev. in mine is bottom of no. 1 - Maclean Extension
 Elev. - 2722' below sea level
 3632' below sea level.

AMERICAN SMELTING AND REFINING COMPANY
 BUCHANS UNIT
 COMPOSITE VERTICAL SECTION
 DRAWING NO. 2-161



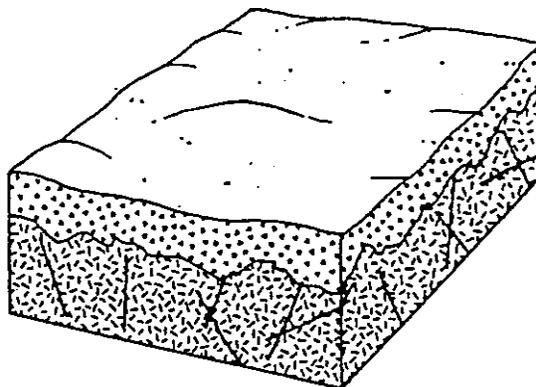
COMPOSITE VERTICAL SECTION OF MINERALIZED
 ZONES AND MINES
 (Courtesy G. Neary)

NORTHEAST AND SUPERIOR UPLANDS

2.80

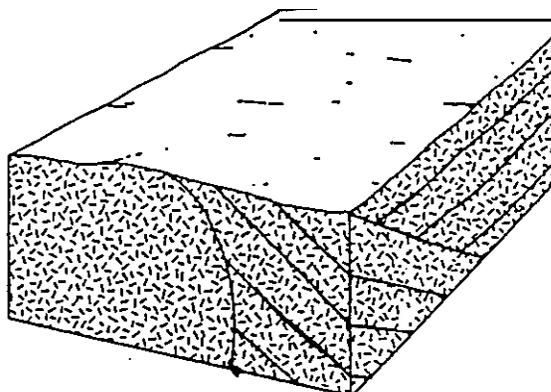
(90a) **Glacial Till Over Crystalline Bedrock**

This hydrogeologic setting is characterized by moderately low topographic relief and varying thicknesses of glacial till overlying severely fractured, folded and faulted bedrock of igneous and metamorphic origin with minor occurrences of bedded sedimentary rock. The till is principally unsorted deposits which may be interbedded with localized deposits of sand and gravel. Although ground water occurs in both the glacial deposits and fractured bedrock, the bedrock is typically the principal aquifer. The glacial till serves as a recharge source. Although precipitation is abundant, recharge is only moderately high because of the low permeability of the glacial till and the surficial deposits which typically weather to loam. Depth to water is extremely variable depending in part on the thickness of the glacial till, but is typically moderately shallow.



(91) **Bedrock Upland**

This hydrogeologic setting is characterized by moderately low topographic relief and exposed fractured, folded and faulted bedrock of igneous and low-grade metamorphic origin with minor occurrences of bedded sedimentary rocks. Recharge is primarily controlled by precipitation but is limited by the hydraulic conductivity of the rock. Where present, soils are commonly sandy. These areas typically serve as limited aquifers.

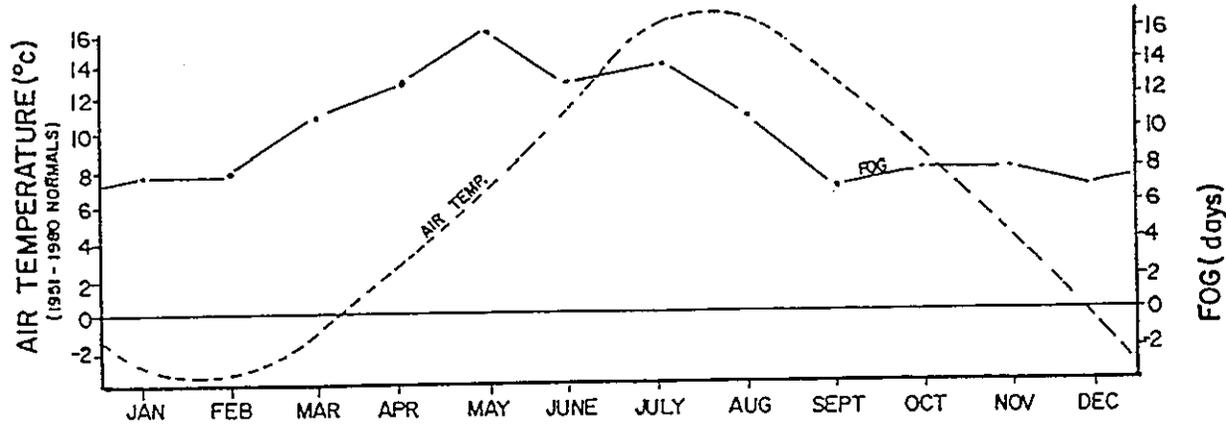
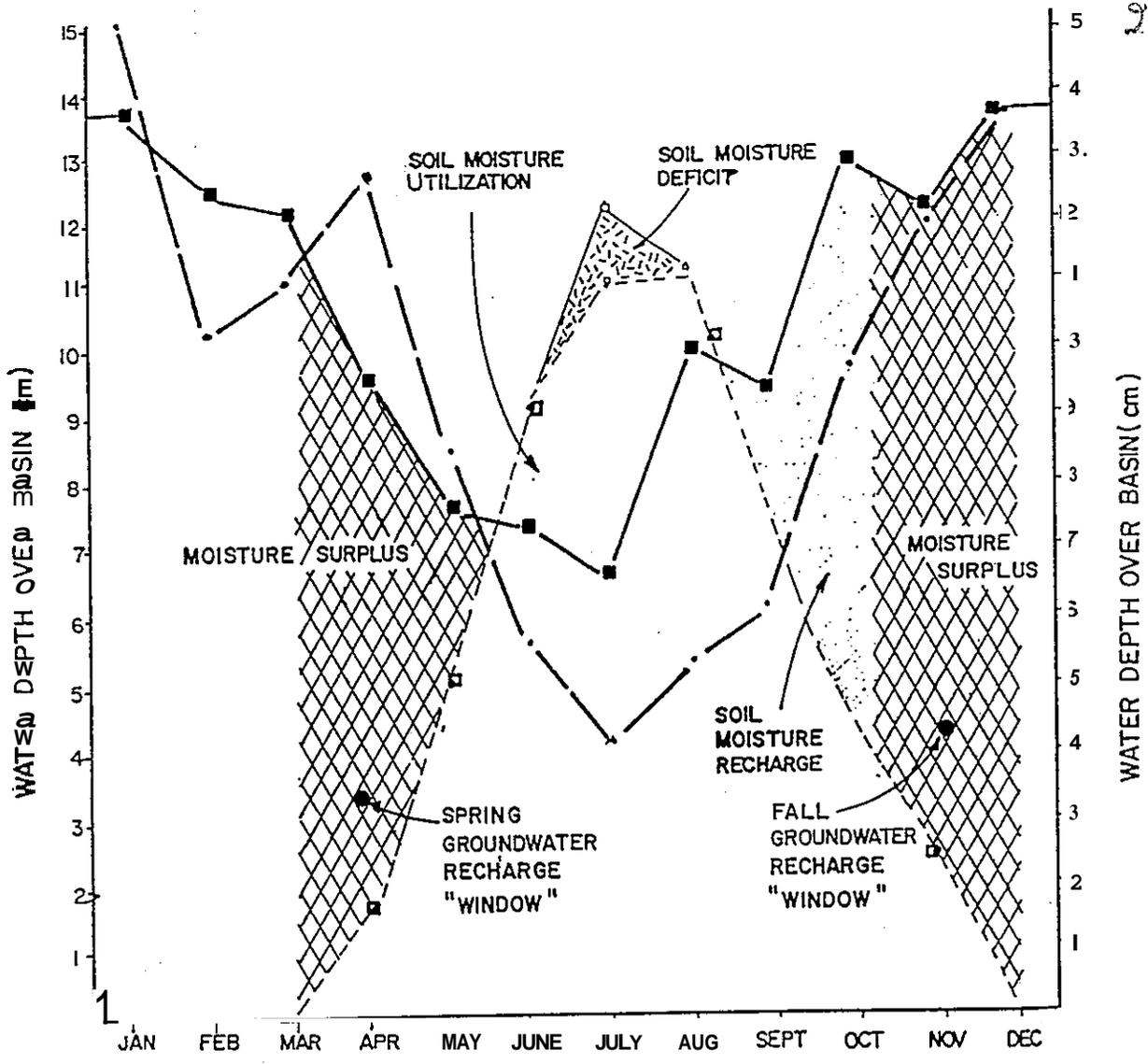


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& ASSOCIATES

FIGURE 6-1
HYDROGEOLOGICAL SETTINGS

(after Aller et al, 1987)

2-21

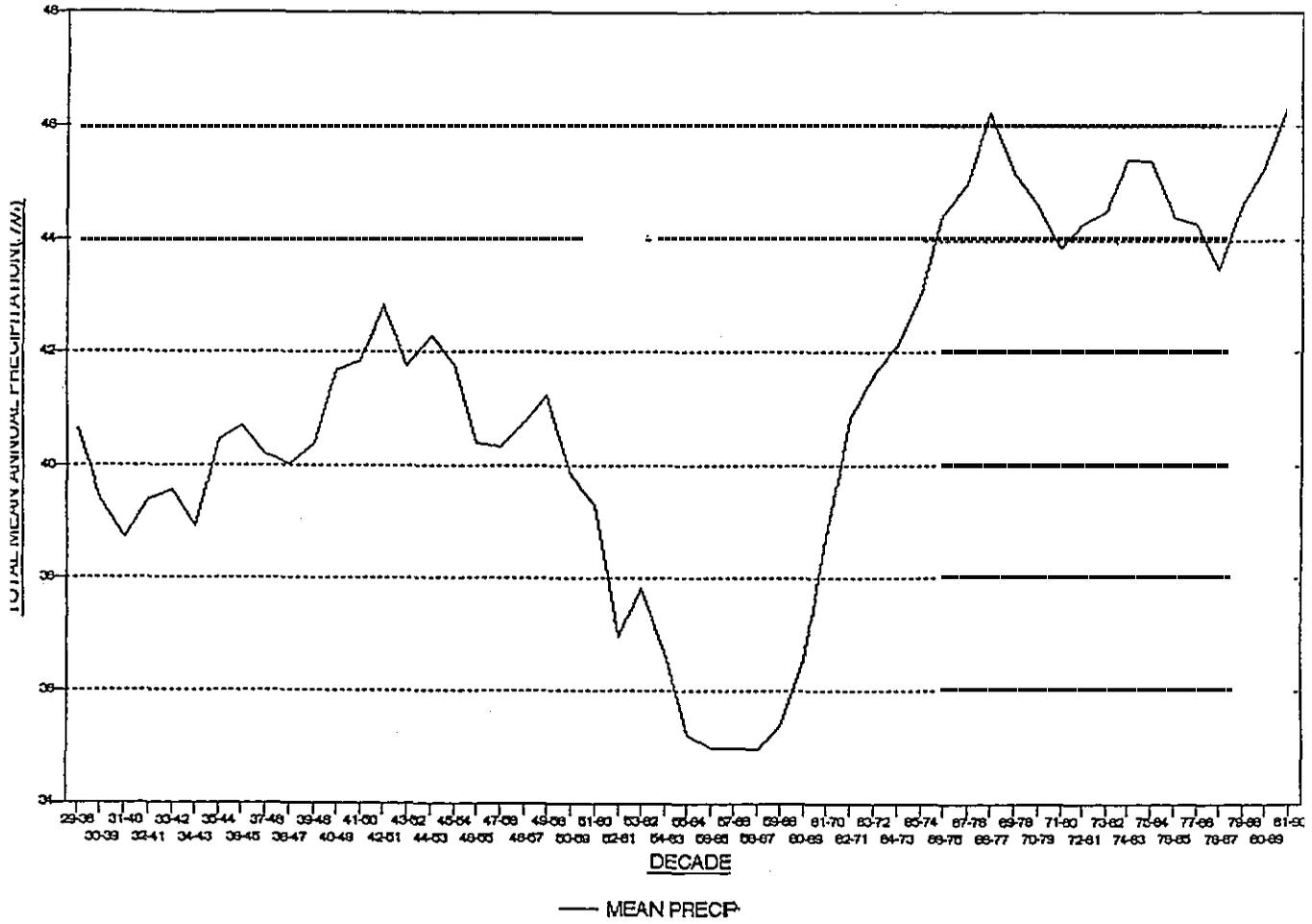


- Precipitation (1951-1980 normal)
- Potential evapotranspiration (1951-1980 normal)
- Actual evapotranspiration
- .- Surface runoff (Rocky River avg. 1948-1986 corrected for Bell Island)



FIGURE 6-2
 WATER BALANCE DIAGRAM
 FOR SEAL COVE

RUNNING DECADAL MEANS FOR MEAN ANNUAL TOT. PRECIP. FOR BUCHANS(1929-1990)



**NOLAN, DAVIS
& ASSOCIATES**

FIGURE 6-3
**RUNNING DECADAL MEANS ANALYSIS FOR TOTAL ANNUAL
PRECIPITATION AT BUCHANS**

2-53

L 200

282

LIST OF REFERENCES

Aller, L., Bennett, T., Lehr, J., Petty, R., and Hackett, G., 1987. DRASTIC A Standardized System for Evaluating Groundwater Pollution Potential Using Hydrogeologic Settings EPA 600/2-87-035, 455 pp.

Boyer, S.E. and Elliott, D., 1982. Thrust Systems. America Association Petroleum Geologists Bull, V66 #9, pp. 1196 - 1230.

Dunne, T., and Leopold, L., 1978. Water in Environmental Planning, W.H. Freeman and Co., San Francisco, 818 p.

Heath, R.C., 1988. Hydrogeological Settings of Regions in Hydrogeology, The Geology of North America. Edited by Back, W., Rosenshien, J., and Seaber; Geological Society of America, 524 pp.

Matheson, D., and Thompson, S., 1973. Geological Implications of Valley Rebound, Can. J. Earth Science. Vol 10, pp. 961-978.

Narasimham, T.N., 1990. Flow Modelling in Massifs of Complex Geological Structure, in IAH Memoirs Col XXII Part 1 - XII congress, Water Resources in Mountainous Regions. Edited by A. Parriaux.

Randall, A., Francis, R., Frimster, M., and Emery, J., 1988. Region 19, Northeastern Appalachians in the Geology of North America, Vol. 0-2 Hydrogeologic Environment, Geological Society of America Inc. pp. 177-188.

Swanson, E., Strong, D., and Thurlow, J., (Ed) 1981. The Buchans Orebodies, Fifty years of Geology and Mining, GAC Special Paper 22.

Thurlow, J.G., 1988. Geology of the Buchans Orebodies - A 1988 Summary in The Volcanogenic Sulphide Districts of Central Newfoundland.

Thurlow, J.G. and Swanson, E.A., 1986. Stratigraphy and Structure of the Buchans Group; in Buchans Geology, Nfld. Edited by R.V. Kirkham, GSC paper 86-24, pp. 35-46, Report 2.

Toth, J., 1970. A Conceptual Model of the Groundwater Regime and the Hydrogeologic Environment, Contribution 461, Alberta Research Council.

**Toth, J., 1962. A Theoretical Analysis of Groundwater Flow in Small Drainage Basins, in
proceedings of Hydrology Symposium No. 3 - Groundwater National Research
Council of Canada, Associate Committee of Geodesy and Geophysics pp. 81 - 90.**

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ASARCO - BUCHANSTHE DRAINAGE TUNNEL AND THE LUCKY STRIKE PITINTRODUCTION

The Old Buchans Drainage Tunnel, started in late 1926 and completed in July 1928, runs from the main Lucky Strike shaft at elevation 800 ft (243.8 m) to a portal near the Buchans River at elevation 786 ft (239.6 m). It was started from the portal at Buchans River, immediately below the uneven bedrock surface, and it repeatedly encountered water-saturated overburden. After a cave-in near the 500-ft mark, the tunnel was lowered by 12 ft (3.66 m). The tunneling project was speeded up in 1927 by starting additional headings from two intermediate shafts. The total length of the tunnel is 3560 ft (1085 m); it is approximately 6.5 ft (1.98 m) high, 4.0 ft (1.22 m) wide at roof level, and 6.0 ft (1.83 m) wide at floor level.

Upon mine closure, concrete bulkheads were installed in the two branches of the tunnel at the Lucky Strike shaft, to prevent water entering the tunnel from the shaft during and after flooding of the mine. In 1988 an additional 16 ft (4.9 m) long concrete plug was installed in the tunnel at the #1 Intermediate shaft, 2075 ft (632.5 m) from the Lucky Strike shaft. The installation was completed on 10 June 1988. During this operation, the water from the upstream portion of the tunnel was pumped to the surface at the #1 Intermediate shaft. This achieved a decrease in the discharge from the portal from about 135 USgpm (8.5 L/s) to about 50 USgpm (3.2 L/s). When pumping was discontinued after completion of the plug, flow from the portal stabilized at about 108 USgpm (6.8 L/s), indicating that some 60 USgpm (3.6 L/s) of water from the upper 2075 ft (632.5 m) of the tunnel and its surrounding ground found its way into the lower 1484 ft (452.3 m) of the tunnel. The zinc concentration decreased from about 27 mg/L to about 20 mg/L. At present, the water discharged from the Drainage Tunnel flows untreated into the Buchans River.

By the beginning of 1991, the waterlevel in the Lucky Strike pit reached elevation 832.5 ft a.s.l. (253.7 m); overflow from the pit would start if the level were to reach elevation 928.0 ft a.s.l. (282.9 m). It is expected that this potential future rise of 95.5 ft (29.1 m) in the waterlevel would lead to at least some increase in the rate of discharge from the drainage tunnel, even with the effective length of the tunnel

shortened to 42% of the original length, and the presence of the concrete bulkheads in the tunnel.

In this report, available topographic, hydrologic and water-chemistry data for the Lucky-Strike/Drainage-Tunnel area are reviewed and interpreted. Preliminary modelling of the groundwater system was used to aid in the interpretation, and to provide some insight into the future performance of the system. In the **final** section, geochemical simulation is employed to estimate saturation degrees and sources of the dissolved-solid contents of the pit and tunnel waters, and to provide a preliminary evaluation of potential disposal options for the Drainage Tunnel discharge.

Every effort has been made to insure that the data used in the interpretation and predictions presented in this report are the best available. Any errors found, and significant new information that could affect the interpretation and predictions should be brought to the attention of the author as soon as possible to enable correction and, where necessary re-interpretation.

1. TOPOGRAPHY and DRILLHOLE DATA

Information on surface elevation, bedrock elevation, and overburden thickness is available from a number of exploration drillholes in the area (Table 1-1). The information has been used to prepare shaded contour maps for ground elevation (Figure 1-1), bedrock elevation (Figure 1-2), and overburden thickness (Figure 1-3), using the program SHADEMAP (Geol. Survey of Canada, 1988). The coordinates listed in Table 1-1 and shown at the upper-left and lower-right corners of the three maps refer to the existing mine grid. The location of the Drainage Tunnel is indicated on the three maps by a solid line.

2. WATER CHEMISTRY

A. Monitor Data

At more or less regular intervals, water samples are collected from the Drainage Tunnel (DT) outflow, and from the pond in the Lucky Strike (LS) pit. Temperature and pH of the waters, the DT discharge rate, and the waterlevel in the LS pond are measured at the time of sample collection. The samples are subsequently analysed for pH, Cu and Zn, in the mine laboratory.

Figures 2-1, 2-2, and 2-3 present a comparison between the DT discharge and the LS pond water, for pH, [Cu] and [Zn], respectively. Several points should be noted here.

- (1) All three parameters show significant seasonal variations in the LS pond water, but the range of variation is much smaller in the DT discharge.
- (2) Over the past 5 years, pH has been consistently higher in the LS pond than in the DT discharge.
- (3) . Over the past 5 years, [Cu] values in the LS pond water have gradually decreased from well above those in the DT discharge in 1987, to generally below those in the DT discharge in 1991.
- (4) Over the past 5 years, [Zn] values in the LS pond water have gradually decreased from well above those in the DT discharge in 1987, to well below those in the DT discharge in 1991.

It can be concluded that the water sampled in the LS pond (as analysed) can contribute only part of the Cu and Zn content of the DT discharge. Water from deeper in the LS pit or the mine workings and/or surrounding ground must contribute to the DT discharge.

B. Data from Exploration Drillholes

In late 1989 a number of existing drillholes (DHs) were checked for ease of access and general condition, with a view to using some of those holes for (a) measurement of waterlevels at regular intervals, and (b) the collection of groundwater samples for analysis. Data on the location, waterlevel, temperature and pH for the usable DHs found in 1989 are listed in Table 2-1. In May 1991, water samples were collected from those and from several additional DHs near the LS pit, and their waterlevels were measured, by staff from Nolan, Davis & Associates (Sydney, N.S.). Subsequently, a number of the holes were pumped by airlifting, in August 1991, and the recovery of their waterlevels after pumping was recorded. New water samples were collected, and water temperature, pH, conductivity and Eh were measured. The results of the field measurements are included in Table 2-1.

The results of the chemical analyses for the 1989 and 1991 DH samples are listed in Table 2-2, which also includes available analyses for water samples collected from the DT discharge and the LS pond in 1989 and 1991. Unfortunately, comparisons of the analyses for the 1989 and 1991 samples from the same source are complicated

by several facts, namely:

- (1) no field measurements were made for any of the samples collected in early August 1991;
- (2) Eh values were not determined in 1989;
- (3) [Cl] was not determined for the 1989 and May 1991 samples;
- (4) [HCO₃] (or TIC) was not determined for the 1989 samples;
- (5) , the August 1991 samples were analyzed for concentrations >1 mg/L only;
- (6) ion-balance errors are high for almost **all** the analyses in Table 2-2 (ranging from +30.7 to +59.5%, and from -27.0% to -46.5%, except for the May 1991 samples, which showed errors ranging from -14.7% to +24.0%).

Major-ion and metal concentrations in the DT discharge and in the LS pond are shown together for comparison, in Figure 2-4 for the 1989 samples, and in Figure 2-5 for the 1991 samples. The generally lower concentrations in the LS pond in 1991 may reflect seasonal dilution or the progressive decrease shown by the monitor data in Figures 2-2 and 2-3, or both.

Analyses for samples collected from the drillholes in May and August of 1991 (before and after pumping) are compared for DH#3325, DH#3341, DH#3342, and DH#3344, in Figures 2-6, 2-7, 2-8, and 2-9, respectively. The results of the field measurements on waters from the drillholes in the LS area (from Tables 2-1 and 2-2) are illustrated in Figure 2-11. The pumping resulted in increased temperature, conductivity, pH, and major-ion and metal concentrations, and decreased Eh in DH#3325; minor changes in DH#3341 and DH#3343; increased temperature, conductivity and elemental concentrations, and decreased pH and Eh in DH#3342; and increased temperature and conductivity, decreased pH and Eh, and minor changes in elemental concentrations in DH#3344. For comparison, two analyses of samples collected from the Sandfill spring in April 1989 and July 1991 are shown in Figure 2-10. In the DH#3325 water **all** elemental concentrations (with the exception of [K]) are higher than in the spring water; in the samples from the other drillholes the concentrations are similar to, or lower than, those in the spring water.

The results suggest that the samples collected from DH#3325 and DH#3342 before pumping represented, at least in part, drilling fluid, and that the water samples

collected after pumping are more representative of the groundwater in the open-hole subsurface section beneath the bottom of the casings in these holes.

3. HYDROLOGY

A. Tunnel Discharge vs. LS Pit and DH Waterlevels

Since the pumps for the Lucky Strike mine were shut down on 14 February 1985, the waterlevel in the mine system has risen due to natural surface and subsurface inflow and water pumped (or syphoned) into the Lucky Strike and Rothermere mines between 27 February 1985 and 18 January 1986. The continued rise in the waterlevel of the LS pond since that time is interrupted annually in mid-summer by short-term reversals when evaporation exceeds inflow.

Figure 3-1 presents a Comparison of the changes in the DT discharge rate with the changes in waterlevel in the LS pond. There is some indication in this graph that the DT discharge rate has increased slowly since the tunnel plug was completed in June 1988. This point is perhaps illustrated more convincingly by the plot of DT discharge rate vs. LS pond waterlevel in Figure 3-2. Extrapolation of the slow rise in LS pond waterlevels to 900 ft (274 m) and 920 ft (280 m) suggests that the DT discharge rate could go as high as 175 to 191 USgpm (11 to 12 L/s) by the time the LS pond level stabilizes.

It should be pointed out here, however, that the DT discharge is not "driven" by the waterlevel in the LS pond, but rather by the generally higher (recharge driven) waterlevels in the ground overlying and surrounding the tunnel. The LS pit in fact collects not only surface runoff (and direct precipitation in the form of rain and snow), but also groundwater discharging from the surrounding area where waterlevels are 54.1 to 89.7 ft (16.5 to 27.3 m) higher, as shown Table 3-1 and Figure 3-3. It should also be noted that the DH waterlevels are higher the farther away the holes are from the LS pit.

A quick calculation also suggests that, if the active length of the Drainage Tunnel was effectively reduced (by the 1988 plug) from 3560 ft (1085 m) to 1484 ft (452.3 m), discharge should have decreased to about 42% of the pre-plug value, or from about 135 USgpm (8.5 L/s) to about 56 USgpm (3.5 L/s). In actual fact, the post-plugging discharge of about 108 USgpm (6.8 L/s) represented about 80% of the pre-plugging discharge. This proves that the 16 ft (4.88 m) long plug with a 32.5

sq.ft (3.01 m²) cross-section presents a smaller-than-expected obstacle to flow into the Drainage Tunnel.

B. Climatic Parameters

Monthly mean precipitation and temperature for the Buchans area, for the period from January 1985 to December 1990, are Listed in Table 3-2. As suggested by F.Baechler of NDA, lacking evaporation data for Buchans, one can attempt to adapt data from a different station where such information is available, e.g. Seal Cove, Nfld. Table 3-3A, lists monthly precipitation (P), temperature (T), evapo(transpi)ration (E) and runoff (R) data for Seal Cove (in part from NDA report Figure 6-2; it should be noted that the sum of annual evaporation and annual runoff exceeds annual precipitation in Table 3-3A). The last column lists estimated recharge, calculated as 0.5 times the difference P-E. This value may well be excessive, but it will serve to illustrate the next point. Table 3-3B Lists monthly precipitation and temperature data for Buchans; evaporation was calculated as E(Seal Cove) times T(Buchans) divided by T(Seal Cove). Zero evaporation is assumed for months with T < -1.0°C, although loss of water by sublimation from snow may be significant. Runoff data are not available (NA) and therefore values for (E+R) are also NA. Recharge was again calculated as 0.5 times (P-E), leading to estimated annual recharge of 145.8 mm (about 0.5 ft). The hydrological comparison in Table 3-3 is illustrated in Figure 3-4 for Seal Cove and Figure 3-5 for Buchans.

It should be noted that the mean annual P value for the 1985-1990 period (1124.6 mm) is about 5.5% higher than the long-term 1951-1980 mean annual P (1071.5 mm). During the recent period, mean monthly T values were higher than, or the same as those in the long-term period for the months from April to October, and lower for the months from November to March.

C. Model Simulations

1. Layout

The finite-difference groundwater-flow simulation program MODFLOW was used to run a much simplified model of the Lucky-Strike/Drainage-Tunnel area. Associated utility programs (MODOUT, MODGRAF, and TRANSLATE) were used to transform the output from MODFLOW into maps of waterlevel contours.

The initial model covered an area 1500 ft (457.2 m) wide on each side of the

Drainage Tunnel, from 1960 ft (597.4 m) SW of the Lucky Strike shaft to 480 ft (146.3 m) NE of the tunnel portal (see Figure 3-6). The area was divided into 15 columns and 30 rows of cells, 200x200 ft (61x61 m). The column containing the tunnel was further subdivided into three columns of 85, 30 and 85 ft (25.9, 9.15, and 25.9 m) width. After some preliminary runs, the model was expanded with *six* 400 ft wide rows on the NE side, and five 400 ft wide columns on the SE side (see Figure 3-6).

2. Model Parameters

Homogeneous, isotropic hydraulic conductivity (HC) was assigned to the general model area (see Table 3-5). Slightly lower HC was assigned to some cells near the Lookout to account for the hill, and to a number of cells on the SE side of the model, to account for the presence of the long bend in Simms Brook. A higher HC value was assigned to the cells in column 9, rows 9-26, containing the tunnel; the "active" portion of the tunnel (initially column 9, rows 9-26; later only rows 9-16) was treated as a drain with inflow conductance equivalent to 5.0 ft/s. The HC values used for the model are intermediate between those suggested by F.Baechler (NDA) for sand/gravel and bedrock in the area. They are higher than any of the HC values derived by NDA from the recovery tests carried out after pumping of the exploration drillholes.

A number of steady-state runs with different values for HC, drain conductance, recharge, and elevation of the aquifer bottom were made to try and match the existing conditions; measured waterlevels in DH#3325, DH#3341, DH#3342, and DH#3344 were used as a check during this "calibration" of the model.

3. Current Situation

Initially, the drain was made the full 3600 feet in length. With recharge set at 150 mm/year (0.15×10^{-7} ft/s), general HC at 0.14×10^{-5} ft/s and tunnel HC at 0.5×10^{-5} ft/s, this achieved the desired DT discharge of 108 USgpm, but waterlevels in DH#3325 and DH#3341 became much too low.

The drain was subsequently shortened to 1400 feet; to achieve the same discharge, recharge had to be increased to about 327 mm/year (0.34×10^{-7} ft/s), general HC to 0.4×10^{-5} ft/s, and tunnel HC to 0.65×10^{-5} ft/s. This also achieved a reasonable representation of the drillhole waterlevels. Figure 3-7 shows the model output for

the 1991 conditions, with the waterlevel in the LS pond at 832.5 *ft* a.s.l. (253.75 m a.s.l.). Relevant data are listed in Table 3-5.

The increased recharge represents approximately 50% of the estimated precipitation minus evaporation for the Buchans area, which seems unreasonably large. Further model runs should probably take the possible presence of fault zones with higher or lower HC into account.

4. Future Situation

The steady-state model was rerun several times for future situations with the waterlevel in the LS pond varying from 930 *ft* down to 900 *ft*. The latter was the highest pond level that allowed groundwater levels to remain below the known topographic elevation. Figure 3-8 shows the model output for the "future" situation with waterlevel in the LS pond at 900 *ft* a.s.l. (274.32 m a.s.l.). Relevant data are listed in Table 3-5. It should be noted that the tunnel discharge would increase by less than 7%.

A time-frame for the attainment of the "future" situation cannot be determined on the basis of the results of the steady-state model. It would need the running of transient simulations, for which values would be required for the storage coefficients of the overburden (0.3?) and the pit (1.0?), as well as an assumed hydraulic conductivity for the pit space.

An estimate of the time required for filling of the LS pit to the various possible final levels can be derived, however, from the recorded historic levels of the LS pond and an assumed simplified pit geometry. For the calculation results shown in Table 3-6 it was assumed that the pit shape represents an inverted cone, in which the pond at 832.5 *ft* a.s.l. occupied just over 200,000 sq.ft; that the pond area for the final pond level will be about 350,000 sq.ft; and that input will equal the mean input over the last three years. If these assumptions are reasonably representative, the 900-*ft* level would be reached in about 14 years, in early 2005. The calculation results are illustrated in Figure 3-9.

Refinement of the above predictions regarding the final waterlevel in the LS pond and the time required to reach it would require two types of new information:

- (a) detailed survey data to enable determination of the surface area of the LS

- pond for a series of waterlevels between the current and final levels: and
- (b) output from a transient groundwater model using a realistic value for annual groundwater recharge in the area, based on local observations.

4. GEOCHEMICAL CALCULATIONS

A. Introduction

All of the geochemical calculations carried out for this report were to some degree hampered by various shortcomings of the available data, outlined earlier in the section on water chemistry. Of particular concern were the lack of Eh and other field data for a number of the samples, and the generally poor ion-balances for most of the samples. Where necessary, estimated values for Eh and temperature have been used, and ion-balance error was forced to zero percent by the addition of S or Ca during geochemical simulations.

B. Saturation Indices

The geochemical simulation program PHREEQE was used to determine the saturation index ($SI = \text{Log}[IAP/KT]$) with respect to any minerals, for water samples from the LS pit, DT discharge, and the Oriental East and West pits (OEP and OWP, respectively). The latter two sources were included in view of the disposal options under consideration for the DT discharge.

The results of the calculations are listed in Table 4-1, in which a positive value for a particular mineral indicates saturation (or the potential for precipitation of the mineral in question), and a negative value indicates undersaturation (or the potential for dissolution of the mineral, if present). All four waters show some saturation with respect to secondary Al and Fe minerals, quartz, and several silicates.

C. Potential Sources of Dissolved Solids

The geochemical calculation program BALANCE was used for the determination of potential source(s) of the dissolved solids in (1) DT discharge: (2) LS pond water; (3) OWP water: and (4) OEP water. Potential sources included:

- (1) for DT discharge - pure H₂O +/- minerals
 - Sandfill spring water +/- minerals
 - DH#3325 water +/- pure H₂O +/- minerals

- LS pond water + pure H₂O +/- minerals
- (2) for LS pond water - pure H₂O +/- minerals
- (3) for OWP water
- pure H₂O +/- minerals
 - Sandfill spring water +/- minerals
- (4) for OEP water
- pure H₂O +/- minerals
 - Sandfill spring water +/- minerals
 - OWP water +/- minerals

A number of other mixture combinations were tried but found to give unrealistic (or impossible) results. The results for the above combinations, in terms of minerals dissolved (positive values) or precipitated (negative values) and, where appropriate, mixing percentages are listed in Table 4-2.

The DT discharge can be derived by dissolution of several minerals in pure water (recharge from rain or snow), followed by precipitation of some Fe-hydroxide, silica, and Al-sulfate. It could also be derived from a mixture of about 90% pure water with 10% water similar to that from DH#3325, or from 87% pure water with 13% LS-pond water, both with some dissolution and precipitation. All three possibilities would require solution of halite (or input of Cl-bearing water). The DT discharge cannot be produced from water similar to the Sandfill spring water, as this would require precipitation of pyrite and dissolution of Fe-hydroxide.

The three pit waters can all be derived by mineral dissolution in pure water, followed by precipitation of the same minerals as in the DT case. The OWP water cannot be derived from water similar to Sandfill spring water, because this would require precipitation of halite (both waters are undersaturated with respect to halite). The OEP water can be derived from either Sandfill spring water or OWP water (by dissolution and precipitation of some minerals), but a mixture of the two would require an impossible mixing ratio.

D. Disposal of DT water in Oriental Pits

The available area between the Drainage Tunnel outfall and Buchans River appears inadequate for any arrangement for the biological treatment of the DT discharge.

It has therefore been suggested that a possible option is pumping the DT discharge to one of the Oriental pits, where the water would eventually flow through the treatment system for discharge from the Oriental East Pit, currently being tested.

To test the possible geochemical consequences of this option, several aspects have to be evaluated, in addition to the hydraulic engineering challenge. These aspects include:

- (1) the mixing ratio of DT discharge with Oriental water;
- (2) the potential for dissolution or precipitation of minerals by the mixture;
- (3) the introduction of additional oxygen into the Oriental system; and
- (4) the percentage increase in the total output from the Oriental system.

The mixing ratio between the DT discharge and OWP water can only be estimated on the basis of the volume and assumed turnover rate of the OWP. Estimated values, and the resulting ratios of DT discharge to OWP turnover, ranging between 0.87:1 and 5.24:1, are given in Table 4-3A. A range of ratios from 1:1 to 5:1 has been used for the simulations.

The available monitor data indicate that the ratio of the DT discharge rate to the OEP discharge rate has, over the last four years, ranged between 0.41:1 and 2.20:1 (see Table 4-3B and Figure 4-1). For the simulations a range of ratios from 0.5:1 to 2.5:1 has been used.

The input for the simulation of pumping DT discharge into the Oriental East pit included analyses of the OEP and DT waters, and the range of mixing ratios (Table 4-4). The results of the simulation, given in Table 4-4 and illustrated by Figures 4-2 and 4-3, indicate that all mixtures would have concentrations of S, Zn, Al and Mn lower than those currently found in the OEP water, whereas both [Fe] and particularly [Cu] would be somewhat higher; pH would be lowered somewhat. The SI values with respect to all minerals (except quartz) would be lower in the mixtures than in the current OEP water. The decreased SI values would make

precipitation of any of these minerals from the mixtures slightly more difficult than it is for the current OEP water.

The input for the simulation of pumping DT discharge into the Oriental West pit included analyses of the OWP and DT waters, and the range of mixing ratios (Table 4-5). The results of the simulation, given in Table 4-5 and illustrated by Figures 4-4 and 4-5, indicate that all mixtures would have concentrations of S, Zn, Al, Mn, Fe and Cu lower than those currently found in the OWP water. The pH would be increased from 3.9 at least to above 4.5. However, the SI values with respect to most minerals would be increased, while the SI for Fe-hydroxide would initially decrease somewhat before increasing, and the SI value with respect to gypsum would decrease, relative to the current OWP water. The increased SI values suggest that precipitation of any of these minerals from the mixtures would be more Likely than it is for the current OWP water. The increased pH would make dissolution of sulfide minerals in the subsurface less likely. However, entrainment of oxygen in the DT discharge could counteract this perceived potential advantage. Further simulation tests, using more complete field data and more reliable laboratory analyses would be required to evaluate the effects of pH change and oxygen entrainment in more detail.

In either case, an increased rate of discharge from the Oriental system would have to be accommodated in the treatment area in the Meadows. This increased discharge rate would tend to increase flow velocities and reduce residence time, which may be detrimental to the stability and treatment efficiency of the system, respectively. The higher flow rates could also result in changes in the ice buildup in the Meadows during the winter.

5. CONCLUSIONS

- a. Water from the LS pit and/or the mine workings can contribute only a portion of the DT discharge.
- b. The original water samples collected from the drillholes represented drilling fluid in at least some of the holes; pumping has provided samples that are more representative of the local groundwater.
- c. Discharge from the Drainage Tunnel is not "driven" by the waterlevel in the Lucky Strike pond, but by the generally higher waterlevels in the surrounding ground.

- d. Results ~~of~~ preliminary simplified model simulations suggest that the waterlevel of the Lucky strike pond would not be able to rise much above 900 *ft* a.s.l.
- e. The results of the model simulations also suggest that the ultimate rise of the waterlevel of the Lucky Strike pond would increase the Drainage-Tunnel discharge rate by less than 10 percent.
- f. The ultimate waterlevel ~~of~~ the Lucky Strike pond could be reached in about 14 years.
- g. Pumping Drainage-Tunnel discharge into the Oriental West pit would result in lower elemental concentrations in the pit water, but higher saturation with respect to most minerals (except gypsum); increased pH would tend to limit dissolution of metal-sulfides in the subsurface, but entrained oxygen may have the opposite effect.
- h. Pumping Drainage-Tunnel discharge into the Oriental East pit would result in lower [S], [Zn], [Al] and [Mn] values and higher [Fe] and [Cu] values in the pit water, and lower saturation with respect to most minerals (except quartz).

6. RECOMMENDATIONS

Refinement ~~of~~ the predictions of future Drainage-Tunnel discharge rate, ultimate waterlevel in the Lucky Strike pond, and the time required to reach that level would require more detailed simulation tests, as well as information on:

- a. Annual recharge rate in the Lucky-Strike/Drainage-Tunnel area.
- b. Detailed geometry of the Lucky Strike pit.
- c. Periodic measurements of waterlevels at additional points in the area.

Refinement of the predictions regarding the potential effects ~~of~~ pumping Drainage-Tunnel discharge to either of the Oriental pits would require complete and reliable field data and laboratory analyses for representative samples from the various monitoring stations.

The potential effects of increased flow velocities and decreased residence time on the Oriental discharge treatment system in the Meadows should also be evaluated.

R.O. van Everdingen

28 November 1991

TABLE 1-1. BEDROCK ELEVATIONS - BUCHANS AND VICINITY

D.D.H.#	Collar	Coordinates		Bedrock	Overburden
	Elev. ft	North(Y) ft	East(X) ft	Elev. ft	Thickness ft
858	901	7000	2500	896	5
811	916	6480	2500	915	1
804	914	6250	2500	902	12
801	909	5990	2490	895	14
805	916	5090	2500	908	8
304	917	4650	2500	907	10
376	922	3790	2540	896	26
798	913	6250	2750	906	7
793	912	5970	2750	896	16
787	925	5260	2655	921	4
512	920	5000	2650	913	7
1460	922	4900	2600	913	9
322	923	4160	2800	905	18
308	921	4050	2900	896	25
1044	920	3500	2750	902	18
870	890	7000	3000	872	18
792	912	6190	3010	905	7
791	913	5970	2990	895	18
79	921	5490	3220	903	18
3344	923	5270	3000	893	30
1001	924	5180	3000	898	26
243	924	4810	3060	906	18
317	922	3940	3000	896	26
777	919	3650	3130	905	14
224	922	6070	3500	899	23
225	916	6240	3390	895	21
227	915	6320	3340	897	18
42	927	5190	3490	916	11
190	923	5170	3320	915	8
237	925	4870	3250	908	17
244	925	4930	3440	913	12
241	918	4500	3340	898	20
438	919	4150	3400	903	16
439	919	3820	3260	900	19
1029	918	3750	3500	903	15
1033	917	3500	3500	907	10
922	945	7000	4000	922	23
175	934	5470	4090	918	16
25	927	4980	3950	916	11
240	921	4350	3800	911	10
1021	916	4000	3750	910	6
1025	917	3750	3750	901	16
743	919	4240	3980	913	6
772	926	4160	4120	911	15
753	919	4000	4000	908	11
755	913	3760	4000	901	12
350	942	5990	4200	924	18
2875	934	5970	4600	913	21
2878	933	5860	4500	915	18

TABLE 1-1. BEDROCK ELEVATIONS - BUCHANS AND VICINITY

D.D .H.#	Collar	Coordinates		Bedrock	Overburden
	Elev. ft	North(Y) ft	East(X) ft	Elev. ft	Thickness ft
2877	931	5770	4600	900	31
2873	932	5760	4800	884	48
2871	927	5660	5000	881	46
77	933	5670	4490	913	20
.73	934	5570	4490	908	26
69	934	5470	4500	901	33
3341	932	5770	4500	906	26
56	936	5270	4500	914	22
40	929	4720	4520	913	16
234	924	4470	4500	914	10
298	925	4490	4660	914	11
289	915	4200	4800	893	22
309	917	4000	4500	900	17
318	929	3500	4600	912	17
918	961	7000	5000	954	7
2872	923	5760	5000	866	57
2874	922	5560	5200	863	59
65	923	5570	5100	854	69
436	915	4350	4970	896	19
437	912	4260	4970	887	25
1904	913	4000	5000	897	16
81	924	6350	5280	893	31
80	921	5970	5160	871	50
82	919	5790	5430	848	71
86	922	5520	5400	857	65
84	924	5460	5200	870	54
246	925	5190	5260	899	26
415	913	4430	5240	883	30
414	911	4350	5200	881	30
402	913	4310	5060	882	31
1908	910	4000	5175	878	32
1894	918	3500	5250	884	34
154	905	4180	5260	875	30
403	904	4130	5350	856	48
404	904	4040	5340	861	43
405	902	3980	5420	857	45
1881	913	3750	5500	875	38
1877	917	3500	5500	879	38
3325	914	4750	5500	846	68
218	900	3540	5830	881	19
937	910	7000	6000	886	24
2800	902	6500	6250	862	40
252	890	4900	6090	810	80
568	894	4380	6020	824	70
219	900	3620	5960	873	27
1026	897	7000	6750	863	34
892	889	6000	6700	812	77
560	881	5110	6710	810	71
963	895	7000	7000	871	24

TABLE 1-1. BEDROCK ELEVATIONS - BUCHANS AND VICINITY

D.D.H.#	Collar	Coordinates		Bedrock	Overburden
	Elev. ft	North(Y) ft	East(X) ft	Elev. ft	Thickness ft
553	881	51 10	71 10	813	68
3345	896	3370	7000	882	14
1824	888	3020	7010	878	10
1835	872	2520	7020	859	13
1448	890	6870	7200	849	41
1023	887	6750	7250	834	53
1083	879	6650	7400	819	60
247	871	5860	7330	792	79
550	875	5270	7440	805	70
1184	933	4170	4370	921	12
2572	864	7450	8000	833	31
1012	869	7000	7750	835	34
92	866	6720	7750	814	52
548	860	5610	7780	815	45
998	864	7300	8000	823	41
2500	860	7310	8150	813	47
788	855	6980	8020	808	47
884	822	6400	8010	797	25
885	852	7440	8290	815	37
771	845	7270	8290	805	40
790	790	7000	8280	785	5
573	802	6510	8210	790	12
532	811	6210	8250	788	23
534	816	6150	8180	792	24
546	839	5800	7970	799	40
T-7	844	6000	8720	844	0
T-9	912	4080	7210	912	0
T-10	922	3450	4720	922	0
MAXIMA	961	7450	8720	954	80
MINIMA	790	2520	2490	785	0

TABLE 2-1. DRILLHOLE DATA (units as listed)

LOCATION	Northing ft	Easting ft	Collar Elev., ^m	T.D. ■	DATE	DEPTH, ^m		Sample depth	TEMP. degree C	pH units	CONO. microS/cm	Eh mV
						Bedrock	Water					
ORIENTAL AREA												
D.D.H. I												
209	7005	11997	239.27		89-11-15	17.98	4.57	TOP	6.5	7.10	100	
			239.27		91-05-31		4.11	60 ■	7	8.70	60	15
253	8255	10659	254.20		91-08-23		0.00	FLOU	10.0	7.00	108	-30
292	7100	12630	235.31		89-11-15	37.49	5.49	TOP	7.1	8.20	21	
295	8500	10994	252.07		89-11-15	9.14	0.91	TOP	5.8	7.70	328	
300	8759	10514	259.38		89-11-15	6.10	1.52	TOP	6.1	8.20	205	
					91-08-23		2.25	TOP	8	6.46	120	-36
1062	7999	11199	245.06		89-11-15	20.73	1.27	TOP	7.0	9.50	85	
			245.06		91-05-31		3.43	60 ■	9	9.90	90	-62
			215.06		91-08-23		4.12	TOP	9	1.84	125	-85
1080	7992	11816	248.72		89-11-15	13.41	0.00	TOP	6.0	7.60	98	
			248.72		91-08-23		0.00	FLOU	9	7.31	122	-78
1084	7999	10501	252.68		89-11-15	12.19	2.74	TOP	7.1	8.70	53	
			252.68		91-08-23		2.41	TOP	10	7.18	125	-67
1579	10048	10137	260.91		89-11-15	42.67	17.07	TOP		7.90		
1606	10166	13411	245.67		89-11-15	21.08	12.80	TOP	5.2	9.20	128	
2353	7130	11999	236.83		89-11-15	25.30	9.45	TOP	5.1	6.80	53	
			236.83		91-08-23		9.1	TOP	9	7.25	7	-67
2367	6899	11509	212.93		89-11-15	8.23	8.23	TOP	5.2	7.10	14	
			212.93		91-05-31		7.17	60 ■	8.3	7.20	70	41
			242.93		91-08-09		9.13	TOP				
LUCKY STRIKE AREA												
3325	1750	5500	278.59	529.4	91-05-31	20.70	7.87	TOP	7.0	7.18	240	-24
			278.59		91-05-31			60 ■	7.0	8.06	320	-50
			278.59		91-08-01		7.49	TOP				
3344	5270	3000	281.33	365.8	91-05-31		2.71	TOP	1.0	7.84	75	-14
			281.33		91-05-31			60 ■	6.0	7.14	220	-44
			281.33		91-08-02		3.66	TOP				
			281.33		91-08-23		3.72	TOP	9	6.9	360	-228
3311	5765	1500	281.07	683.1	91-05-31	7.90	8.57	TOP	6.0	7.65	150	10
			281.07		91-05-31			60 ■	6.0	7.72	150	-3
			284.07		91-08-02		8.64	TOP				
3342	6249	4500	286.82	763.5	91-05-30	7.60	3.29	TOP	4.0	7.15	40	26
			286.82		91-05-30			60 ■	5.0	7.01	15	9
			286.82		91-08-02		4.47	TOP				
			286.82		91-08-23		4.57	TOP	12	6.94	125	-89
3313	7500	1500	289.86	1158.8	91-05-31	3.10	10.29	TOP	5.0	7.51	80	36
			289.86		91-05-31			60 ■	5.5	7.65	80	31

TABLE 2-2. CHEMICAL ANALYSES - DRILLHOLE SAMPLES (mg/L)

SAMPLE DATE	89-11-21	91-05-31	91-08-03	91-08-23	89-11-21	89-11-21	91-08-23	91-05-31	91-08-23	89-11-21	91-08-23
SAMPLE VOLUME	250	100	100	250	250	250	250	100	250	250	250
ASSAYERS CODE	1521	2777	3140	3184	1522	1523	3185	2778	3186	1524	3187
SAMPLING LOCATION	BUCHANS D.D.H. OH209	BUCHANS D.D.H. OH209(D)	BUCHANS D.D.H. NOA 7	BUCHANS D.D.H.	BUCHANS D.D.H.	BUCHANS D.D.H. OH292	BUCHANS D.D.H. OH300	BUCHANS D.D.H. OH1062(D)	BUCHANS D.D.H. 1062	BUCHANS D.D.H. 1080	BUCHANS D.D.H. 1080
Processing code	FA	FA	FA	FA	FA	FA	FA	FA	FA	FA	FA
XX FIELD XX											
Temp. (C)	6.5	7		10	7.1	6.1	8	9	9	6	9
pH	7.1	8.7		7	8.2	8.2	6.46	9.9	7.84	7.6	7.31
Cond. (umhos/cm)	100	60		108	21	205	120	90	125	98	122
Eh (mV)		15		-30			-36	-62	-85		-78
ELEMENTS At.weightDet.lim.											
Al	26.9815	1					1	0.03	2		2
B	10.8100	1						0.03			
Ba	137.3300	1	0.2	0.27		0.4	0.2	0.19		0.1	
Ca	40.0800	1	7.3	5.2	8	28	4.2	7	23	4.9	14
Cu	63.5460	1									
Fe	55.8470	1									
K	39.0983	1		3	7			2			
Mg	24.3050	1	0.4	0.7			0.1	0.2	1	0.5	1.1
Mn	54.9380	1	0.03	0.09			0.01	0.03			
Na	22.9898	1	9.1	14.3	51	9	2.5	3.1	7	26.1	29
P	30.9738	1		0.2		3			2	0.1	2
S	32.0600	1	4.6	2.75	9	9	2.8	3.6	15	4.24	6
Si	28.0855	1		0.3	4	6			8		6
Sr	87.6200	1	0.01	0.04				0.01		0.05	0.04
Zn	65.3800	1	0.3				0.1	0.06	4		
Cl	35.453				4	1.6			1.7		2.1
F	18.9984	0.1			2	0.3				2	
SO4	96.06		13.8	8.25	23	23	8.4	10.8	43	12.72	19
HCO3	61.01			73.2						97.6	18
NO3		0.2				1.8			1.8		1
TIC	12.001				6	47			26		48
CATION SUM, e.p.m.		0.80	1.02	2.80	1.79	0.33	0.50	1.77	1.48	2.18	1.47
ANION SUM, e.p.m.		0.29	1.37	1.19	4.39	0.17	0.22	3.07	1.86	4.49	0.37
RATIO		2.80	0.74	2.35	0.41	1.89	2.24	0.58	0.79	0.49	3.93
ERROR %		47.32%	-14.70%	40.35%	-42.12%	30.72%	38.28%	-26.97%	-11.61%	-34.62%	59.47%

SAMPLE DATE	91-08-23	91-08-23	91-05-31	91-08-09	91-05-31	91-08-01	91-05-30	91-08-02	91-05-30	91-08-02	91-08-23	91-08-02	
SAMPLE VOLUME	250	250	100	100	100	100	100	100	100	100	250	100	
ASSAYERS CODE	3188	3189	2776	3146	2771	3147	2772	3148	2770	3149	3190	3150	
SAMPLING LOCATION	BUCHANS D.O.H.	BUCHANS D.O.H.	BUCHANS D.O.H. DH2367(D)	BUCHANS D.O.H. ND 8	BUCHANS D.O.H. DH3325	BUCHANS D.O.H. S91-184 1	BUCHANS D.O.H. DH3341	BUCHANS D.O.H. ND 3	BUCHANS D.O.H. DH3342	BUCHANS D.O.H. ND 4	BUCHANS D.O.H. 3342	BUCHANS D.O.H. 3342	BUCHANS D.O.H. ND 6
Processing code	1084 FA	2353 FA	2367(D) FA	2367 FA	3325 FA	3325 FA	3341 FA	3341 FA	3342(D) FA	3342 FA	3342 FA	3344 FA	
=====													
XX F I E L D XX													
Temp. (C)	10	9	8.3		7		6		5		12		
pH	7.18	7.25	7.2		8.06		7.72		7.01		6.94		
Cond. (umhos/cm)	125	7	70		320		150		45		125		
Eh (mV)	-67	-67	41		-50		-3		9		-89		
=====													
ELEMENTS At.weight													
Al	26.9815		2	0.01			5	0.03		0.04		1	
B	10.8100						0.03						
Ba	137.3300			0.58			0.15		0.37		0.42	1	
Ca	40.0800	29	22	19.3	20	63.6	200	44.5	41	9.5	21	15	87
Cu	63.5460					0.06	1						
Fe	55.8470							0.2		0.2			
K	39.0983			14	3	2	12	1	1				
Mg	24.3050			1.6	1	7.3	28	2.8	3	0.7		6	
Mn	54.9380			0.06		0.52	1	0.07		0.03			
Na	22.9898	7	21	4	7	29.8	72	4.3	4	2.7	6	4	17
P	30.9738	1	2	0.2		0.2	3		2			2	1
S	32.0600	5	6	3.22	4	67.3	218	5.59	7	1.7	3	3	5
Si	28.0855	7	4	6.5	6	0.7	5	10.3	8	3.5	3	5	9
Sr	87.6200			0.06		0.37	1	0.07		0.03			
Zn	65.3800			0.01		0.11	2	0.05		0.01			
Cl	35.453	1.5	1.8		2		10		3		2	2	4
F	18.9984	0.3	0.7		0.4		0.7			0.1			0.1
SO4	96.06	14	19	9.66	10	201.9	556	16.77	4	5.1	5	5	14
HCO3	61.01			61		24.4		89.06		18.3			
NO3		1.5	0.4		0.4		0.2		1.5		0.2	0.5	
TIC	12.001	50	64		3		6		6		3	26	15
=====													
CATION SUM, e.p.m.	1.75	2.23	1.63	1.46	5.15	16.43	2.68	2.49	0.66	1.31	0.92	5.69	
ANION SUM, e.p.m.	4.45	5.73	1.20	0.53	4.60	12.39	1.81	0.66	0.41	0.41	2.29	1.64	
RATIO	0.39	0.39	1.36	2.75	1.12	1.33	1.48	3.78	1.63	3.18	0.40	3.47	
ERROR %	-43.49%	-43.89%	15.21%	46.66%	5.64%	14.03%	19.40%	58.15%	24.01%	52.15%	-42.59%	55.25%	
=====													

SAMPLE DATE	91-08-23	89-04-05	91-07-05	91-08-22	91-08-22	89-04-05	91-07-05
SAMPLE VOLUME	250	250	100	150	150	250	100
ASSAYERS CODE	3191	944	2914	3207	3208	943	2908
SAMPLING LOCATION	BUCHANS D.D.H.	BUCHANS Drainage Tunnel	BUCHANS Drainage Tunnel	BUCHANS Tunnel Weir	BUCHANS Tunnel Outflow	BUCHANS LUCKY LSP	BUCHANS STR LUCKY LSP
Processing code	3344 FA	DT FA	DT FA	DT FA	DT FA	LSP FA	LSP FA
** F I E L D **							
Temp. (C)	9	6	6.1	6.5	9.8	10	12.2
pH	6.9	6.6	5.61	5.8	6.53	6.4	6.84
Cond. (umhos/cm)	360		483	210	240		1291
Eh (mV)	-228		150	165	163		82
ELEMENTS At.weight							
Al	26.9815	59	2			69	3
B	10.8100			1			
Ba	137.3300	2	0.04			0.03	
Ca	40.0800	100	57.8	37	54	48	577
Cu	63.5460		0.6	0.1			1
Fe	55.8470	11	5.9				42.6
K	39.0983	1	5.1	2	1	1	
Mg	24.3050	3	6	5	7	7	57
Mn	54.9380		0.4				15
Na	22.9898	12	23	13	16	16	219
P	30.9738	2					
S	32.0600		49	31	45	40	520
Si	28.0855	14		8	6	6	
Sr	87.6200		0.1				3.3
Zn	65.3800		28	17	25.4	20.6	65
Cl	35.453	4.7	19	16			151
F	18.9984		9.9				
SO4	96.06	2	147	106			540
HCO3	61.01		95.16	4.88			445.3
NO3		0.4		10			
TIC	12.001	194					
CATION SUM, e.p.m.	6.18	12.17	3.62	4.77	4.32	54.85	7.56
ANION SUM, e.p.m.	16.07	13.90	2.74	2.81	2.50	22.80	5.30
RATIO	0.38	0.88	1.32	1.70	1.73	2.41	1.43
ERROR %	-44.47%	-6.63%	13.87%	25.84%	26.75%	41.27%	17.60%

TABLE 3-1. DRILLHOLE WATERLEVEL DATA (in METRES)

LOCATION	Northing ft	Easting ft	Collar Elev. m	T.D. m	Depth to Bedrock m	DATES:									
						89-11-15	91-05-31	91-08-02	91-08-12	91-08-19	91-08-23	91-09-02	91-09-09	91-09-23	91-10-07
ORIENTAL AREA						Waterlevel Elevations (m a.s.l.):					Waterlevel Elevations (m a.s.l.):				
O.E. Pit						231.40	231.40	231.40	231.40	231.40	231.40	231.40	231.40	231.40	231.40
Sandf. Spr						231.65	231.65	231.65	231.65	231.65	231.65	231.65	231.65	231.65	231.65
O.D.H. #															
209	7005	11997	239.27		17.98	234.70	234.93	234.87	234.87	234.86	234.88	234.90	235.00	234.90	234.92
253	8255	10659	254.20			-	-	254.00	254.20	254.20	254.20	254.20	254.20	254.20	254.20
292	7400	12630	235.31		37.49	229.82	-	-	-	-	-	-	-	-	-
295	8500	10994	252.07		9.14	251.16	-	251.00	251.07	250.81	251.35	251.42	251.47	251.45	251.51
300	8759	10544	259.38		6.10	257.86	-	257.58	256.61	256.41	257.13	256.73	256.83	256.88	257.19
1062	7999	11499	245.06		20.73	240.79	241.63	240.69	240.82	240.63	240.94	240.71	240.83	240.84	241.21
1080	7992	11816	248.72		13.41	248.72	-	248.72	248.72	248.72	248.72	248.72	248.72	248.72	248.72
1084	7999	10501	252.68		12.19	249.94	-	250.07	250.05	249.96	250.27	250.11	250.14	250.10	250.19
1579	10048	10437	260.91		42.67	243.84	-	-	-	-	-	-	-	-	-
1606	10166	13441	245.67		24.08	232.87	-	-	-	-	-	-	-	-	-
2353	7130	11999	236.83		25.30	227.38	-	227.89	227.71	227.56	227.73	227.47	227.57	227.48	227.62
2367	6899	11509	242.93		8.23	234.70	235.76	234.45	233.89	233.80	233.80	233.75	233.81	233.79	233.88
LUCKY STRIKE AREA															
L.S. Pit							254.60	254.54	254.51	254.48	254.54	254.54	254.54	254.60	254.78
O.D.H. #															
3325	4750	5500	279.20	529.4	20.73	-	271.33	271.71	270.99	270.88	271.10	270.30	271.33	271.37	271.67
3341	5765	4500	284.07	683.4	7.92	-	275.50	275.43	275.58	275.38	275.59	275.64	275.92	276.12	276.75
3342	6249	4500	286.82	763.5	7.60	-	283.53	282.35	281.85	281.97	282.25	282.27	282.44	282.52	282.91
3343	7500	4500	289.86	1158.8	3.10	-	279.57	278.63	278.66	278.48	278.61	278.57	278.76	278.46	279.36
3344	5270	3000	281.33	365.8	9.14	-	278.59	277.67	277.63	277.42	277.61	277.62	277.94	278.04	278.53

TABLE 3-2. MONTHLY MEAN PRECIPITATION AND TEMPERATURE, BUCHANS, 1985-1990

STATION : BUCHANS, Newfoundland
 Location : 48°50'N 56°52'W
 Elevation: 280 m

1985-1990	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Mean RAIN	28.3	18.9	25.0	63.2	53.7	95.8	68.8	96.9	85.9	99.2	79.4	35.4	750.5
Mean SNOW	90.8	91.8	48.2	13.8	5.5	0.3				2.8	43.0	77.8	374.2
Mean TOTAL	119.1	110.8	73.2	77.0	59.2	96.1	68.8	96.9	85.9	102.1	122.4	113.3	1124.6
DAILY MAX.	-4.6	-5.4	-2.2	5.0	12.0	17.7	21.4	20.9	14.9	8.9	2.3	-2.7	7.3
DAILY MIN.	-12.2	-12.5	-10.0	-1.9	3.1	7.6	11.4	12.1	7.3	2.6	-2.8	-8.5	-0.3
DAILY MEAN	-8.4	-9.0	-6.1	1.5	7.5	12.6	16.4	16.5	11.1	5.7	-0.2	-5.6	3.5

TABLE 3-3. WATER BALANCES

A - SEAL COVE, NEWFOUNDLAND (from fig.6-2, Baechler report)

MONTH	PRECIP. mm	TEMP. C	EVAP. mm	RUNOFF mm	E+R mm	RECHARGE mm
J	138	-2.9	0	151	151	0
F	125	-3.1	0	102	102	0
M	122	-0.8	0	110	110	0
A	96	2.9	18	128	146	39
M	77	6.9	51	85	136	13
J	73	12.1	91	57	148	0
J	67	16.6	110	42	152	0
A	100	16.5	112	53	165	0
S	94	12.7	71	62	133	11.5
O	129	8.1	42	98	140	43.5
N	122	4.4	25	119	144	48.5
D	137	-0.5	0	137	137	68.5
TOTALS	1280	6.1	520	1144	1664	224

B - BUCHANS, NEWFOUNDLAND

MONTH	PRECIP. mm	TEMP. C	EVAP. mm	RUNOFF mm	E+R mm	RECHARGE mm
J	119.1	-8.4	0.0	NA	NA	0
F	110.8	-9.0	0.0	NA	NA	0
M	73.2	-6.1	0.0	NA	NA	0
A	77.0	1.5	9.3	NA	NA	33.8
M	59.2	7.5	55.4	NA	NA	1.9
J	96.1	12.6	94.8	NA	NA	0.7
J	68.8	16.4	108.7	NA	NA	0
A	96.9	16.5	112.0	NA	NA	0
S	85.9	11.1	62.1	NA	NA	11.9
O	02.1	5.7	29.6	NA	NA	36.3
N	22.4	-0.2	0.0	NA	NA	61.2
D	13.3	-5.6	0.0	NA	NA	0
TOTALS	1 24.8	3.5	471.8	653.0	NA	145.8

Table 3-5. MODEL PARAMETERS AND RESULTS

A. MODEL INPUT		VALUES
PARAMETERS		

CELL SIZE (ft):	30x200; 85x200; 200x200; 200x400; 400x200; 400x400	(see Fig.3-6)
HYDRAULIC CONDUCTIVITIES:		
	GENERAL	4.0E-06 ft/sec
	TUNNEL	6.5E-06 ft/sec
	CREEK	3.3E-06 ft/sec
DRAIN (TUNNEL):		
	LEVEL AT SHAFT	800 ft a.s.l.
	LEVEL AT PORTAL	786 ft a.s.l.
	CONDUCTANCE	5.0E+00 ft/sec
RECHARGE		
		3.4E-08 Ft/sec
BASE OF AQUIFER		
		250 ft below ground
	UPPER RIGHT CORNER	455 Ft a.s.l.
	UPPER LEFT CORNER	635 ft a.s.l.
	LOWER CORNERS	670 ft a.s.l.
FIXED HEADS:		
	SANDY LAKE	853 ft a.s.l.
	BUCHANS R 825 -	702 ft a.s.l.
	SIMMS BRK 905 -	702 Ft a.s.l.
	TAILINGS POND #1	923 Ft a.s.l.
	LUCKY STRIKE POND	832.5 ft a.s.l.
	raised for FUTURE to	900 ft a.s.l.

8. MODEL RESULTS

WATER INPUT	1991		FUTURE	
	cu.ft/d	USgpm	cu.ft/d	USgpm
RECHARGE	84656	439.7	83833	435.5
CONSTANT HEAD AREA (Tailings Pond #1)	2624	13.6	888	4.6
TOTALS	87280	453.4	84721	440.1

WATER OUTPUT	1991		FUTURE	
	cu.ft/d	USgpm	cu.ft/d	USgpm
CONSTANT-HEAD AREAS (Buchans R. and Simms Brk.)	66982	347.9	63131	327.9
DRAINAGE TUNNEL	20303	105.5	21595	112.2
TOTALS	87285	453.4	84726	440.1

Table 3-6. PROJECTED RISE IN LUCKY STRIKE PIT WATERLEVEL

AREAS	sq.ft	m ²
Pit	400,000	121,920
Pond	150,000	45,720

HISTORIC WATERLEVELS

DATE	ft a.s.l.	m a.s.l.
85-10-15	734.0	223.72
85-11-30	738.0	224.94
85-12-31	804.0	245.06
86-01-18	824.0	251.16
86-12-31	813.0	247.80
87-12-31	811.0	247.19
88-12-31	818.8	249.57
89-12-31	825.0	251.46
90-12-31	832.5	253.75

WATERLEVEL PROJECTION

WATERLEVEL ft a.s.l.	AREA sq.ft	ADDED cu.ft	ELAPSED TIME YEARS	ELAPSED TIME DAYS	CUMULATIVE YEARS from 91-01-01	DATE
734	100		0.00000	0.00		
740	13000	39300	0.02905	10.60		
750	34500	237500	0.17556	64.08		
760	56000	452500	0.33449	122.09		
770	77500	667500	0.49342	180.10		
780	99000	882500	0.65235	238.11		
790	20500	1097500	0.81128	296.12		
800	42000	1312500	0.97021	354.13		
810	63500	1527500	1.12914	412.14		
811	65650	164575	0.12166	44.40		
818	80700	1212225	0.89609	327.07		
825	95750	1317575	0.97396	355.50		
832.5	11875	1528594	1.12995	412.43	0.0	Jan-91
840	228000	1649531	1.21935	445.06	1.2	Mar-92
850	249500	2387500	1.76486	644.17	3.0	Dec-93
860	271000	2602500	1.92379	702.18	4.9	NOV-95
870	292500	2817500	2.08272	760.19	7.0	Dec-97
880	314000	3032500	2.24165	818.20	9.2	Mar-2000
890	335500	3247500	2.40058	876.21	1.6	Aug-2002
900	357000	3462500	2.55951	934.22	4.2	Mar-2005
910	378500	3677500	2.71844	992.23	6.9	Nov-2007
920	400000	3892500	2.87737	1050.24	19.8	Oct-2010

TOTAL ADDED from 832.5' to 900':		19,199,531 cu.ft	14.2 years	5180.2 days		
=====						

TABLE 4-1. Saturation Indices from PHREEQE Simulations.

Run #	1	2	3	4
Sample	Drainage Tunnel	Lucky Strike Pit	Oriental East Pit	Oriental West Pit
Temperature, C	6.1	12.2	13	14.8
pH, units	5.61	6.84	6.47	3.9
PE, units	6.8154	5.8462	5.0493	8.8637
Al(OH) ₃	-0.4274	0.7146	1.2303	-3.7304
Al(OH)SO ₄	0.2966	-1.1941	0.3600	0.0571
Al ₄ SO ₄ (OH) ₁₀	8.2500	8.8278	1.7553	-3.8173
Alunite	8.2540	7.9557	0.2594	(no K)
Diaspore	3.2027	4.3042	4.8149	-0.1576
Fe(OH) ₃	-0.6941	(no Fe)	0.0154	-2.3240
Fe(OH) _{2.7}	4.5388	(no Fe)	5.2421	3.1092
Goethite	2.9776	(no Fe)	3.9605	1.6901
Gypsum	-1.3611	-0.7287	0.0465	-0.8105
Quartz	0.4437	0.0391	0.3305	0.1725
CuFerrite	8.3653	(no Fe)	11.0292	3.8440
ZnSiO ₃	-0.2718	1.9821	1.6476	-3.1680
Kaolinite	7.3591	8.7273	10.3280	0.0597
Albite	-1.4565	-0.2342	1.7216	-7.5970
Muscovite	7.6070	11.8261	12.9874	(no K)
K Felspar	-0.2789	1.7743	1.9190	(no K)
Montmorillonit	2.4554	4.2409	6.4746	-6.5867
Chlorite	22.2302	(no Fe)	32.1663	0.7898

=====
 Positive value indicates saturation with respect to the mineral.
 =====

DATES:

LOCATION 91-09-02 91-09-09 91-09-23 91-10-07

Water level Elevations (m a.s.l.):				
O.E. Pit	231.40	231.40	231.40	231.40
Sandf. Spr	231.65	231.65	231.65	231.65
O.O.H. #				
209	234.90	235.00	234.90	234.92
253	254.M	254.20	254.20	254.20
292	-	-	-	-
295	251.42	251.47	251.45	251.51
300	256.73	256.83	256.88	257.19
1062	240.71	240.83	240.84	241.21
1080	248.72	248.72	248.72	248.72
1084	250.11	250.14	250.10	250.19
1579	-	-	-	-
1606	-	-	-	-
2353	227.47	227.57	227.48	227.62
2367	233.75	233.81	233.79	233.88

L.S. Pit	254.54	254.54	254.60	254.78
D.O.H. #				
3325	270.30	271.33	271.37	271.67
3341	275.64	275.92	276.12	276.75
3342	282.27	282.44	282.52	282.91
3343	278.57	278.76	278.46	279.34
3344	277.62	277.94	278.04	278.53

IGNORE THIS TABLE.

DATA REPEATS TABLE 3-1, PAGE 2-106.

TABLE 4-2. Results of BALANCE Calculations.

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RUN #	1	2	3	4	5	6	7	8	9	10
Sample	Drainage Tunnel	Drainage Tunnel	Drainage Tunnel	Drainage Tunnel	Lucky Strike	O.West Pit	O.West Pit	O.East Pit	O.East Pit	O.East Pit
from	Pure H2O	SFS	DH#3325+ Pure H2O	LSP+ pure H2O	Pure H2O	Pure H2O	SFS	Pure H2O	SFS	OWP
INIT #1			90.25%	86.69%						
INIT #2			9.76%	13.31%						
Calcite	0.7776	0.3534	0.3615	0.7295	0.3605	0.6646	0.2404	1.6966	1.2727	1.0320
Albite	0.1014	0.0362	-0.1693	0.0714	0.2254	0.1317	0.0665	0.7806	0.7167	0.6489
Chlorite	0.0675	0.0344	0.0306	0.0484	0.1434	0.1509	0.1177	0.5475	0.5145	0.3967
Epidote	0.0728	0.0728	0.0373	-0.0726	1.0922	0.7281	0.7281	4.0045	4.0045	3.2764
Sericite	0.0639	-0.4156	0.0265	0.0043	0.4476	0.0000	-0.4796	0.0639	-0.4219	0.0639
Barite	0.0002	0.0001	0.0002	0.0001	0.0000	0.0001	0.0001	0.0001	0.0001	0.0000
Halite	0.4513	0.3949	0.4238	0.4295	0.1636	0.0423	-0.0141	3.4694	3.4130	3.4271
CO2 gas	-0.6976	-0.3734	-0.3304	-0.6682	-0.2206	-0.6446	-0.3204	-1.2716	-0.9474	-0.5438
Pyrite	0.6121	-0.1430	0.0230	0.1908	3.1646	2.2282	1.4731	9.7352	9.1128	7.4028
Chalcopyr	0.0016	0.0016	0.0000	0.0014	0.0011	0.0105	0.0105	0.0006	0.0006	-0.0050 Malachite
Galena	0.0000	0.0000	0.0000	0.0000	0.0000	0.0048	0.0048	0.0000	0.0000	-0.0048 Cerussite
Sfalerite	0.2600	0.2600	0.2570	0.2335	0.1988	0.5353	0.5353	0.3518	0.0704	-0.0367 Hydrozink
O2 gas	2.8564	0.1945	0.8142	1.2257	12.2477	9.6801	7.0262	37.2547	34.5278	27.5904
Fe-hydrox	-0.7536	0.0587	-0.0904	-0.1718	-4.3691	-3.0455	-2.2332	-14.0907	-13.4110	-10.9511
Silica	-0.6722	0.8411	0.4742	0.0867	-5.6997	-2.8937	-1.3804	-16.1850	-14.6565	-13.2913
Al-sulfat	-0.5207	0.8960			-3.9103	-1.7427	-0.3260	-9.9668	-8.5342	-8.2242
RATING	OK	NG	??	??	OK	OK	OK	OK	OK	OKOK

Positive values indicate dissolution, negative values precipitation.

TABLE 4-3. MIXING RATIOS FOR GECHEMICAL SIMULATION

A. Drainage Tunnel vs. Oriental West Pit RATIOS

OWP turnover, m ³ /year			DT discharge rates		
			MIN	MAX	
			6.5	8.5	11.0 L/s
			204,984	268,056	346,896 m ³ /year
MIN	66,245	RATIOS:	3.09	4.05	5.24
MAX	235,000	RATIOS:	0.87	1.14	1.48
Range of ratios to use:			MIN	1.0	
			MAX	5.0	

8. Drainage Tunnel vs. Oriental East Pit RATIOS

OEP discharge, L/s			DT discharge rates		
			MIN	MAX	
			6.5	8.5	11.0 L/s
MIN	5.0	RATIOS:	1.30	1.70	2.20
MAX	16.0	RATIOS:	0.41	0.53	0.69
Range of ratios to use:			MIN	0.5	
			MAX	2.5	

TABLE 4-4. Mixtures of Drainage Tunnel Water and Oriental East Pit Water.

	EAST PIT WATER	0.5 DT in 1 EP	1.0 DT in 1 EP	1.5 DT in 1 EP	2.0 DT in 1 EP	2.5 DT in 1 EP	DRAINAGE TUNNEL
S added	2.811						0.4042
Fraction	0.000	0.333	0.500	0.600	0.667	0.714	1.000
Temp.	13.00	10.70	9.55	8.86	8.40	8.07	6.10
pH	6.47	6.39	6.32	6.26	6.21	6.16	5.61
Eh	5.05	5.20	5.32	5.40	5.47	5.53	6.82
S	9.45738	8.68665	6.88972	5.81371	5.09279	4.58706	1.10370
Ca	9.72155	6.79175	5.32245	4.44263	3.85315	3.43964	0.92335
Mg	1.64798	1.16771	0.92684	0.78262	0.68598	0.61820	0.20570
Zn	0.35242	0.32168	0.30627	0.29704	0.29085	0.28651	0.26011
Al	0.37123	0.27230	0.22269	0.19298	0.17307	0.15911	0.07414
Mn	0.20056	0.13377	0.10028	0.08022	0.06678	0.05736	
Fe	0.00161	0.00167	0.00170	0.00172	0.00173	0.00174	0.00179
cu	0.00055	0.00089	0.00106	0.00117	0.00123	0.00128	0.00157
Na	4.26977	3.03628	2.41768	2.04726	1.79908	1.62499	0.56559
Cl	3.47509	2.46820	1.96324	1.66087	1.45829	1.31617	0.45140
C	0.43281	0.31533	0.25641	0.22113	0.19749	0.18091	0.08000
Si	0.13339	0.13333	0.13330	0.13328	0.13327	0.13326	0.13320
K	0.05123	0.05121	0.05120	0.05119	0.05118	0.05118	0.05116
Saturation Indices	LOG [IAP/KT]						
Al(OH) ₃	1.2303	0.9119	0.7202	0.5875	0.4873	0.4095	-0.4274
Alunite	10.2594	9.8928	9.6736	9.5249	9.4145	9.3297	8.254
Diaspore	4.8149	4.5114	4.3272	4.1992	4.102	4.0263	3.2027
Fe(OH) ₃	0.0154	-0.0585	-0.151	-0.2382	-0.3166	-0.3843	-0.6941
Fe(OH) _{2.7}	5.2421	5.1502	5.051	4.9613	4.8825	4.8155	4.5388
Goethite	3.9605	3.7971	3.6591	3.5445	3.4476	3.367	2.9776
Gypsum	0.0465	-0.1511	-0.2899	-0.395	-0.479	-0.5466	-1.3611
Quartz	0.3305	0.3677	0.3865	0.3978	0.4055	0.4108	0.4437
Cuferrite	11.0292	10.965	10.794	10.6202	10.459	10.3169	8.3653
ZnSiO ₃	1.6476	1.3941	1.2098	1.066	0.9481	0.8512	-0.2718
Kaolinite	10.328	9.8049	9.479	9.2485	9.0715	8.9322	7.3591
Albite	1.7216	1.2425	0.9158	0.6719	0.4781	0.3224	-1.4565
Muscovite	12.9874	12.0965	11.5243	11.1109	10.7888	10.5328	7.607
K feldspar	1.919	1.6213	1.4105	1.2491	1.1183	1.0117	-0.2789
Montmoril	6.4746	5.7758	5.3369	5.0246	4.7838	4.5939	2.4554
Chlorite	32.1663	31.179	30.3454	29.6505	29.0595	28.5621	22.2302

Temp. in degree C; pH and PE in units; concentrations in millimole/L.

TABLE 4-5. Mixtures of Drainage Tunnel Water and Oriental West Pit Water.

	WEST PIT WATER	1 DT in 1 WP	2 OT in 1 WP	3 DT in 1 WP	4 DT in 1 WP	5 DT in 1 WP	DRAINAGE TUNNEL
S added	0.3797						0.4060

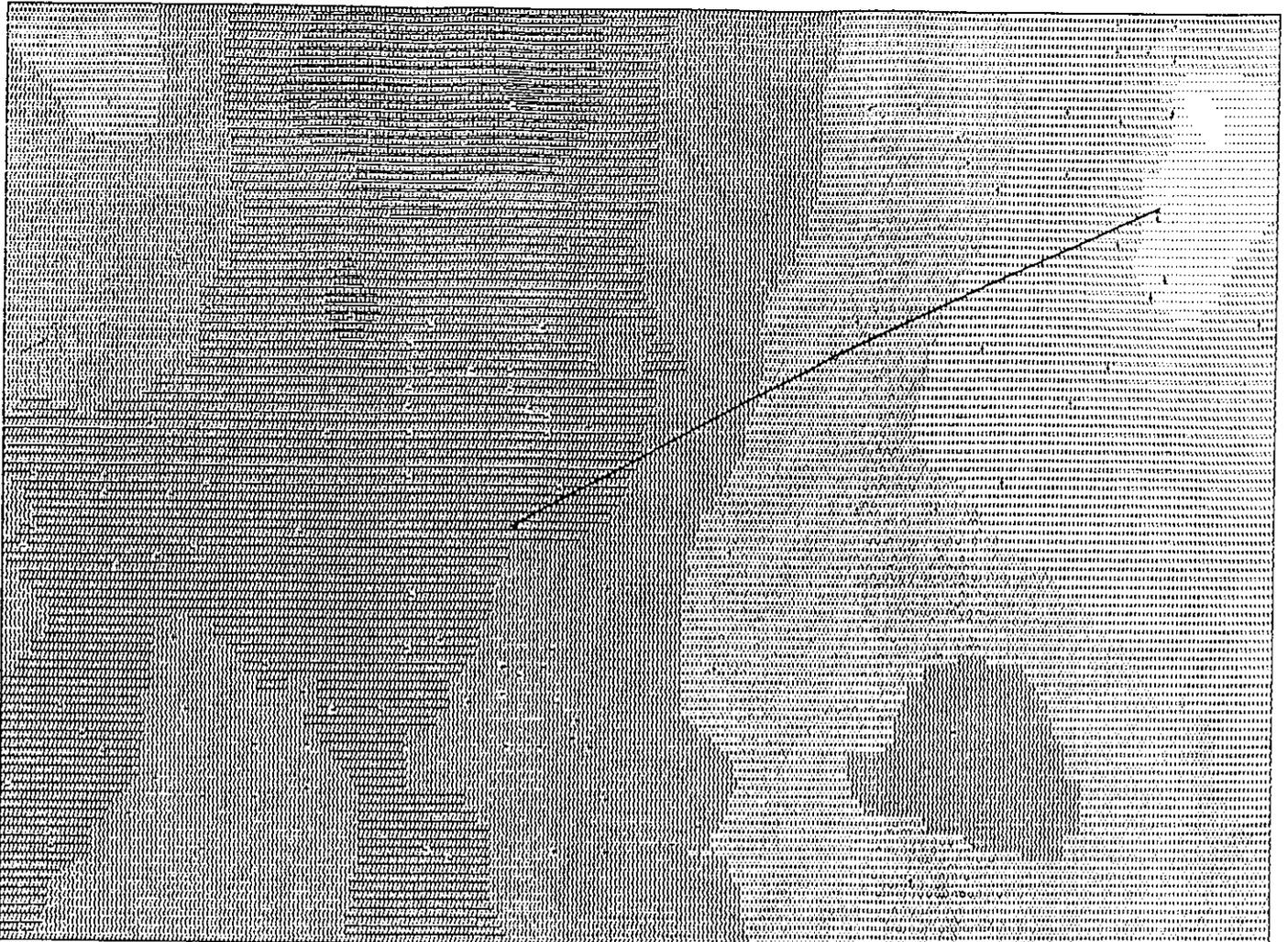
DT FRACTION	0.000	0.500	0.667	0.750	0.800	0.830	1.000

Temp	14.80	10.45	9.00	8.28	7.84	7.58	6.10
Eh	8.86	6.50	6.57	6.62	6.65	6.67	6.82
pH	3.90	4.68	4.99	5.12	5.19	5.24	5.61
S	3.29112	2.59027	2.22935	2.04998	1.94192	1.87709	1.10370
Ca	2.12176	1.52256	1.32242	1.22297	1.16304	1.12708	0.92335
Mg	0.45267	0.32919	0.28794	0.26744	0.25510	0.24769	0.20570
Zn	0.53567	0.39789	0.35187	0.32900	0.31523	0.30696	0.26011
Al	0.22480	0.14831	0.12354	0.11123	0.10381	0.09936	0.07414
Mn	0.03642	0.01821	0.01213	0.00911	0.00728	0.00619	
Fe	0.03583	0.01881	0.01313	0.01030	0.00860	0.00758	0.00179
cu	0.01055	0.00606	0.00456	0.00382	0.00337	0.00310	0.00157
Na	0.17407	0.36983	0.43521	0.46771	0.48729	0.49903	0.56559
Cl	0.04233	0.24686	0.31518	0.34913	0.36959	0.38186	0.45140
si	0.09993	0.11656	0.12212	0.12488	0.12655	0.12755	0.13320
C	0.02034	0.05017	0.06014	0.06509	0.06807	0.06986	0.08000
K		0.02558	0.03412	0.03837	0.04093	0.04246	0.05116

Saturation Indices	LOG [IAP/KT]						
Al(OH) ₃	-3.7304	-1.8413	-1.1322	-0.9190	-0.8134	-0.7549	-0.4274
Alunite		5.8334	7.3783	7.8143	8.0079	8.1025	8.2540
Diaspore	-0.1576	1.7597	2.4784	2.6964	2.8050	2.8652	3.2027
Fe(OH) ₃	-2.3240	-2.7199	-1.8685	-1.5690	-1.4046	-1.3078	-0.6941
Fe(OH) _{2.7}	3.1092	2.7120	3.5006	3.7768	3.9268	4.0144	4.5388
Goethite	1.6901	1.1256	1.9196	2.1903	2.3372	1.0484	2.9776
Gypsum	-0.8105	-1.0209	-1.1135	-1.1659	-1.2000	-1.2215	-1.3611
Quartz	0.1725	0.3114	0.3562	0.3783	0.3914	0.3993	0.4437
CuFerrite	3.8440	6.3280	7.2882	7.5856	7.7369	7.8227	8.3653
ZnSiO ₃	-3.1680	-1.8483	-1.3019	-1.1014	-0.9842	-0.9111	-0.2718
Kaolinite	0.0597	4.1901	5.7233	6.2064	6.4518	6.5890	7.3591
Albite	-7.5970	-4.2858	-3.0870	-2.6693	-2.4430	-2.3111	-1.4565
Muscovite		1.6865	4.4065	5.2946	5.7572	6.0204	7.6070
K feldspar		-3.2868	-2.0130	-1.5654	-1.3226	-1.1813	-0.2789
Montmoril	-6.5867	-1.5198	0.3661	0.9658	1.2731	1.4461	2.4554
Chlorite	0.7898	12.4528	16.9635	18.4536	19.2331	19.6771	22.2302

=====
Temp. in degree C; pH and PE in units; concentration in millimole/L.

2500,7500



8800,3000

Figure 1-1. GROUND ELEVATIONS. ft a.s.l.

(LINE indicates DRAINAGE IHNEL)

- ▨ (960.00
- ▧ (940.00
- ▦ (920.00
- ▥ (900.00
- ▤ (880.00
- ▣ (860.00
- ▢ (840.00
- (820.00
- (800.00

2500,7500



800,3000

Figure 1-2. BEDROCK ELEVATION. ft a.s.l
(LINE indicates DRAINAGE TUNNEL)

- < 950.00
- ▨ < 930.00
- ▩ < 910.00
- ▧ < 890.00
- ▦ < 870.00
- ▥ < 850.00
- ▤ < 830.00
- ▣ < 810.00
- ▢ < 790.00

2500,7500



8800,3000

Figure 1-3. OVERBURDEN THICKNESS, ft
 (LINE indicates DRAINAGE TUNNEL)

- < 80.00
- ▨ < 70.00
- ▩ < 60.00
- ▧ < 50.00
- ▦ < 40.00
- ▥ < 30.00
- ▤ < 20.00
- ▣ < 10.00
- < 5.00

Figure 2-1
DRAINAGE TUNNEL / LUCKY STRIKE PIT: pH

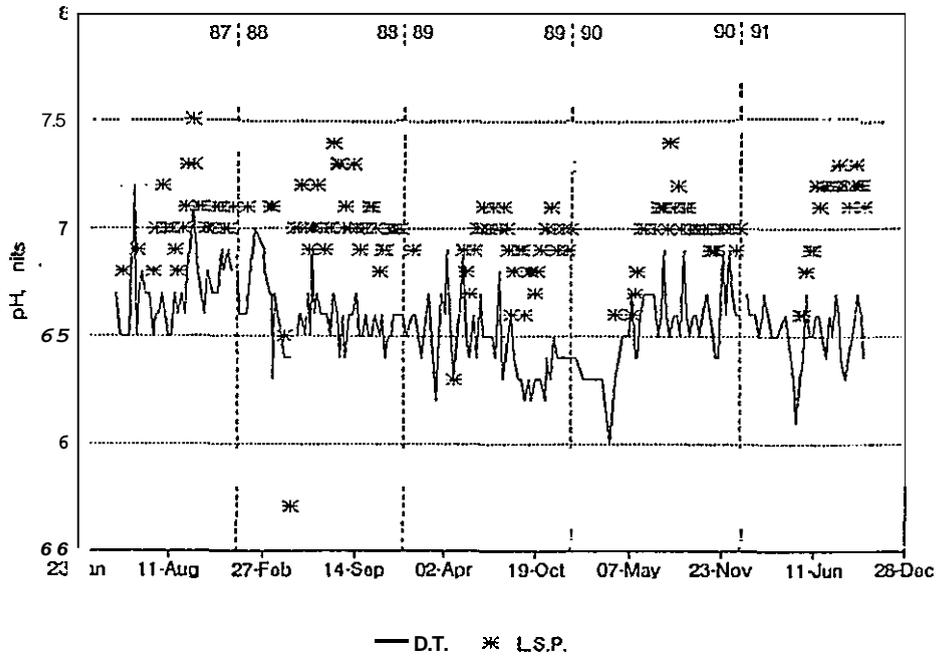


Figure 2-2
DRAINAGE TUNNEL / LUCKY STRIKE PIT: Cu

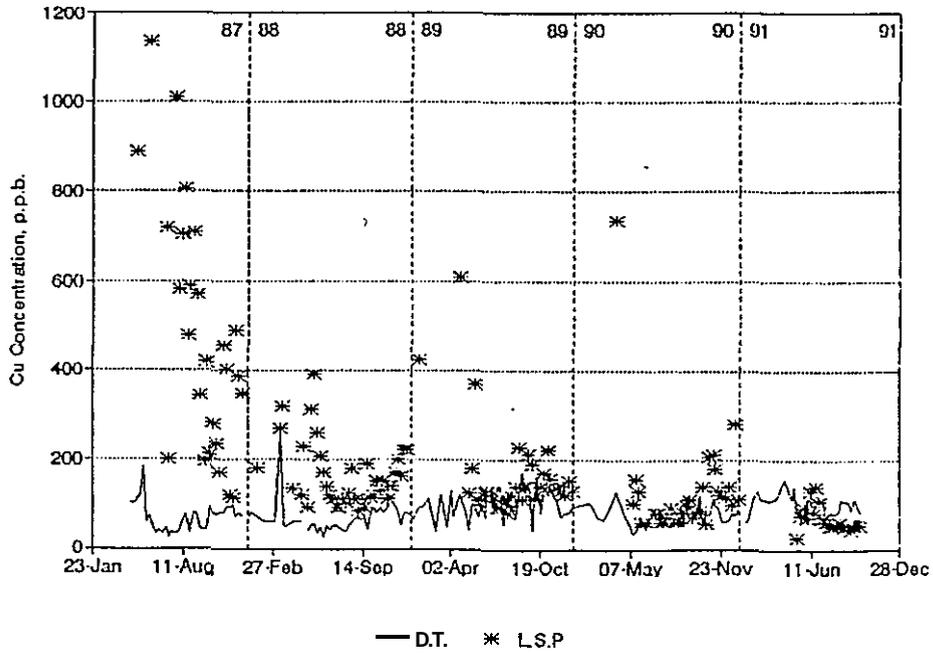


Figure 2-3
DRAINAGE TUNNEL / LUCKY STRIKE PIT: Zn

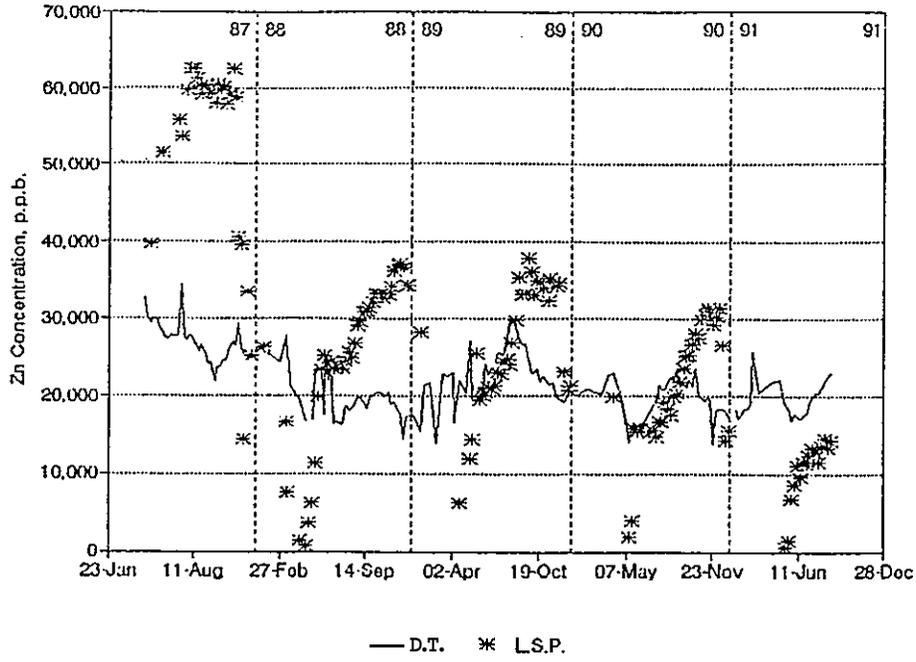


Figure 2-4
DT AND LSP WATERS CHEMISTRY 1989

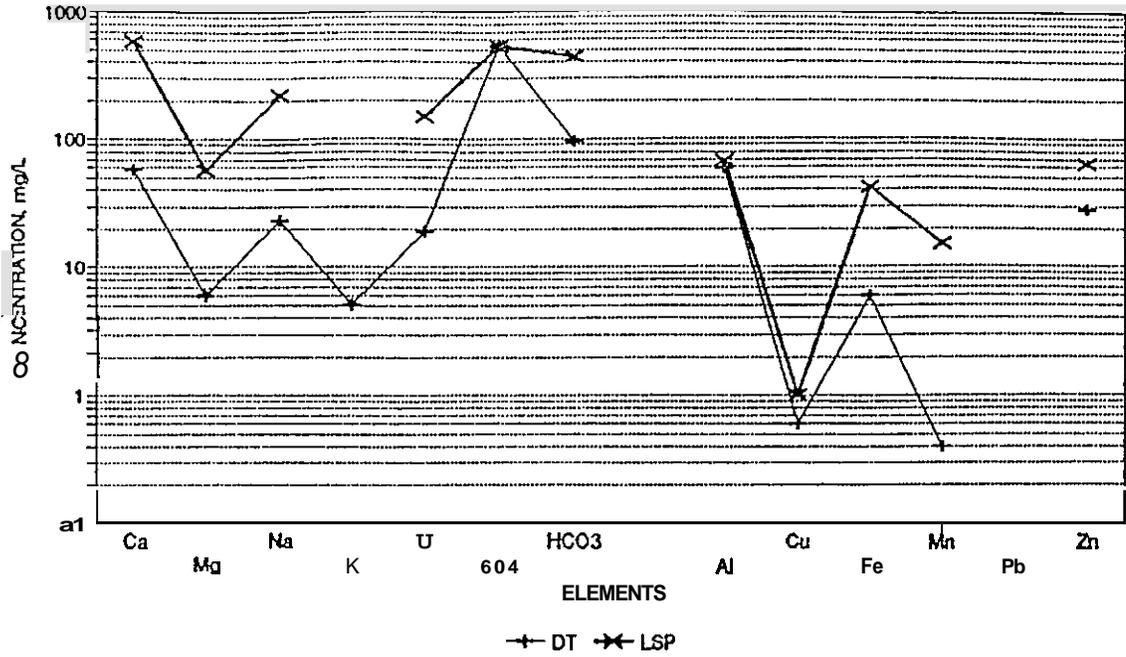


Figure 2-5
DT AND LSP WATERS: CHEMISTRY 1991

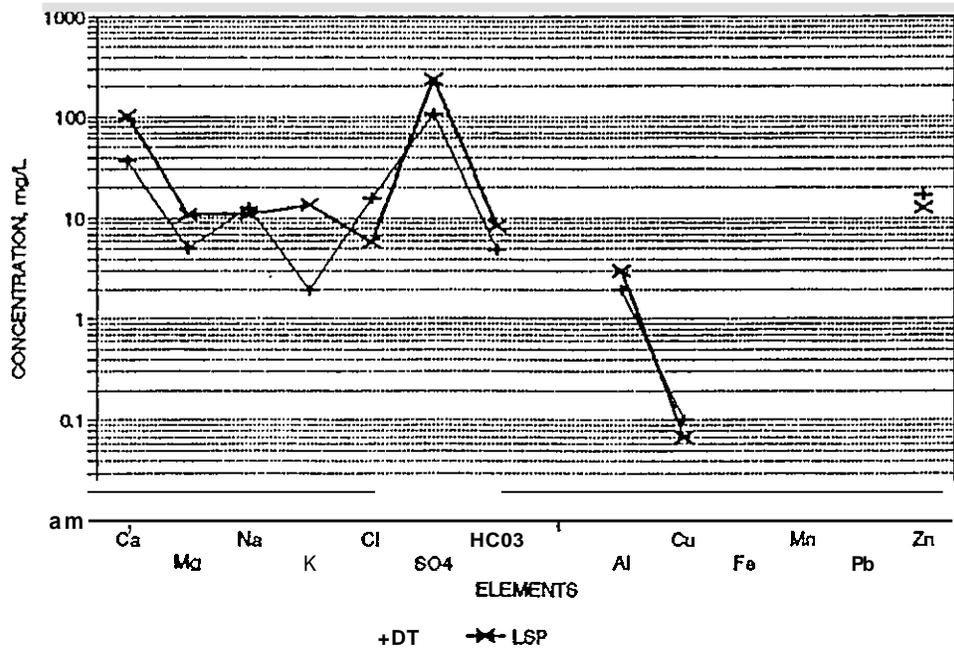


Figure 2-6
DRILLHOLE # 3325: CHEMISTRY

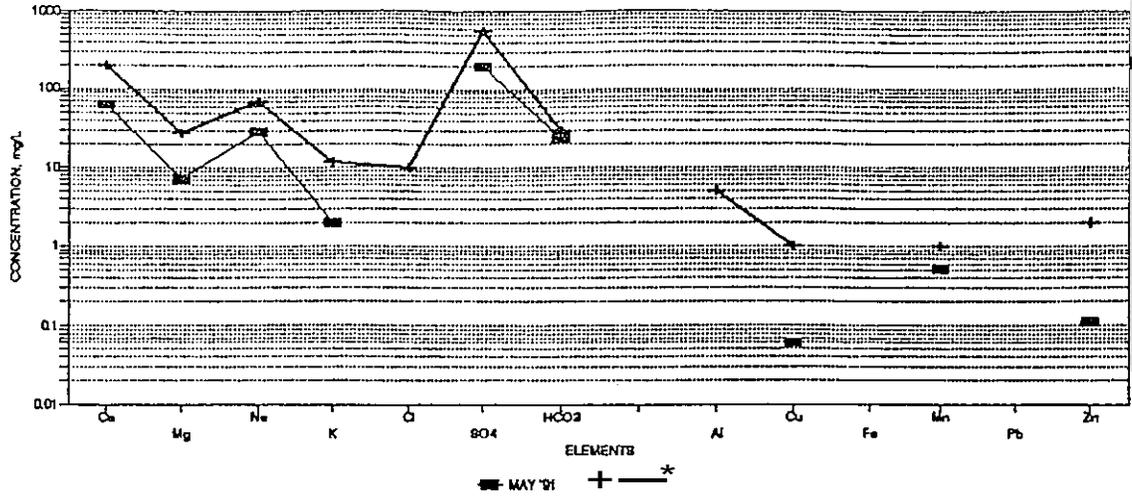


Figure 2-7
DRILLHOLE # 3341: CHEMISTRY

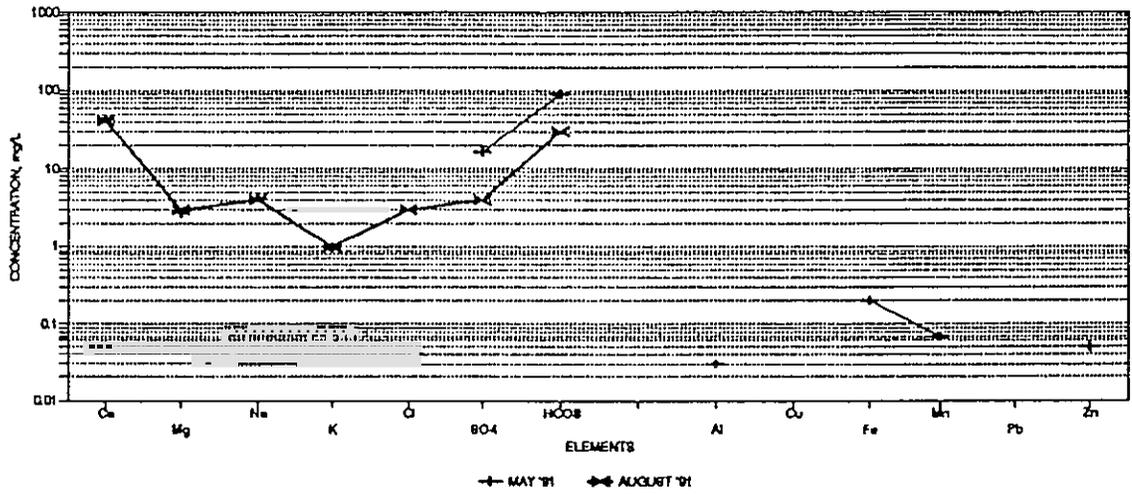
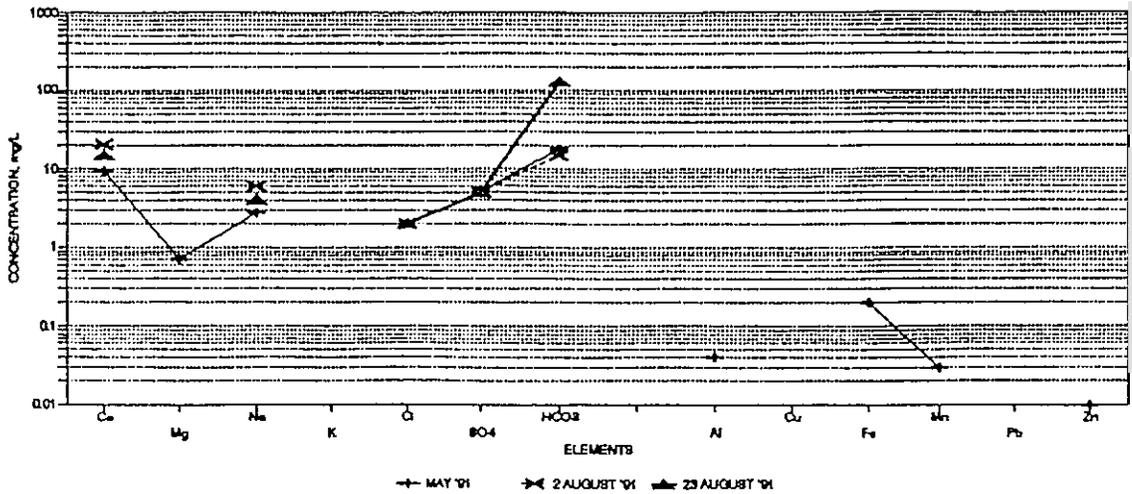


Figure 2-8
DRILLHOLE # 3342: CHEMISTRY



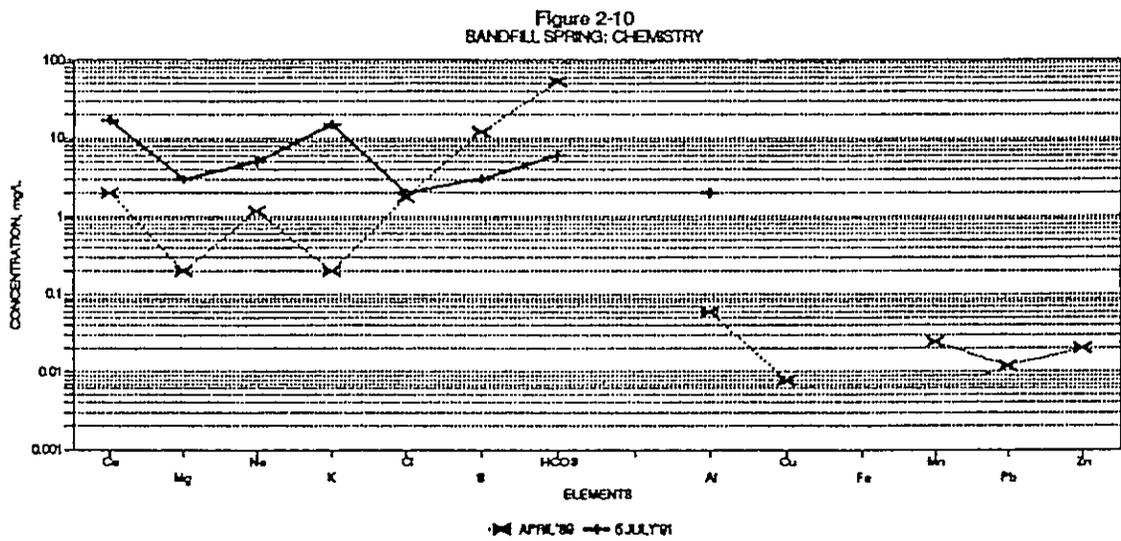
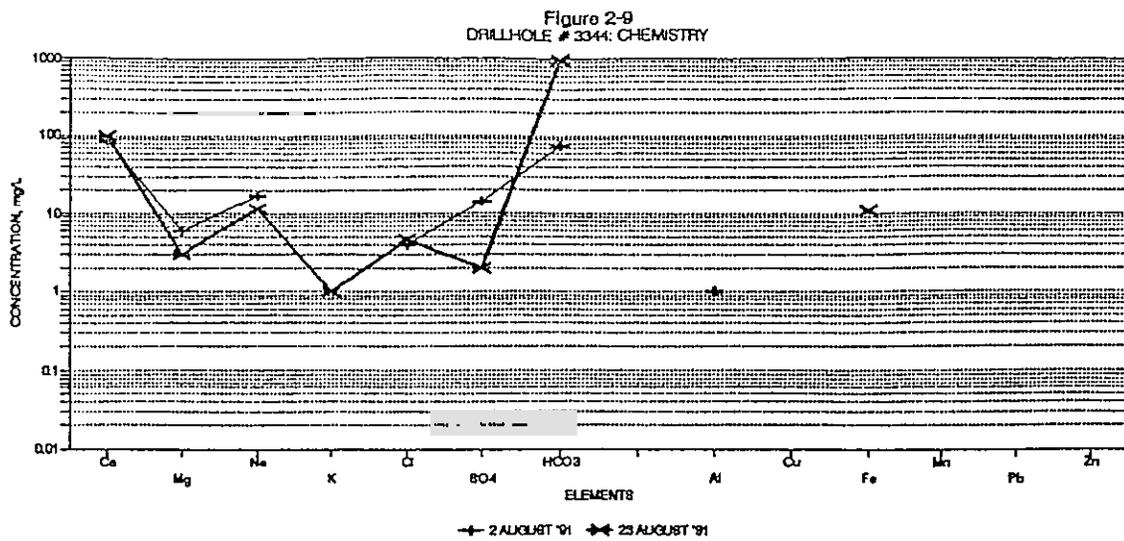


Figure 2-11
LUCKY STRIKE D.D.H.: Field

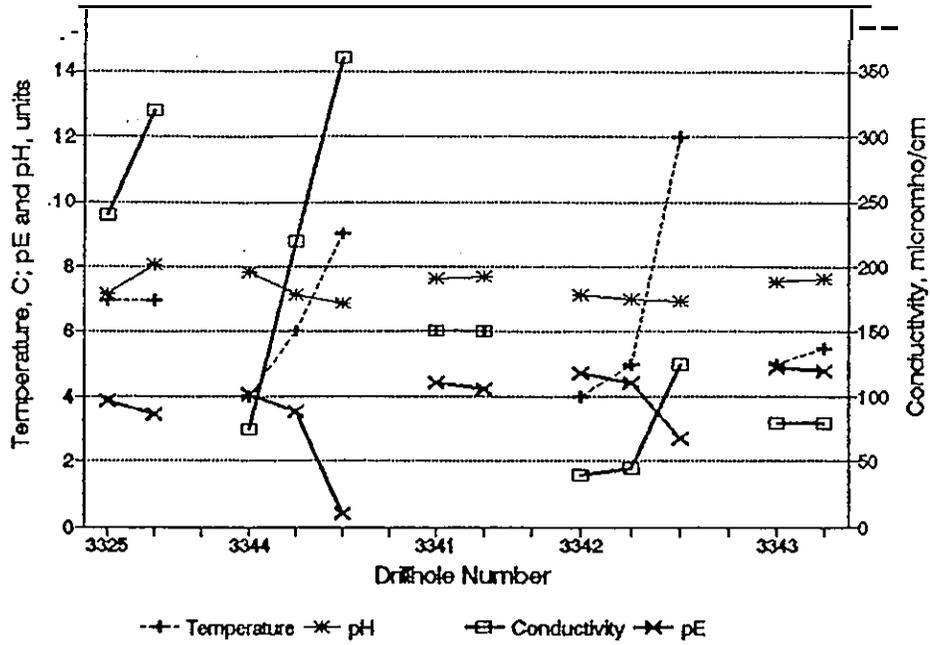


Figure 3-1
TUNNEL FLOW vs. PIT WATERLEVEL

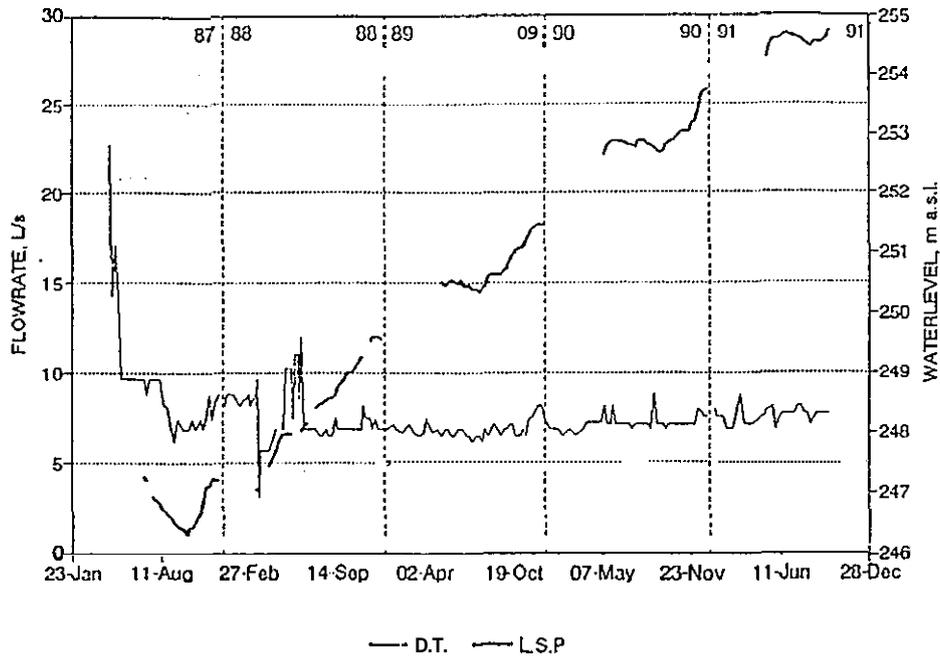


Figure 3-2
TUNNEL FLOW vs LUCKY STRIKE WATERLEVEL

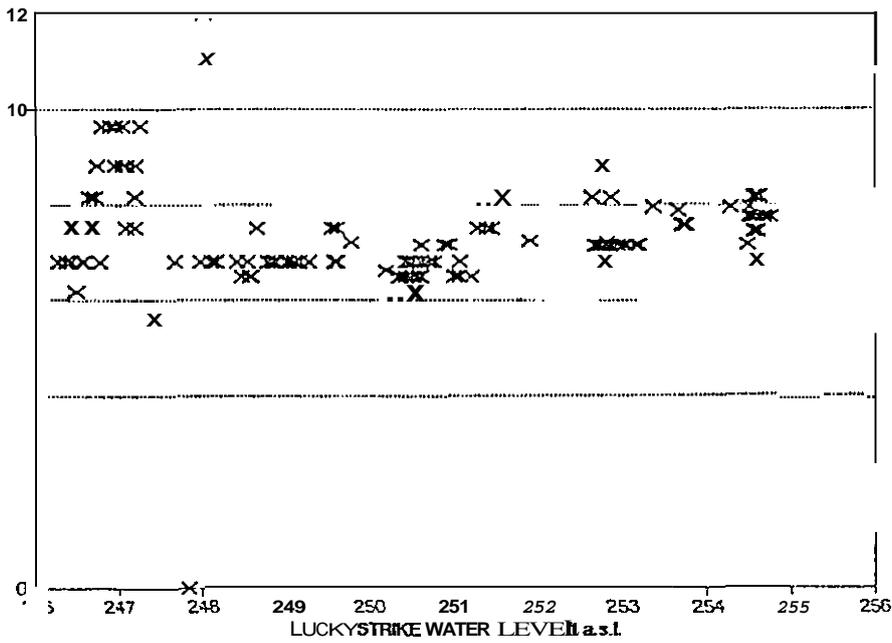


Figure 3-3
WATER LEVELS IN DRILLHOLES, 1991

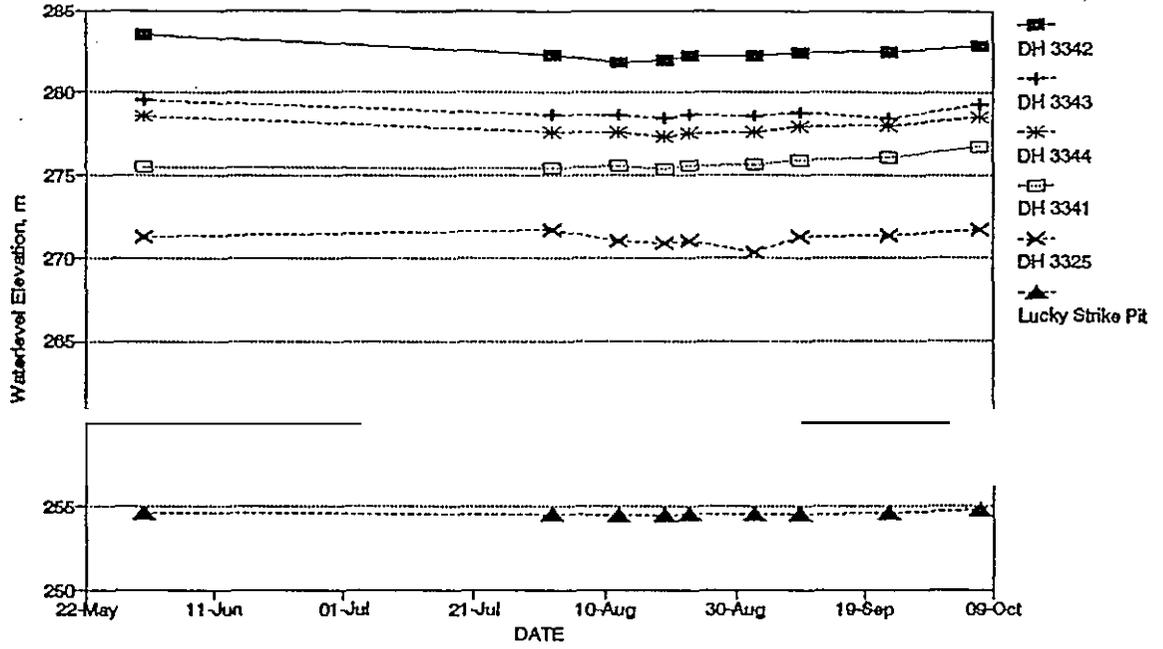


Figure 3-4
HYDROLOGY, SEAL COVE

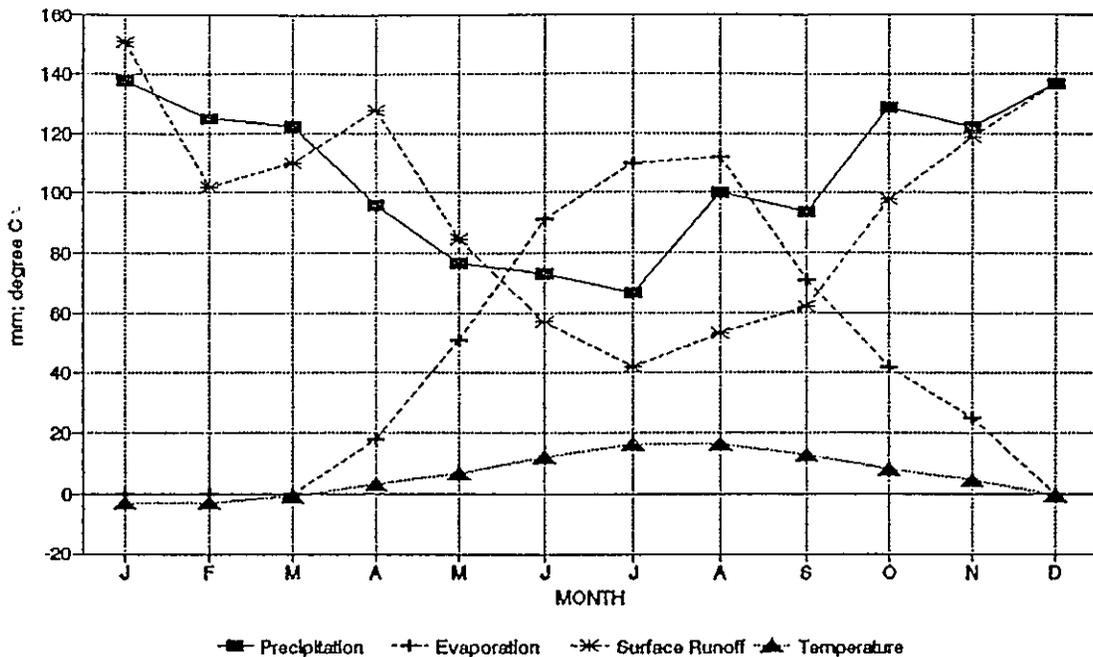


Figure 3-5
HYDROLOGY, BUCHANS

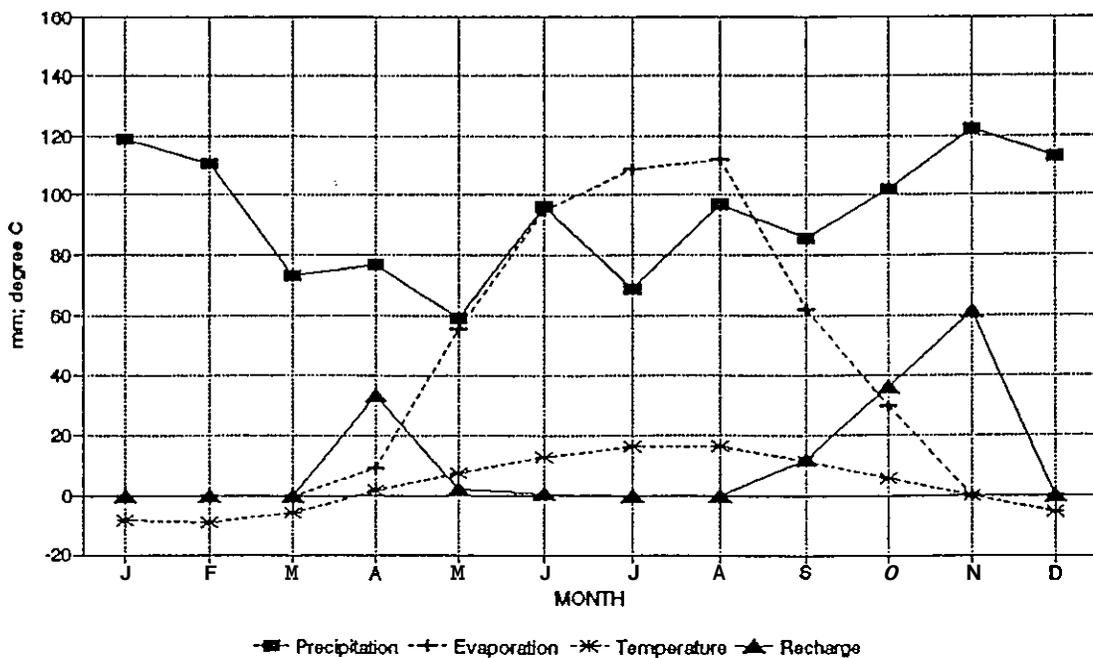


FIGURE 3-6 BUCHANS MODFLOW MODEL GRID

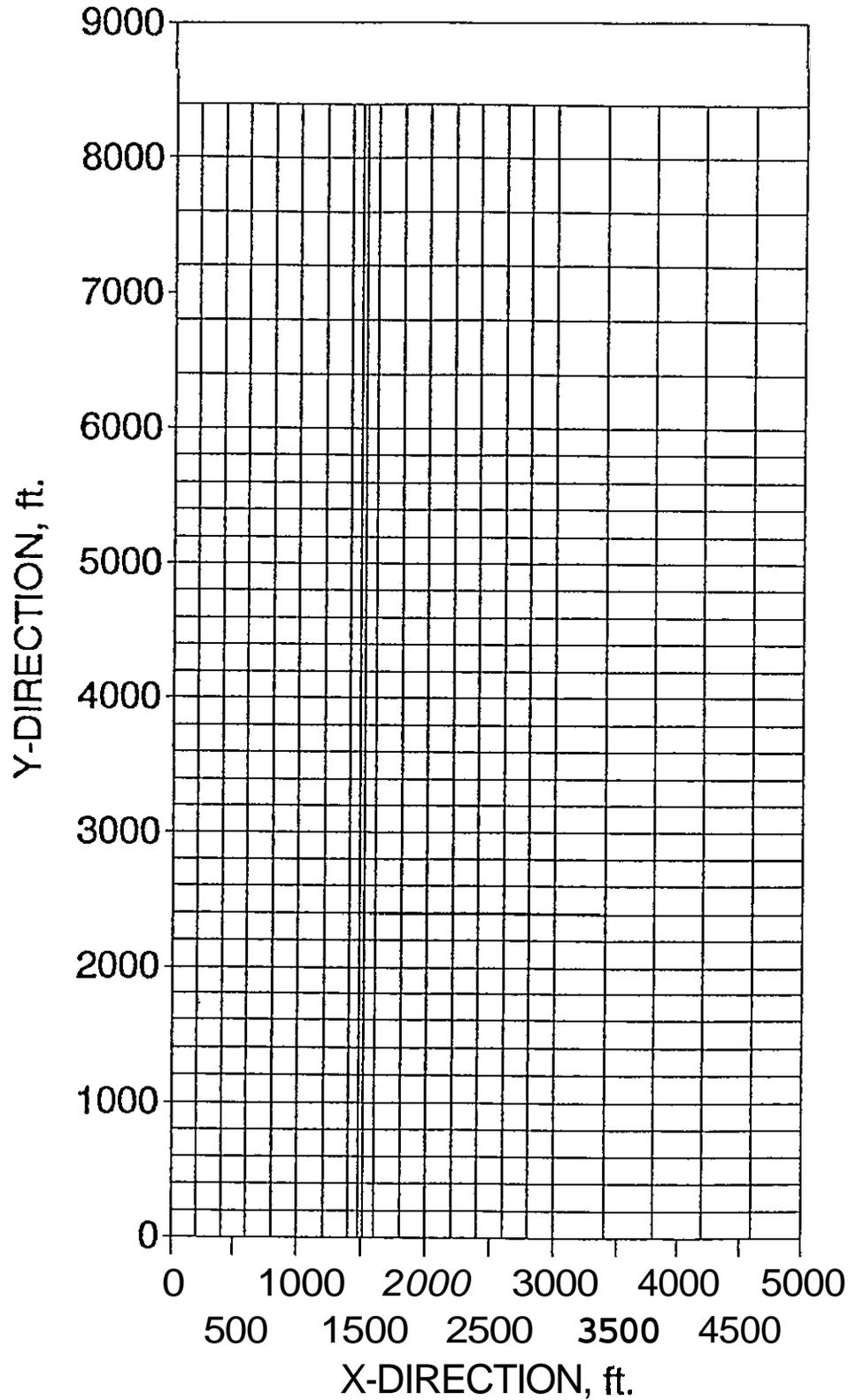


Figure 3-7
BUCHANS - 1991 WATERLEVELS

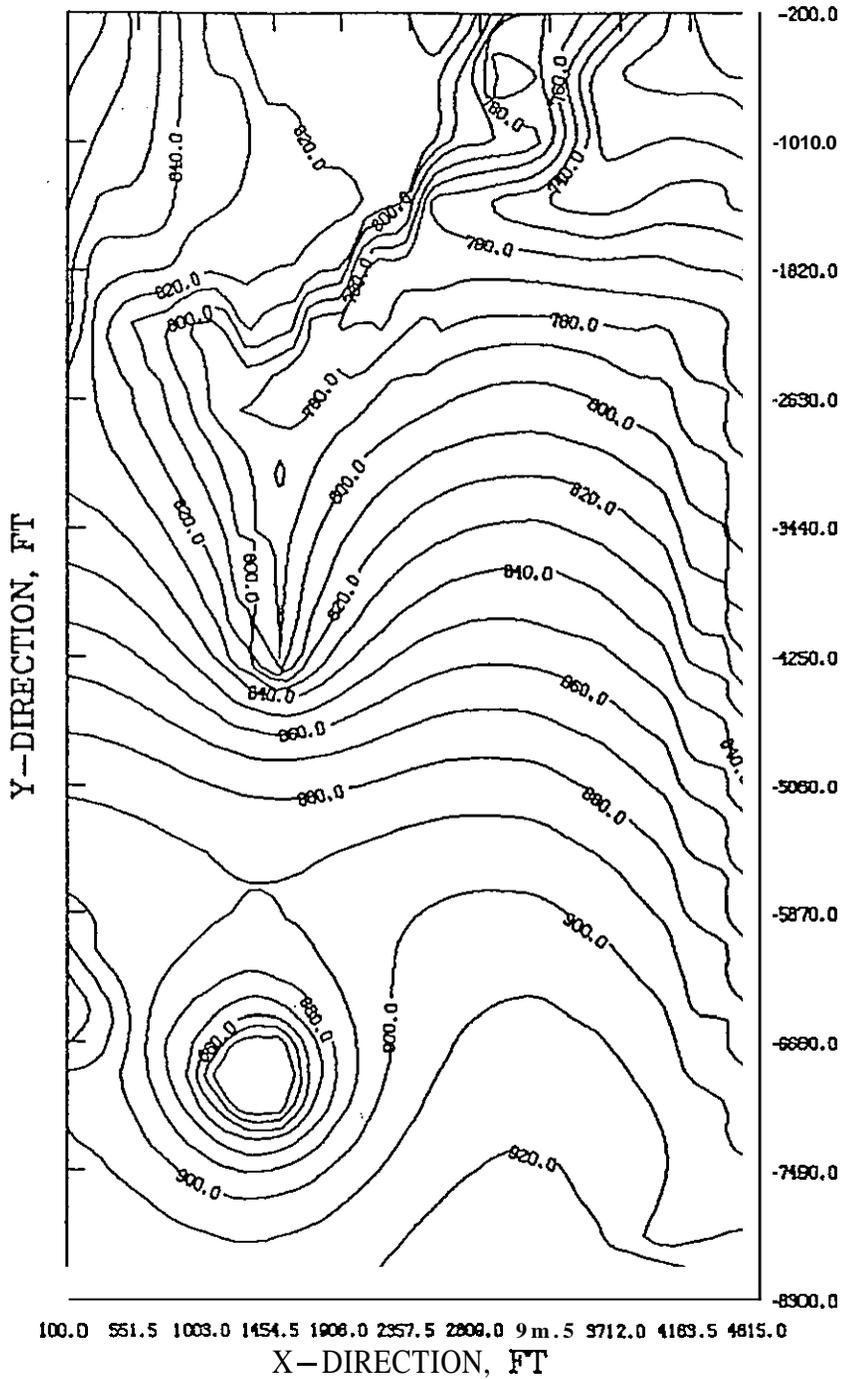


Figure 3-8
BUCHANS - FUTURE WATERLEVELS

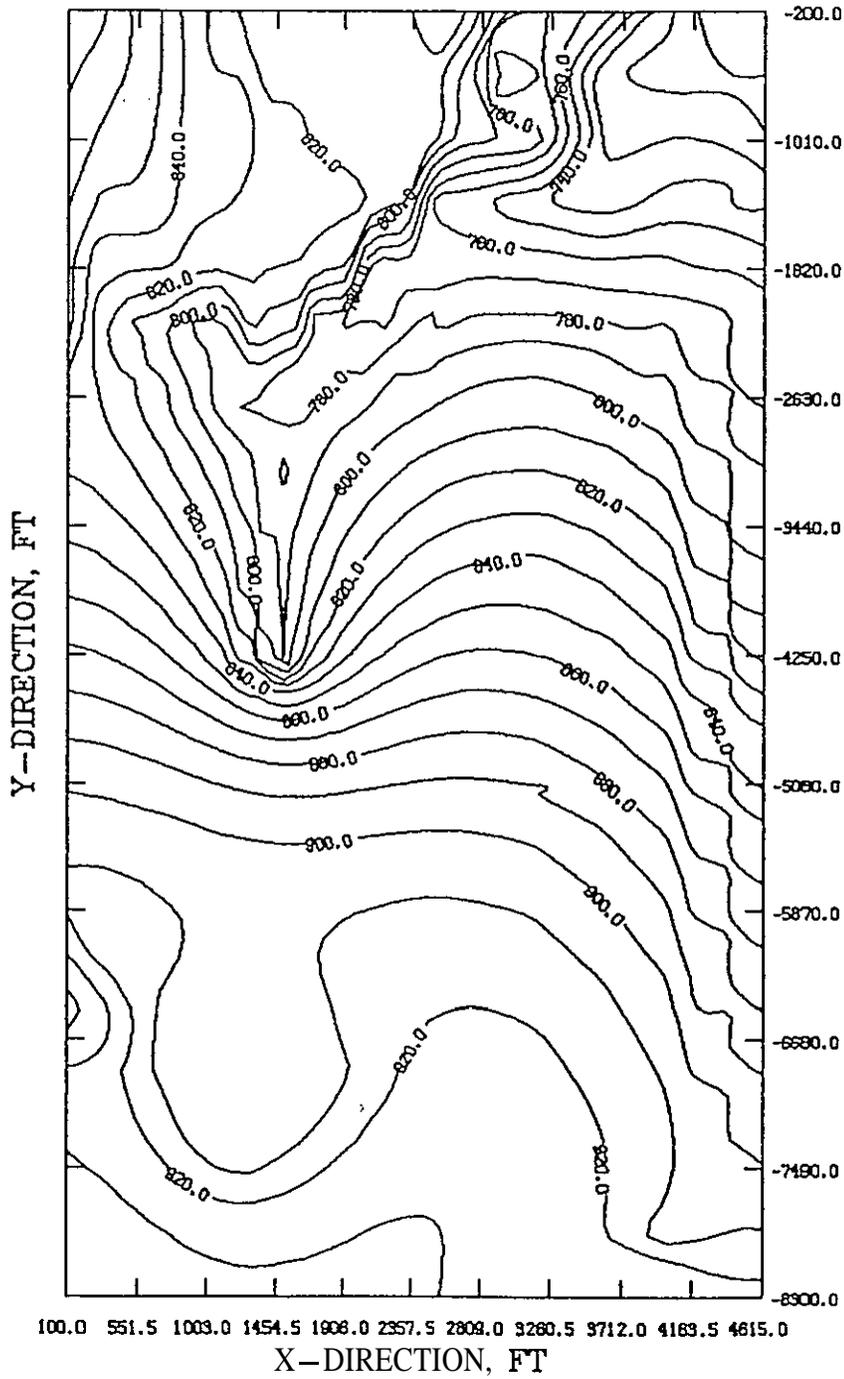


Figure 3-9
PROJECTED LEVEL OF LUCKY STRIKE POND

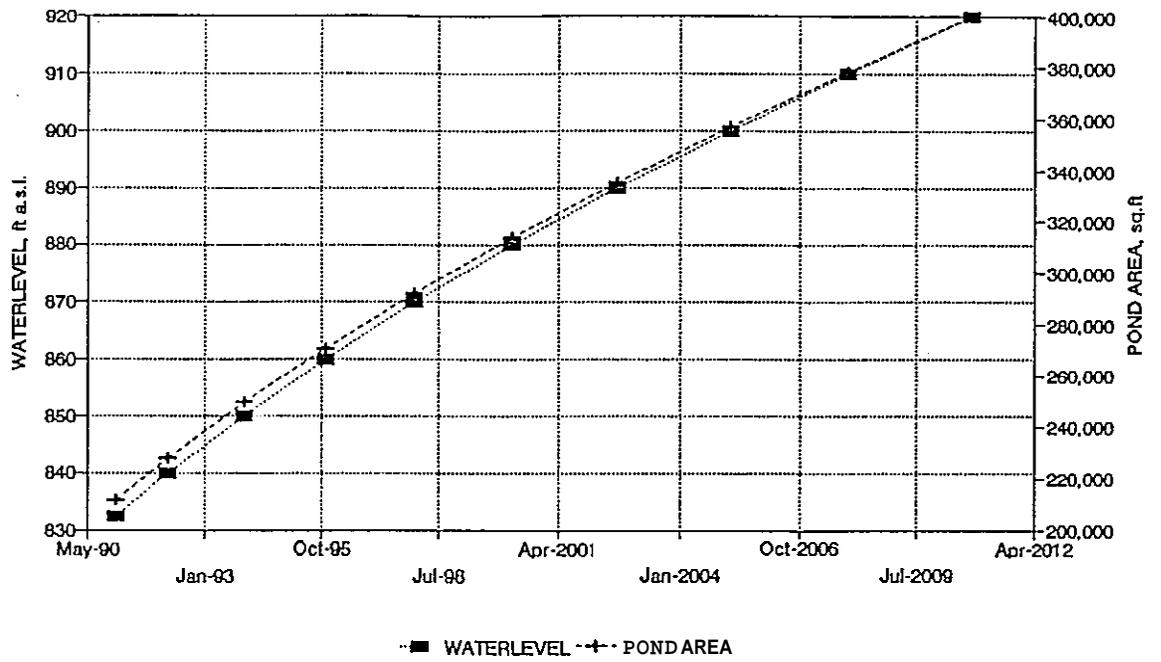


Figure 4-1
TUNNEL DISCHARGE / PIT DISCHARGE RATIO

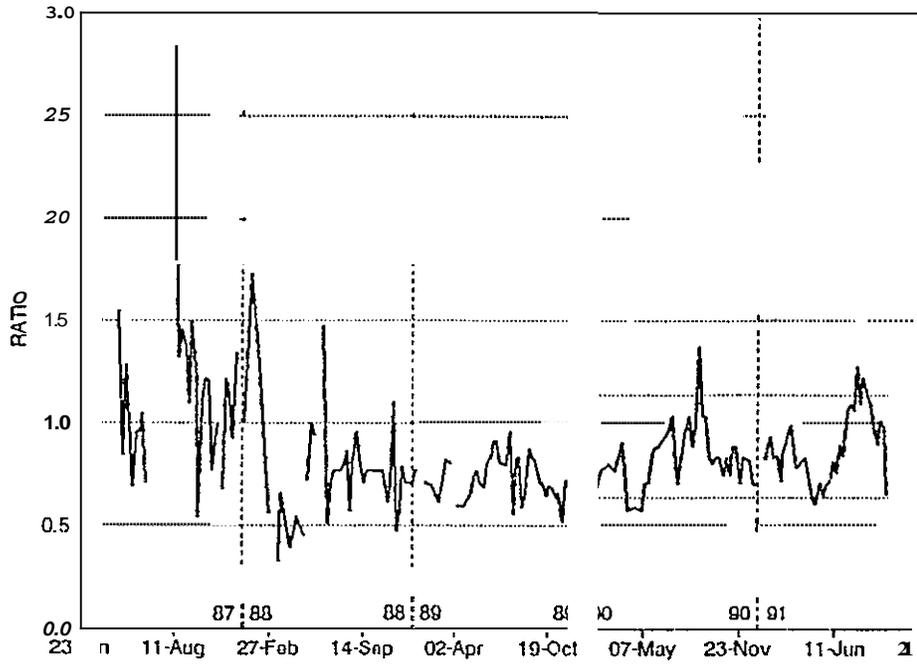


Figure 4-2
DRAINAGE TUNNEL DISCHARGE INTO EAST PIT

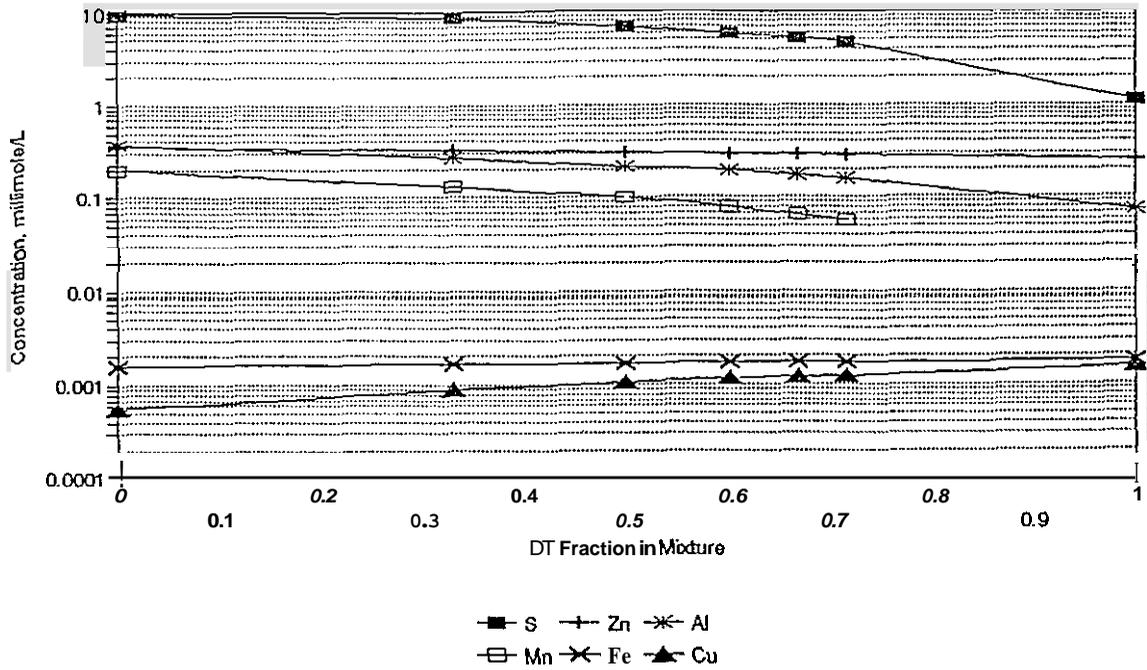


Figure 4-3
DRAINAGE TUNNEL DISCHARGE INTO EAST PIT

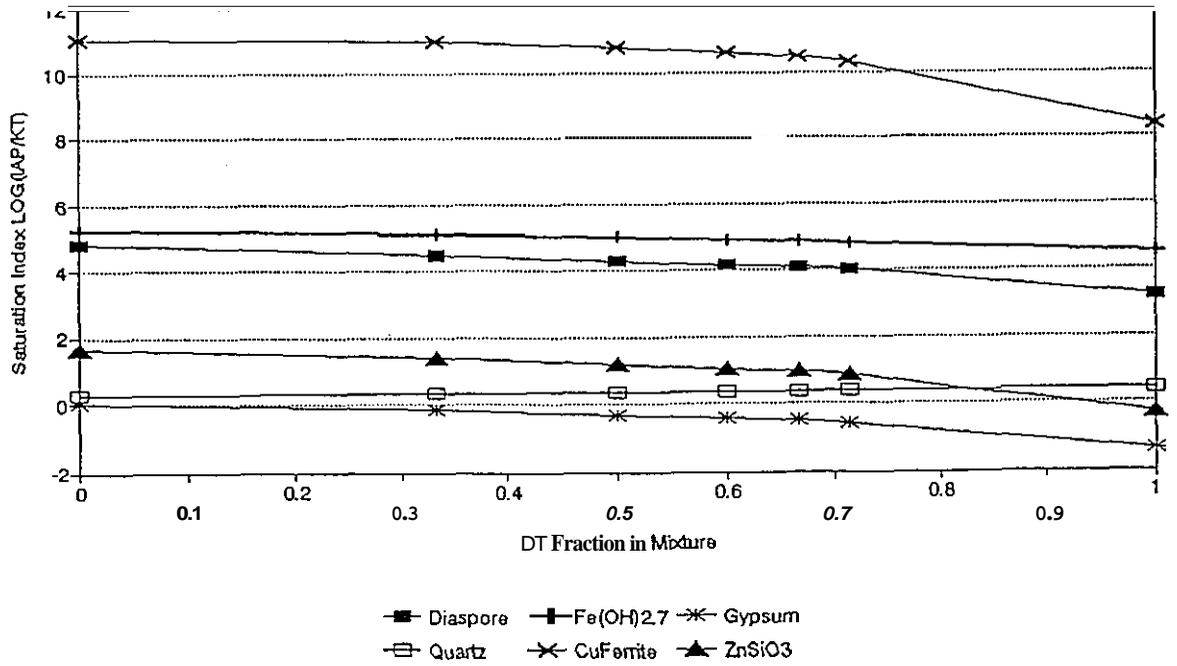


Figure 4-4
DRAINAGE NNNEL DISCHARGE INTO WEST PIT

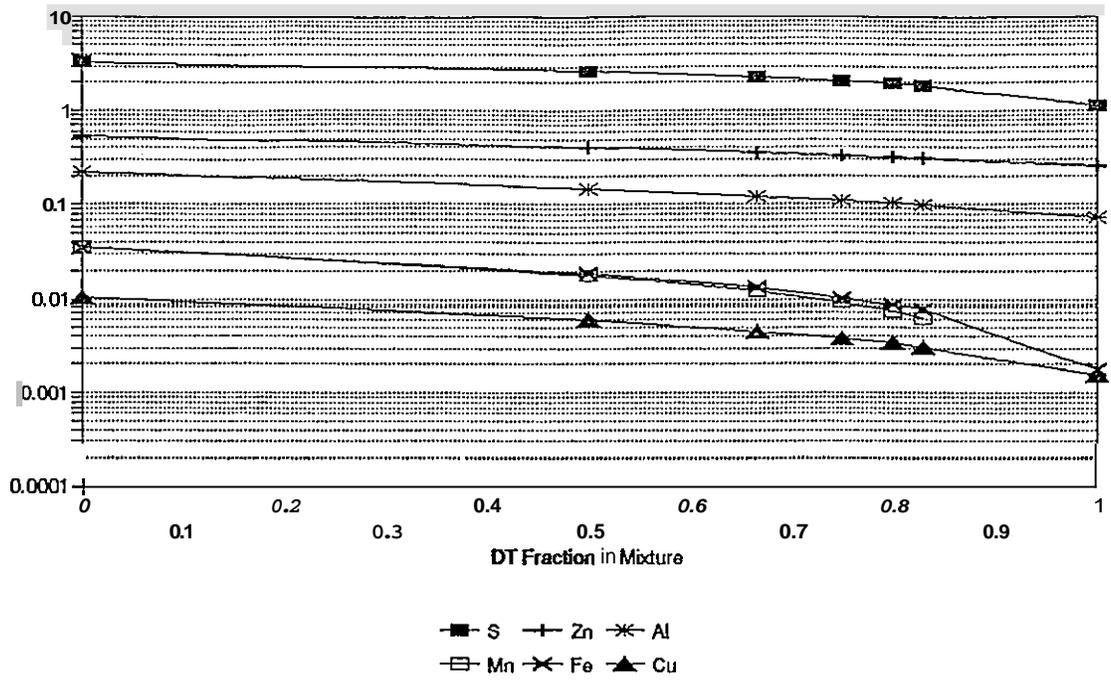


Figure 4-5
DRAINAGE NNNEL DISCHARGE INTO WEST PIT

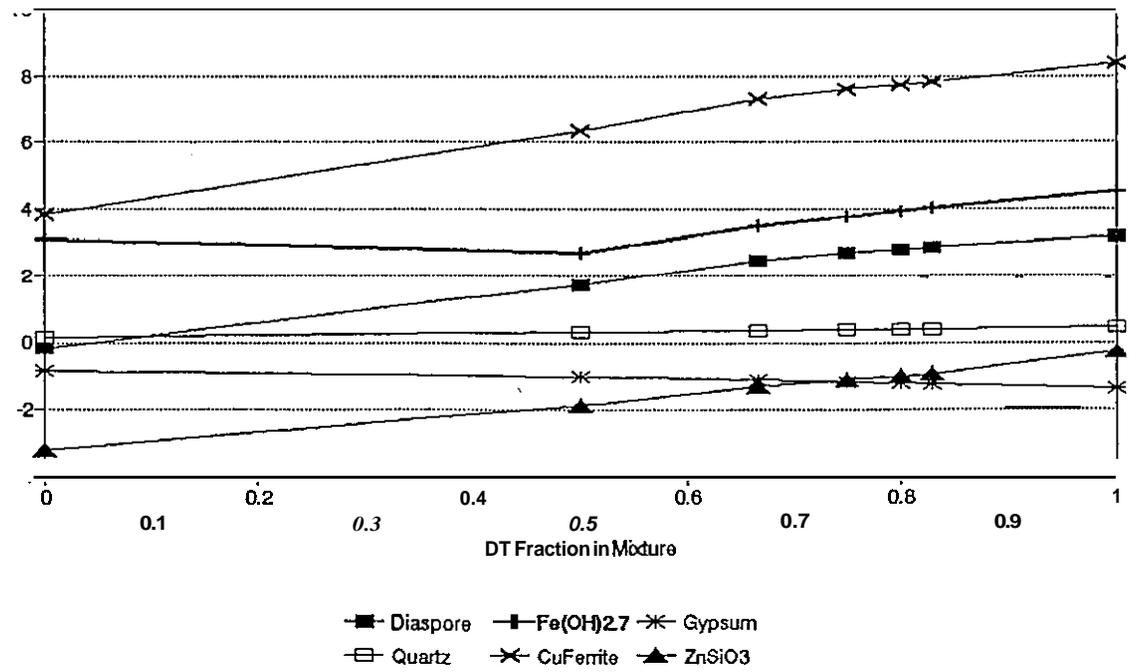


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ASARCO - BUCHANS UNIT

TAILINGS DRAINAGE

1. INTRODUCTIONA. Tailings

During its 57-year operating life (1928-1984), the milling operation at Buchans has produced some 11.3 million SD tons of mill tailings. Initially these were deposited into Red Indian Lake, via Buchans River. From late 1965 till the end of 1972, 1.9 million SD tons of tailings were placed in what is known as Tailings Pond #1 (TP#1); an additional 0.9 million SD tons of tailings were placed in Tailings Pond #2 (TP#2) between early 1973 and the end of operations in the fall of 1984. Details about the surface area of the tailings basins, and about the ponds in the basins, are given in Table 1-1.

The elemental and mineral compositions of the tailings are only known from two sets of analyses, presented in Table 1-2, parts A and B. Both sets of analyses indicate that the tailings contain around 6% metal-sulfides (by dry weight). It should be borne in mind, however, that temporal variations in the composition of the ore fed to the mill will have resulted in spatial variations in the composition of the tailings.

Results of analyses of the acid-generation and neutralization potentials of a number of samples from the tailings are given in Table 1-2, part C. From these data it is clear that the Buchans tailings do possess significant net acid-producing potential.

Results of particle-size analyses on two sets of tailings samples are listed in Table 1-3, and illustrated by a triangular particle-size plot in Figure 1-0. The location of the samples in the triangle suggest that maximum hydraulic conductivity of the tailings would be between 2.7×10^{-5} and 2.9×10^{-5} m/s (8.7×10^{-5} and 9.5×10^{-5} ft/s).

Every effort has been made to make sure that the data used in the interpretations presented in this report are the best available. Any errors found, and significant new information that could affect the interpretations should be brought to the

attention of the author as soon as possible to enable correction and, where necessary, re-interpretation.

B. Effluent Discharge Rates

The rates of surface discharge of effluents from the two tailings basins are determined at more or less regular intervals during the ice-free season. Results of those measurements over the last five years are shown graphically in Figures 1-1 to 1-3, for TP#1, TP#2, and Simms Brook (the receiving stream), respectively. Figure 1-4 illustrates the relative magnitude of the annual cumulative discharges from TP#1 and TP#2, in comparison with the downstream discharge in Simms Brook.

Sofar there are no reported occurrences of seepage through or below any of the dams around the two tailings basins. However, in view of the estimated hydraulic conductivity of the tailings and underlying unconsolidated materials, it may be advisable to check for seepages as part of the planned evaluation of dam stability.

2. MONITOR DATA

At the time of the discharge measurements, water temperatures are measured and water samples are collected for the determination of pH, [Cu] and [Zn]. The results of the monitoring are discussed briefly in the following sections.

A. pH

The results of the pH measurements are shown in Figures 2-1 to 2-3. The annual patterns of pH values have remained relatively similar from year to year. In the past two years there have been pronounced low pH periods during spring runoff, followed by higher pH values in summer and fall. The pH values for Simms Brook showed two unexplained peaks (8.1 and 8.4) in August and September 1991. No long-term trend is apparent.

B. Copper

The graphs for [Cu] in Figures 2-4 to 2-6 do not show any obvious long-term trend. The [Cu] values fall generally in the 30-50 ppb range. Compared to 1989 and the first part of 1991, they were somewhat lower during 1990.

C. zinc

The graphs for [Zn] in Figures 2-7 to 2-9 show relatively low values in spring and

higher values during summer and fall. The [Zn] values for discharge from TP#1 (Figure 2-4) show no obvious long-term trend, but the [Zn] values for the discharge from TP#2 reveal a relatively steady long-term decrease. The [Zn] values for Simms Brook show a minor long-term decrease, directly related to the decrease in [Zn] values in the TP#2 discharge. The latter may well reflect a progressive decrease in accessible metal-sulfides.

D. Loadings

Copper loadings from TP#1, from TP#2, and in Simms Brook are shown in Figures 2-10 to 2-12, respectively; zinc loadings are shown in Figures 2-13 to 2-15. Both Cu and Zn loadings from the TP#1 discharge are high during spring runoff, fall and early-winter, but low during the summer months. Summer low values have increased somewhat since 1989. Cu and Zn loadings from the TP#2 discharge are lower, with much smaller seasonal variations. Both Cu and Zn loadings in Simms Brook are similar to those from TP#1, because TP#1 supplies the major proportion of the total effluent in Simms Brook.

3. WATER CHEMISTRY

Available chemical analyses for samples from the tailings drainage are listed in Table 3-1 and illustrated by Figures 3-1 to 3-5. The analyses suffered from several shortcomings, including:

- (1) Eh values were not determined for any of the samples;
- (2) [Cl] was only determined for the July 1991 samples;
- (3) [HCO₃] (or TIC) was not determined for the August 1991 samples.
- (4) the August 1991 samples were analyzed for elemental concentrations >1 mg/L only, which for these dilute samples resulted in rather significant ion-balance errors, ranging from -98.5% to +52.1% (Table 3-1); Cu and Zn were determined separately for some of the samples, to 0.01 mg/L.

For comparison purposes, Figure 3-1 shows a plot of selected elements for three 1988 and 1991 samples from Lake #1. Figures 3-2 and 3-3 show similar plots for three 1988 and 1991 samples from TP#1 and TP#2, respectively. The major-ion parts of the plots reflect mostly seasonal dilution effects; the metal-ion parts of the plots have more 'noise', which may be related to the effect of the 1 mg/L cutoff used for the 1991 laboratory analyses.

Comparisons of the variations in the concentrations of selected metals and sulfur along the tailings drainages, for July 1988 and August 1991, are shown in Figures 3-4 and 3-5, respectively. The apparent absence of Al, Mn, Fe, and Cu from most of the 1991 samples (Figure 3-5) undoubtedly reflects the analytical-precision cut-off rather than the real situation.

4. GEOCHEMICAL CALCULATIONS

A. Introduction

The geochemical calculations carried out for this report were to some degree hampered by the various shortcomings of the available data, outlined in the preceding section on Water Chemistry. Of particular concern were the absence of Eh data, and the generally poor ion-balances (see Table 3-1). Where necessary, estimated values of Eh have been used, and ion-balance errors were forced to zero percent by the addition of S or Ca during geochemical simulations.

B. Potential Sources of Dissolved Solids

The geochemical calculation program BALANCE was used for the determination of potential mineral sources for the dissolved-solid contents in the discharges from TP#1 and TP#2. The starting point in both cases was taken as pure water, to represent rain or snowmelt. The results of the calculations are listed in Table 4-1, in terms of millimoles of mineral dissolved per litre water (positive values), or precipitated per litre water (negative values).

For the two analyses used, the main constituents taken up are: oxygen, carbon-dioxide, pyrite, and calcite. The main precipitates, presumably deposited in the tailings are likely to have been Fe-hydroxide, silica, and Al-sulfate.

C. Saturation Indices

The geochemical simulation program PHREEQE was used to determine the saturation index ($SI = \log[IAP/KT]$) with respect to any minerals, for water samples from both the TP#1 and TP#2 discharges, collected on 11 July 1991. To force the ion-balance errors to zero percent, 0.02891 millimole/L sulfur was arbitrarily added to the TP#1 analysis, and 0.07735 millimole/L calcium to the TP#2 analysis; as an alternative, Cl and Na could have been added.

The analyses for the two discharges are listed as the first and last columns in the

upper part of Table 4-2, where concentrations are given in millimole/L. The corresponding saturation indices for the two discharges with respect to selected minerals are given in the same columns in the lower part of Table 4-2, in which a positive value for a particular mineral indicates saturation (or the potential for precipitation of the mineral in question), and a negative value indicates undersaturation (or the potential for dissolution of the mineral, if present).

Both of the tailings-discharge analyses show **some** saturation with respect to secondary Fe and Al minerals and several silicates (kaolinite, nontronite, chlorite). The tailings discharges were undersaturated with respect to the metal-sulfides in the tailings.

D. Fe precipitated

The amount of Fe lost (FeX) from each of the water samples represented by the analyses in Table 3-1 can be estimated as the difference of [S] minus the sum of [Cd] + [Cu] + [Fe] + [Pb] + [Zn] (where **all** concentrations should be expressed in millimole/L), if one assumes that **all** sulfur in the analyses was derived from oxidation of heavy-metal sulfides, and that Fe was the only heavy-metal lost by precipitation. The calculation gave values for FeX ranging from 2.6 to 41.6 mg/L, which represented 89.8 to 100% of the original dissolved Fe (the 100% loss figures refer to the analyses where the 1 mg/L cut-off was used). Most of the FeX was presumably deposited in or on the tailings.

E. Effects of Mixing

For the simulation of mixing of TP#2 discharge into the stream of TP#1 discharge, a series of mixing ratios was used, ranging from 1(TP#2):9(TP#1) to 1(TP#2):1(TP#1), for fractions of TP#2 in the mixture ranging from 0.1 to 0.5.

The resulting elemental concentrations in the various mixtures *are* given in the upper portion of Table 4-2, in millimole/L, and illustrated for 5 metals and sulfur in Figure 4-1. The calculated SI values for selected minerals are listed in the lower portion of Table 4-2, and illustrated for **six** potential precipitate minerals by Figure 4-2.

All the mixtures show saturation with respect to barite, diaspore, Fe-hydroxides, Cu-ferrite, ZnSiO₃, and the same silicates **as** in the two discharge samples.

5. LEACH TESTS

From late-April *till* early-November 1989, a tailings-leach experiment was run, in which tailings were leached with (1) tap water, (2) tap water with air bubbled through, and (3) tap water acidified to pH 3.0 with concentrated nitric acid. Three batches of Ba-rich tailings and three batches of Ba-free tailings were prepared, each by mixing 500 g of tailings with 500 mL of water. The acidified slurry for the Ba-rich tailings had 9.0 mL of nitric acid added, and the acidified slurry for the Ba-free tailings 14.8 mL of nitric acid, to establish an initial pH of 3.0.

Chemical analyses were made of the initial and final supernatants at the start and end of the experiment. The results of those analyses *are* listed in Table 5-1, parts A and B, for the Ba-rich and Ba-free tailings, respectively. Ion-balance errors were fairly large (-18.5% to +20.9%) in the analyses of the water and watertair leachates; they were extremely large (+77.2% to 97.3%) in the watertacid leachates, probably because [NO₃] (from the acid) was not determined.

The results for Ba-rich tailings are illustrated by plots for selected elements in Figures 5-1 to 5-3; Figure 5-4 presents a comparison between the analyses of the final leachates, the tapwater, and the discharge from TP#2. The results for Ba-free tailings are illustrated by plots for selected elements in Figures 5-5 to 5-7; Figure 5-8 presents a comparison between the analyses of the final leachates, the tapwater, and the discharge from TP#2.

Elemental concentrations were generally somewhat higher in the final leachates than in the initial leachates; [B] values were as much as two orders of magnitude higher. Elemental concentrations were considerably higher in the leachates from the acidified batches than in those from the non-acidified batches, as expected. Initial and final leachates from the Ba-free tailings resembled one another more closely than those from the Ba-rich tailings. The two [Mg] values in the final Ba-rich leachates that were lower than [Mg] in the tapwater contributed to this. With the exception of those two [Mg] values, two [Mn] values, and one [Al] value (all for Ba-rich tailings), the leachates carried elemental concentrations that were higher than those found in the July 1991 discharge from TP#2 (Figures 5-4 and 5-8).

Temperature, pH and conductivity were measured at increasing intervals during the course of the experiment; the results of those measurements are presented in

Figures 5-9 and 5-10 for leaching by water, in Figures 5-11 and 5-12 for leaching by watertair, and in Figures 5-13 and 5-14 for leaching by watertacid.

Temperature was not controlled during the experiment which was run in the laboratory; the temperature curves in Figures 5-9 to 5-14 reflect seasonal variations in temperature over the experiment period. The fluctuations in the curves for the conductivity reflect the temperature dependence of this parameter; the continued rise in conductivity shown in Figures 5-9 to 5-12 reflects continued mineral dissolution, by water and by water+air, from both the Ba-rich and Ba-free tailings. The conductivity curves in Figures 5-13 and 5-14 indicate that maximum dissolution was established very early in the acidified slurries for both types of tailings.

The Buchans tailings reportedly contain around 6% metal-sulfides by dry weight (see Table 1-2). If one assumes that all Cu, Fe, Pb, Zn, and S in the leachate analyses was derived from metal-sulfides in the tailings samples, then the dissolved heavy metals and sulfur in the leachate represent at least 1.0 to 1.9% of the metal-sulfides available in the Ba-rich tailings, and 0.4 to 2.4% of the metal-sulfides available in the Ba-free tailings. These values are conservative, because at least some Fe will have been lost from the water, in the form of Fe-hydroxide precipitate. If the Fe loss (FeX in Table 5-1) is taken into account, the percentages become 2.7 to 4.1% for the Ba-rich tailings, and 1.0 to 5.6% for the Ba-free tailings.

As a check on the potential progress of metal-sulfide oxidation in the tailings, it would be useful to have some test pits dug at several points on the exposed portions of the tailings in the two tailings basins. At any point where the pH of water encountered in such a test pit is found to be low, water samples should be collected for complete analysis. In addition, waterlevels in the exposed tailings should be measured at a number of points along lines perpendicular to the 'shoreline', to evaluate the extent of water circulation through exposed tailings.

6. CONCLUSIONS

- a. The Buchans tailings possess positive net acid-generation potential.
- b. Discharges from the two tailings basins have pH values generally between 6.5 and 7.5, but [Cu] and [Zn] in the discharges exceed the guideline values.

- c. Leaching experiments resulted in the dissolution of up to 5.6% of the metal-sulfides estimated to be available in average tailings.
- d. Monitor data show a slow long-term decrease in [Zn] in TP#2 discharge, and no obvious long-term trend in [Zn] in TP#1 discharge, or [Cu] in either discharge.
- e. Most of the dissolved Fe resulting from sulfide oxidation is precipitated in or on the tailings.

7. RECOMMENDATIONS

- a. The possible occurrence of seepage of tailings effluent, through dams or through the subsurface below the tailings basins, should be checked.
- b. pH should be checked in a number of places where the tailings are exposed above pond level; if pH is found to be low, water samples should be collected for complete analysis.
- c. Subsurface waterlevels in exposed tailings should be measured at a number of points along lines perpendicular to the 'shoreline', to evaluate the extent of water circulation through exposed tailings.
- d. Flow-control structures at the points of discharge from the tailings basins should be arranged in such a way that reliable discharge measurements can be made.
- e. A proper discharge-measurement station should be established on Simms Brook, preferably at or near the highway bridge.
- f. In addition to the regular sampling for determination of pH, [Cu], [Zn] and [Pb], samples for complete analysis of TP#1 and TP#2 discharge should be collected at least once during (1) the high-discharge spring runoff, (2) the low-discharge mid-summer period, and (3) the high-discharge fall and early-winter period.

4 December 1991

R.O. van Everdingen

TABLE 1-1. DIMENSIONS OF TAILINGS PONDS

Parameter	TP-#1		TP #2	TP-#1		TP #2
	Units			Units		
Period Used		12/65-12/72	1/73-9/84	Months	84	141
Tailings ***	S.D.Tons	1,900,000	900,000	Tonnes	1,723,680	816,480
WL Elevation	ft asl	922.5	928	m asl	281.2	282.9
Surface Area	sq.ft.	4,000,000	3,700,000	m ²	371,612	343,741
Max.Depth	ft	10	19	m	3.05	5.79
Avg.Depth	ft	5	10	m	1.52	3.05
Volume, approx.	cu.ft.	20,000,000	37,000,000	m ³	566,337	1,047,723
Volume, approx.	USgallon	150,000,000	278,000,000	L	567,810,000	1,052,341,200
Drainage Area	acres	730	170	m ²	2,954,164	687,956

*** Total tailings output 11,297,237 S.D.Tons
 Difference of about 8.5 million S.D.Tons disposed via
 Buchans River into Red Indian Lake.

Table 1-2. ANALYSES OF TAILINGS

A. Analyses by E.M.R. (July 1972)

SAMPLE: 50 lbs (dry weight), 2-3 week composite.

Sieve Analyses		Physical Properties	
	% by weight		
-35 + 48	0.3	0 pH solids	8.2 units
-48 + 65	1.3	1.8 Bulk density	92 lb/ft ³
-65 + 100	11.7	6.6 Moisture content	13 %
-100 + 150	7.3	8.5 S.G.	3.3
-150 + 200	12.6	8.5	
-200 + 325	12.7	16.8 Cation Exch. Cap.	1.73 meq/100g
-325	54.1	57.8	
Total	100.0	100.0	

Chemical Analysis			Mineralogical Analysis		
	% by weight (g/100g)		% by weight (g/100g)		moles/kg*
Al	4.3		Quartz	23.5	3.91
AS	0.04		Silicates/acid	24.0	
Ca	1.3		Silicates/basic	5.0	
CO ₂	1.2		Carbonates	2.5	0.25
Cd	0.004	0.005 CdS *	Sulphates and	34.5	****
cu	0.13	0.38 CuFeS ₂ *	phosphates		
Fe	4.3	3.60 FeS ₂ *	Magnetite, hematite	2.0	
K	1.2	~~~~	iron hydroxide		
Mg	1.1		limonite etc.		
Mn	0.05		Metallic sulphides	6.0	
Na	0.9				
Ni	0.004	0.006 NiS *	SUM	97.5 ?	
P	0.04			=====	
Pb	0.24	0.28 PbS *			
S	7.5		Mole /kg *		
Si	18.3		Ca	0.32	
Zn	1.21	1.80 ZnS *	CO ₃	0.27	
SUM	41.82	6.07 Sulphides*		****	
	=====	~~~~	Fe	0.77	
			cu	0.02	
			Pb	0.01	
			Zn	0.19	
			SUM	0.99	
			S	2.34	

* - calculated values

Table 1-2. ANALYSES OF TAILINGS

B. Analyses of Sand Slimes and Tailings (no date).

Element	Units	SAMPLE			
		Sand Slimes		Tailings	
		0-15 cm	15-25 cm	0-15 cm	15-25 cm
Sand	% dry weight	35	68	84	79
Silt	% dry weight	64.9	32	16	21
Clay	% dry weight	0.1	0	0	0
	SUM	100	100	100	100
pH	units	5.6	5.4	6.45	6.65
Organics	% dry weight	2400.0	700.0	2800.0	6900.0
Al	mg/kg	7829.2	8252.4	22482.5	22694.1
Ca	mg/kg	6320.1	5981.1	9879.7	11308.4
Co	mg/kg	5.5	4.5	9.0	12.0
Cr	mg/kg	26.0	26.5	27.0	30.0
cu	mg/kg	15.0	14.5	823.3	920.2
Fe	mg/kg	9080.6	8717.4	20655.4	29106.4
K	mg/kg	1670.8	140.4	5254.6	5157.8
Mg	mg/kg	1222.0	1190.3	8499.5	9811.1
Mn	mg/kg	169.3	211.6	301.5	370.3
N	mg/kg	15.0	2.0	15.0	20.0
Na	mg/kg	653.8	605.4	435.9	339.0
Ni	mg/kg	42.5	39.5	43.5	41.5
P	mg/kg	171.3	233.8	328.8	246.3
Pb	mg/kg	10.0	10.0	25.0	25.0
Zn	mg/kg	52.5	31.5	3874.4	5424.2
SUMS	mg/kg	29,684	26,179	75,455	92,406
Mineral	Mol. Weight	% dry weight			
CuFeS2	183.513	0.0043	0.0042	0.2378	0.2657
FeS2	119.967	1.9478	1.8699	4.2816	6.0787
cos	90.9932	0.0008	0.0007	0.0014	0.0019
NiS	90.76	0.0066	0.0061	0.0067	0.0064
PbS	239.26	0.0012	0.0012	0.0029	0.0029
ZnS	97.44	0.0078	0.0047	0.5774	0.8084
SUM, Sulfides		1.97	1.89	5.11	7.16

Table 1-2. ANALYSES OF TAILINGS

C. Acid/Base Potentials (1)

Sample #	Location	Lime % CaCO ₃	Neutraliz. Potential (2)	Acid Potential (3)	Acid-Base Potential (4)	pH units (5)

TP-1						
1	TP #1	1.0	10	376	178.0	7.0
2	TP #1	1.1	11	325	151.5	7.0
3	TP #1	2.8	28	526	235.0	7.5
4	TP #1	2.8	28	505	224.5	7.5
5	TP #1	3.1	31	300	119.0	7.3
6	TP #1	2.8	28	469	206.5	7.2
	AVERAGES	2.3	22.7	417	185.8	7.3
TP-2						
7	TP #2	2.9	29	381	161.5	7.5
8	TP #2	2.8	28	287	115.5	7.5
9	TP #2	2.3	23	438	196.0	7.7
10	TP #2	2.7	27	417	181.5	7.2
	AVERAGES	2.7	26.8	381	163.6	7.5
LSP						
11	Lucky Strike	<0.1	<1.0	66	33.0	3.3
12	Lucky Strike	(0.1	<1.0	43	21.5	3.0
13	Lucky Strike	<0.1	<1.0	166	83.0	3.3
14	Lucky Strike	(0.1	<1.0	34	17.0	3.3
	AVERAGES	NA	NA	77	38.6	3.2
OWP						
15	O.West Pit	(0.1	<1.0	34	17.0	3.8
16	O.West Pit	<0.1	<1.0	36	18.0	3.4
	AVERAGES	NA	NA	35.0	17.5	3.6
OMD						
17	O.Main Dump	<0.1	<1.0	63	31.5	4.5
18	O.Main Dump	0.2	2	59	27.5	4.6
	AVERAGES	0.1	1	61.0	29.5	4.6
OSH						
19	O.Small Heap	<0.1	<1.0	65	32.5	3.5
20	O.Small Heap	1.3	13	93	33.5	5.4
	AVERAGES	0.7	6.5	79.0	33.0	4.5

(1) Analyses by Energy Laboratories, Billings, Montana, January 1988

(2) millimoles CO₃ per 100 g

(3) millimoles H⁺ per 100 g

(4) as kg CaCO₃ per 100 tonnes dry material
(+ = excess neutralization potential)

(- = excess acid-generation potential)

(5) 20 mL of sample in 60 mL of tap water (pH 7.4)

TABLE 1-3. PARTICLE-SIZE ANALYSES

RETAINED ON	MESH	1968		1972		mm
		(ASARCO)	CUMUL.	(E.M.R.)	CUMUL.	
	35					
		0	0	0.3	0.3	
	48					
		1.8	1.8	1.3	1.6	
	65					
		6.6	8.4	11.7	13.3	
	100					0.149
		8.5	16.9	7.3	20.6	
	150					
		8.5	25.4	12.6	33.2	
	200					0.074
		16.8	42.2	12.7	45.9	
	325					0.044
		57.8	100	54.1	100	
TOTALS		100		100		
		Sand Slimes (undated)		Tailings (undated)		
		0-15 cm	15-25 cm	0-15 cm	15-25 cm	
Sand		35	68	84	79	
Silt		64.9	32	16	21	
Clay		0.1	0	0	0	
TOTALS		100	100	100	100	
Estimated Hydraulic Conductivity,						
ft/s (approximate)		1.4E-05	6.4E-05	9.5E-05	8.7E-05	
m/d (approximate)		0.37	1.68	2.50	2.29	

TABLE 1-4. DISCHARGE FROM TAILINGS PONDS

Parameter	Units	TP-#1		TP #2		Units	TP-#1		TP #2	
Min.Daily Flow	USgpm	50	20	L/min	189	76				
Max.Daily Flow	USgpm	4500	550	L/min	17034	2082				
Min.Retention	Days	23	351	Days	23	351				
Min.Ann.Flow	USgpy	26,280,000	10,512,000	m ³ /a	99,480	39,792				
Max.Ann.Flow	USgpy	2,365,200,000	289,080,000	m ³ /a	8,953,228	1,094,283				
Average Daily Flows										
1987	USgpm	497	106	L/min	1881	401				
1988	USgpm	943	99	L/min	3570	375				
1989	USgpm	549	88	L/min	2078	333				
1990	USgpm	1071	121	L/min	4054	458				
Runoff		32.50%	29.50%							
Rain *ONLY**	TOTAL	NET	NET							
1987, mm/a	1032.4	335.5	304.6	m ³ /a	991,211	209,523				
1988, mm/a	1243.1	404.0	366.7	m ³ /a	1,193,504	252,283				
1989, mm/a	1191.1	387.1	351.4	m ³ /a	1,143,579	241,730				
1990, mm/a	1255.4	408.0	370.3	m ³ /a	1,205,314	254,780				
Annual Flows from Average of Measured Flows										
1987	USgpy	261,223,200	55,713,600	m ³ /a	988,834	210,898				
1988	USgpy	495,640,800	52,034,400	m ³ /a	1,876,199	196,971				
1989	USgpy	288,554,400	46,252,800	m ³ /a	1,092,294	175,085				
1990	USgpy	562,917,600	63,597,600	m ³ /a	2,130,868	240,742				
Annual Flows from Measured Flows										
1987				m ³ /a	649,429	142,668				
1988				m ³ /a	1,311,066	143,609				
1989				m ³ /a	788,838	135,966				
1990				m ³ /a	1,314,854	148,757				

TABLE 3-1. CHEMICAL ANALYSES - TAILINGS DRAINAGE (µg/L)

SAMPLE DATE	88-07-16	88-07-16	88-07-16	88-07-16	88-07-16	88-07-16	88-07-16	88-07-16	88-07-16	88-07-16	91-07-11	91-07-11	91-07-11
SAMPLE VOLUME											100	100	100
ASSAYERS CODE	532	560	536	537	534	538	533	564	565	2926	2927	2928	
SAMPLING LOCATION	LAKE #1	LAKE #1	TP-1	TP-1	TP-1/D	TP-1/D	TP-1/D	TP-2/D	TP-2/D	TP 1	TP 2	Lake #1	
										Discharge	Discharge	Upstream	
	101-LAKE	102-LAKE	1201-TP1	202-TP1	301-TP1/D	305-TP1/D	306-TP1/D	501-TP2/D	503-TP2/D			from TP1	
Temp. (C)	15.5	18.0	19.0	20.0	16	14.5	14.5	15	13.5				
pH	6.45	6.23	6.54	6.59	6.43	5.83	5.21	5.95	6.23	7.2	7.2	7.6	
Cond. (µmhos/cm)	220	30	100	100	90	95	95	180	140	68	115	160	
Eh (mV)													
Lab. pH	4.80	5.57	4.91	4.97	4.95	3.30	4.96	6.17	6.14				
ELEMENTS	At. Wght												
Al	26.9815	0.1	0.1	0.2	0.06	0.1	0.6	0.2	0.1	0.2	0.025	0.001	0.015
As	74.9216						0.2		0.03	0.02			
Ba	137.3300	0.02	1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.125	0.076	0.043
Ca	40.0800	9.9	5.8	19	18	18	9	20	33	26	13.2	23.4	9.7
Cd	112.4100		0.03	0.02		0.01	0.03	0.02	0.05	0.04	0.007	0.003	
Cu	63.5460	0.01	0.03	0.01	0.03	0.01	0.08	0.02	0.03	0.05	0.024	0.024	0.185
Fe	55.8470	0.3	0.1	0.1	0.04	0.1	0.2	0.1	0.05	0.02	0.2		0.1
K	39.0983	1	1	2	1	1	2	2	2	4	2		2
Mg	24.3050	0.8	0.5	0.9	0.8	0.9	1.6	1	1.9	1.7	0.712	1.41	0.948
Mn	54.9380	0.08	0.02	0.2	0.1	0.2	1	0.2	0.3	0.1	0.116	0.213	0.02
Na	22.9898	1	1.5	1	1	2	1	2	4.2	3.7	1.83	2.61	2.61
Ni	58.7000	0.01	0.01	0.01			0.02		0.01	0.02	0.018	0.01	
Pb	207.2000		0.07	0.1	0.07	0.1	0.1	0.1	0.1	0.09	0.094	0.041	
S	32.0660	1.7	1.8	12	10	11	16	11	26	20	6.1	11.4	4.3
Si	28.0855	0.5					2.1				0.15	0.51	0.46
Sr	87.6200	0.02	0.02	0.05	0.05	0.05	0.04	0.06	0.1	0.08	0.046	0.082	0.033
Zn	65.3800	0.01	0.1	1.8	1.7	1.9	4.2	1.7	4.1	2.8	1.44	1.93	0.166
Cl	35.453										1	1.4	1.2
HCO3	61.01	6.1	29.9	7.3	21.9	33.5	21.9	11.6	37.8	59.1	30.5	61	36.6
SO4	96.06										18.4	34.3	13
CATION SUM, e.p.m.	0.65	0.44	1.21	1.10	1.17	0.92	1.31	2.19	1.82	0.91	1.47	0.74	
ANION SUM, e.p.m.	0.21	0.60	0.87	0.98	1.24	1.36	0.88	2.24	2.22	0.91	1.75	0.90	
RATIO	3.18	0.73	1.39	1.12	0.94	0.68	1.49	0.98	0.82	1.00	0.84	0.82	
ERROR %	52.12%	-15.32%	16.32%	5.56%	-2.87%	-19.25%	19.67%	-1.18%	-9.91%	-0.00%	-8.82%	-9.63%	

SAMPLE DATE	91-08-21	91-08-20	91-08-19	91-08-22	91-08-22	91-08-19	91-08-19	91-08-19	91-08-19	91-08-19	91-08-19	91-08-19
SAMPLE VOLUME	150	150	150	150	150	150	150	150	150	150	150	150
ASSAYERS CODE	3204	3203	3192	3205	3206	3193	3194	3195	3196	3197	3198	3199
SAMPLING LOCATION	LK2 BYP	TP 1	TP 2	TP 2R	TP 2R	D2	D3	D4	D5	D6	D7	D8
	Bypass	Discharge	Discharge	Decant	Pipe Discharge	Discharge						
		At culver				TP 2						
Temp. (C)	12.5	16	18	16.9	16.1	18.1	18	19.6	18.9	19.5	18	18.9
pH	6.4	6.54	6.96	6.94	6.77	7.13	6.63	6.84	6.78	6.74	6.62	6.82
Cond. (umhos/cm)	90	75	158	110	150	138	158	130	129	212	141	118
Eh (mV)												
Lab. pH												
ELEMENTS At.Wght												
Al	26.9815	2										1
As	74.9216			I			1	2				1
Ba	137.3300											
Ca	40.0800		14	2		9	3	2			12	
Cd	112.4100											
cu	63.5460		0.035	0.04		0.035						
Fe	55.8470											
K	39.0983			3	2	3	1			2	1	1
Mg	24.3050		2	1	3		3					2
Mn	54.9380										10	
Na	22.9898											
Ni	58.7000			2			2	2				2
Pb	207.2000			3			3	3				3
S	32.0600	10	9	16	14	16	14	13	12	10	10	11
Si	28.0855											
Sr	87.6200											
Zn	65.3800	0.18	232	249	256	293	24	208	1.09	.11	0.52	1.01
Cl	35.453											
HCO3	61.01											
SO4	96.06											
CATION SUM, e.p.m.	0.01	1.16	0.43	0.38	0.62	0.59	0.26	0.24	0.09	1.00	0.03	0.23
ANION SUM, e.p.m.	0.62	0.56	1.00	0.87	1.00	0.87	0.81	0.75	0.62	0.62	0.69	0.69
RATIO	0.01	2.06	0.43	0.43	0.62	0.68	0.32	0.32	0.14	1.61	0.05	0.33
ERROR %	-98.25%	34.68%	-39.45%	-39.77%	-23.63%	-19.15%	-51.37%	-51.20%	-75.99%	23.37%	-91.38%	-50.61%

SAMPLE DATE	91-08-19	91-08-19	91-08-20
SAMPLE VOLUME	150	150	150
ASSAYERS CODE	3200	3201	3202
SAMPLING LOCATION	D9	D10	D10-R
	Discharge	Discharge	Discharge
	TP 2	TP1/TP2	TP1/TP2
Temp. (C)	15	17	12.5
pH	6.39	6.2	6.46
Cond. (umhos/cm)	110	100	40
Eh (mV)			
Lab. pH			
ELEMENTS At. Wght			
Al	26.9815		
As	74.9216		
Ba	137.3300		
Ca	40.0800		
Cd	112.4100		
cu	63.5460		
Fe	55.8470		
K	39.0983	5	
Mg	24.3050	3	4
Mn	54.9380		
Na	22.9898		
Hi	58.7000		
Pb	207.2000		
S	32.0600	7	8 3
Si	28.0855		
Sr	87.6200		
Zn	65.3800	1.73	0.79 0.19
Cl	35.453		
HCO3	61.01		
SO4	96.06		
CATION SUM, e.p.m.	0.43	0.35	0.02
ANION SUM, e.p.m.	0.44	0.50	0.19
RATIO	0.98	0.71	0.13
ERROR %	-1.04%	-17.10%	-77.13%

TABLE 4-1. Results of BALANCE Calculations

```

=====
Sample      Tailings Tailings
            pond #1  Pond #2

            from      Pure H2O  Pure H2O
-----
Calcite     0.2449    0.4288
Albite     0.0386    0.0740
Chlorite    0.0087    0.0193
Epidote     0.0422    0.0775
Sericite    0.0639    0.0000
Barite      0.0009    0.0006
Halite      0.0282    0.0395
CO2 gas     0.2550    0.5711
Pyrite      0.2445    0.3010
Chalcopyr   0.0004    0.0004
Galena      0.0005    0.0002
Sfalerite   0.0220    0.0295
O2 gas      0.9763    1.2128
Fe-hydrox   -0.2933   -0.3944
silica      -0.4658   -0.5043
Al-sulfat   -0.3229   -0.2774
=====
Positive values indicate dissolution,
negative values precipitation.

```

TABLE 4-2. Mixtures of Tailings Pond #2 Water into Tailings Pond #1 Water.

	TP #1 WATER	1 TP2+ 9 TP1	1 TP2+ 7 TP1	1 TP2+ 4 TP1	1 TP2+ 1.5 TP1	1 TP2+ 1 TP1	TP #2 WATER
Added S:	0.02891					Ca:	0.07735
Fraction	0.000	0.100	0.125	0.200	0.400	0.500	1.000
Temp., C	16.00	16.00	16.00	16.00	16.00	16.00	16.00
pH, units	7.20	7.20	7.20	7.20	7.20	7.20	7.20
pE, units	6.10	6.07	6.07	6.06	6.04	6.04	6.10
S	0.19156	0.23413	0.23755	0.24780	0.27513	0.28879	0.35711
Ca	0.32936	0.36255	0.37085	0.39574	0.46212	0.49531	0.58391
Mg	0.02929	0.03216	0.03288	0.03503	0.04077	0.04365	0.05800
Zn	0.02203	0.02278	0.02297	0.02353	0.02503	0.02578	0.02953
Al	0.00093	0.00084	0.00082	0.00075	0.00057	0.00048	0.00004
Mn	0.00211	0.00229	0.00233	0.00246	0.00282	0.00299	0.00388
Fe	0.00358	0.00340	0.00336	0.00322	0.00287	0.00269	0.00179
cu	0.00038	0.00038	0.00038	0.00038	0.00038	0.00038	0.00038
Pb	0.00045	0.00043	0.00042	0.00040	0.00035	0.00033	0.00020
Ba	0.00091	0.00087	0.00087	0.00084	0.00077	0.00073	0.00055
Na	0.07961	0.08300	0.08385	0.08639	0.09318	0.09657	0.11354
Cl	0.02821	0.02934	0.02962	0.03047	0.03272	0.03385	0.03949
C	0.49829	0.54812	0.56058	0.59796	0.69763	0.74746	0.99664
Si	0.00250	0.00310	0.00325	0.00370	0.00491	0.00551	0.00853
K	0.05115	0.04604	0.04476	0.04092	0.03069	0.02558	NA
Saturation Indices	LOG[IAP/KT]						
Barite	0.258	0.260	0.260	0.259	0.253	0.247	0.190
Calcite	-1.744	-1.664	-1.646	-1.592	-1.464	-1.408	-1.174
Quartz	-1.451	-1.357	-1.336	-1.280	-1.157	-1.107	-0.917
Kaolinite	2.024	2.124	2.141	2.180	2.189	2.143	0.293
Muscovite	1.384	1.488	1.503	1.522	1.409	1.259	
Nontronite	20.808	21.097	21.158	21.321	21.634	21.741	21.736
Chlorite	22.652	22.834	22.865	22.929	22.908	22.795	19.570
Pyrite	-126.034	-125.649	-125.572	-125.373	-125.061	-126.016	-125.999
Chalcopyrite	-128.226	-127.800	-127.715	-127.497	-127.161	-127.120	-128.267
Galena	-66.686	-66.525	-66.495	-66.421	-66.340	-66.359	-67.116
Sfalerite	-68.000	-67.852	-67.806	-67.683	-67.472	-67.425	-67.824
Al(OH) ₃	0.592	0.548	0.536	0.499	0.381	0.307	-0.807
Diaspore	2.450	2.406	2.395	2.357	2.239	2.166	1.051
Fe(OH) ₂	7.226	7.206	7.201	7.186	7.141	7.116	6.960
Hematite	18.729	18.681	18.668	18.631	18.523	18.465	18.113
Mg-Ferrite	6.926	6.916	6.913	6.901	6.854	6.823	6.500
Cuferrite	15.737	15.681	15.667	15.623	15.500	15.434	15.046
Tenorite	-0.901	-0.909	-0.911	-0.917	-0.932	-0.940	-0.976
Cerussite	-0.499	-0.514	-0.519	-0.533	-0.579	-0.607	-0.800
Smithsonite	-1.109	-1.058	-1.046	-1.011	-0.927	-0.889	-0.729
ZnSiO ₃	0.685	0.790	0.814	0.878	1.019	1.078	1.304
Gypsum	-2.463	-2.402	-2.388	-2.347	-2.248	-2.204	-2.016

Temperature, pH and PE estimated; concentrations in millimole/L.

Table 5-1. CHEMICAL ANALYSES OF "EFFLUENTS" FROM LEACH TESTS
A. Ba-rich Tailings

SAMPLE DATE	89-05-01	90-03-01	89-05-01	90-03-01	89-05-01	90-03-01
SAMPLE VOLUME	(taken from original 500 mL)					
ASSAYERS CODE	1611	1598	1608	1601	1606	1599
SAMPLING LOCATION	START	END	START	END	START	END
	Ba-rich	Ba-rich	Ba-rich	Ba-rich	Ba-rich	Ba-rich
	Tap Water	Tap Water	Tap Water	Tap Water	Tap Water	Tap Water
			with O ₂	with O ₂	w. Acid	w. Acid
PROCESSING CODE	B6A	81	83A	84	B1A	82
	FA	FA	FA	FA	FA	FA
Temperature, C	17.0	21.0	17.5	21.0	17.5	21.0
pH, units	6.69	5.81	7.07	5.9	4.23	4.9
Cond., microS/cm	1200	2200	1700	2000	11000	26000
ELEMENTS	AT. WGT Concentrations in mg/L:					
Al	26.9815	0.4	0.01	1.1	0.3	14
B	9.0122				3.3	5.6
Ca	40.0800	511	855	1037	1395	9127
Cd	112.4100	0.2	0.08	0.1	0.4	2.8
Cu	63.5460	0.04	0.01	0.1	0.07	6.7
Fe	55.8470	8.3				41
K	39.0983	17	22	25	29	31
Mg	24.3050	17	0.09	23	41	110
Mn	54.9380	2.1	0.1	3.8	0.1	95
Na	22.9898	24	52	30	42	34
Ni	92.9064	1.2	0.02	0.2	0.2	1.1
Pb	207.2000	3.4	0.1	5.3	5.1	48
S	32.0600	679	752	590	879	504
Si	28.0855	3.4	3.7	5.3	6.1	32
Sr	87.6200	0.2	0.4	0.3	0.4	2.1
Zn	65.3800	9.5	18	11	23	530
	milli-equivalents/L:					
SUM of CATIONS	29.15	46.07	56.25	76.37	490.31	328.64
SUM of ANIONS	42.36	46.91	36.81	54.83	31.44	35.43
ION-BALANCE ERROR	-18.46%	-0.91%	20.89%	16.41%	87.95%	80.53
	mg/L:					
SUM (HMETALS)/L	701	770	607	907	1124	844
(HMETALS+S)/500 mL	351	385	303	454	562	422
% of SULFIDES *	1.17%	1.28%	1.01%	1.51%	1.87%	1.41
Fe/L lost (=FeX/L)	1184	1325	1039	1552	1303	1211
(HMETALS+S+FeX)/L	1886	2095	1645	2460	2427	2055
same/500 mL	943	1048	823	1230	1214	1028
% of SULFIDES *	3.14%	3.49%	2.74%	4.10%	4.05%	3.43

* Based on average of 6% metal-sulfides in tailings.

Table 5-1. CHEMICAL ANALYSES OF "EFFLUENTS" FROM LEACH TESTS
8. Ba-free Tailings

SAMPLE DATE	89-05-01	90-03-01	89-05-01	90-03-01	89-05-01	90-03-01	
SAMPLE VOLUME	(taken from original 500 mL)						
ISSAYERS CODE	1607	1602	1610	1600	1609	1603	
SAMPLING LOCATION	START Ba-free Tap Water	END Ba-free Tap Water	START Ba-free Tap Water with 02	END Ba-free Tap Wdter with 02	START Ba free Tap Water w.Acid	END Ba-free Tap Water w.Acid	
PROCESSING CODE	B2A FA	85 FA	B5A FA	83 FA	B4A FA	B6 FA	
Temperature, C	17.0	21.0	17.0	21.0	17.0	21.0	
pH, units	5.29	5.87	6.85	5.9	3.66	4.7	
Cond., microS/cm	600	2000	700	2600	22000	26000	
ELEMENTS	AT.WGHT	Concentrations in mg/L:					
Al	26.9815	0.3	0.6	0.4	0.2	35	0.9
B	9.0122		3.6		2.7		2.4
Ca	40.0800	277	1745	323	1259	15140	6666
Cd	112.4100	0.1	0.5	0.1	0.4	2.7	2.2
Cu	63.5460	0.05	0.1	0.07	0.08	5.1	0.2
Fe	55.8470	5.1	6.2	6.8		344	
K	39.0983	24	33	14	29	187	34
Mg	24.3050	14	32	14	33	187	266
Mn	54.9380	4.3	8.8	5.2	1.9	180	153
Na	22.9898	18	23	19	30	24	22
Ni	92.9064	0.2	0.2	0.9	0.1	2.7	1.1
Pb	207.2000	4.5	7.8	4.2	2.5	60	61
S	32.0600	207	999	234	884	181	786
Si	28.0855	5.2	7.7	4.2	4.3	60	15
Sr	87.6200	0.3	0.7	0.3	0.6	6	4.5
Zn	65.3800	11	47	15	38	627	605
		milli-equivalents/L:					
SUM of CATIONS		17.16	93.74	19.47	68.92	820.09	381.49
SUM of ANIONS		12.91	62.32	14.60	55.15	11.29	49.03
ION-BALANCE ERROR		14.11%	20.13%	14.31%	11.10%	97.28%	77.22%
		mg/L:					
SUM (HMETALS+S)/L		228	1060	261	925	1215	1453
(HMETALS+S)/500 mL		114	530	130	462	607	727
% of SULFIDES *		0.38%	1.77%	0.43%	1.54%	2.02%	2.42%
Fe/L lost (=FeX/L)		366	1776	415	1573	525	1903
(HMETALS+S+FeX)/L		594	2837	676	2498	1739	3356
same/500 mL		297	1418	338	1249	870	1678
% of SULFIOES *		0.99%	4.73%	1.13%	4.16%	2.90%	5.59%

* Based on average of 6% metal-sulfides in tailings.

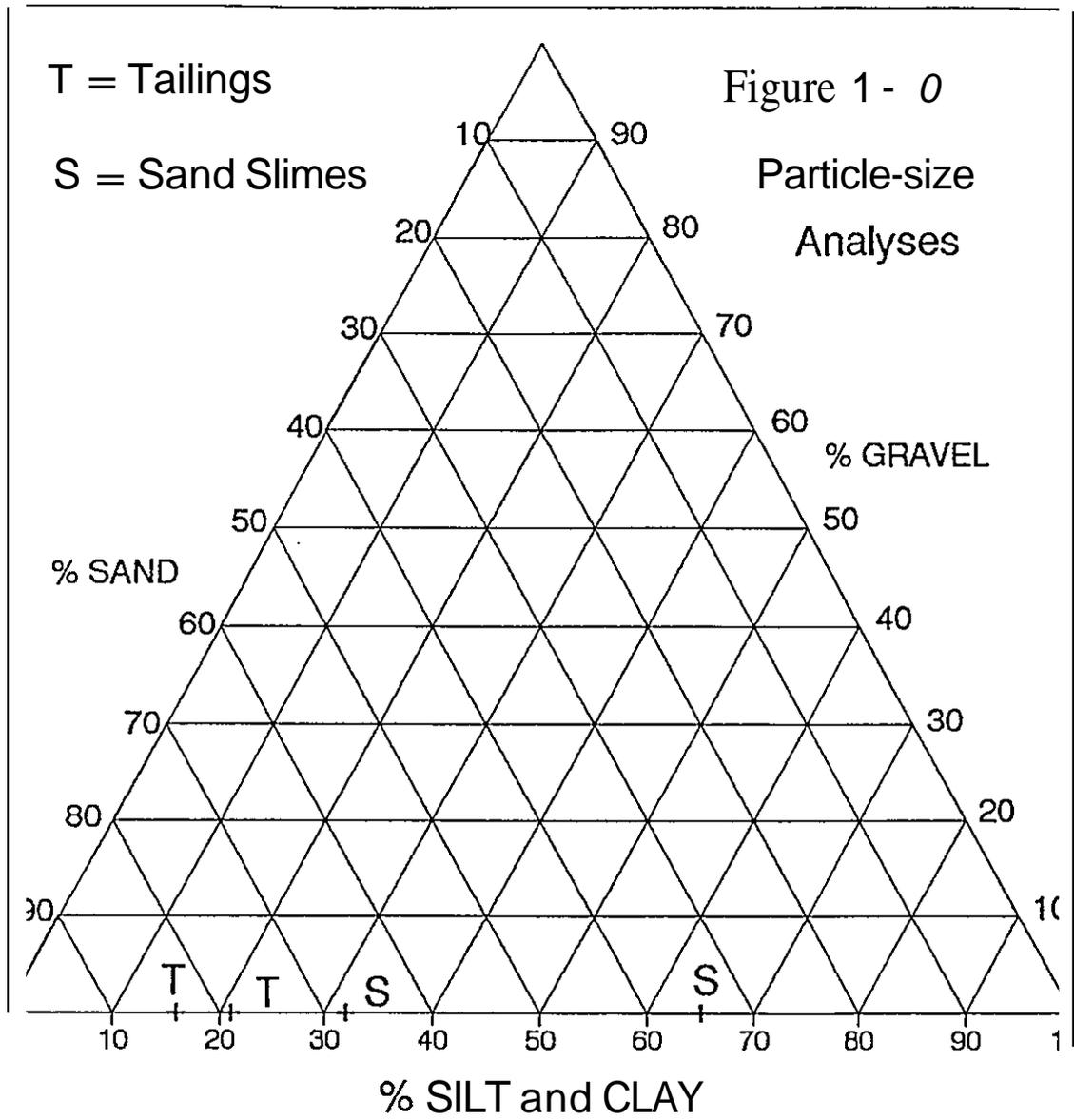


Figure 1-1
TAILINGS POND #1: DISCHARGE

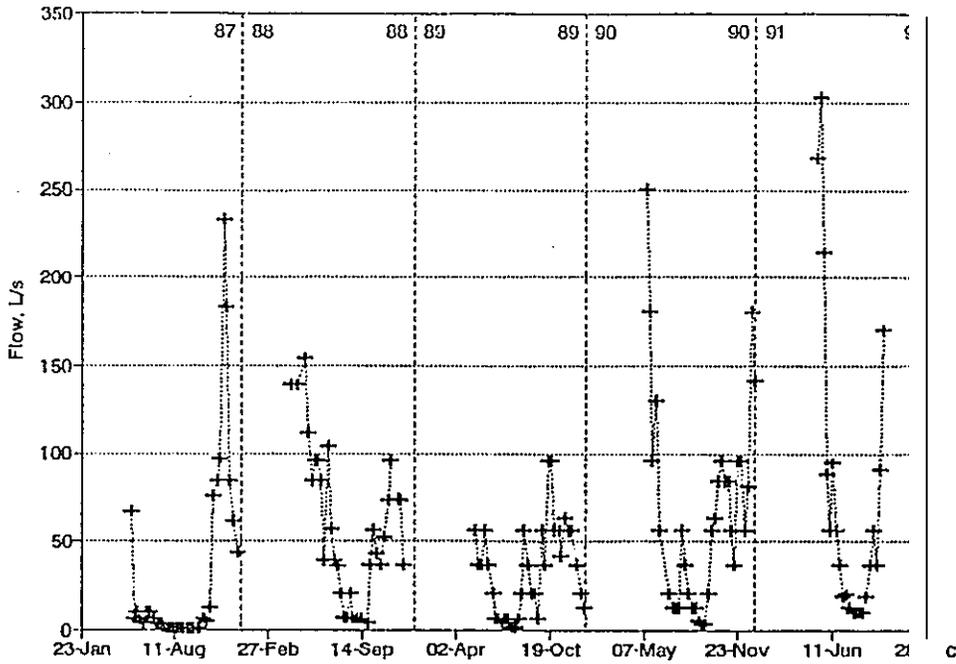


Figure 1-2
TAILINGS POND #2: DISCHARGE

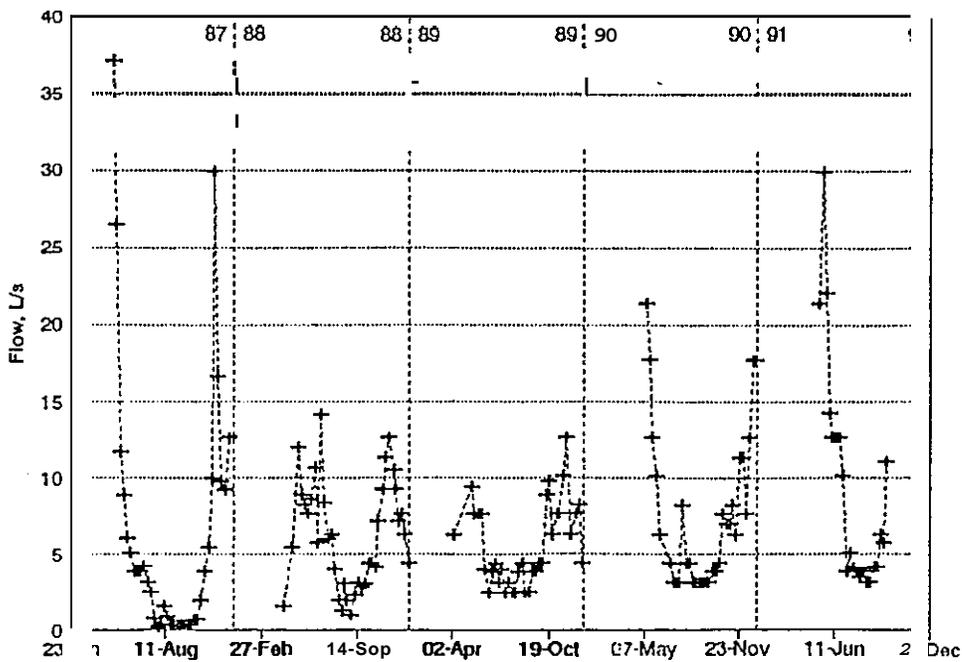


Figure 1-3
SIMMS BROOK: DISCHARGE

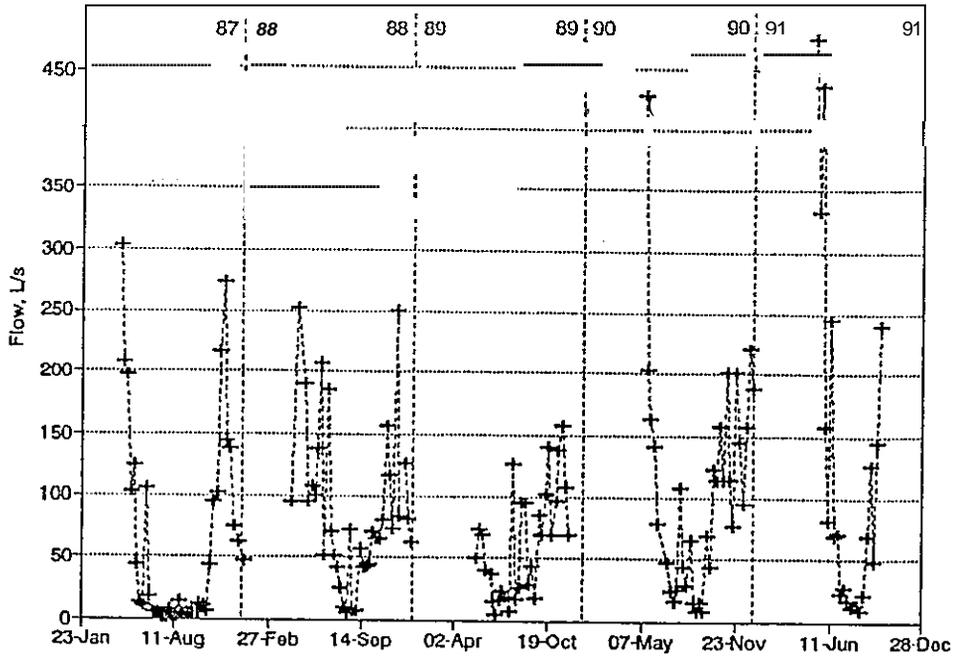


Figure 1-4
TP1, TP2 and SIMMS BROOK DISCHARGE

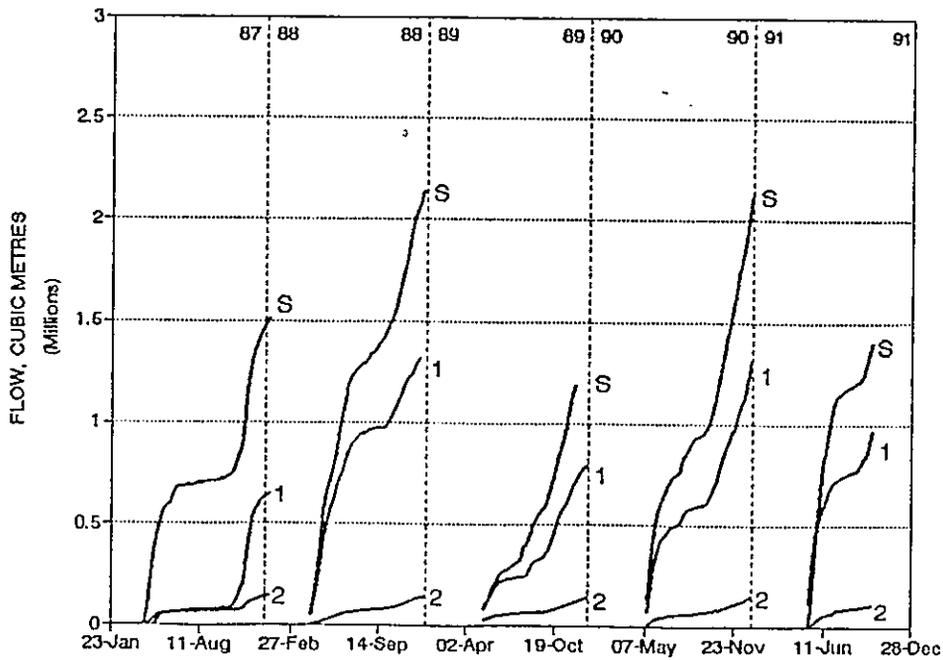


Figure 2-1
TAILINGS POND #1 EFFLUENT: pH

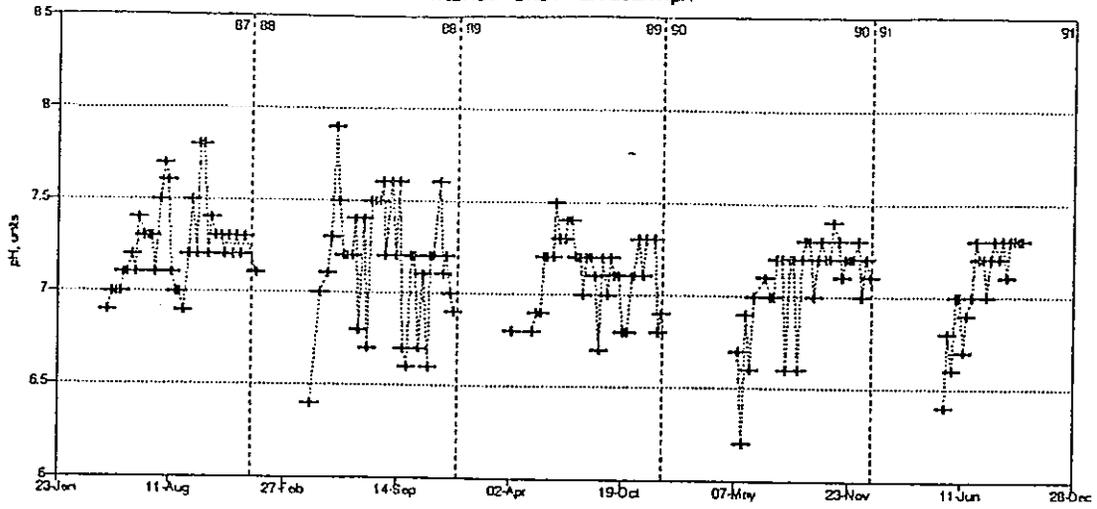


Figure 2-2
TAILINGS POND #2 EFFLUENT: pH

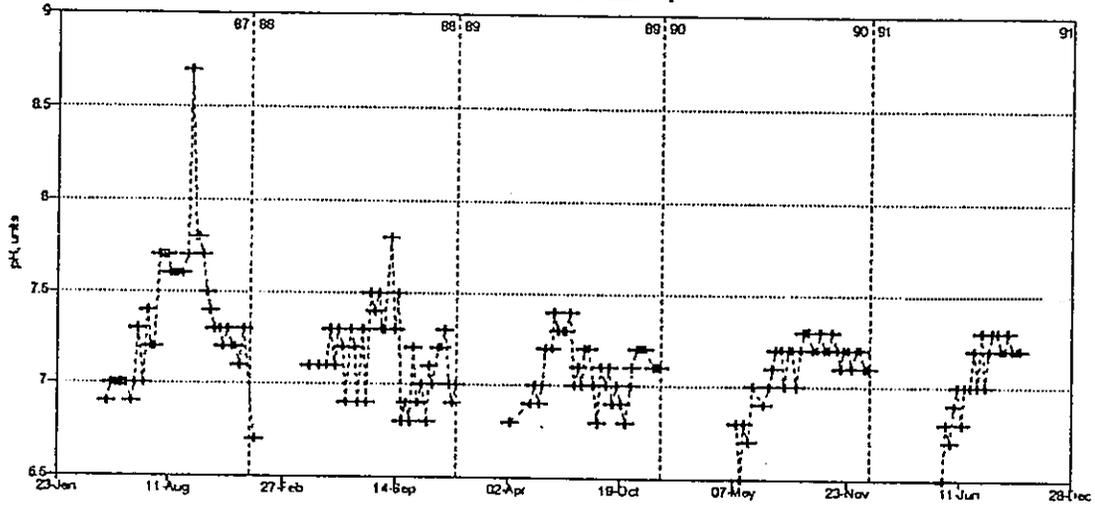


Figure 2-3
SIMMS BROOK WATER: pH

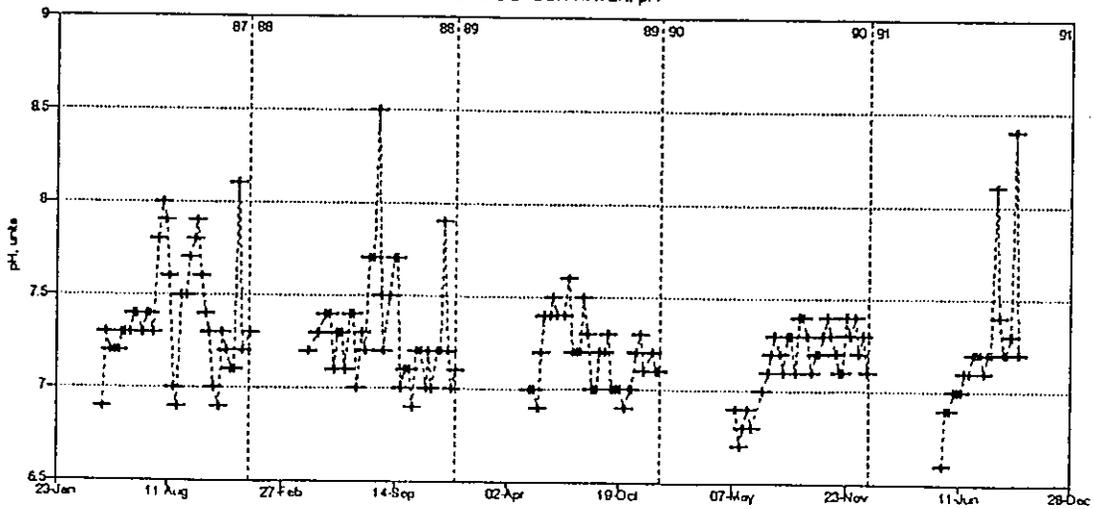


Figure 2-4
TAILINGS POND #1 EFFLUENT: Cu

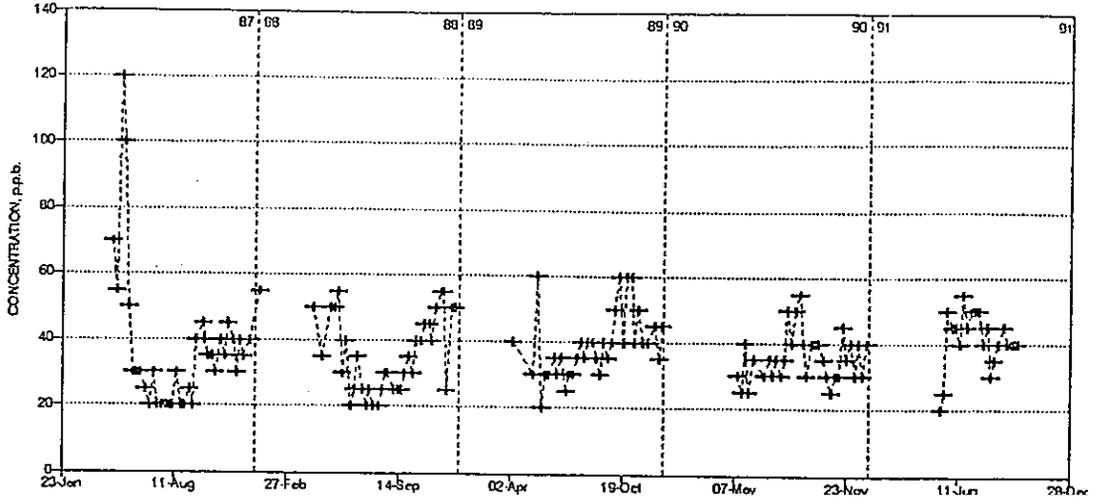


Figure 2-5
TAILINGS POND #2 EFFLUENT: Cu

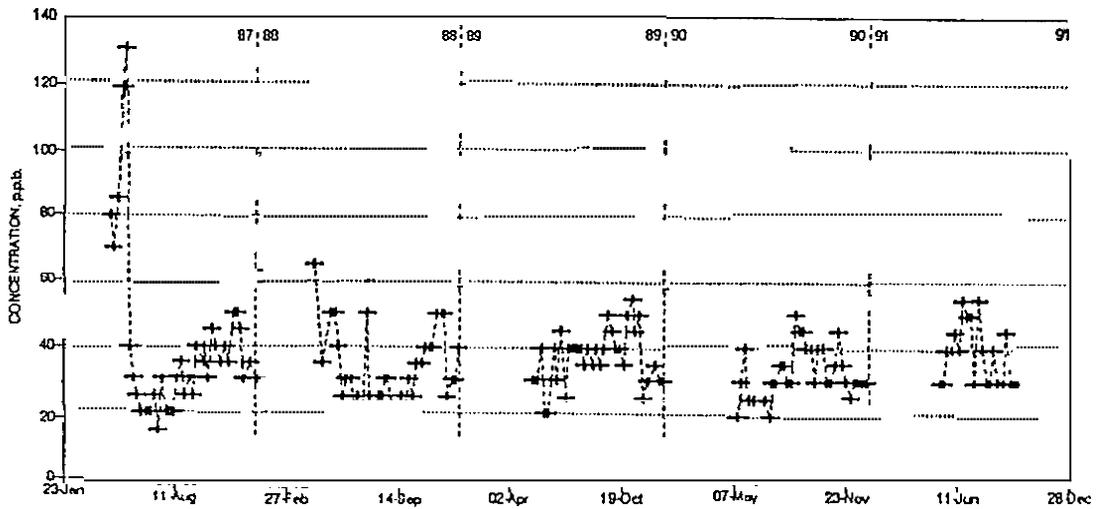
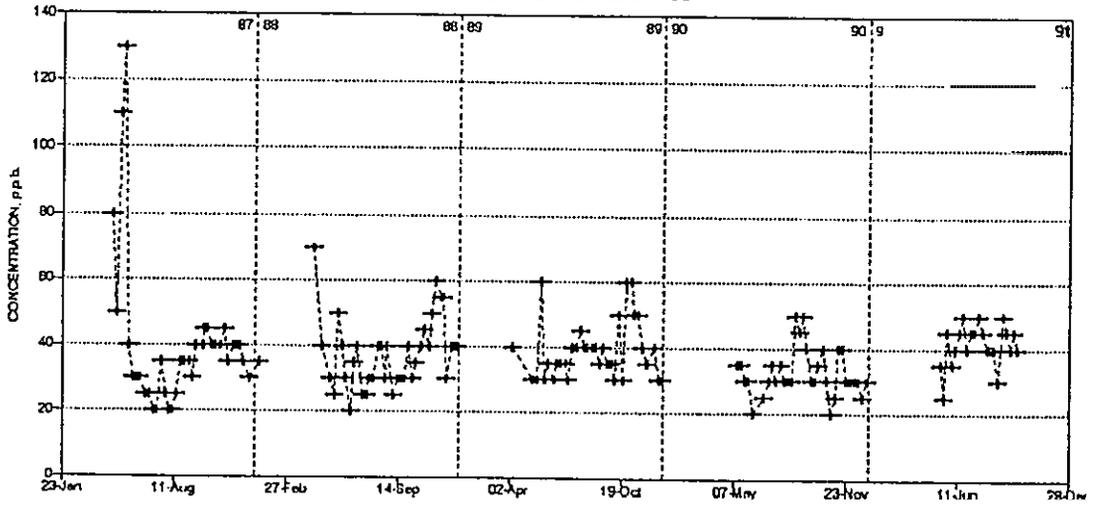


Figure 2-7
TAILINGS POND #1 EFFWEM: Zn

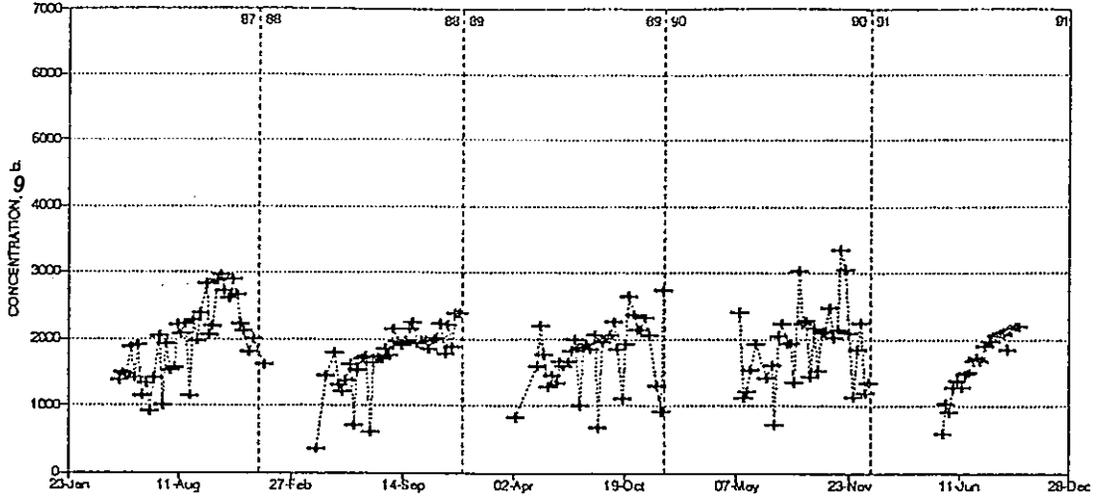


Figure 2-8
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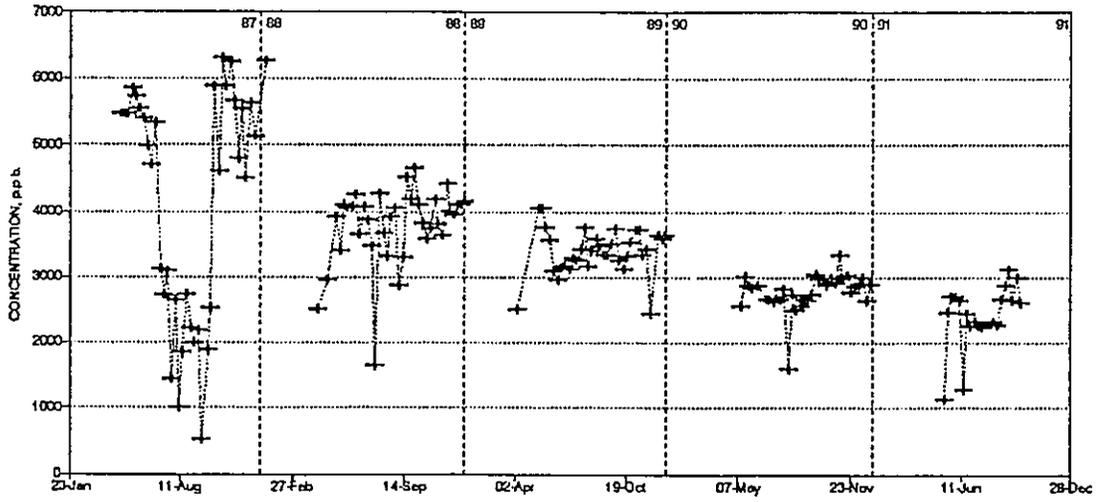


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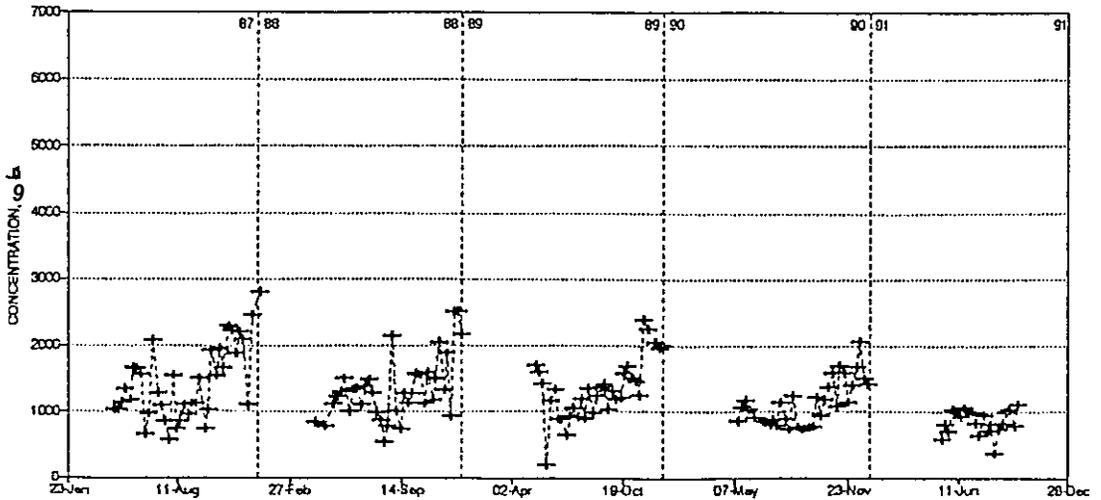


Figure 2.10
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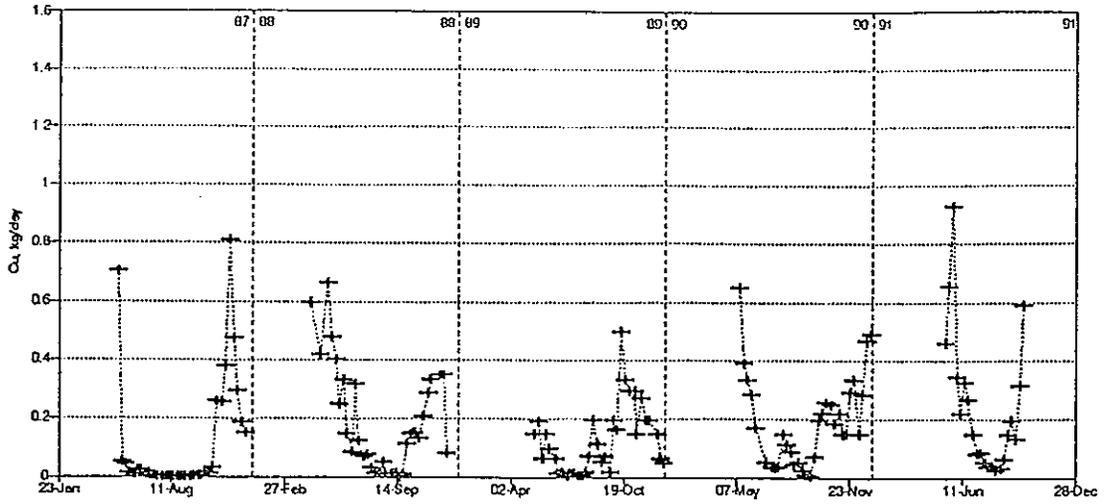


Figure 2-11
TAILINGS POND #2 Cu LOADING

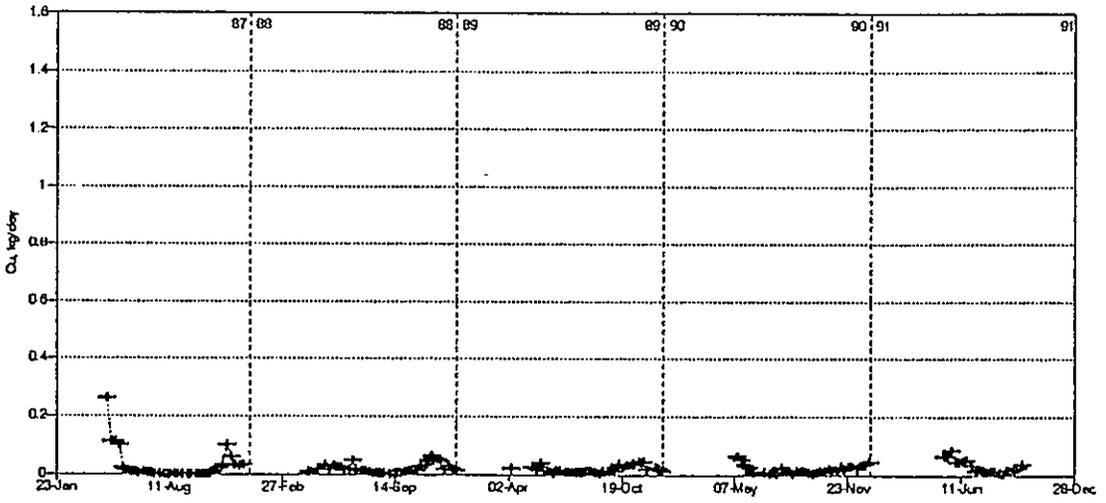


Figure 2-12
SIMMS BROOK: Cu LOADING

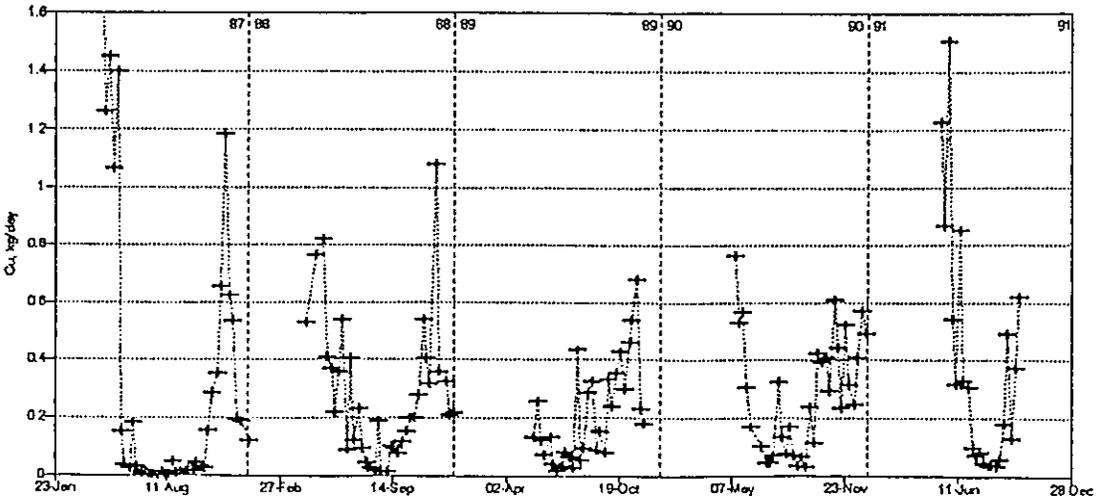


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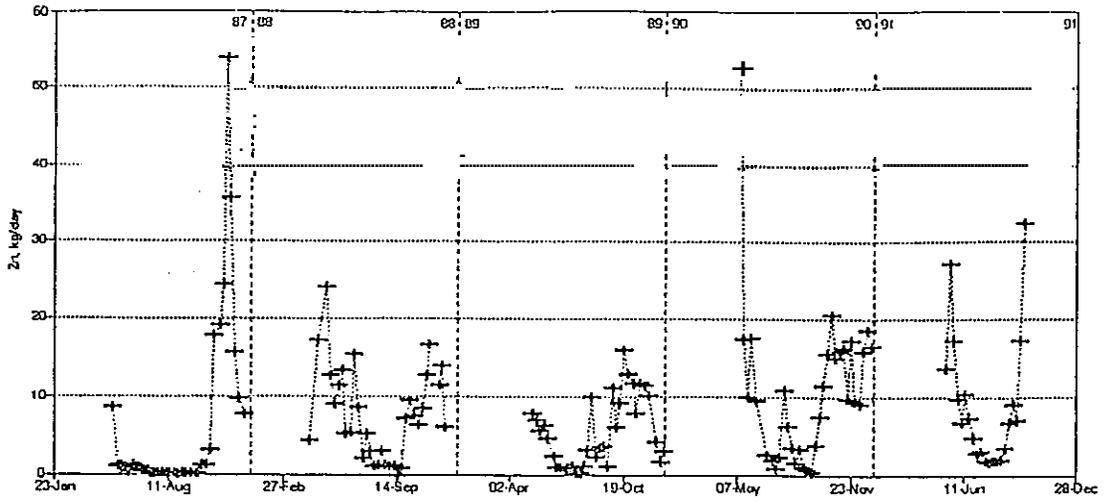


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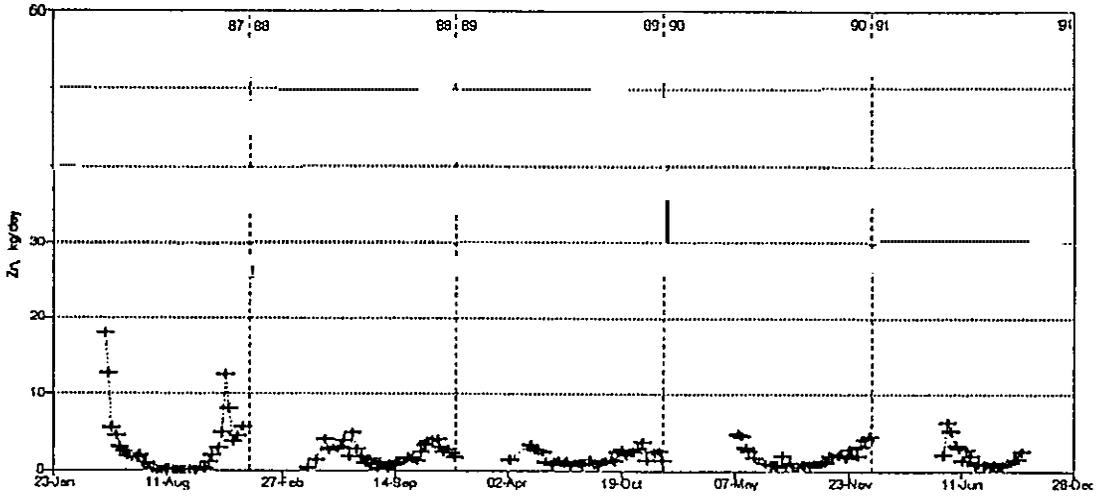


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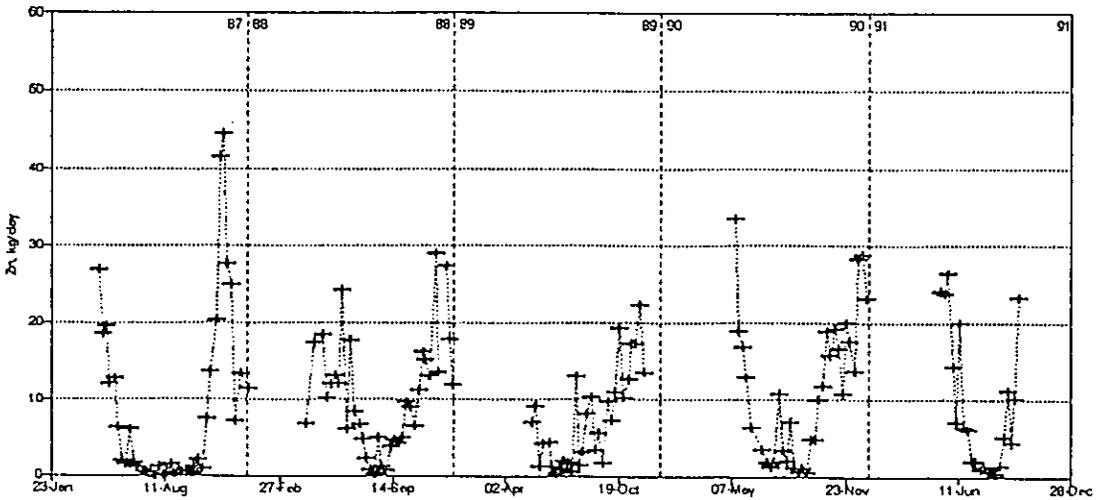


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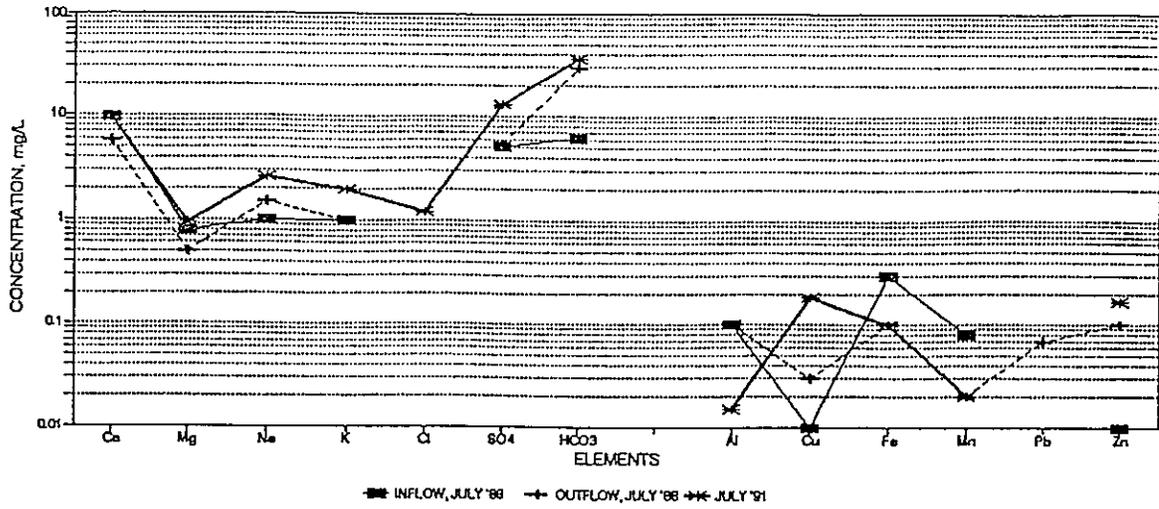


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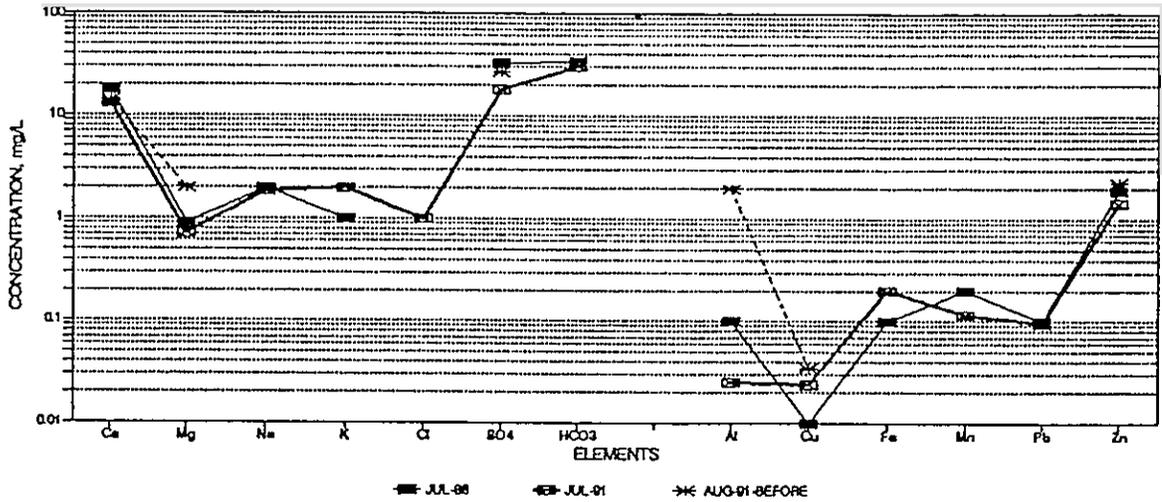


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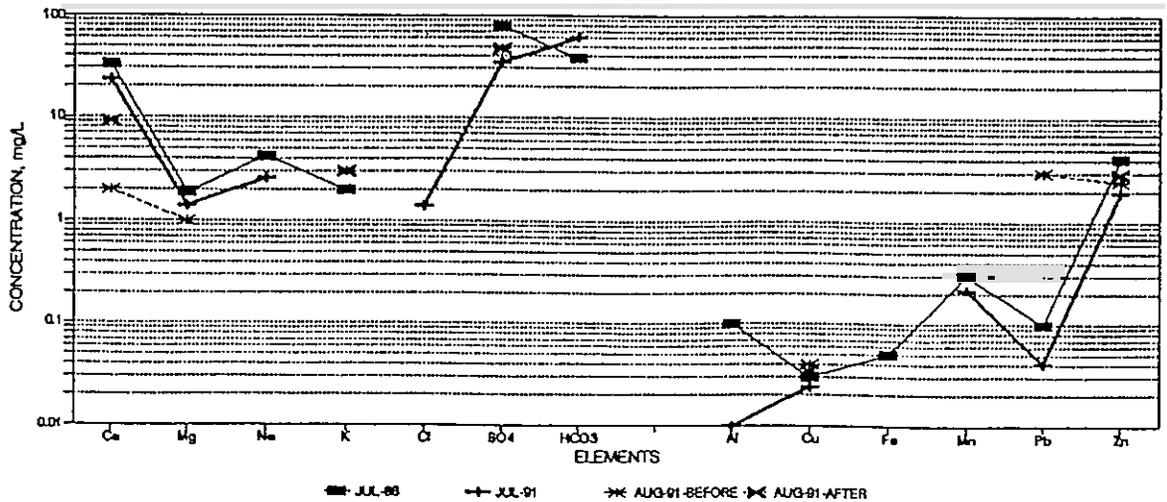


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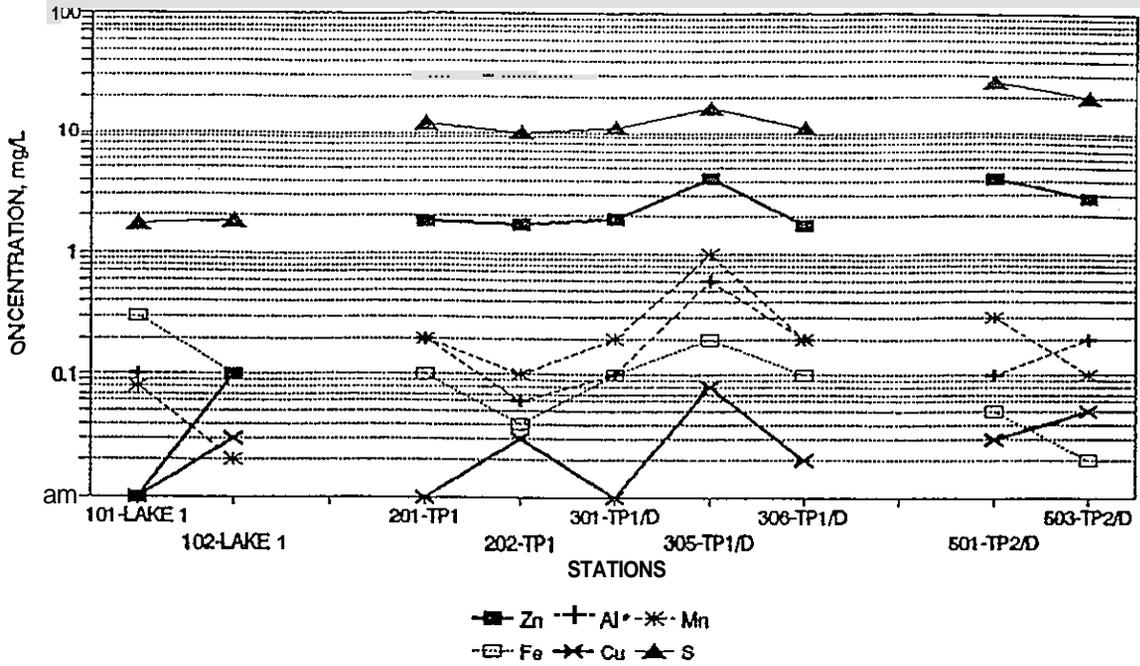


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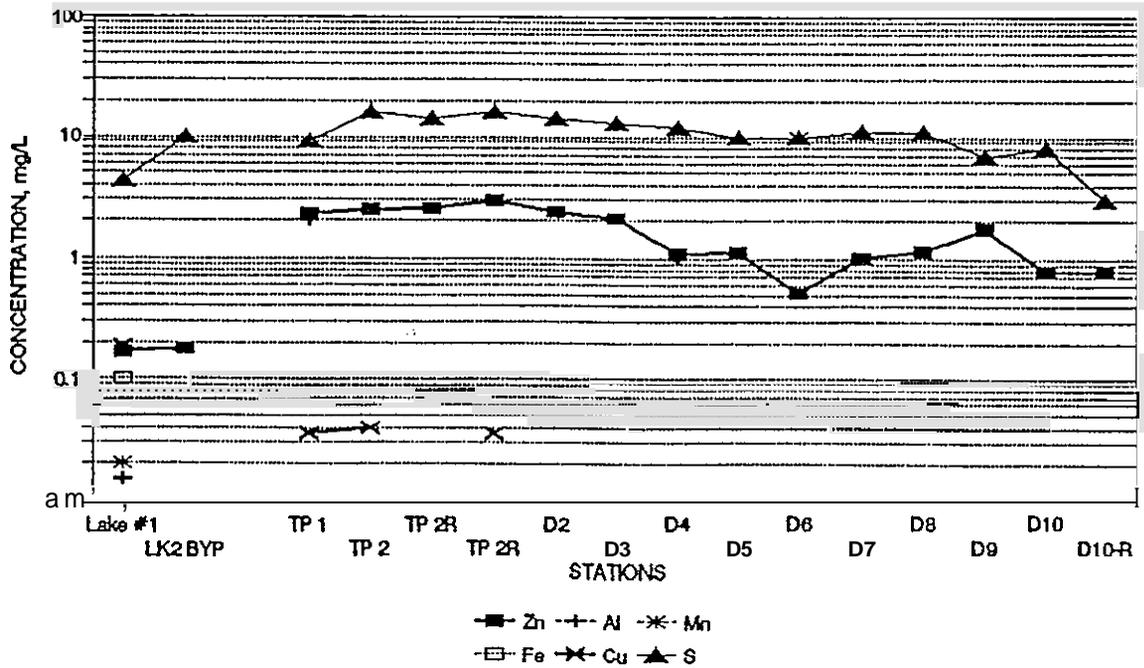


Figure 4-1
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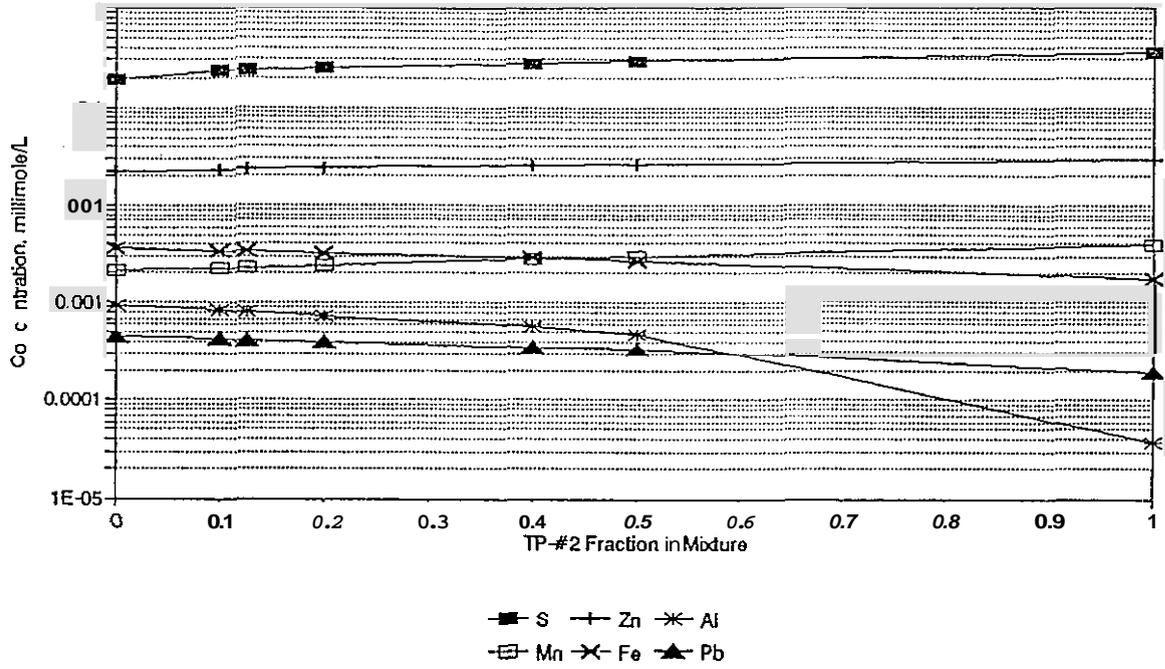


Figure 4-2
TP-#2 DISCHARGE INTO TP-#1 DISCHARGE

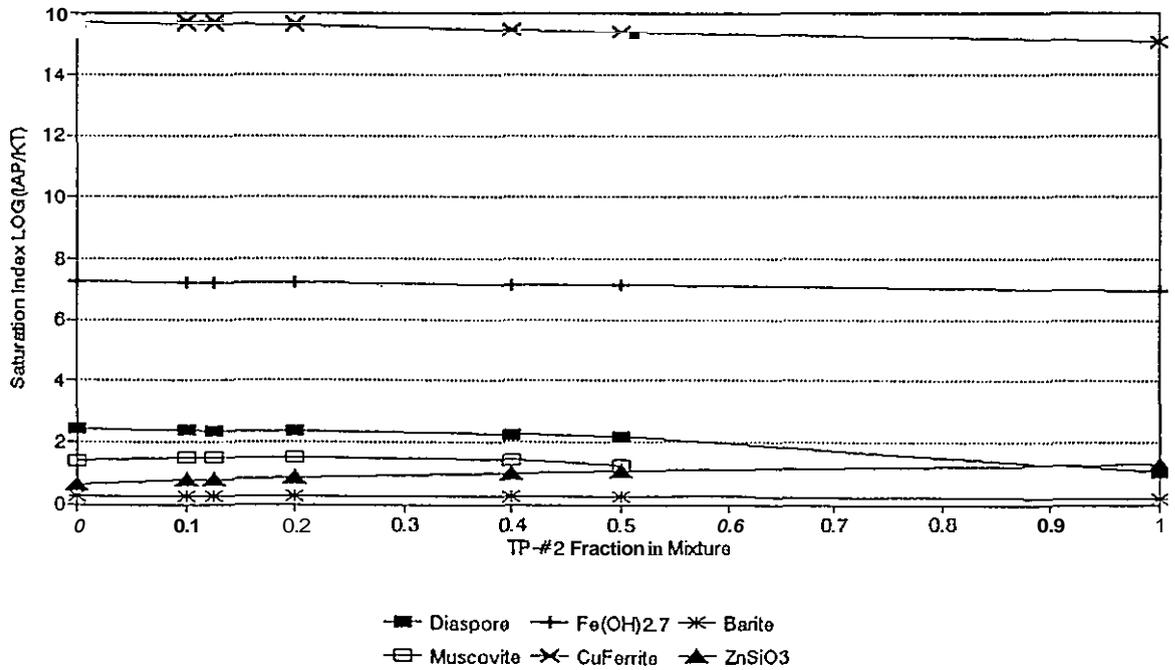


Figure 5-1
BARITE-RICH TAILINGS. +WATER

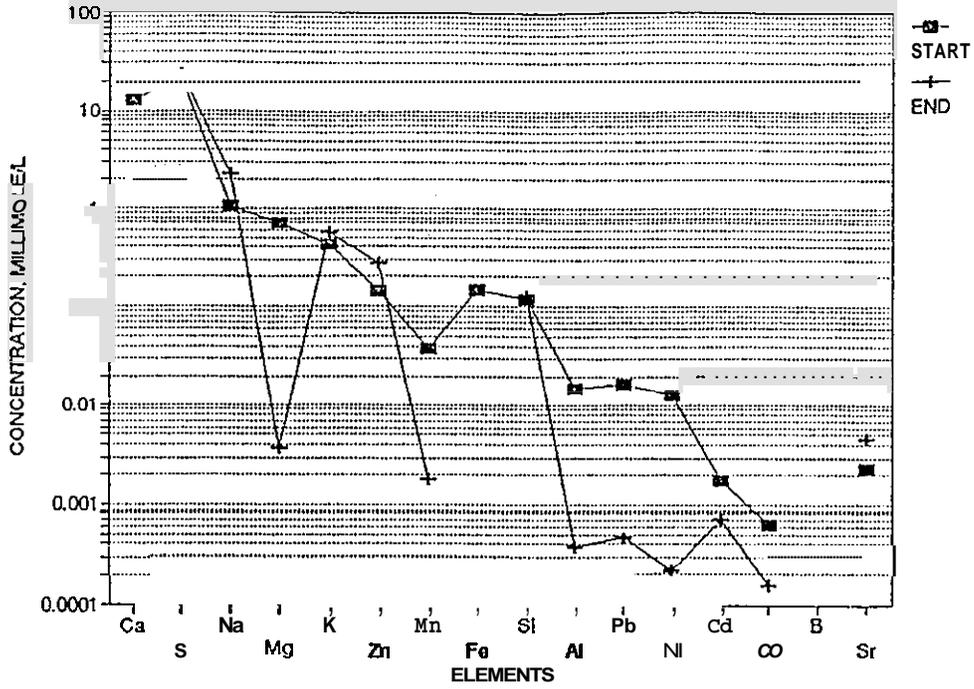


Figure 5-2
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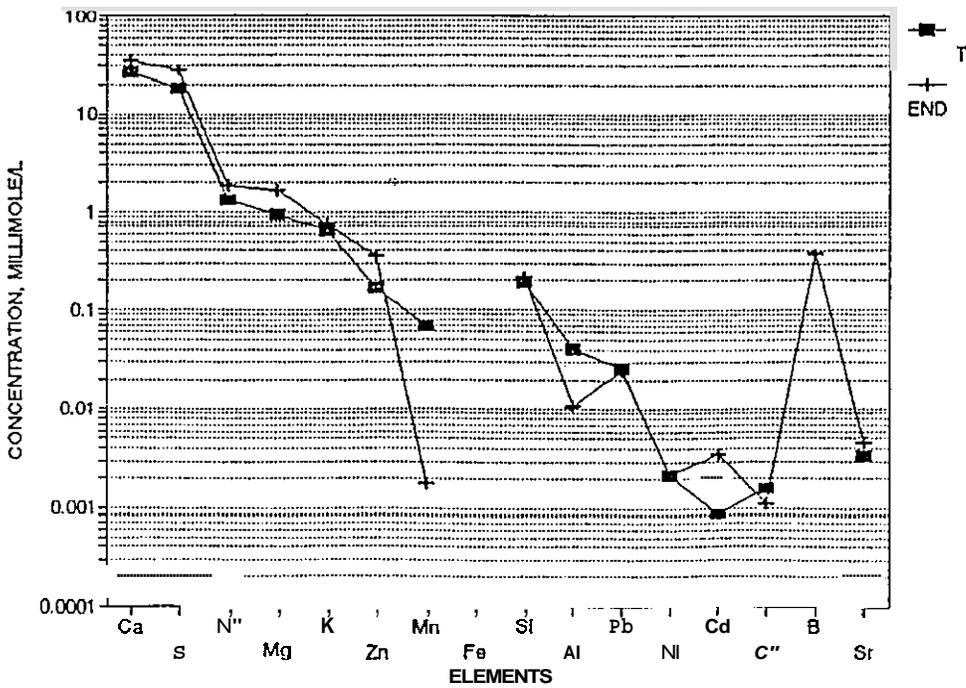


Figure 5-3
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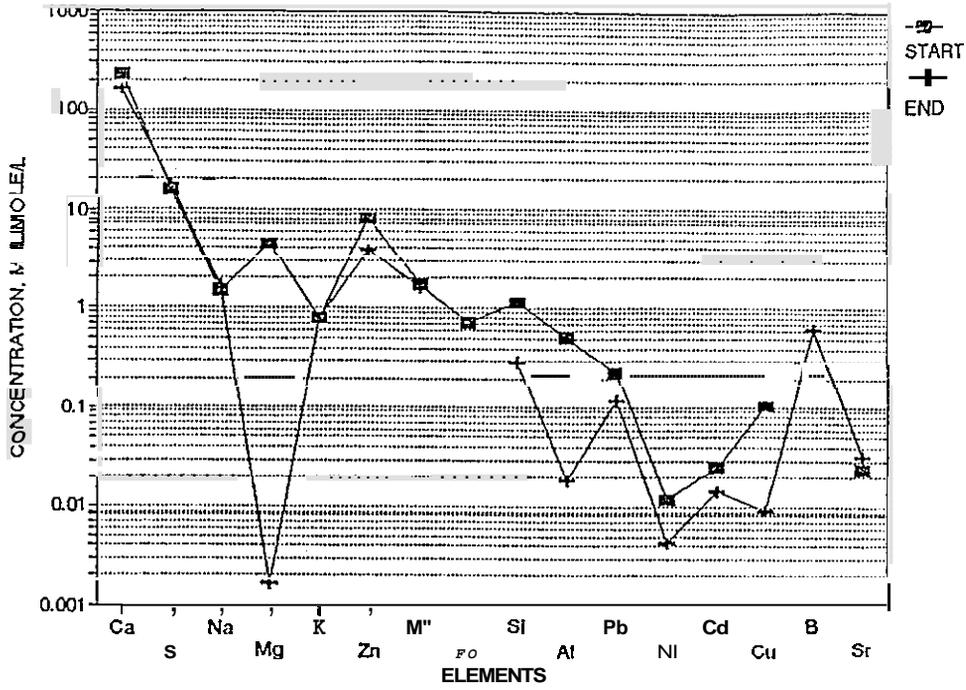


Figure 5-4
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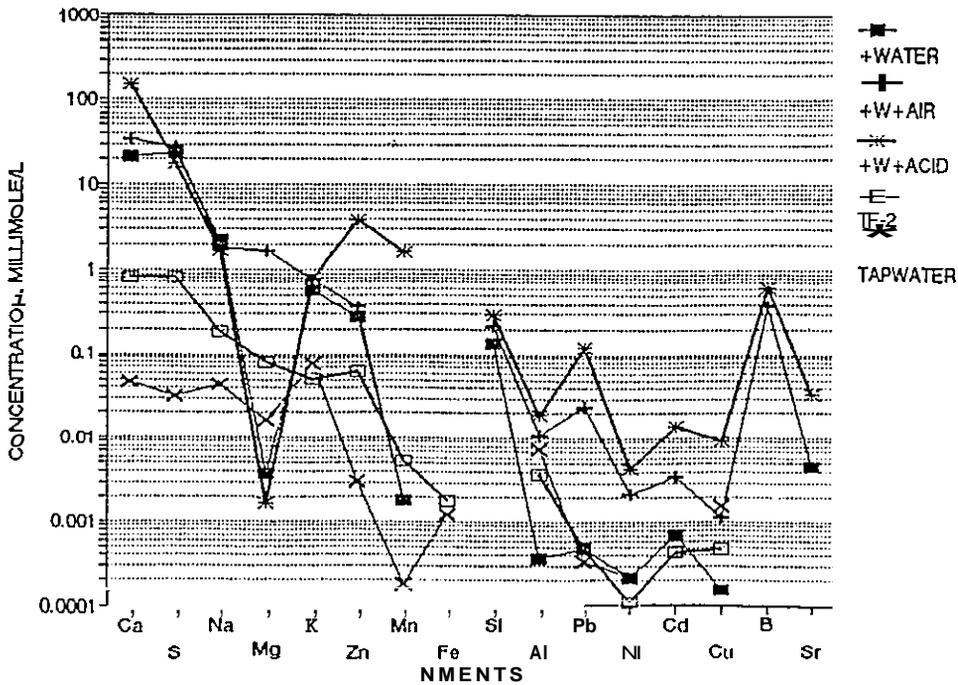


Figure 5-5
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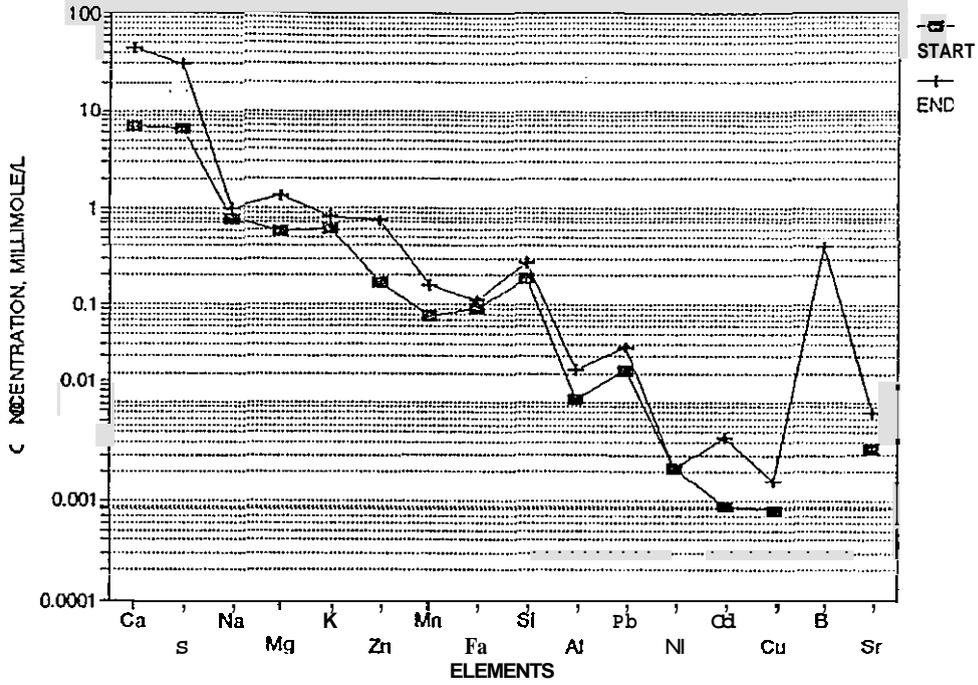


Figure 5-6
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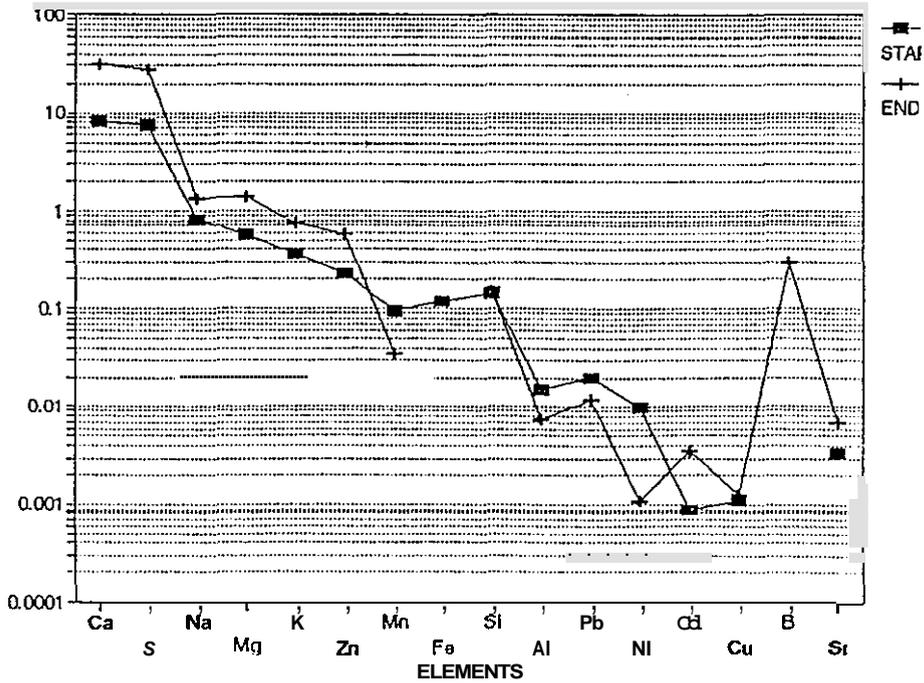


Figure 5-7
BARITE-FREE TAIUNGS, +WATER+ACID

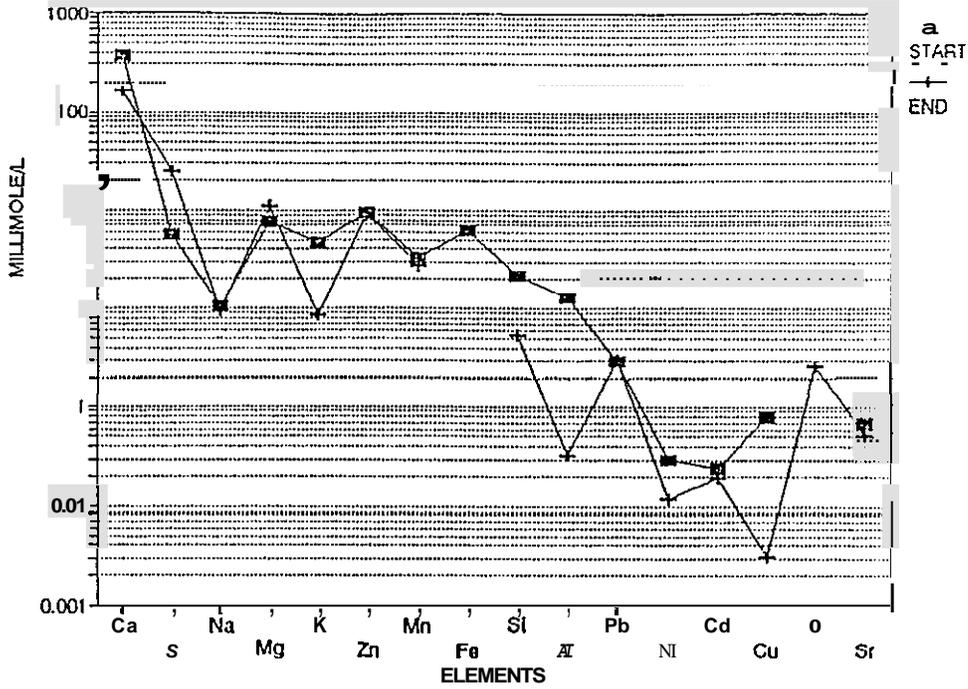


Figure 5-8
BARITE-FREE TAIUNGS. FINAL RESULTS

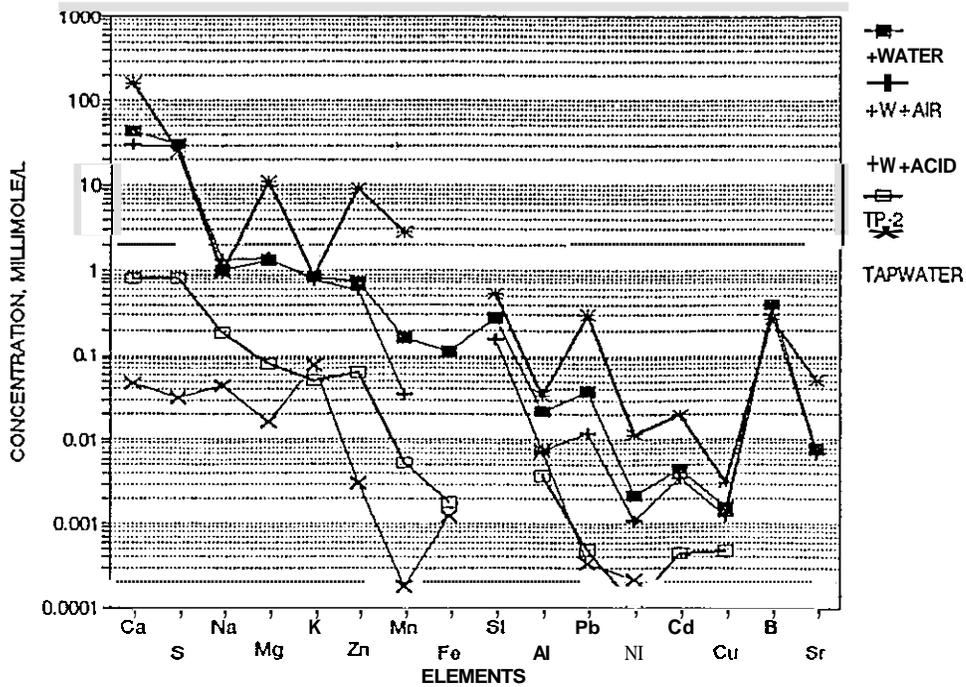


Figure 5-9
BARITE-RICH TAILINGS, +WATER

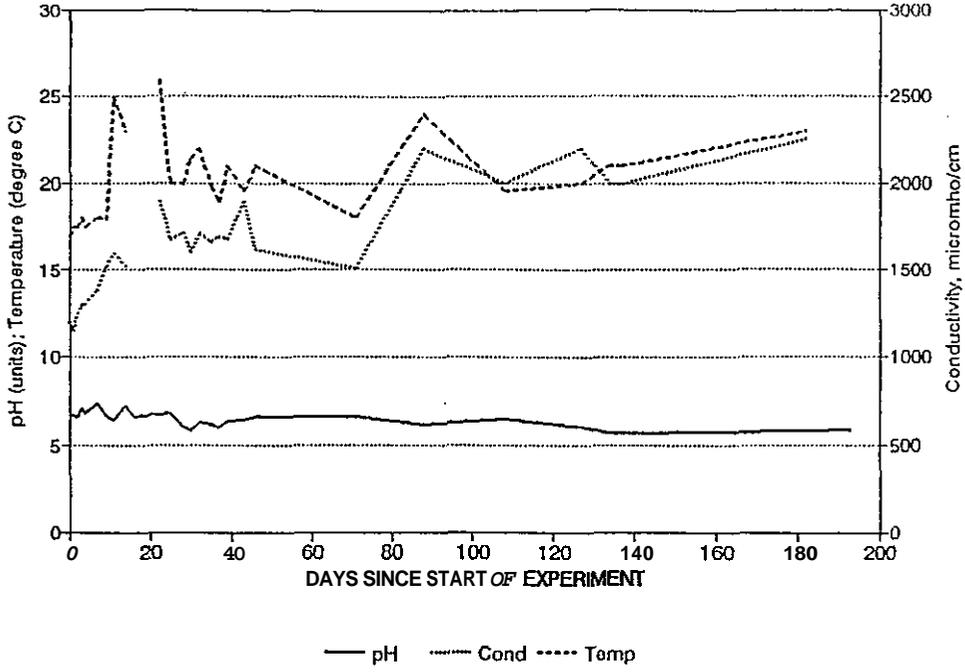


Figure 5-10
BARITE-FREE TAILINGS, +WATER

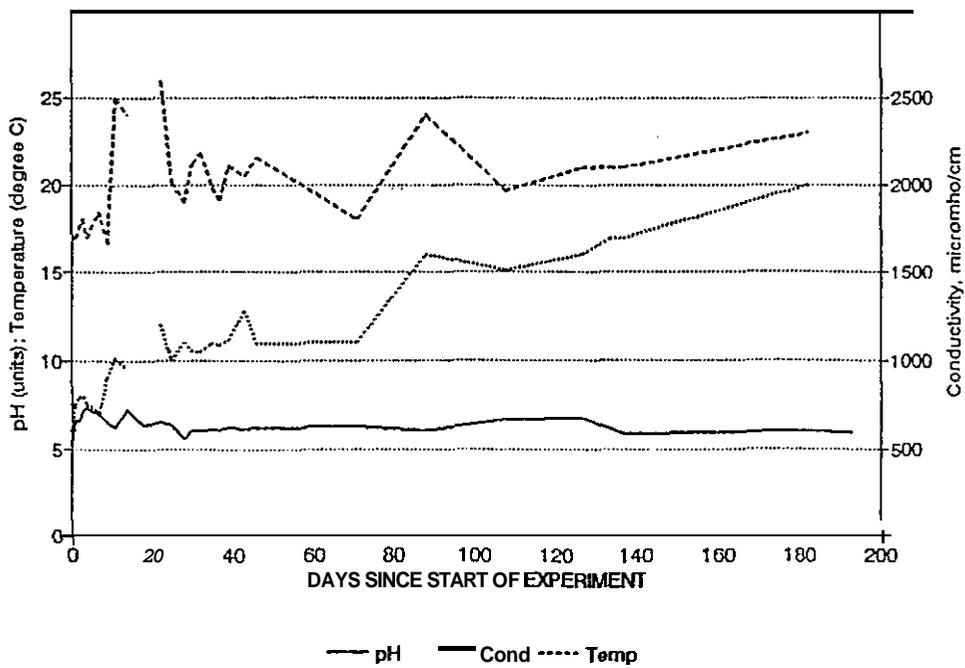


Figure 5-11
BARITE-RICH TAILINGS. +WATER +AIR

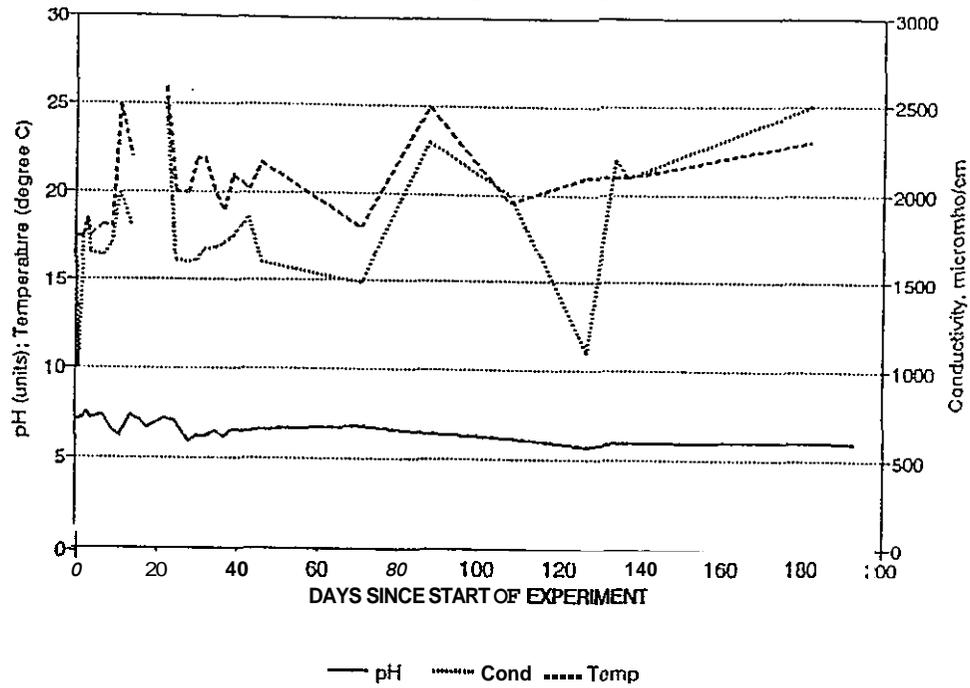


Figure 5-12
BARITE-FREE TAILINGS. +WATER +AIR

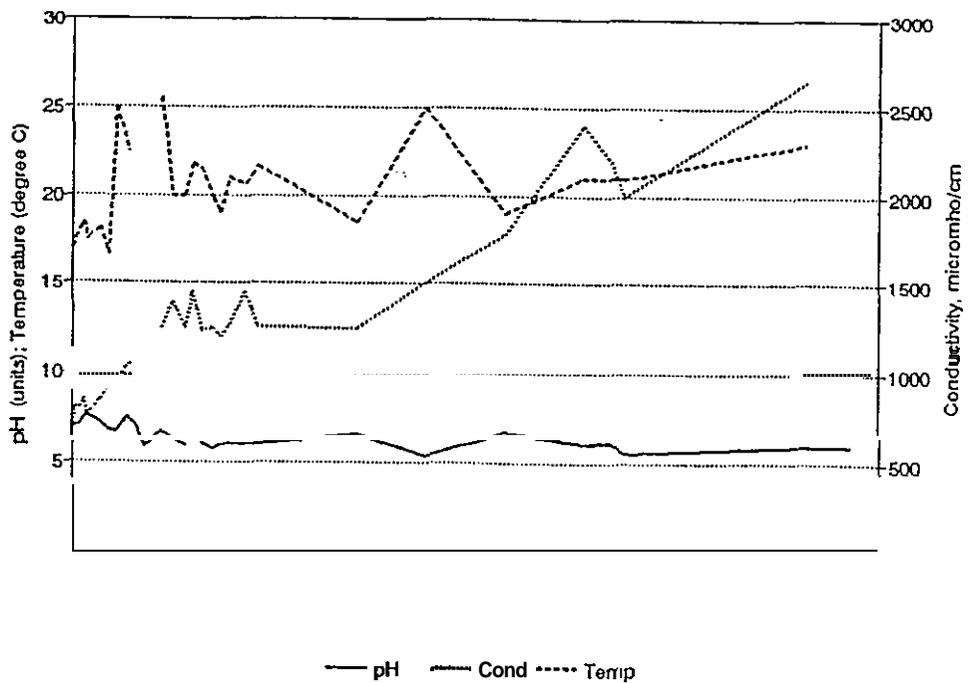


Figure 5-13
BARITE-RICH TAILINGS, +WATER+ACID

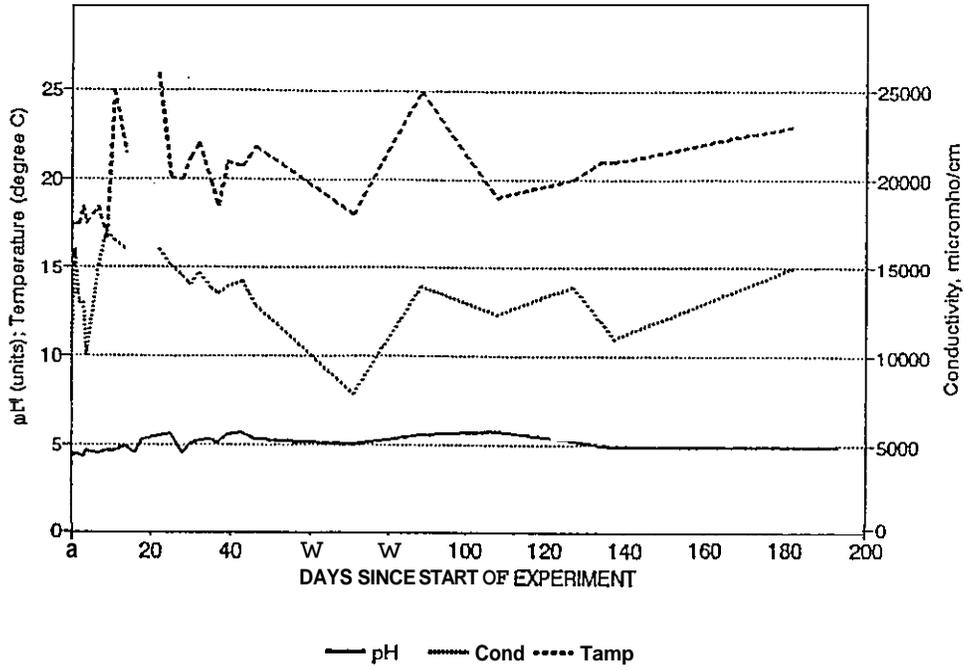


Figure 5-14
BARITE-FREE TAILINGS, +WATER+ACID

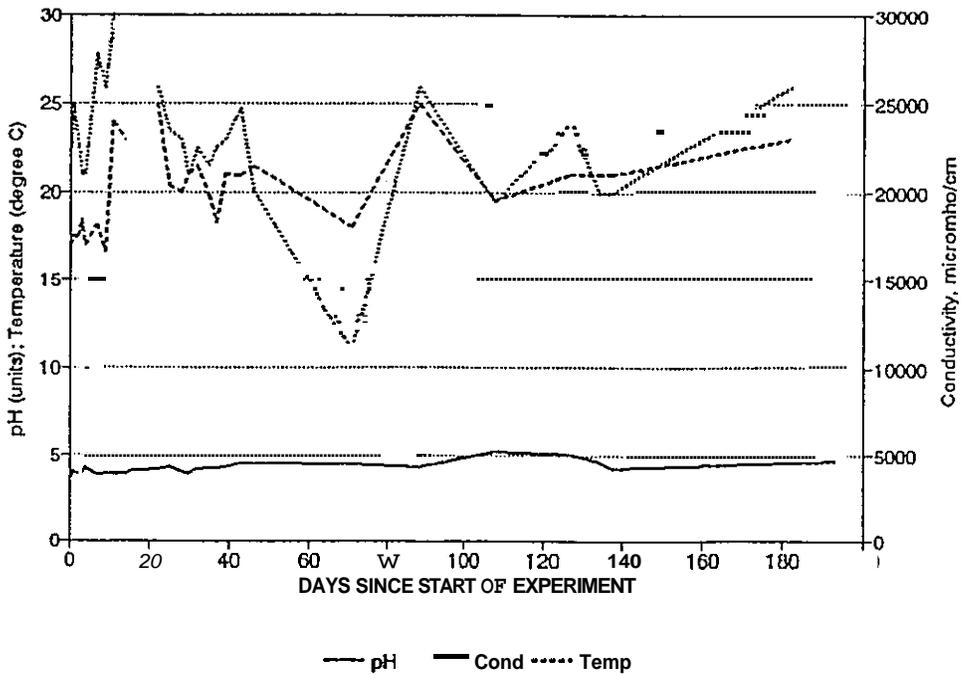


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2.5 Potential Long-term Trends in Water Characteristics

To implement decommissioning measures for any effluent stream, it is of utmost importance that those are based on water characteristics which will prevail in the long-term. If the effluent characteristics are prone to change, then it follows that the decommissioning measures which are implemented could fail. The hydrological and geochemical conditions in Buchans are such, that changes in the effluent characteristics in the long term are not likely.

The monitoring data for zinc and copper are utilized in this section to examine if differences can be noted in their concentrations over the long term. With the comprehensive understanding which has been gained during the investigation on the Buchans effluents and the ground water chemistry and the geochemistry of the effluents, interpretation of the long term changes in the concentrations will facilitate identification of the contaminant sources. Based on this information it will then be possible to make long term predictions on the characteristics of the effluents in the future.

Based on comparison of OEP and OWP the long term trends for zinc and copper are different for the two pits. The zinc concentrations have been decreasing at different rates over the past five years. Between 1987 and 1989 zinc in the OEP dropped by **45 mg/L**, while in the OWP, zinc concentrations declined by only 8.8 mg/L (Figure 2.5-1). The zinc concentration decreases between 1990 and 1991 are smaller in the OEP with a decrease of only **4.6 mg/L**. In the OWP the decrease is 8.7 mg/L which represents the largest annual

decrease since the OWP has been filled. The recent change in the OWP in zinc concentration can be accounted for by ARUM, as discussed in detail in Section 4.1.4. Essentially, in 1991, both pits have reached a similar average annual concentration (FIGURE 2.5-1).

The long term trend for copper on the other hand is different than zinc, and significantly differs between the pits (FIGURE 2.5-2). Annual average concentrations in the OEP are constant whereas in the OWP concentrations decreased by 0.36 mg/L between 1989-1990.

Although these differences in the long term trends were noted at the time the investigation began, they are now much more pronounced. The general assumption was made, that the water from the OWP enters to the OEP, and hence contributes to the characteristics of the OEP effluent. In fact, given the history of the filling of the Orientals and the hydrostatic heads, this connection sounds reasonable (Schematic 1-1). However as will be demonstrated with the long term trends in concentrations both pits are not significantly connected. The importance of the connection with relation to treatment is self evident, since if all the zinc in the OEP originates in the OWP, then only the OWP would have to be treated. If this were the case, rates of decrease in zinc concentrations should be the same in both pits. The differences in the long term concentrations trends clearly suggest that both pits have independent sources of zinc and copper.

There are three potential sources of copper and zinc with acid mine drainage. One source is precipitates, which form when acid mine drainage mixes with ground water. Such precipitates will be formed at the time of flooding of the underground workings. A second source are zones of mineralization, where no acid mine drainage take place. The third possibility for copper and zinc in the effluents are those areas in the mine workings where acid generation is indeed occurring.

Locations where acid generation is occurring are clearly the tailing beaches and the mine slimes in the Drainage tunnel. For these locations, if the contaminant sources identified above are correct, the long term trend in the copper and zinc concentrations should therefore be free of changes. The data for the Drainage Tunnel and the tailings are presented in Figure 2.5-3 for zinc and in 2.5.4 for copper. It is evident that since 1988, the time at which the work on plugging the Drainage Tunnel was completed (see Section 2.3), both copper and zinc concentrations have not changed. The TP- 2 effluent has also stabilized in the last three years. Of the records examined including previous years, a steady decrease is noted Figure 5.3-2. Based on the investigation of the tailings beaches in TP-2 it can be concluded, that only one beach remains which generates acid, as discussed in detail in Section 5.3. Therefore the slowly decreasing trends in the previous years are due to the exhaustion of the contaminants in the other beaches.

It is now possible to interpret the long term changes in the effluents for the OWP and the OEP as follows. For the OWP, both elements decrease, suggesting the redissolution of precipitates, which are being depleted, since they are no longer formed. The quantity of the

precipitates slowly decreases, producing less dissolved zinc each year. **As** the underground workings no longer generate AMD in the absence of oxygen, no new precipitates will be formed. Precipitates in the workings were formed when ground water mixed with AMD generated from chalcopyrite /sphalerite mineralization. If the exposed walls in the OWP would generate acid, then the trend would be expected to be similar to that of the Drainage Tunnel. Furthermore when the acidity in the OWP is evaluated, the concentrations of aluminum and iron are sufficient to account for the low pH. **This** is due to the hydrolysis of aluminium salts and oxidation of ferrous iron to ferric iron.

For the OEP, monitoring data suggest that the source of zinc is the dissolution of precipitates produced at the time of flooding, hence the decreasing trend. However the mineralization contained mainly sphalerite which, during AMD generation, resulted in solutions with mainly zinc precipitates and very little copper. Copper concentrations in the OEP have not changed in the last several years. They are significantly lower in the OEP than in the OWP (Figure 2.5.2). Therefore the copper concentrations originate from ground water, which moves through mineralized areas where no acid generation is occurring.

In summary therefore, the sources of both copper and zinc are as follows for the Orientals effluents:

- 1 AMD generation ongoing - Drainage Tunnel and tailings beach # 1
- 2 Redissolution of precipitate formed during mine flooding - OWP and
- 3 ground water carrying copper which travelled through mineralized areas with precipitates rich in zinc - OEP.

It follows, therefore that in the future it can be expected that **OEP** zinc concentrations **will** continue to drop, to a concentration which is unknown. Copper concentrations can be expected to remain the same, as they are part of the ground water entering the pit.

The downward trend seen for zinc and copper in the **OWP** will continue until precipitates of underground workings are used up.

Concentrations of zinc in the Lucky Strike can be expected to continue to decrease as water added to the pit is basically precipitation (snow and rain) which precipitates zinc as zinc carbonate. **As** discussed in the Section 3, the minimum zinc concentration for both Lucky strike and Tailings Pond 2 is expected to be 1 to 2 mg/L. For TP-2 in the long term, the concentrations **will** decrease, as the acid generation **will** finally cease in beach # 1 and the same can be expected for the effluent from the Drainage Tunnel.

Fig. 2.5-1 West & East Pits Zinc

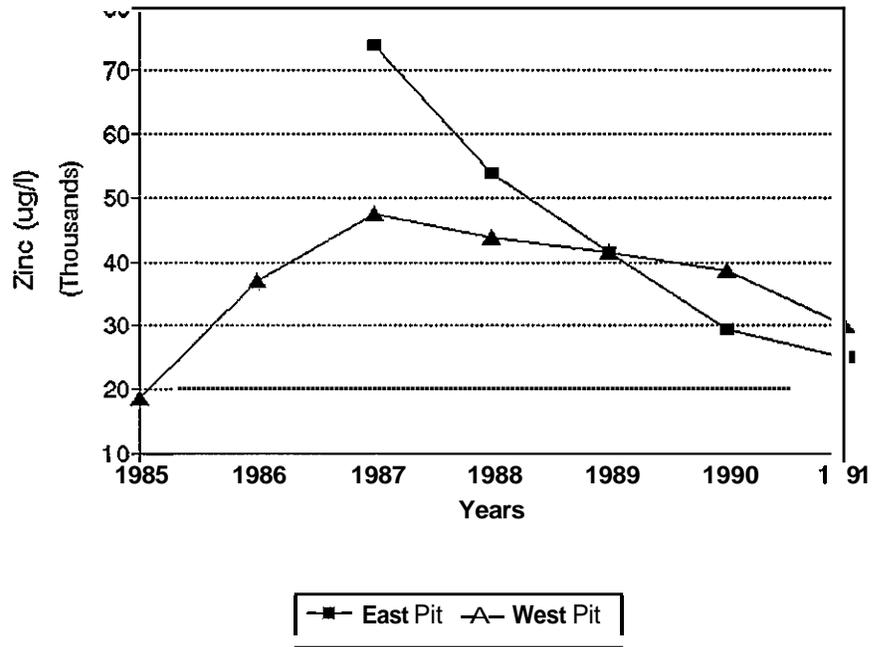


Fig. 2.5-2 West & East Pits Copper

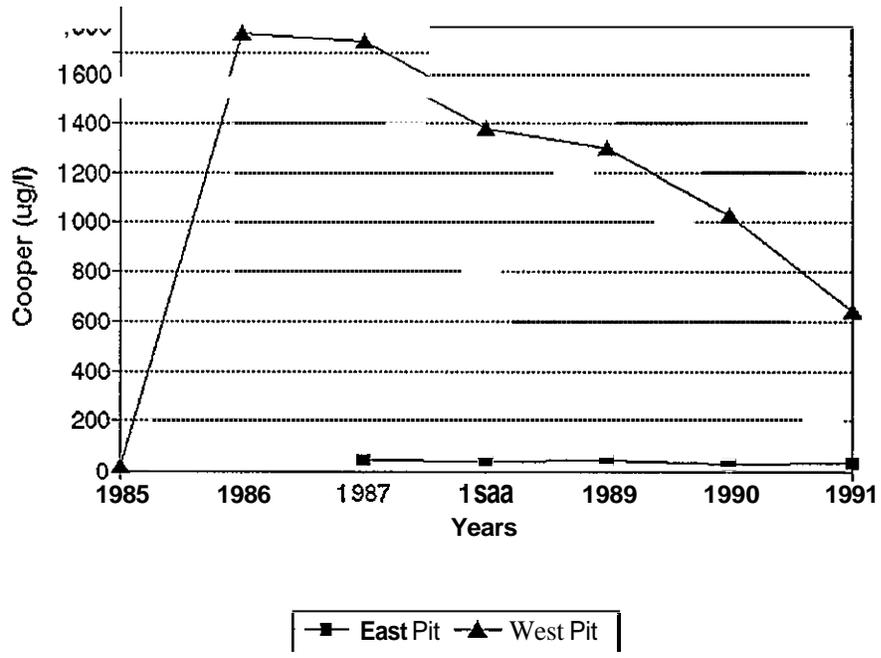


Fig. 2.5-3 TP2 & Drainage Tunnel Zinc

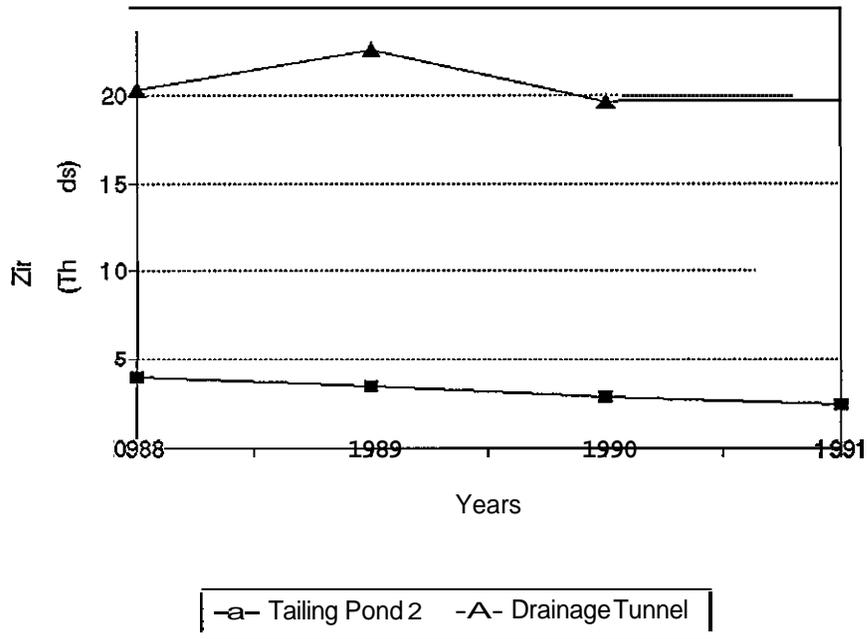


Fig. 2.5-4 TP2 & Drainage Tunnel Copper

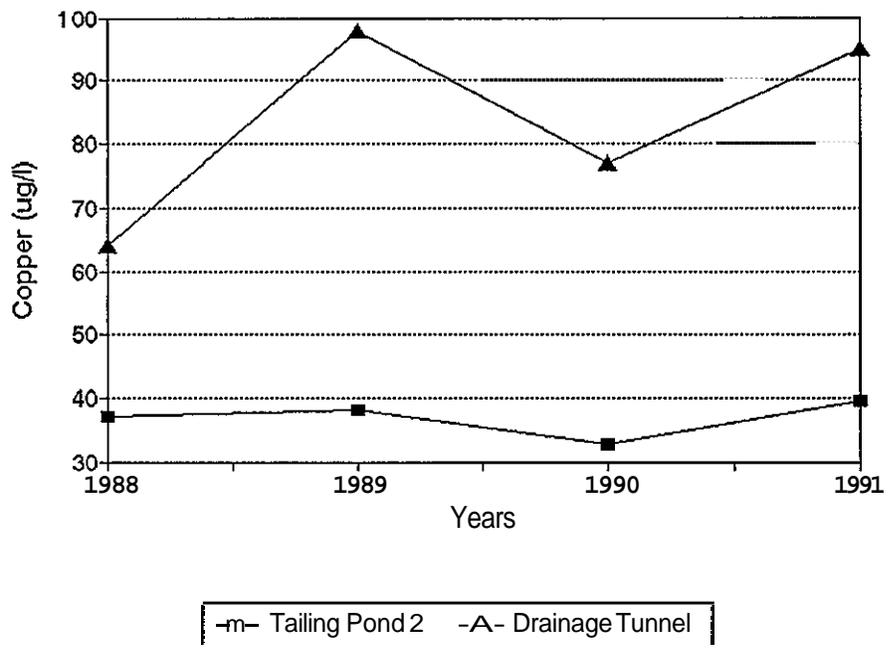


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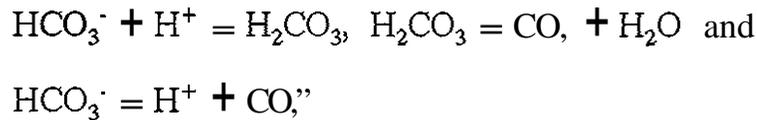
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significantly and rapidly, whereas in the lime treated OEP water, the changes in zinc concentrations were slow but steadily increasing to about 1.5 to 3 mg/l. These changes are due to the replacement of zinc hydroxide, which will change over time, to zinc carbonate, by absorbing carbon dioxide. Therefore, utilizing conventional treatment technology, such as liming, will not produce the required removal of zinc below 1 mg/l.

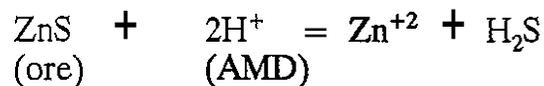
3.2 The Bicarbonate Buffering System

The alkalinity of Buchans effluent is produced by carbonate/ bicarbonate which is present in the groundwater. Bicarbonate buffering systems generally can be described as follows:

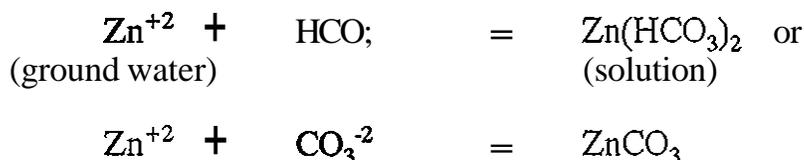


The loss of carbon dioxide, as expressed in the formulas above, brings about a change in pH, which in turn produces changes in the dominant zinc species.

(1) Sphalerite dissolved in AMD water can be presented as



(2) When the solution is mixed with ground water, it reacts as



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3.0 INTRODUCTION

Water cleansing processes, be they biological or chemical, have to be based on the characteristics of the waste water. During development of Ecological Engineering measures for decommissioning of the Orientals, it became evident that ground water neutralizing capacity existed. This was particularly evident in the OEP, Lucky Strike, and in the tailings ponds. On the other hand, acid generation in ground water also takes place, as evidenced by the depressed pH in OWP and that emerging from the Waste Rock Pile.

The combination of these conditions brings about effluent which needs to be treated. The mandate for 1991 work on decommissioning was to finalize an approach for overall treatment of Buchans mine waste water. To do this, the chemical interactions of AMD with precipitation and ground water had to be elucidated. In this section, the fundamental chemical processes which occur in the existing effluent which describe their characteristics are presented. The chemical reactions which lead to precipitation of zinc and thereby remove dissolved zinc from the effluent are outlined.

3.1 Acidity and Alkalinity of Buchans Water

As many of the effluents have a circumneutral pH, water can possess acidity and/or alkalinity. Acidities and alkalinities for a number of sites around Buchans are displayed in **TABLE 3-1**. Both values indicate a reaction potential of the solution, whereby acidity is the ability of the solution to react with OH ions. Acidity is usually the result of the presence

in the water. On the other hand, alkalinity indicates the buffering capacity of the solution to react with hydrogen ions.

The causes of alkalinity are usually the presence of carbonate or weak electrolytes such as phosphate. It can be seen from the values of acidity and alkalinity expressed as Calcium carbonate equivalents (Table 3-1), that all waters, with the exception of the **TP-2** water have both alkalinity and acidity. From our work carried out on the Buchans effluent, it is clear that the AMD characteristics are significantly ameliorated in all effluents by mixing with ground water which is rich in carbonates. **This** is particularly evident when acidities are compared to that in the test pits on TP -2 beach 1 (see Table 3-1, #9 testhole), which represents AMD without ground water or rain water.

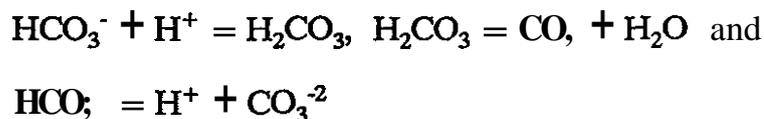
To illustrate the importance of the acidity/alkalinity of effluent, waters were titrated with 0.01N NaOH. Some of the titration curves are shown in FIGURE 3-1. The titrations indicate that the amount of CaO or CaCO₃ required to consume the acidity and precipitate zinc is different among the effluents. For Lucky strike, it would require **0.0196** g of CaO to neutralize 1 L of water, in contrast to OWP water, which would require **0.0868** g of CaO to bring the pH up to 7.5.

A liming experiment was carried out in **1988** by George Neary, liming OEP with soda ash and with hydrated lime. The experiment was run from mid-March **1988** to the end of May, monitoring pH, Cu and Zn concentrations, with changes in the overlying water occasionally. In the treatments with soda ash, representing a carbonate, the zinc concentrations increased

significantly and rapidly, whereas in the lime-treated OEP water, the zinc concentrations were slowly but steadily increasing to about 1.5 to 3 mg/l. These changes are due to the replacement of zinc hydroxide, which will change over time to zinc carbonate, by absorbing carbon dioxide. Therefore, utilizing conventional treatment technology, such as liming, will not produce the required removal of zinc below 1 mg/l.

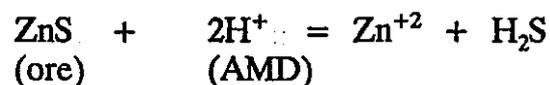
3.2 The Bicarbonate Buffering System

The alkalinity of Buchans effluent is produced by carbonate/ bicarbonate which is present in the groundwater. Bicarbonate buffering systems generally can be described as follows:

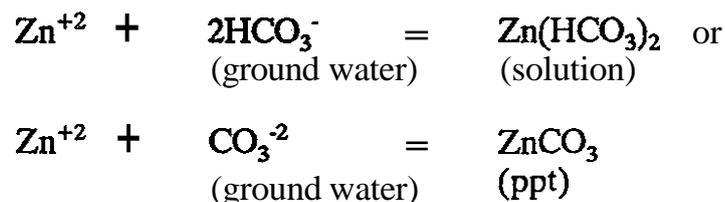


The loss of carbon dioxide, as expressed in the formulas above, brings about a change in pH, which in turn produces changes in the dominant zinc species.

(1) Sphalerite dissolved in AMD water can be presented as



(2) When the solution is mixed with ground water, it reacts as

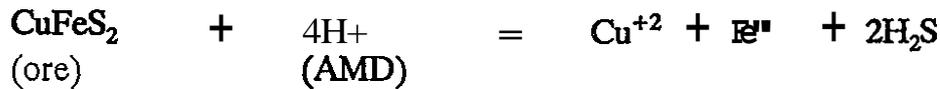


(3) The carbonate precipitates, but it may later dissolve in water rich in CO₂,

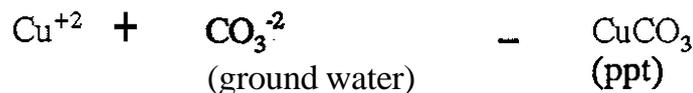
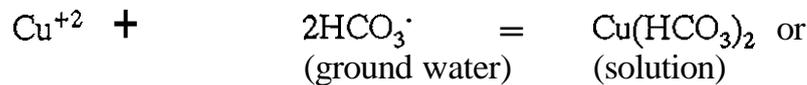


For copper, the chemical interaction with the ground water are similar.

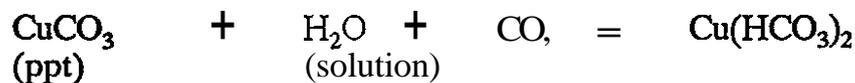
(1) Chalcopyrite dissolved in AMD water may be represented as:



(2) When the solution is mixed with groundwater, it reacts as



(3) The carbonate precipitates later may dissolve in water rich in carbonate.



From the above, it is evident that the bicarbonate buffering system can bring about changes in both copper and zinc concentrations. In FIGURE 3.2, the relative proportions of the carbon species are given with respect to pH. For example, at pH 7.5 in natural waters, the CO₃²⁻ species will represent about 0.01% of total inorganic carbon. Given the shifts in the curves, the relative fractions of HCO₃⁻ and carbonic acid (H₂CO₃) will change with pH. Taking the pH of both Lucky Strike and OEP, relative fractions of carbonate species can be calculated and are given below. In our analysis, we determined the following TIC concentrations.

Using the pH values and the relative fractions given in figure 3.2, the concentrations derived from the molarities of the carbon species are as follows.

Lucky Strike	OEP
TIC = 3.70 mg/l	TIC = 6.96 mg/l
CO ₂ = 0.34 mg/l	CO ₂ = 1.91 mg/l
HCO ₃ ⁻ = 62.07 mg/l	HCO ₃ ⁻ = 125.8 mg/l
H ₂ CO ₃ = 6.66 mg/l	H ₂ CO ₃ = 1.98 mg/l

At pH 7 to 8, most of the TIC exists as HCO₃⁻ ions, and zinc bicarbonate does not precipitate. If we now apply the equations presented in relation to zinc carbonate precipitation (2) discussed previously, it will be clear that when taking the solubility products into account, that both OEP and Lucky Strike water are saturated with zinc carbonate. However, bicarbonate is very easily affected by wind mixing, temperature, and CO₂ pressure which result in a pH change in the water. Refer to the equation (3) and the equation given below.



When CO₂ is removed from water, either by plants or through degassing, the pH increases and zinc precipitates as zinc carbonate. **This** phenomenon is especially obvious in OEP water.

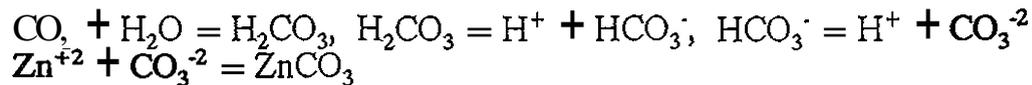
Carbon dioxide exerts a major effect on the zinc removal through zinc carbonate precipitation. If degassing is as strong a zinc removal process as indicated from the chemical

equation, empirical results should confirm this behaviour. When samples are stored for different periods of time in the laboratory, changes in zinc concentrations should be measured. The results from different aged samples (Boojum Research Lab) are given (FIGURE 3-3). It is evident that, indeed, zinc concentration changes can be as large as 25 mg/l over a period of 20 months for OEP water and, for Lucky Strike, over a period of 7 months, zinc concentrations dropped by half. Therefore, the pragmatic conclusion from these observations is that the zinc concentrations in Lucky Strike water, when left sitting in the gloryhole, will ultimately drop to a level of about 1 to 2 mg/l. The same would be the case for OEP where, however, the retention time does not allow for such equilibration of the zinc concentrations.

3.2.1 The Effect of Aeration

As discussed above, dissolved zinc concentration is affected by carbonate ions and carbon dioxide. Experiments were carried out with aeration, to modify the ambient carbon dioxide concentration. Aeration is one method of enhancing zinc carbonate precipitation, and therefore bubbling air with a compressor in both Lucky Strike and OEP was considered as a potentially viable option for zinc removal. It has to be noted, however, that this was prior to arriving at the understanding of the zinc carbonate solubilities.

The aeration probably could function in two ways, depending on the pH and the degree of saturation of the water with respect to CO₂: (1) By bubbling air, more carbon dioxide is dissolved in the water, which in turn reacts with zinc ions.



(2) When the water is stirred or bubbled, zinc bicarbonate releases CO₂ and precipitates as zinc carbonate.

Aeration of 1 litre samples of **OEP** and Lucky Strike water decreases zinc concentration rapidly for the first three days (Table 3-2). **Zn⁺²** concentrations stabilized at **1-2 mg/l**. In contrast, aeration of **OWP** water did not affect zinc concentrations, as would be expected, since **OWP** water pH is about **3**. At that pH, as can be seen from Figure 3.2, inorganic carbon is not in the form of bicarbonate or carbonate, hence precipitation as zinc carbonate will not occur.

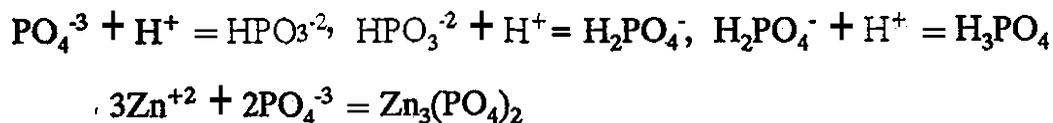
The aeration experiments determined experimentally that zinc concentrations can be reduced to a certain level through precipitation as zinc carbonate, which is 1 to 2 mg/l. These dissolved zinc concentrations can also be derived by calculations, taking solubility products of zinc carbonate, solubility of carbon dioxide in natural waters, as well as the pH of the effluent, into account. Therefore, we can conclude that the lowest concentrations to be expected in any of the circumneutral effluents of the Buchans workings will be around 1 to 2 mg/l.

Therefore, natural formation of zinc carbonate can reduce zinc concentration to a level no lower than 1 mg/l; this concentration cannot be reduced other than by finding a substitute precipitate which has lower solubility. This may be possible if zinc phosphate is substituted

for zinc carbonate.

33 Precipitation of Zinc Phosphate

In acidic solutions, phosphate ions **can** react with zinc ions to precipitate zinc, based on the following equations.



Long Harbour sand is phosphate rock. It can form the precipitate, zinc phosphate, the solubility of which is lower than that of zinc carbonate. Zinc phosphate does not redissolve and is not affected by aeration.

Phosphate sand was used **to** treat effluent from the Buchans operations without aeration. The results are shown in **TABLE 3-3**.

Regression analysis of experimental results shows that 1 g of phosphate rock can precipitate **0.7 mg/l** zinc in OWP water. In Lucky Strike water, 1 g can precipitate 0.26 mg/l zinc, and **in** OEP water, 1 g of phosphate rock precipitates 0.11 mg/l zinc within 24h.

The quantity of rock necessary to precipitate zinc in the field, however, may be greater, as the efficiencies are high in laboratory vessels. However, the elegance of this precipitation

process is that these results have been obtained within **24** h, and zinc removal will continue **as** the phosphate rock slowly dissolves.

It follows that, if acidity is low and pH is neutral, dissolution of the phosphate rock will be slow, and it will last for a long time. This is particularly the case for OEP and Lucky Strike waters, where pHs are close to **7**. Phosphate rock does not dissolve well in neutral pH water; therefore, it reacts slowly.

In order to speed the reaction, phosphate fertilizer may be used. In aeration experiments **discussed** earlier, zinc concentration came to an equilibrium at **1-2 mg/l**. Then **0.5** g of Osmocote fertilizer (slow-release phosphate) was added to the water. The next day, zinc concentration was **<1 mg/l** (colorimetric: Taylor test).

Both the precipitate and the water from the slow-release fertilizer experiment were sent out for ICP analysis. The results are shown in TABLE 3-4. The solids in the filter paper contain the equivalent of **6.5 mg/l** of Zn, which had been removed from the treated water. Furthermore, the result of slow-release fertilizer treatment increased phosphate in the solid fraction, suggesting the formation of zinc phosphate.

These experiments' indicate that phosphate rock **can** treat OWP water, both increasing the pH and decreasing zinc concentrations. For more neutral water, such **as** OEP and Lucky Strike, slow-release calcium phosphate fertilizer or phosphate rock **can** reduce zinc concentrations.

3.4 Precipitate Formation in Oriental East Pit

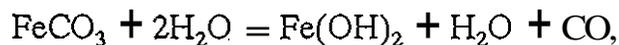
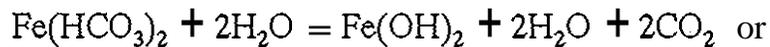
In the OEP, precipitate is formed, which is accumulated in the meadows. **As** this precipitate contains zinc, its formation and its characteristics are of utmost importance. Elucidation of the process of precipitate formation **will** lead to information about the stability of the precipitate, and about **conditions** which **will** affect its potential dissolution in the long term.

In order to quantify the amount of precipitate which forms in the OEP, **two** sediment traps were set up in the pit last autumn. Collections were made at different intervals to arrive at potential seasonal differences in sedimentation rates. Results are presented in **FIGURE 3-4**. The sedimentation rate is larger at 2.7 m depth than at 20 m in the bottom of the OEP. It should be noted that the sedimentation traps in the shallows represent a significant underestimation of the actual quantities of precipitate formed, since the traps have been placed on the downstream side of the curtains and brush. These installations can be expected to have removed some of the precipitate formed. The results in Figure 3-4 also show the seasonal variations of the precipitate formation. The traps placed and retrieved in autumn collected significantly less than those traps placed during the following spring and summer. At lower temperatures, a smaller fraction of the thermocline is oxygenated, and hence less ferrous iron **will** precipitate, as explained below. In conclusion, the precipitation rate in the upper part of the OEP is controlled by the oxygen availability. The precipitates collected at the bottom of the pit represent that fraction of precipitate formed which settles to the bottom of the pit.

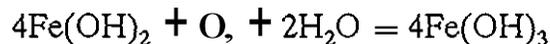
The chemical stratification of the OEP (based on oxygen profiles) for the last three years is presented in FIGURE 3-5 a, b, c. Given the absence of significant oxygen concentrations below 4 to 6 m throughout the year, it can be assumed that iron below the thermocline is present in the reduced form, i.e., as ferrous iron. That precipitate is **only** formed above the thermocline was also noted from observations on the curtains, which were stained **only** to a depth of about 5 m.

The chemical reactions which take place during precipitate formation are expected to be as follows.

(1) ferrous salt hydrolysed in the water



(2) ferrous hydroxide oxidized by air



Ferrous iron is stable in water with low oxygen, as found below the thermocline in the OEP (see FIGURE 3-5 a, b, c). At the surface of the pit, however, hydrolyzed ferrous ions will be gradually oxidized by air to hydrolyzed ferric ions, which then form ferric hydroxide and precipitate immediately at pH 6. Therefore, at the surface of the pit, dissolved iron concentrations are much lower than at the bottom of the pit (TABLE 3-5). Water analyses for OEP, both above the thermocline and near the bottom, indicate a large difference in the iron concentration.

If we consider the zinc concentrations in OEP water, it is evident that the bottom water has a 10mg/l higher concentration ~~than~~ the overlying water. At pH 6, these concentrations of zinc represent water which is saturated with respect to zinc hydroxides. Therefore, it can be expected that, with the formation of the iron precipitate, some co-precipitation of zinc hydroxide may occur.

Precipitates ~~from~~ the top ~~and~~ the bottom sedimentation traps were ~~also~~ sent for ICP analysis. The results indicate that the largest component is iron, ~~as~~ expected (reported ~~as~~ iron oxide; **TABLE 3-6**). The orange colour of the precipitate (or in layman's terms, yellow boy) suggests the dominance of the oxidized form, ferric hydroxide, rather than ferrous hydroxide (reduced compound of iron).

In order to confirm the presence of ferric hydroxide, precipitate samples were collected from the Junction between the First and Second Meadow which receives the main precipitate loading. Samples were also collected in the First Meadow in the vicinity of the polishing ponds, where precipitate has accumulated longer, is older, and represents a potential source of dissolved zinc, if the meadows are flooded by a new polishing pond. During the 1990 investigation, sediments in the meadows were sampled for concentrations of metals. In the upper portions of soil profiles in the First Meadow, very high zinc concentrations were determined.

The precipitates from these locations were oven-dried, redissolved in acid and titrated with an NaOH solution. The titration curves are shown in **FIGURE 3-6**. As a reference,

sulphuric acid is titrated, which shows the expected behaviour of a pure solution, i.e., free of ferric or ferrous iron. The changes in the slope of the curves between pH 2.5 and 3.5 indicate the presence of ferric iron. The slight bump around pH 7 in the curves, however, suggests the presence of ferrous iron.

Based on these titration curves, precipitate that accumulated at the lower end of the First Meadow contained mostly ferric iron, whereas the precipitate at the proximal end of the meadow and in the direct flow path from the OEP contained both ferric and ferrous iron. These results were to be expected, as precipitate formed over longer periods of time in oxygenated water (meadow) will contain ferric iron. Precipitates formed more quickly and directly in the main flow path (junction) will contain some ferrous iron, which has not yet been oxidized.

Given the composition of the precipitates which have accumulated in the meadow, upon exposure of these precipitates to AMD from the Waste Rock pile, resolubilization could be expected. Therefore, for the scale-up of the polishing ponds, it is important to keep the Waste Rock drainage away from the areas in which the OEP precipitates have accumulated.

3.5 Acid Mine Drainage In Tailings Pond 2

All of the previous chemistry addressed the Buchans effluent with circumneutral pH's. The chemistry of AMD which is forming in the tailings and the drainage tunnel will now be briefly presented.

All the exposed beaches of Tailings Pond 2 were investigated to determine which beach would show extensive acid generation. Holes were excavated and conductivity was used as an indicator as to whether the water is likely acid mine drainage. The criterion, conductivity values significantly higher than those of the tailings pond at large, **was** used during sample collection.

Water samples collected from these holes were brought back to the laboratory and titrated with NaOH solution. The titration curves show that most tailings porewaters contain ferrous iron, as indicated by the change in slopes at around pH 6 to 7 (see FIGURE 3-7a,b). As the ferrous iron oxidizes, acid generation or the production of H⁺ ions is given by the following reaction:



Thus, if AMD is exposed to the **air**, ferrous iron is oxidized to ferric iron. Precipitates are formed, the acidity of the water increases and pH decreases. This has occurred, as evidenced by titration **curves** of **tailings** hole water, and further exemplified by the change in the titration curve for the water from hole No.11 after exposure to the air for 24 hours (FIGURE 3-7 b). Therefore, the oxidation and the subsequent hydrolysis of ferrous iron is the major cause of the acidity found.

Table 3-1

Location	Acidity mg/l CaCO ₃	Alkalinity mg/l CaCO ₃
Drainage Tunnel	82	38
Lucky Strike	35	40
OEP	25	105
OWP	165	0
Tailings Pond 2	50	12.5
TP 2 (#9 testhole)	29000	0

Table 3-2

Time	Zn ppm	Condition
Initial	7	aeration
1 day	1.5	aeration
2 days	1	aeration
3 days	1	no aeration

Table 3-3

Location	initial 500 ml	2g 1 day	10g 1 day	15g 1 day	20g 1 day	30g 1 day	30g 10 days
OWP-Zn	47.5	>44	50		40	22.5	14
OWP-pH	3.41	4.17	4.37		5.21	5.65	5.98
LS-Zn	5.5	4.5	2.5	1.5	0		
OEP-Zn	1.0	1.0	0				

All zinc values are in mg/l.

Table 3-4

Test Material	Zn mg/l	P mg/l	Mn mg/l	Ca mg/l
ppt	6.56	8.2	3.06	12.2
water	0.67	5.3	4.3	420

Table 3-5

Element Distribution in Oriental East Pit

Date	Assayer#		Iron (Fe)		Aluminum (Al)		Zinc (Zn)		Sulphur (S)		Silicon (Si)	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
Jul-88	545	544	0.08	58	0.3	0.3	47	61	398	508	5.6	9.4
Dec-88		727				0.09		33		443		6.8
Mar-89	* 924		0.01		0.01		31		380		8.5	
Jun-89	CHEMEX	CHEMEX	0.6	21.8	<0.2	<0.2	>10	>10				
Aug-89		1269		36		0.01		45		875		11
Sep-89	1361		0.01		0.03		37		825		8.3	
Oct-89	1381	1383	2.8		0.3	0.1	37	38	366	386	8.7	9.1
Oct-89	1382		8.7		0.3		36		373		8.7	
Jun-90	1741		0.02		0.08		29		432		5.1	
Jun-90	# 1734		0.02		0.04		27		427		4.6	
Jul-90	1808	@ 1809	6.1	56	<0.01	<0.01	30	40	312	383	6.1	7.3
Jul-90		& 1810		42		<0.01		38		378		7.1
Jul-90	1947	@ 1949	4.4	68	0.03	0.1	30	41	329	400	5.7	7.4
Jul-90	1950	& 1951	0.3	46	0.06	0.1	28	39	339	407	5.1	7.1
May-91	2775	2758	2.2	61.2	0.31	0.05	24	35.1	277	419	7.6	11.8
Aug-91	3243	3244	1	60	8	12	19	30	303	415	7	11
Oct-91	3557	3558	1.5	88.9	9.9	12.4	20	33.2	297	479	6.8	10.8

* - Precipitation experiment

- OE Outflow

@ - with precipitation

& - without precipitation

Table 3-6 Analysis of OEP Precipitate

	mg/l	mg/l
B	488	619
Ba	2317	1211
Cd	250	39
Cu	700	273
La	277	10
Pb	6608	228
S	1950	<DL
Zn	27304	50482
Fe2O3	451507	288460
CaO	13652	20755
MgO	1950	1375
K2O	4875	655
TiO2	975	1721
MnO	957	2741
Al2O3	33156	8133

Fig. 3-1 Buchans Water Titration experiment on Nov.29,1991

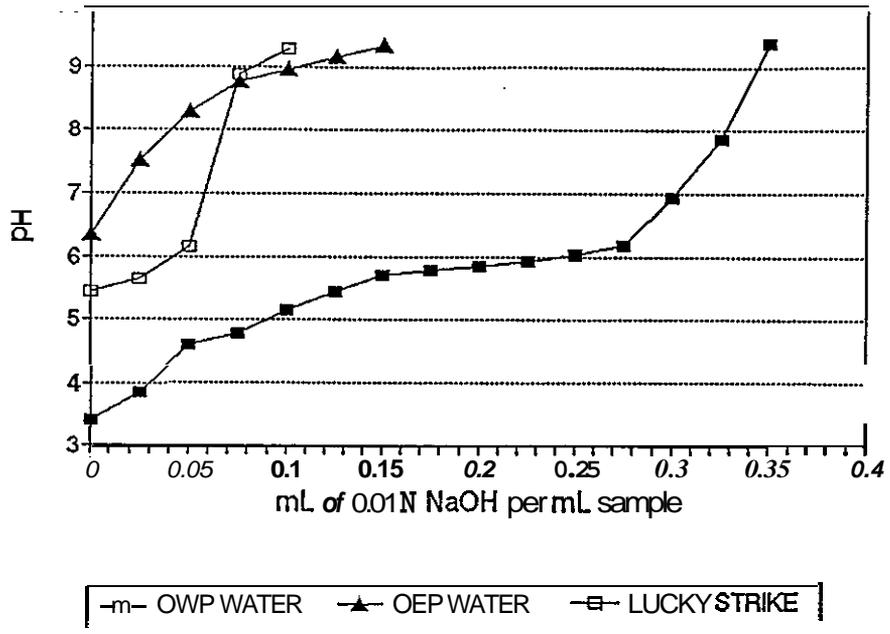
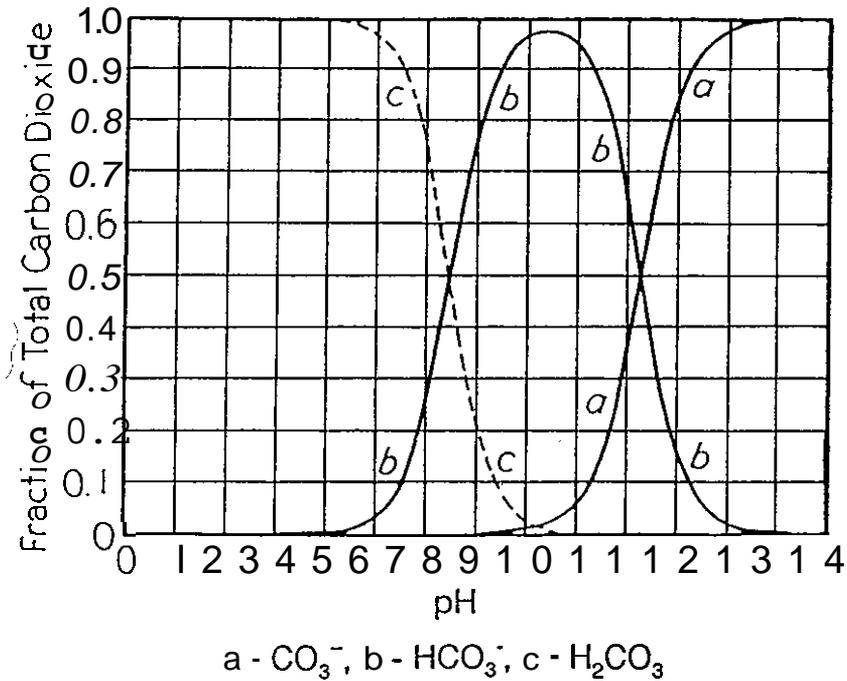


Fig. 3-2 Curves Showing Fractions of Total Carbon Dioxide Present as the Respective Ions at Various Hydrogen Ion Concentrations



a - CO₃²⁻, b - HCO₃⁻, c - H₂CO₃

Fig. 3-3 Zinc Changes in Solutions

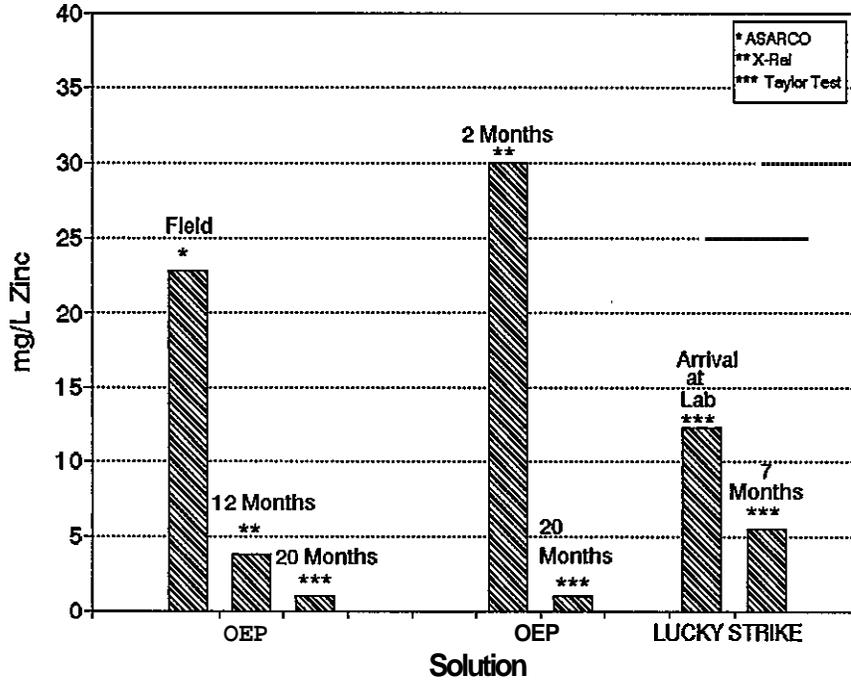


Fig. 3-4 Sedimentation Rate in Traps

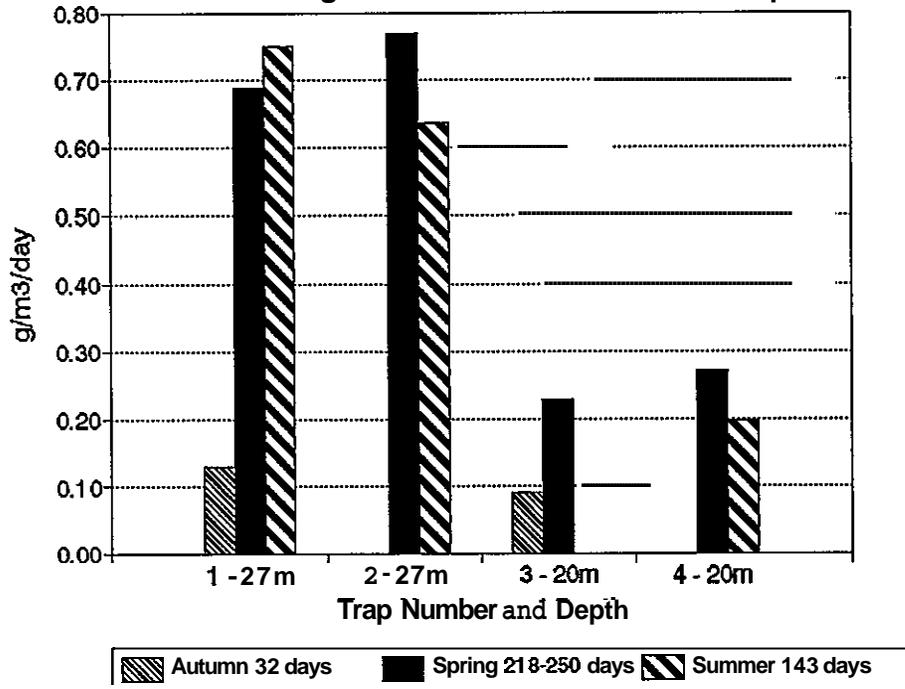


Fig. 3-5a Oxygen profile in OEP, 1989

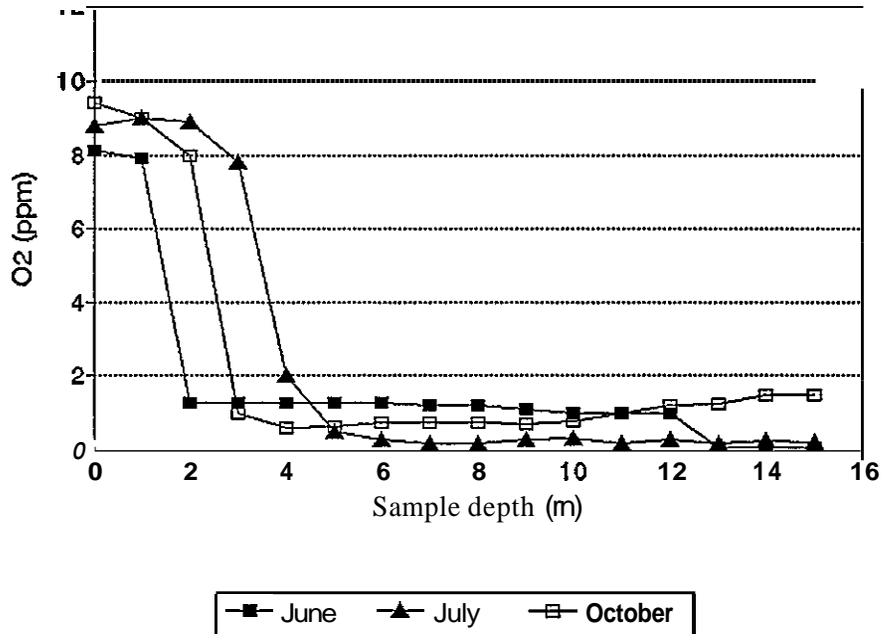


Fig. 3-5b Oxygen profile in OEP, 1990

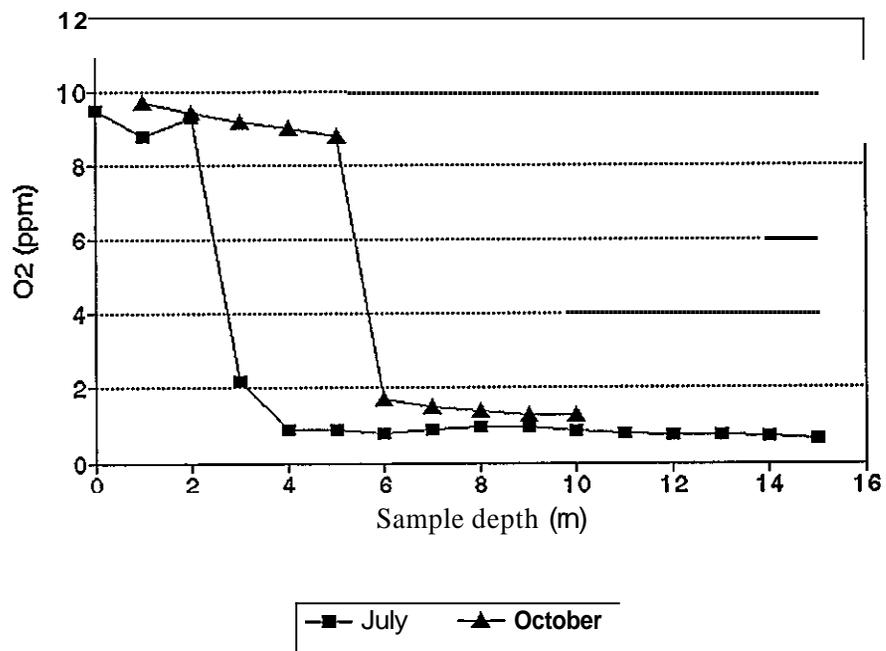


Fig. 3-5c Oxygen profile in OEP, 1991

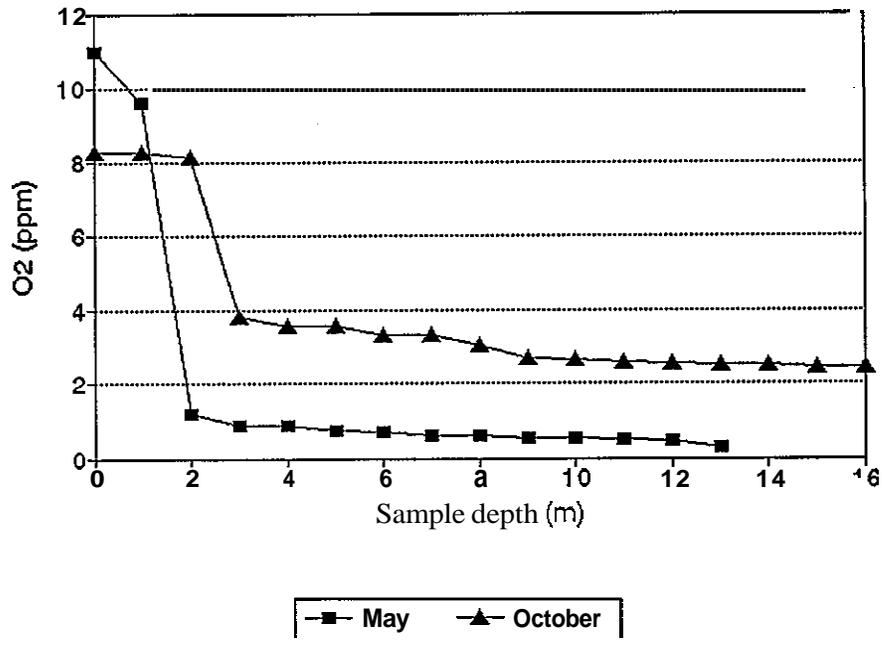


Fig. 3-6 Buchans Precipitate Titration

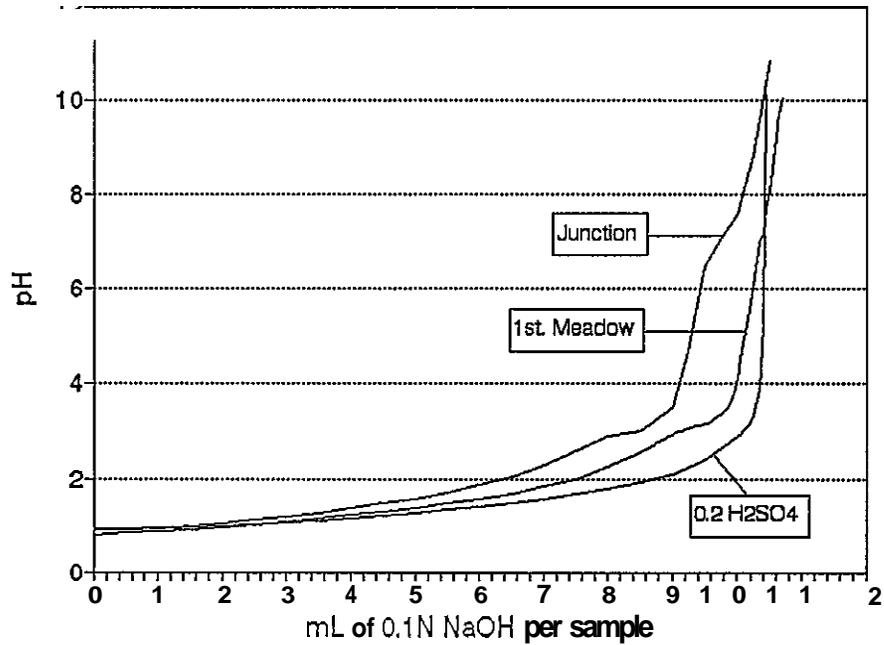


Fig. 3-7a TP-2 TestHole Water Titration
sampled in October 1991

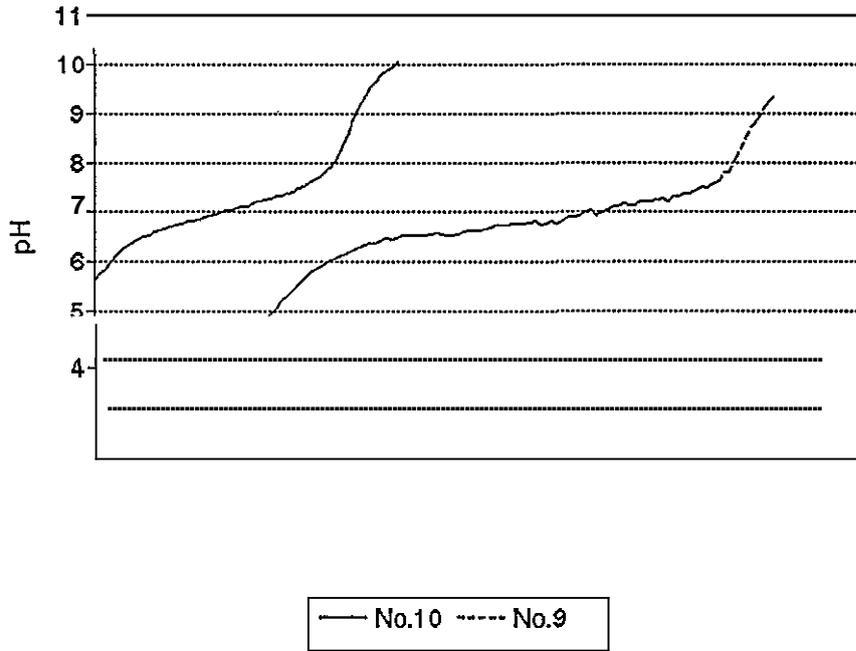
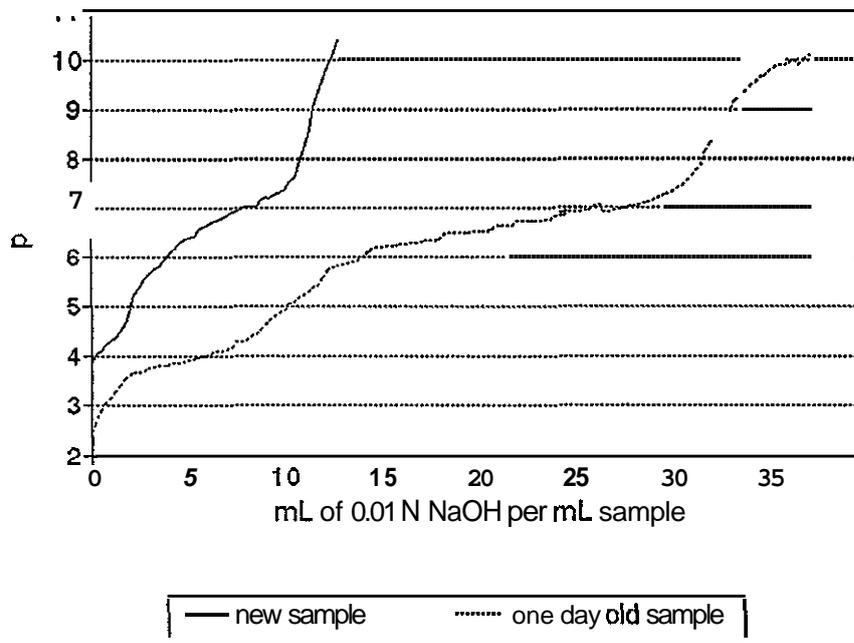


Fig. 3-7b TP-2 TestHole Water Titration
sampled in October 1991



4.0 ECOLOGICAL ENGINEERING EXPERIMENTS

The Ecological Engineering close-out scenario in the Buchans setting relies on biological systems to generate alkalinity for the removal of zinc in the OWP, or the seepage from the Waste Rock Pile. This appears to be feasible based on experimental work carried out in the last three years. By providing appropriate combinations of organic matter to microbial communities established in experimental settings (Pools 7 to 9, and limnocoarals in both the OEP and OWP), sulphate is converted to hydrogen sulphide which in turn precipitates ZnS. These processes take place naturally in lake sediments and wetlands, and have been incorporated in the Ecological Engineering measures used at Buchans.

Experiments were set up in 1989 in which different combinations of organic matter were tested in enclosures, both in the OEP and OWP. The layout of the experimental enclosures (limnocoarals, LC, and curtains) is given in plan view and cross section for both Orientals in Schematic 4.1-1 (page 4-48). As can be expected, the different effluent characteristics will present unique conditions for each microbial community.

Experimental results of the technology development behind Ecological Engineering was sufficiently promising in 1989 and 1990 that measures were taken to scale up. Curtains, in which organic material served as sediment, were installed in both the OEP and OWP. This configuration resembled most of those sediments in which **ARUM** (Acid Reduction Using Microbiology) is found naturally in the environment.

The microbial communities consist of decomposing bacteria, fungi, and sulphate reducing

bacteria, but their interaction is defined only in principle, and not in detail. Test **pools** were, therefore, installed in the seepages of the waste rock pile, and limnocorrals set up in both the OEP and OWP to study these interactions. The limnocorrals were amended with either sawdust or peat, while amendment (hay) was also placed in the Pools. Results of these experiments and their interpretation is presented in Section **4.1.1** to **4.1.2**.

The 1991 work addressed in detail the parameters controlling the ARUM process. The controlling factors of the established microbial systems in the limnocorrals and the curtains were determined through observations in the field and experimentation in the laboratory on two different scales - in 40 ml vials and in 11 jars (Section **4.1.3** and **4.1.4**).

As the microbial processes require the decomposition of organic matter, experiments have been carried out to determine to what degree organic material essential to the ARUM process is indeed decomposing (Section **4.1.5**).

One important element of the Ecological Engineering close-out was to develop a living, floating cover over the sediment to provide a continuous supply of organic matter to the microbial community below. In 1989, germination tests were carried out, and the conditions under which cattails effectively germinate determined. In 1990, the first floating rafts were installed in both pits. Growth of cattails on the rafts was monitored throughout 1990 and 1991, and the amount of organic matter produced from the floats quantified. Improvements to the methods by which cattails are germinated and transferred to the pits were made during 1991. Details of the work on establishing and quantifying the living, floating cover are

given in Section 4.1.6.

Although one of the main Ecological Engineering processes is ARUM, each treatment system should be accompanied by a polishing stage for effluent water. Biological polishing can be established through the use of attached algae. Attached algae growing naturally in the Buchans effluents were found to contain high concentrations of zinc. To determine the characteristics needed to optimize the treating capacity of the biological polishing system, such as required retention time, ~~six~~ ponds were constructed in the first meadow. Brush was placed in the ponds to provide surface area for the algae to grow. In Table 4.1-1 (page 4-49), details of the construction and placement of material is given. Results of the work on biological polishing, including the determination of growth rates, and the uptake and adsorption of zinc in the experimental ponds and laboratory, are presented in Section 4.2.

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4.1 The Orientals and the Waste Rock Seepage

4.1.1 Limnocorrals

Columns of OEP and OWP water 3 to 4 m deep were enclosed within circular Fabrine curtains (limnocorrals) in order to examine the initiation and performance of microbial alkalinity generation (ARUM) in 34 to 60 m³ batches of pit water under field conditions.

These limnocorrals (LC's) were set up in the Oriental pits in May 1989, and peat or sawdust were added as potential sources of organic nutrients supplying the demands of alkalinity generating bacteria. The dimensions and contents of the LC's are summarized in Table 4.1-1. Water quality monitoring has been performed for a period now of over 900 days since set-up in May 1989. The monitoring data on LC water chemistry is summarized in Figures 4.1-1 to 4.1-10.

The LC data were analyzed with the objective of trying to identify factors which could be used as diagnostics on the microbial activities in the LC's. Changes in water chemistry attributable to ARUM in the added amendments were first observed at the end of summer 1989. All four LC's with amendments were effective, to varying degrees, through 1990 in increasing alkalinity and eliminating Zn from the water column. Both LC's amended with sawdust (LC1 and LC4) in both the acidic OWP and circumneutral OEP completely failed in the spring of 1991, indicated by rising Zn concentrations approaching pit values (Figures

4.1-5,10). Although "pockets" or localized areas of ARUM activity (negative Eh, H₂S smell of amendment) were still detectable in the amendment layer in the summer of 1991, some factor had become limiting to the ARUM process. Meanwhile, the peat LC's (LC4 and LC5) continue to maintain very low Zn and Cu concentrations in the water column after 920 days (Figures 4.1-4, 5, 9, 10).

Comparisons are carried out between sawdust and peat amendments, including seasonal trends in the zinc concentrations. In Figures 4.1-5a, 5b, 10a and 10b, seasonal fluctuations in zinc concentrations in the sawdust and peat LC's can be seen. Zinc concentrations diminished in LC's 1 and 4 (sawdust) between October 1989 and spring 1990, whereupon zinc concentrations jumped to 10 - 20 mg/l in spring. The concentration of zinc in LC1 fluctuated between 1 and 40 mg/l, but prior to the 1991 spring melt, had declined to below 5 mg/l. However, with spring melt, zinc concentrations rose to ambient OWP concentrations and remained so over the remainder of 1991. In the OEP LC4, zinc concentrations follow this pattern, except that lower concentrations were maintained over 1990.

Concentrations of zinc in the peat LC's diminished after October 1989 and remained low through the spring of 1990 until, in spring of 1991, zinc concentrations rose to as high as 10 mg/l during spring melt, then diminished to low levels over the remainder of 1991.

Differences in performance of the peat and sawdust LC's may be reflected in patterns of oxygen concentrations and redox conditions. Oxygen and Eh profiles were determined in the LC's and the pits at large during October 1990 when all amended LC's were maintaining

low concentrations of zinc, and in October 1991, after the sawdust LC's had failed (Figures 4.1-11, 12, 13). Low Eh is required for sulphate reduction and decomposition of organic matter is however a combination of aerobic and anaerobic fungal and microbial processes.

In the OWP at large, the oxygen profiles indicate little change with depth in the 1990 or 1991 October measurements (Figures 4.1-11a, b). In contrast, in 1990 a chemocline existed in OEP, but the depth was greater than 4m and below the bottom of LC's 4, 5 and 6 (Figures 4.1-12,13). However, in October 1991 the chemocline was only 25 m deep, and surrounded the bottom half of LC's 4, 5 and 6. Overall, the LC's in the OWP are continuously surrounded by oxygenated water, while the lower halves of OEP LC's are adjacent to waters periodically low in oxygen.

In 1990, oxygen concentrations remained very low (< 3 mg/l) at depths greater than 0.5 m in all Lc's with amendment, in contrast to the control Lc's, where oxygen concentrations were comparable to the pits at large. Redox values were correspondingly low (< -50 mV) in bottom waters of all amended LC's, with those LC's with peat having even lower Eh values than LC's with sawdust. Clearly, the microbial activity associated with highly active ARUM results in the consumption of oxygen entering the LC's.

Lower Eh values in peat LC's co-occurred with greater hydrogen sulphide degassing in LC2 and LC5 (peat), compared with the sawdust LC's. During 1991, only mild odours of hydrogen sulphide were detectable early in the year in any of the Lc's. **This** was a significant contrast to 1990, when the smell was at times unbearable.

If significant hydrogen sulphide degassing, combined with precipitation of metals as sulphides occurred, then lower S values would be expected in the amended Lc's. This could only be expected if the Lc's did not leak, and diffusion through the walls was slow. In fact, sulphur determinations performed on LC water in October 1991 indicates that the peat Lc's contained much less sulphur, as well as iron, aluminum and zinc, than the sawdust Lc's. Specifically, LC2 contained 64, 0.2, 2.5 and 1 mg/l S, Fe, Al and Zn (n=2), respectively, while LC1 contained 108mg/l, 10mg/l, 7.8 mg/l and 30 mg/l respectively (OWP at large, 119 mg/l, 15 mg/l, 7.4 mg/l and 39 mg/l). Clearly, the higher microbial activity in LC2 in 1989/1990 is expressed by lower concentrations of those compounds responsible for acidity.

In October 1991, LC1 and LC2 oxygen concentrations were up to 6 - 8 mg/l, but still lower than the control LC3 or OWP. The Eh was no lower than + 220 mV, much higher than October 1990 values. Hydrogen sulphide degassing was not detected from any Lc's. There was no clear oxygen or Eh difference between the LC1 (sawdust, high zinc values) and LC2 (peat, low zinc values), overall suggesting that the (diminished) microbial activities are similar in each or that failure of the LC2 with peat is imminent.

The pH in LC2 remains high (6.5-7.0, top and bottom), despite diminished microbial activity (restricted primarily to the amendment layer). This suggests that ARUM in LC2 succeeded, in that most acidity has been removed, and the combination of high pH and some microbial activity in the amendment continues to hold the precipitated zinc immobile.

In contrast, LC1 (Sawdust) has been ineffective, in that zinc concentrations have increased

to ambient pit concentrations and pH has slipped to ambient pit pH's. Long-term monitoring indicates that pH only sporadically approached that of LC2 over 1989-91 (Figure 4.1-1a, b), and by the time microbial activity diminished in LC1, significant amounts of acidity remained in LC1 and resulted in pH decrease and re-solubilization of zinc.

Turning now to the LC's in the OEP, a **similar** analysis of the relatively poor performance of the sawdust LC compared to the peat LC can be made. As in the OWP LC's, Eh was lower in October 1990, and pH values typically higher, in the peat LC (LC5) compared to the sawdust LC (LC4: Figure 4.1-6). Similarly, greater degassing of hydrogen sulphide was noted from LC5 in 1990.

Using the same rationale as for the OWP LC's, changes in major compounds' concentrations should reflect the cumulative results of **ARUM** activity in each amended LC. Specifically, LC5 (peat) contained 121, 0.4, 6.5 and 0.48 mg/l S, Fe, Al and Zn (n=2), respectively, while LC4 (sawdust) contained 291, 8, 10 and 17 mg/l respectively (n=2: OEP at large, 388, 45, 11 and 27 mg/l, respectively). Therefore, 9.7 **kg**, or 50% more sulphur has been removed from LC5's water column (as precipitated metal sulphides and degassed hydrogen sulphide) compared to LC4's water column. This means that zinc precipitated as solid sulphides in LC5 is being held among a much greater mass of other sulphides (including iron) at pH's typically greater than pH 7.0.

A sulphate reduction rate of 2.49 g $\text{SO}_4/\text{m}^2/\text{day}$ can be calculated based on the S concentration decrease after 900 days. However, LC5 removed all zinc in within the first

250 days, indicating that the effective rate, is $0.67 \text{ g zinc/m}^2/\text{day}$.

Although many of these considerations stated above can be supported by data collected during the field program, in principal, the zinc removal processes are of a chemical nature mediated by microbiology. Therefore, the hydrogen sulphide production by sulphate reducing bacteria, and carbon dioxide production by aerobic bacteria, will produce precipitation processes which are governed by the relative proportions of presence of these gases.

In the period between May 1989 (limnocorral set-up) and October 1990, **LC4** and **LC5's** water columns' chemistry changed from oxic to anoxic conditions. With initial carbon dioxide production, zinc was likely found primarily as soluble zinc bicarbonate. With the onset of sulphate reduction, alkalinity was generated, and as pH increased, a fraction of the zinc was probably precipitated as zinc carbonate. With high rates of hydrogen sulphide and carbon dioxide production in **LC5**, zinc was probably re-released from carbonates (in localized regions of high carbon dioxide) and recaptured as insoluble zinc sulphides. Meanwhile, in **LC4**, a much smaller fraction of zinc was captured as precipitated zinc sulphide, while another fraction was precipitated as zinc carbonates.

When sulphate reduction decreased to low rates in spring of 1991, continued carbon dioxide production in **LC4** resolubilized the zinc carbonate fraction as soluble zinc bicarbonate and dissolved zinc concentrations rose to 25 mg/l . **This** may suggest than only the zinc carbonate fraction in **LC4** has redissolved, and the zinc precipitated as zinc sulphide is still trapped in

the anoxic sediments. Meanwhile, most zinc may have been precipitated as zinc sulphide in LC5, and with continued low rates of sulphide production, zinc is remaining immobilized in the amendment of LC5.

4.1.2 Oriental Pit Curtains and First Meadow Cells

Oriental Pit Curtains : The success of the LC's led to the construction of curtains (booms) in both pits in May 1990. Sawdust and alfalfa were chosen as amendments as sawdust appeared to be as effective as peat at the time the scale-up experiment was implemented designed, while preliminary results suggested that alfalfa, in moderate quantities, stimulates the onset of ARUM.

The Oriental East Pit curtains are near the outflow of the pit. The curtains enclose a volume of 750 m³. In the area between curtains 2 and 3, 15.1 tonnes (dry weight) of sawdust and 0.84 T of alfalfa were added (Table 4.1-1, section 4.1), based on the amendment:water ratios of the LC's. Effluent, totalling 860 m³/day, must pass through this area, although movement as a sheet in the upper strata is most likely. The Oriental West Pit curtain encloses a volume of 390 m³. In July 1990, 12.9 T (dry weight) of sawdust and 0.66 T alfalfa were added (Table 4.1-1). LC's are, physically, quite different than the large areas in OEP and OWP, in that water circulation from upper to lower strata driven by wind (OWP) and water flow-through (OEP) simply do not occur in the LC's. Therefore, LC's are effectively 'batch' reactors, while the areas enclosed by curtains are 'flow-through' reactors. To date,

examinations for the development of a chemocline in the area enclosed by the curtain in OWP indicate that the transition from oxic to anoxic conditions occurs at the water-amendment interface (Figure 4.1-14a). Although sulphate reducing bacteria have colonized the amendment layer, circulation of water within the area, and import of oxygenated, high-zinc water from beyond the burlap curtain, would not allow the establishment of a chemical stratification in strata of water overlying the amendment. **As ARUM** is based on sediment processes, treatment should occur as the overlaying water contacts the active sediment. In fact, as the data indicate this is occurring in the OWP, where a significant reduction in the long term trends is indicated for zinc and a reduction in acidity since 1990.

A chemocline already exists in the OEP in the vicinity of the area enclosed by the OEP curtains. A second chemocline, characterized by much lower Eh values and the presence of sulphate reducing bacteria, has developed just above the amendment surface (Figure 4.1-14b). Again, however, this chemocline has not been observed to reach higher than 0.5 m above the amendment-water interface.

Zinc concentration decreases in water overlying the areas cannot be expected, but a gradual overall decrease in zinc and acidity can be expected from a working **ARUM**. A second curtain has been installed at the east end of OWP in September 1991 with 8.5 T of peat and, most importantly 0.77 T of potato waste (Table 4.1-1), an amendment which is anticipated to stimulate the rapid onset and a high rate of ARUM.

First Meadow • Cells 7-9 : A series of three cells were constructed in Meadow 1 in July

1989 to remove metals from seepage draining from the waste rock pile. A total of 1.1 T (dry weight) of straw bales was placed in these shallow pools in August, 1989.

Monitoring data for Zn, Cu and pH for water entering and leaving the cell system is shown in Figure 4.1-15. From the Zn concentration of water entering Cell 7 and the flow rates, one can estimate that 0.4 to 1.0 T of Zn is entering the cell system.

Zn and Cu concentrations are considerably reduced during passage of the seepage water through the cells. There is also a small but consistent increase in pH. Zn and Cu concentrations were reduced on the first sampling date (Aug 8, 1989) before addition of amendment to the cells (Aug 19, 1989), suggesting that alkalinity generation was initiated in the peat underlying the cells when exposed to the oxygenated seepage during construction.

Data for one sampling date are shown in Figure 4.1-16 and Table 4.1-2. The reduction in metal concentrations is not due to dilution from the bog as the concentration of Na, for instance, is approximately the same in Cell 7 inflow and Cell 9 outflow. There is a slight increase in pH and a reduction in conductivity and acidity within the amendment. The changes in chemistry and the more effective Zn reduction in summer (Figure 4.1-15) are strongly suggestive of ARUM with precipitation of Zn as ZnS. The pH in the cells is near the lower limit for sulphate reduction. Therefore, a small increase in pH can be very important in determining the role for this process in further alkalinity generation.

4.13 Why did sawdust (LC2 and LC4) stopped working ?

In order to address this question 7 experiments were carried out in 40 ml weaton vials, representing those conditions, which are expected to take place in the sediment. The objective of these experiment was to a) provide background microbiological data.

b) determine why the ARUM process was not maintained in LC1 with the sawdust in the Oriental West Pit and c) to recommend a solution on which would provide new life to the sawdust. The first experiment provided background information on the functional status of the microbial community in the ARUM substrates in the field experiments. The second experiment addressed, if those microbial groups present as identified by experiment #1, are actually active. The third experiment then addressed those factors which could have lead to the reduced activity in the LC1. The forth experiment tested, if inorganic nutrients or glucose could initiate microbial activity. The sulphate reduction rates were examined in experiment number five and number 6 in the peat from LC2. Finally, in the last experiment the decomposition of the material was addressed, through investigation on aerobic microbial activity which would produce soluble carbohydrates. The seven experiments and the results are presented in sequence below.

EXPERIMENT #1: Comprehensive Analysis of Samples Obtained in June 1991

Analyses were conducted to provide background information on the functional status of the components of the ARUM ecosystem in various field test sites at Buchans. The samples

were tested for pH, ATP, total soluble carbohydrates, volatile fatty acids and for numbers of sulphate reducing bacteria (SRB). The results are summarised in Table 1. ATP levels ranged from 7 to 100 ng per mL. This indicates high numbers of viable microorganisms were present at each site and therefore that the environments of these sites were hospitable for microbial growth.

All samples had at least moderate numbers of sulphate reducing bacteria (SRBs). Since SRBs depend on the activity of volatile fatty acid-producing bacteria to supply their carbon source, this indicates that these organisms must also have been active at the test sites. However, total soluble carbohydrate levels and volatile fatty acid levels (VFAs) were low in all conditions. This indicates that most of these compounds were being metabolised as soon as they were produced and/or that inhibitors of soluble carbohydrate and VFA production were present and/or that insufficient amounts of degradable carbon remained in the amendment.

EXPERIMENT #2: Generation of Alkalinity in Buchans Amendment Samples

The purpose of this study was to demonstrate if the ecological groups involved in the ARUM process in the field were functional. Field samples obtained from Buchans Mine site (not including Linnocorral 1 and 2) were tested under controlled laboratory conditions to determine whether the microbial groups were active and could initiate alkalinity. LC1 and LC2 field samples were tested in detail in the following experiments.

Test conditions were set up in 40 mL Wheaton vials. The order of addition to the vials were field sample amendment and OWP water. The vials were incubated at ambient temperature and pH was monitored. The vials were also observed for sulphate reduction. The results are summarized in Table 2A. Visible sulphide production was achieved in all test conditions by day 14, except amendment condition containing Oriental East Pit alfalfa curtain and LC2 Peat amendment. LC2 Peat #2 produced acidity.

VFA and Thiobacillus ferrooxidans analyses were conducted on LC2 Peat (conditions 9 and 10) to explain why the pH in these conditions had decreased. It was found that the production of acidity was not due to the presence of Thiobacillus ferrooxidans or the high levels of VFAs. Following a two week incubation period, copper, zinc and sulphate levels were measured in all tests conditions to determine whether metal removal was occurring. The results are summarized in Table 2B. Low levels of zinc and copper were observed in conditions one through eight. However, LC2 peat amendment failed to remove zinc. This may have been due to the traumatization of the microbial ecosystem during sampling and transport. The samples were received with no liquid phase.

EXPERIMENT #3: Generation of Alkalinity in Buchans Oriental West.

Limnocorral 1-Series I.

The purpose of the study was to determine why the ARUM process in the field site, Oriental West Pit LC1 had failed during 1990. pH decreased to 3.5 while zinc levels had increased to 30 mg/l. Test conditions were set up in 40 mL Wheaton vials. The order of addition to the first set of vials was amendment followed by OWP water. The second set of vials

contained amendment followed by acidic seepage and microbial seed. The vials were incubated at ambient temperature and pH was monitored. The vials were also observed for sulphate reduction. The results are summarized in Table 3A. There was no evidence of sulphate reduction and pH was consistently low following a two week incubation period. Nutrients were then added to various test conditions to determine if the lack of ARUM activity was due to a nutrient deficiency.

Sulphate reduction and alkalinity generation were stimulated following the addition of glucose and inorganic nutrients (conditions 4 and 8). This suggests that the problem in LC1 was insufficient degradable carbon remaining in the amendment. The addition of BOD inorganic nutrients alone did not initiate sulphate reduction. Addition of a supplementary microbial seed was not essential for sulphate-reduction to occur. The effectiveness of adding iron and sodium sulphide to initiate sulphate reduction was also tested. However, excessive addition of these treatments on day 44 spoiled the experiment.

Total soluble carbohydrates and VFA levels were measured in various test conditions prior to and following the addition of nutrients (Table 3B). The results suggest that the added glucose had been converted to VFA to provide the carbon source for the sulphate reducing bacteria. The results of additional tests conducted are given after 59 days (Table 3C). Conditions are compared where ARUM was active and sulphide production occurred (#4) to that where ARUM was inactive (#1). VFA producers and high numbers of SRBs were present. This suggests that the failure of the ARUM process in LC1 in this experiment was not due to the lack of appropriate bacteria necessary for alkalinity generation. However,

without the additional carbon source (glucose), sulphate reduction could not be initiated. Insufficient degradable carbon source was the problem in LC1. Furthermore, there was an appreciable difference in the redox potential. In condition **4**, a negative redox potential, necessary for the growth of SRB, was obtained, while the redox potential was positive in condition **1**. A negative redox potential is required not only for SRB growth but also for fibrolytic generation of VFAs. Therefore, it may be possible that the amendment contains degradable carbon but environmental conditions are too adverse for it to be used.

EXPERIMENT #4: Generation of Alkalinity in Buchans Oriental West Pit.

Limnocorral 1 Amendment-Series II.

In order to further define the most likely cause of failure of the **ARUM** process in LC1, it was necessary to set up additional tests. These were performed to determine whether BOD (inorganic) nutrients in addition to glucose were necessary to initiate the **ARUM** process using LC1 amendment

Test conditions were set up in **40 mL** Wheaton vials. The order of addition to the first set of vials was amendment, followed by additional nutrients and OWP water. The second set of vials contained amendment followed by OWP water and a microbial seed. The vials were incubated at ambient temperature. The pH was monitored and the vials were observed for sulphate reduction. These results are summarized in Table **4A** and a titration curve of Oriental West Pit water is presented in Fig. 1. Sulphate reduction had occurred in all amendment conditions containing glucose. Once again, this suggests that the problem in OW LC1 was carbon limitation. Additional inorganic nutrients (BOD nutrients) were not required to initiate sulphate reduction. Similarly, a microbial seed was not required for sulphate reduction in conditions containing glucose. Excessive additions of iron and sodium sulphide on day 28 to conditions 2 and 7 containing BOD nutrients spoiled the test to determine the effectiveness of these treatments for sulphate reduction.

Culture tests were also performed on day 52 to determine whether the maintenance of low pH in condition 1 was due to the presence of Thiobacillus ferrooxidans. Thiobacillus ferrooxidans was not detected. A review of the data in Table **4A** shows a lag in alkalinity

EXPERIMENT #4: Generation of Alkalinity in Buchans Oriental West Pit.

Limnocorral 1 Amendment-Series 11.

In order to further define the most likely cause of failure of the ARUM process in LC1, it was necessary to set up additional tests. These were performed to determine whether BOD (inorganic) nutrients in addition to glucose were necessary to initiate the ARUM process using LC1 amendment.

Test conditions were set up in 40 mL Wheaton vials. The order of addition to the first set of vials was amendment, additional nutrients and OWP water. The second set of vials contained amendment followed by OWP water and a microbial seed. The vials were incubated at ambient temperature. The pH was monitored and observed for sulphate reduction. These results are summarized in Table 4A and a titration curve of Oriental West Pit water is presented in Fig. 1. Sulphate reduction had occurred in all amendment conditions containing glucose. Once again, this suggests that the problem in OW LC1 was carbon limitation. Additional inorganic nutrients (BOD nutrients) were not required to initiate sulphate reduction. Similarly, a microbial seed was not required for sulphate reduction in conditions containing glucose. Excessive additions of iron and sodium sulphide on day 28 to conditions 2 and 7 containing BOD nutrients spoiled the test to determine the effectiveness of these treatments for sulphate reduction.

Culture tests were also performed on day 52 to determine whether the maintenance of low acidity in condition 1 was due to the presence of Thiobacillus ferrooxidans. Thiobacillus ferrooxidans was not detected. A review of the data in Table 4A shows a lag in alkalinity

generation in conditions 9 and 10 compared to conditions **4** and **5**. All four conditions started with 1000 ppm glucose at the beginning of the experiment but 9 and 10 also had been given a microbial seed. Chemical analysis (see Table 4B) do not readily explain this lag in **ARUM** activity. Total soluble carbohydrate levels had been consumed to a much greater extent than the condition without a microbial seed, and **VFAs** had been produced. Perhaps the addition of the microbial seed in conditions 9 and 10 provided a temporary condition which was less than optimal for alkalinity generation to occur. Another possibility is that the soluble carbohydrates were consumed in non-alkalinity generating processes.

Further tests were performed to determine the cause of the low **ARUM** activity in **LC1** amendment in test conditions not supplemented with glucose. Total soluble carbohydrate analyses of the **LC1** amendment (June and July samples) were performed using the phenol reaction Molisch test with glucose as the standard. Prior to analysis the samples were dried at 40°C for 24 hours. The results indicated that a significant amount of carbohydrates (20% and 50%) was present in the June and July **LC1** amendment sample, respectively.

The low activity observed in **LC1** could be the lack of fibrolytic organisms and/or toxicity at the surface of the fibre. The amendment was analyzed for colonization by bacteria by epifluorescence microscopy using the fluorescent stains, fluorescamine, and acridine orange. Microscopic examination of the amendment by epifluorescence demonstrated that sparse colonization had occurred on the amendment (Figure 2). This is consistent with the suggestion that microbial activity at the surface of the fibre is weak.

Since toxicity may also be a problem, LC1 amendments were further analyzed for zinc and copper, the most likely toxic species at this site. The amendments were gently rinsed in tap water to remove soluble zinc and copper and then dried at 40°C for 72 hours. The results are summarized in Table 8. The concentration of zinc for the June and July amendment samples were 7900 and 7000 mg zinc per kg dry amendment respectively. Since this zinc is in an insoluble form, it will not be available to react with microorganisms. However, it may provide a sufficiently toxic environment to explain the apparent lack of microbial activity at the surface of the fibre.

EXPERIMENT #5: Initiation of the ARUM Process in Oriental West Pit.

Limnocorral 2-Series I.

The purpose of this study was to determine why sulphate reduction rates have diminished in LC2 during 1991. The same experimental design was used as in Experiment #3. The results are summarized in Table 5A and show that alkalinity generation could not be initiated with Oriental West Pit LC2 amendments under laboratory conditions. Sulphate reduction could not be initiated even when glucose or BOD nutrients were added. Tests to determine the effectiveness of iron and sodium sulphide to initiate sulphate reduction was spoiled due to the excessive additions of these treatments.

Total soluble carbohydrates and VFA levels were measured in various test conditions prior to and following the addition of nutrients (Table 5B). The lack of alkalinity generation and low levels of total soluble carbohydrates and volatile fatty acids prior to addition of glucose suggests low microbial activity in the various test conditions. **This** even occurred where

microbial seed had been added. However, following addition of glucose, the total soluble carbohydrates appeared to be consumed and converted to **VFAs**. Carbohydrate consumption occurred to a much greater extent in test conditions containing a microbial seed. Nevertheless, alkalinity was not generated even after the addition of glucose. Therefore further tests were performed to determine whether the key microbial populations were viable in the test conditions.

Results are summarized in Table **5C**. In test condition 1, **SRBs** were not detected and **VFA** producers were present in low numbers. Low concentrations of these microbial groups, in addition to the absence of a negative redox potential could explain the lack of sulphate reduction in the lab conditions. Test condition 5, which had received a microbial seed, contained a larger number of **SRB** and **VFA** producers. Even though the microbial groups necessary for sulphate reduction were present, sulphate reduction did not occur. This indicates unfavourable conditions (toxicity, lack of nutrients, inadequate redox potential) for their activity.

EXPERIMENT #6: Limitation of the ARUM Process in Oriental West Pit.

Linnocorral 2 Series II.

In order to further define the most likely cause of diminished sulphate reduction rates in LC2 it was necessary to set up additional experiments. Similar test conditions were set up as in Experiment **#4**. The results are summarized in Table **6A**. Sulphate reduction and alkalinity generation could not be initiated in Oriental West Pit LC2 test conditions, even when glucose was added. However, significant **VFA** production had occurred in condition

9 and 10 which contained an additional microbial seed (Table 6B). Excessive additions of iron and sodium sulphate on Day 28 to conditions 2 and 7 containing BOD nutrients spoiled the test to determine the effectiveness of these treatments.

Additional tests were also performed on Day 52 to determine whether the maintenance of pH in condition #1 was due to the presence of Thiobacillus ferrooxidans. Negative results were obtained. Since there **was** no evidence of sulphate reduction in the glucose-containing test conditions following a two-week incubation period, total soluble carbohydrate and VFA levels were measured. Lack of **VFA** activity may explain why sulphate reduction **rates** have decreased in **LC2** (Table 6B). In test conditions **4** and **5** which contained glucose, carbohydrate levels remained high, i.e. carbohydrates were not consumed and it is unlikely that significant levels of **VFAs** were being produced. However, in test conditions 9 and 10 which contained an additional microbial seed, carbohydrates were consumed to a great extent and **VFAs** were produced.

The different responses in test conditions **4** and **5** and test conditions 9 and 10 may be explained by the concentration of VFA producers in both test conditions (Table 6C). There were no detectable levels of **VFA producers** in test conditions **4** and **5**. Therefore, since VFA producers were absent, soluble carbohydrates were not consumed, and thus **VFA** levels remained low. However, **VFA** producers were present in conditions 9 and 10. Therefore soluble carbohydrates were converted by VFA. This suggests that the low activity in LC2 may be, in part, due to the lack of alkalinity-generating organisms.

Further tests were performed to further define the cause of the low activity in **LC2** amendment. Total soluble carbohydrate analyses of **LC2** amendment was performed using the phenol reaction Molisch test with glucose as the standard. Prior to analysis the samples were dried at **40°C** for **24** hours. The results demonstrated that greater than **80%** of the dry weight amendment appeared to be carbohydrate. This suggests that the low activity in **LC2** may be due to the absence of fibrolytic organisms and/or toxicity to the organisms rather than a shortage of degradable carbon.

The amendment was also analyzed for colonization by bacteria by epifluorescence microscopy using the fluorescent stains fluorescamine and acridine orange. Microscopic examination by epifluorescence demonstrated that the amendment was poorly colonized, consistent with weak fibrolytic activity (Figure 3). Since toxicity may also be a problem in **LC2**, zinc and copper levels in the amendment were determined (Table 8). The concentration of zinc was **1500** mg per kg dry weight amendment. This suggests that zinc toxicity is less likely to be the cause of the apparent lack of fibrolytic activity than in **LC1**. However, the key to this factor is the bioavailability and the location of the zinc deposit within the amendment.

Another possible factor may be the absence of a sufficiently negative redox potential necessary for growth of fibrolytic bacteria and SRBs. In addition, a lack of other essential nutrients including iron, may also explain why **LC2** has lowered activity levels.

EXPERIMENT #7: Tests to Define the Role of Aerobic Cellulytic Organisms
in the Generation of Alkalinity

The purpose of this experiment was to determine the potential of indigenous aerobic microbial processes to generate soluble carbohydrate for subsequent use in an **ARUM** ecosystem. Test conditions were set up in 250 mL Erlenmeyer flasks. The order of addition to the flasks were field sample amendment and OWP water. The level of the acidic seepage was below the amendment portion allowing exposure to the air. The flasks were incubated at ambient temperature and pH was monitored. The flasks were also observed for sulphate reduction.

Results are summarized in Table 7A. Alkalinity was generated in Oriental West Pit curtain amendment (condition 5 and 6). **This** result was not expected, since the introduction of aerobic condition in a system usually produces a decrease in pH. In contrast, Oriental East Pit LC4 amendment (condition 7 and 8) produced acidity. Total soluble carbohydrate analyses were performed on conditions #1 through #4 on Day 14 and Day 68 (Table 7B). It appears that soluble carbohydrate production was not occurring. There was no evidence of cellulose degrading microorganisms including fungi, forming on the amendment, even after 68 days. Submerged samples are not good sources of aerobic fibrolytic organisms. Other sources of indigenous organisms would be required if an aerobic pre-treatment of amendment is desired.

Tests were performed on conditions 7 and 8 (OEP LC4) to determine whether the production of acidity was due to the presence of Thiobacillus ferrooxidans. Condition 8 tested positive for Thiobacillus ferrooxidans. These results demonstrate that there are

Thiobacillus ferrooxidans species present at this site which are not inhibited by insoluble organics. It would be interesting to determine whether fresh amendment would inhibit these particular species.

4.1.3.1 Summary and conclusions

1. All amendment samples had low soluble carbohydrate and **VFA** levels. Most likely causes are as follows:
 - high **VFA** and soluble carbohydrate utilization;
 - conditions are inhibitory to soluble carbohydrate and **VFA** production; and/or
 - insufficient degradable carbon remaining in the amendment.

2. Active sulphate reduction occurred in picocosm tests of OWP curtain, OEP LC4, and OEP LC5 but not in OEP alfalfa curtain or LC2 peat amendments. OWP LC2 peat produced acidity.

3. The picocosm studies indicate that the **OWP LC2** problem in LC1 (OWP) is carbon limitation. **ARUM** activity with sulphate reduction occurred when glucose was present. Additional inorganic nutrients (BOD nutrients) were not required. Molisch tests were performed at Dearborn on the amendment indicated that approximately 20% of the amendment was carbohydrate. Since there still remains a significant amount of carbohydrate in the amendment yet

in the absence of glucose VFA production was negligible, this suggests that the fibrolytic activity in the amendment is weak. The sparse colonization of the amendment is consistent with this conclusion. (The July sample had 50% carbohydrate content (w/w/dry).

4. The apparent lack of fibrolytic activity in the LC1 amendment may be due to zinc toxicity. There were **7,900** mg zinc per kg dry amendment (note-the dry weight was 21% of the total wet weight). Other explanations include in absence of fibrolytic organisms and/or an inappropriate environment for their activity. VFA production was possible by indigenous organisms. Perhaps the VFA producers are incapable of fibrolytic activity.

5. Sulphate reduction could not be initiated in OWP **LC2** picocosms even when glucose was added. Low numbers of SRB and VFA producers and unfavourable conditions including toxicity, lack of nutrients and inadequate redox potential may explain the lack of sulphate reduction. Addition of a microbial seed may provide the necessary microbiological groups responsible for the initiation of sulphate reduction. VFA production occurred in all picocosms containing glucose inoculated with a supplementary microbial seed. VFA production required glucose plus inorganic nutrients when only indigenous organisms were present. Tests to determine the effectiveness of iron and Na_2S to initiate sulphate reduction by poisoning redox potential and reducing metal toxicity were spoiled due to excessive addition of these

treatments. Again fibrolytic activity appeared weak in this sample of amendment. Photographs showed the amendment to be poorly colonized. Nevertheless, most (>80%) of the dry weight appears to carbohydrate. Zinc toxicity may be less likely in this sample than the LC1 sample as only 1500 mg/kg dry weight of amendment was measured. (The dry weight was 89% of the total wet weight). However, this metal still has potential to be inhibitory to fibrolytic organisms.

6. Attempts to isolate aerobic cellulose degrading microorganisms including fungi have failed. Further tests are required to determine the potential of indigenous aerobic microbial processes to generate soluble carbohydrate for subsequent use in an **ARUM** ecosystem. A Thiobacillus ferrooxidans species which is not inhibited by insoluble inorganics was isolated.

4.1.3.2 Recommended Laboratory program

1. Demonstrate and culture fibrolytic microorganisms. We need to prove they are present and may need to have cultures to spike test conditions. I do not think we have the time or budget for this project to perform any taxonomic identification. Where possible, I suggest working with mixed populations which will more closely simulate field conditions.
2. Determine necessary nutrient/chemical treatments to maintain **ARUM** on partially degraded amendment.

Amendment samples from the curtain would be further leached of soluble nutrients

(by using water column reactors as lysimeters) so that the main nutrients are only associated with the amendment particles. However, some of the amendment would not be leached. This would be incubated in O.W. water as a source of indigenous microorganisms.

The leached amendment would then be distributed into picocosm tests which would be supplemented with an assortment of treatments in order to determine the requirements for ARUM operation with such an amendment.

Note: Due to weak acidity of the O.W. water, 40 mL picocosms are too small. One L jars are recommended. For this task alone, 15 Imperial gallons of water for 3 kg of amendment will be required.

3. Evaluate local low cost nutrient supplements. We have already identified potato processing wastes; wastes from the fishing industry would potentially be a readily degradable C-N-P source. However, we need to find what concentration is applicable; in a case like alfalfa, the nutrient becomes too rich and excessive VFA production rates occur.
4. Compare colonization of degraded amendments from tests showing weak or no ARUM with those with strong ARUM activity. This might be a practical tool to rapidly characterize problems in combination with measurement of soluble glucose and VFAs. Samples of amendment could be incubated with fluorescamine diacetate or INT (to test for electron transport activity) to indicate the physiological status of the cells on the amendment.

Note: After exhaustion of the soluble nutrients from the amendment, all the VFAs must be produced directly or indirectly via the fibrolytic activity of these attached cells. Extracellular enzymes are unlikely to function in the adverse conditions of most AMD's.

4.1.4 Understanding the Controlling Factors

Analysis of the limnocorral performance indicates that low zinc concentrations do not necessarily reflect current microbial activity levels. The best example is the case of LC2 and LC5, where low zinc concentrations predominate as a result of past high microbial activities.

Recent Eh and oxygen measurements in the limnocorrals, combined with the detailed analysis carried out by Dearborn (Section 4.1.3), suggest that ARUM microbial activities in LC's 1, 2, 4 and 5 are all currently low. The experiments in the following section was to examine the role of the sediment and overlaying water bodies in the 1L jars.

Glucose/Osmocote : Jars were set up with 1 l of water and amendments from the limnocorrals. Ratios of amendment to water volume were the same as in the limnocorrals. Some jars were supplemented with glucose (100 mg/L) or Osmocote 19-6-12 slow release fertilizer (250 mg/l). The fertilizer treated jars were placed under lights to stimulate algal productivity as a means of augmenting carbon supply to ARUM. Osmocote has been added to the sawdust limnocorrals (LC1 and LC4) to reactivate ARUM. Chemistry of the jars at set-up and after 80 days are summarised in TABLE 4.1-3.

Zinc concentrations decreased in all LC1 (OWP sawdust) treatments (except Osmocote aerated). With Osmocote and aeration, the zinc concentration rose as expected in the absence of an active ARUM sediment. In the LC4 (OEP sawdust) and LC5 (OEP peat) treatments, zinc concentrations decreased. Zinc concentrations greatly increased in all LC2 (OWP peat) treatments. Clearly these experimental conditions proof that additions to the

water column of glucose is ineffective to stimulate ARUM. The 40 mL picocosms used at Dearborn, where glucose initiated ARUM with LC2 sawdust, suggest that conditions in the small picocosms resemble those of the sediment.

Alternative organic materials, which stimulate very high microbial activities are needed for ARUM. Potato waste is one of the options examined experimentally in the next section.

Potato waste experiment: Experiments carried out by Dearborn in 1990 identified potato waste as a material which provides an immediate supply of available carbon and other nutrients for microbial communities. Potato waste is 65 % starch, a readily decomposable carbon source. The waste also contains substantial amounts of nitrogen (in protein) and phosphorus, either of which may be limiting to microbial activity.

Jars with one litre of OWP water were set up with new peat or with peat collected from LC2 (TABLE 4.1-4). Jars were set up with: 1 g of potato waste (in a layer, or mixed with peat) and 19 g of peat (or 135 mL of LC2 amendment); with potato waste alone (40 g); or with peat alone (Plate 4.1-1). The results may be summarised as follows.

With new or LC2 peat alone, there was an initial decline in acidity followed by a stable period and slight rise towards the end of the experiment (Fig 4.1-17a). Based on smell, there was no indication of H₂S degassing from the jar surface. However, as concentrations of Zn were reduced with the new peat, but not with the LC2 peat, hydrogen sulphide generation via sulphate reduction may have been occurring, while sulphide was directly

consumed by the formation of zinc sulphide (TABLE 4.1-4).

FIGURE 4.1-17b shows that, in the presence of peat (new or LC2) and potato waste, there was a much larger decrease in acidity over a 35 day period than with peat alone (**FIGURE 4.1-17a**), where acidity overall remained constant. Acidity decreased more rapidly in the LC2 peat and potato waste treatment, compared to new peat and potato waste; the LC2 peat was probably already inoculated with sulphate reducing and other **ARUM** bacteria. However, despite a lesser rate of acidity removal, new peat with potato waste removed **all** detectable Zn from the water column (TABLE 4.1-4).

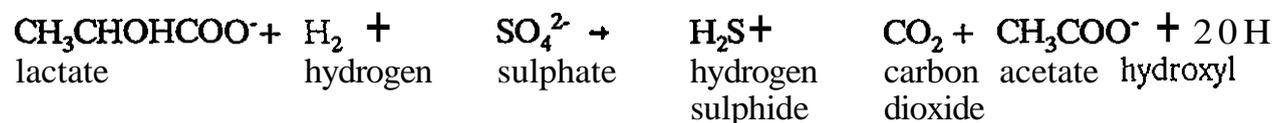
The smell of H_2S in the **jars** with new peat and potato waste or potato waste alone demonstrates that metal sulphide removal was complete and H_2S was degassing from the **jars** without being trapped. The positive Rapidchek test (for sulphate reducing bacteria), and a substantial reduction in sulphate concentration (from 395 to 177 mg/l) in the presence of potato waste, both indicate that **ARUM** is enhanced by this material.

Potato waste alone initially decreased acidity (**FIGURE 4.1-18**), whereafter acidity rose to a peak of 1850 mg/l $CaCO_3$ equivalents by day 35. This may have been due to the production of volatile fatty acids from starch. A decline in acidity began on day 35, which corresponded with a rise in pH and clear evidence of sulphate reduction (H_2S smell). After **75** days, a considerable amount of alkalinity had been generated, and **all** detectable Zn had been removed from the water (TABLE 4.1-4).

Titration of water ~~from~~ the jars (after 75 days) shows the effect of Zn removal on the acidity of the samples (FIGURE 4.1-19). The flat section of the OWP water curve represents the pH range over which Zn is precipitated during NaOH addition. In the presence of peat and potato waste, this flat section is absent, as zinc has already been removed. Potato waste addition to OWP in the presence of peat ~~can~~ remove all the Zn through ARUM (sulphate reduction). Layering or mixing of the potato waste without peat made no difference in ARUM enhancement. From the jar experiment data, it is possible to calculate the requirements of carbon and sulphate to achieve this:

After 75 days, when all detectable Zn had been removed ~~from~~ the jars with new peat and potato waste, the mean acidity of these jars was 110 mg/l equiv. CaCO₃ (TABLE 4.1-4). The OWP water used in this experiment had an acidity of 170 mg/l equiv. CaCO₃ (based on titration with NaOH to pH 8.3). This reduction in acidity of 60 mg/l equiv. CaCO₃ is probably due to microbial alkalinity generation including sulphate reduction.

This process is summarised as:



Lactate is produced ~~from~~ starch in the potato waste by VFA- producing bacteria. Hydroxide (OH⁻) represents a net alkalinity gain.

For every 2 mole of OH⁻ produced, one mole of lactate and one mole of SO₄²⁻ is required. In other words, for 34 mg OH⁻, 89 mg of lactate and 96 mg of SO₄²⁻ is required. The

observed reduction in acidity (60 mg/L) requires **158 mg** lactate and **170 mg** SO_4^{2-} . It appears that the starch in the potato waste (**65 %** or **0.65 g**) supplies all the carbon requirements for sulphate reduction itself and other microbial processes.

With potato waste (new peat), **118 mg/l** sulphate remained, while with new peat alone, **339 mg/l** remained. **This** loss in sulphate (**221 mg**) is more than enough to account for the observed acidity reduction (60 mg/l CaCO_3 equiv.). If sulphate reduction alone is responsible for reductions in acidity then, according to theoretical considerations, **221/96 x 34 mg/l** (theoretic acidity removal), or a **78 mg/l** CaCO_3 reduction in acidity should have been observed. The similarity between the acidity change, calculated from sulphate decrease (**78 mg/l**), and the value of the direct measurements of acidity decrease (60 mg/l) is evident. Therefore, sulphate reduction alone can account for the observed decreases in acidity in the **jars** with new peat and potato waste.

In this experiment, 1 g of potato waste removed all the Zn (about 65 mg/l; Taylor colourimetric test) from 1 L of West Pit water in 75 days. From this result it can be estimated that **32 tonnes** of potato waste would remove the approximately **2.0 tonnes** of Zn in the West Pit in 75 days. The **65 mg/l** used for this estimate is very high for the West Pit. **An** ICP determined Zn concentration for a sample collected from the same site and time as that used in the potato waste experiment gave a Zn concentration of **47 mg/l**. Using this figure, it can be estimated that **42 tonnes** of potato waste would be required to remove **2.0 tonnes** of Zn from the West Pit in 75 days. It can be expected that the amount of potato waste required would **be** in the range of **32 to 42 tonnes** given by these two estimates.

Based on, first, the results from the laboratory experiments (potato waste jars), second, the theoretical requirements of sulphate reduction (ARUM), and third, the performance of limnocorrals, the contribution to zinc removal by the amendments in the curtain can be calculated (a) **LC1**, amended with sawdust, removed Zn from its **35 m³** of water. Extrapolating to the amount of sawdust in the curtain one can estimate a capacity to remove at least **15.4kg Zn** (b) The decomposition experiment results (see Section **4.1.5**) indicate that sawdust in **LC1** lost **29 %** of its weight in **323** days. As the OWP curtain contains **12.87** tonnes of sawdust, **3.73 T** would be lost in a similar period. According to the potato waste experiment, **0.65 g** carbohydrate (starch in potato waste) removed **65 mg** of Zinc from 1litre of OWP water. If all mass lost by sawdust was organic carbon available for **ARUM** (sulphate reduction), the **3.73** tonnes of decomposed sawdust could have been utilized to precipitate **360 Kg** of zinc in **323** days, or **400 Kg/year** (c) Using the figure of **3.73 T** weight loss by sawdust within the curtain, and the theoretical requirements of sulphate reduction (using lactate as a carbon source), sulphate reduction could remove **1.67 T** zinc (**83.3 %** or **25 mg/l**), based on average **1991** concentration) from the OWP, if all biomass was converted to lactate.

This latter figure is unrealistic as some of the weight loss will not be available for sulphate reduction. However, it is clear from the decomposition experiment that sawdust can decompose in *anoxic/anaerobic* conditions and *can* be expected to remove a substantial amount of zinc through ARUM.

Titration of OWP water collected in **1990** and **1991** (FIGURE **4.1-19b**) clearly indicate the

alfalfa after 34 days (54%), possibly attributable to rapid disintegration of the leaf component of the biomass. In contrast, sawdust, straw and *Typha* biomass lost no more than 35% of the weight after 34 days.

After 323 days, all materials showed similar, to substantially greater, weight losses compared to after 34 days. For straw and cattail litter, the weight loss after 323 days was very much greater than that after 32/34 days, indicating that the materials are continuing to break down. Weight losses were as great or greater in the ARUM-active limnocorrals (LC2 and LC5) as in those which are failing (LC1 and LC4). **This** observation and the considerable weight losses at the bottom of the East Pit where reducing conditions favourable for ARUM are apparent, indicate that decomposition can take place in the vicinity of ARUM.

Overall, sawdust exhibited relatively low weight losses, compared with peat, alfalfa, *Typha* and straw; again, low decomposition rates for sawdust may account for the poor performance of sawdust-amended limnocorrals.

Sequential extractions: The results of sequential nutritional analyses of sawdust indicate that, not only does sawdust decompose slowly, as suggested from the weight **loss** experiment, but that it contains no more than 30% acetone and HCl extractable compounds, less than all other amendments examined (Original material; FIGURE 4.1-21a). In contrast, alfalfa has the highest fraction, (45%; FIGURE 4.1-21e), closely followed by *Typha* (42%; FIGURE 4.1-21d) and peat (41%; FIGURE 4.1-21b). This information suggests that *Typha* and peat may be comparable organic carbon sources, in terms of gross content of decomposable

compounds.

Following incubation of the organic substrates in limnocorrals or the Oriental pits at large, the fraction of acetone extractable compounds remaining was, overall, lowest in peat, compared to all other substrates, suggesting that acetone-extractable peat compounds were more readily leached during anoxic decomposition.

Typha biomass lost acetone-extractable compounds, with the exception of material incubated in LC5, where acetone-extractable compounds constituted a higher fraction than in the original material. This is also true for sawdust, alfalfa and straw from LC5, while samples of the peat amendment from LC5 contained a higher fraction of acetone extractable compounds than any other peat collected from the field. This strong trend suggests that, in LC5, the organic composition of all organic materials was modified such that a similar, and even higher fraction of acetone-extractable compounds was generated, compared to original materials added. Given the high **ARUM** activity, and presumably anoxic decomposition activity in LC5, conversion of other compounds in the organic materials to acetone-extractable ones, such as volatile fatty acids, may be occurring.

Generally, the HCl extractable fraction of organic materials examined did not decrease after 323 days, with the exception of alfalfa, where slightly smaller fractions, compared to the original material, were recorded. In fact, for peat and straw, the HCl extractable fraction increased, compared to original material.

Given that decomposition under anoxic/anaerobic conditions is not well understood as compared to aerobic decomposition it may well be that the expected sequence in extractability is altered. The results however indicate that decomposition in peat and a functional ARUM go hand in hand.

4.1.6 Floating cattail covers

In 1990, twenty rafts, 6 x 12 feet in size, were constructed from timber, styrofoam and netting, of which ten were placed on the Oriental West Pit and ten on the Oriental East Pit. Sphagnum moss was used as the substrate for transplanting *Typha angustifolia* seedlings grown in the Buchans greenhouse, or mature *Typha latifolia* plants collected from a population near Tailings Pond 1.

As described in the 1990 report, rafts received either slow release fertilizer and/or bone meal, or no nutrient supplements. Within the first growing season, the growth of *Typha* seedling populations was much greater with the application of both bone meal and fertilizer, than with either supplement alone. Seedlings without supplements fared very poorly.

In the fall of 1990, hay was added to half of each raft, in order to provide some insulation for the seedlings against harsh winter conditions. By spring, it was evident that growth of new shoots from the seedling populations was closely related to supplements added the previous year. In those rafts with fertilizer and/or bone meal, new shoots were visible by May 30, 1991, while new shoots from rafts without supplements were fewer in number and

development was delayed. Later in the growing season, there was some evidence that those halves of rafts amended with hay in the previous fall produced a greater density of shoots. This may be related to the stimulation of alkalinity generation (ARUM) by hay on the surface of the raft, thereby increasing the pH of the substrate.

By July, 1991, *Qpha* populations were more dense with taller shoots on OEP than OWP with the same nutrient supplement regime. Therefore, the 1991 seedlings transplanted from the greenhouse to eight new rafts on OWP received twice as much fertilizer and bone meal as did the seedlings on 12 new rafts on OEP.

In early 1991, old seed heads attached to mature plants transplanted to OEP rafts in 1990 germinated directly on the rafts (see Plate 4.1-2). Given this observation, a different raft design, using a wooden frame and trellis was placed on OEP and local *T. latifolia* seeds planted over the surface. These seeds germinated, and seedlings reached a size by October 1991 which should overwinter. This confirms that, for the OEP at least, germination of seeds in the greenhouse is not necessary. However, it is very unlikely that seeds would germinate on OWP rafts, unless the substrate solution was relatively isolated from the acidic pit water.

In October, 1991, 30 x 30 cm blocks of *Qpha* biomass were cut from the 1990 and 1991 seedling rafts for determination of the above and below substrate surface standing biomass. The fraction of the raft area covered by the *Typha* population was recorded in order to correct for heterogeneity of colonization success over the raft (see Plates 4.1-3 and 4.1-4).

The blocks were sorted into *six* categories: green shoots, brown shoots, rhizomes, roots, seed heads and other species' biomass present. Samples were dried and weighed.

The dry weight of each component were multiplied by a factor so that values were expressed per square meter. These values were multiplied by the fraction of population coverage recorded for each raft. These data, as well as data for the mature (>10 years) *Typha angustifolia* population in Scarborough, Ontario (which served as the seed source population), are presented in Figure 4.1-22a.

This graph clearly shows that the second year *Typha* standing biomasses on OEP have increased immensely since their first year, but have not reached that of the mature Scarborough population. However, the mature stand grows on alkaline clays in a region with a much longer growing season. In addition, as rhizomes can live up to four years, maximum accumulation of below ground biomass in the form of roots and rhizomes cannot be expected for approximately two more growing seasons.

A large difference is evident between OEP and OWP second year populations. The OWP population is probably directly affected by lower Ph and higher acidities while, indirectly, the fertilizer additions may have dissolved more quickly in acid, and nutrients are available over a shorter period of time. Larger standing biomass of 1991 seedlings on OWP, compared to OEP, is evident from the graph; doubling the fertilizer and bone meal supplements to new OWP rafts in 1991 does result in better growth.

Figure 4.1-22b presents data for standing biomass according to supplement addition for the 1990 seedling populations in their second year. The combined effect of fertilizer and bone meal addition at the time of transplant, compared to fertilizer or bone meal alone, is still evident after the second growing season. This may mean that nutrients stored by plants in 1990 continue to determine plant productivity a year later.

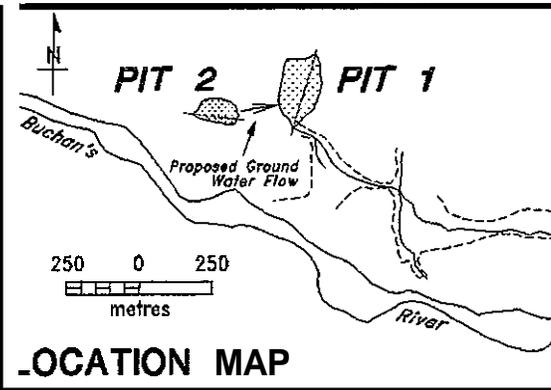
The standing biomass values for the OEP and OWP second year populations were used for estimation of the rate of deposition of organic matter to the raft substrate and underlying water body.

Hogg & Wein (1987) estimate that, in a floating *Typha* population in New Brunswick, all of the annual standing biomass of above ground shoots are deposited each year, while only 23% of shoot bases, 25% of rhizomes and 30% of roots die and are deposited within the floating mat.

Applying these fractions to the present OEP and OWP second year populations' standing biomass values, 291 g/m²/year litter will be deposited in the OWP, while 1,148 g/m²/year will be deposited in OEP. This translates to 1.35 tonnes of *Typha* litter/OWP/year, and 22.4 tonnes *Typha* litter/OEP/year available for microbial decomposition. However, until the Oriental populations are at least four years old, the fractions of deposition suggested by Hogg & Wein cannot be expected, and the actual values may well prove to be site-specific. Meanwhile, standing biomass can be expected to increase as the populations mature, and therefore, higher rates of annual deposition can be anticipated than can be calculated given

current standing biomass.

Hogg & Wein (1987) suggest that the rate of decomposition of *Typha* litter is very low in the New Brunswick population (<1%/year). However, the decomposition bag experiment in the present study sets an upper limit of 50%. ARUM, as indicated by negative Eh values and H₂S production is occurring on most of the cattail rafts in both of the Oriental Pits (Table 4.1-5); rates of decomposition of the Sphagnum, supplemented by *Typha* litter, are high enough to support ARUM locally. The floating *Typha* mats may in themselves make a significant contribution to ARUM and metal precipitation through sealing the underlying water column against oxygenation, thereby assisting in treating the entire water column.



BUCHANS PROJECT Buchans, Newfoundland **CROSS-SECTION of PIT 1 and PIT 2**

December 5, 1991

Schematic 4.1-1

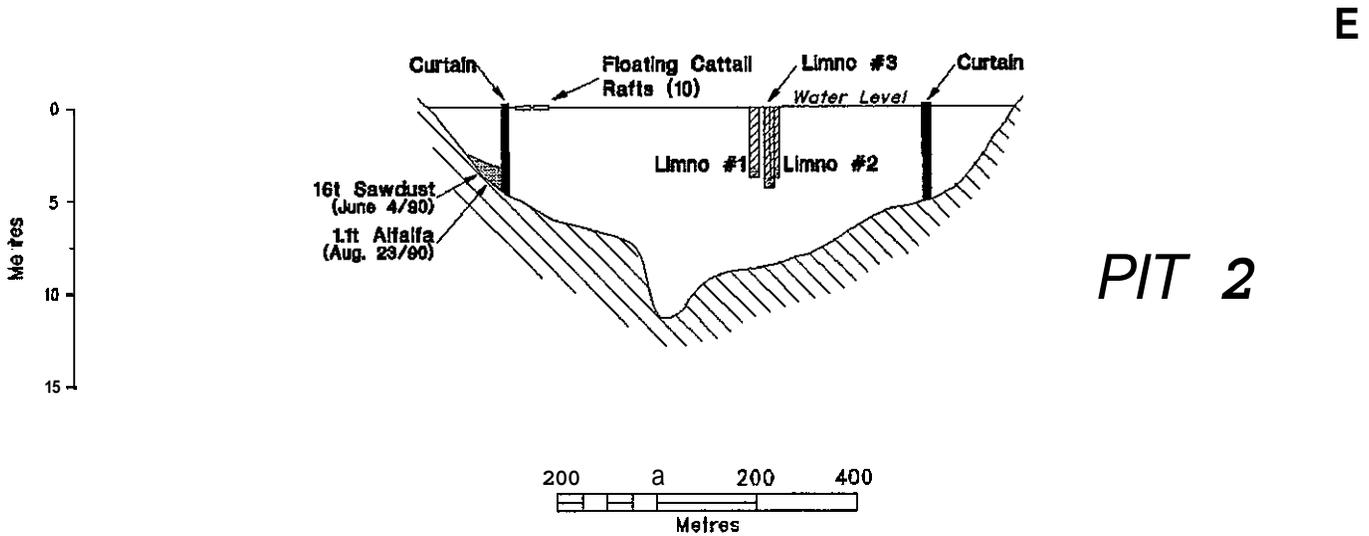
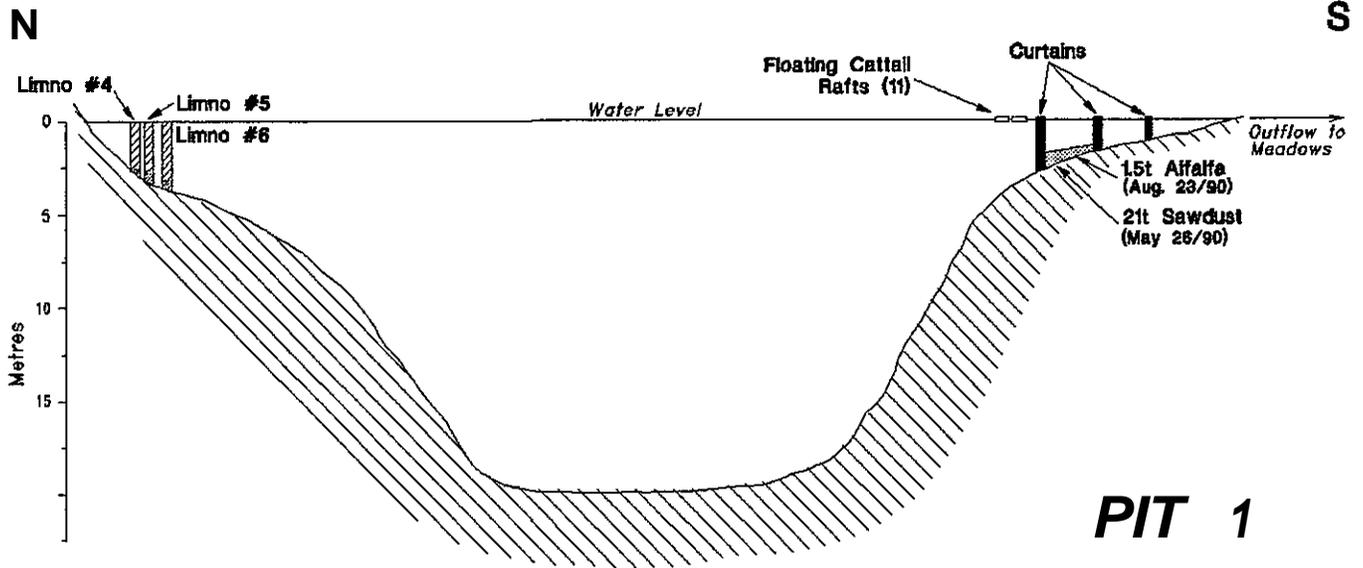


Table 4.1-1

VICINITY	EXPERIMENTAL AREA	Date Constructed/ Filled	Water: Surface Area (m ²)	Water: Volume (m ³)	Flow Rate (L/s)	Retention Time (days)	Dry Wt of Amendment Added (Kg)	Date Amendment Added
OWP		Aug-87	4,645	66,245		Unknown		
	LC1	17-May-89	13	34			1,137(Sawdust)	20-May-89
	LC2	17-May-89	13	36			388 (Peat)	20-May-89
	LC3	17-May-89	13	50			Control	20-May-89
	OWP Curtain 1	Jun-90	125	390			12,870 (Sawdust)	04-Jun-90
							660 (Alfalfa)	25-Aug-90
	OWP Curtain 2	Oct-91	247	770			8,470 (Peat)	14-Oct-91
							770 (Potato Waste)	14-Oct-91
OEP		Aug-87	19,510	208,197	10	240		
	LC4	21-May-89	13	57			1,137(Sawdust)	22-May-89
	LC5	21-May-89	13	57			388 (Peat)	22-May-89
	LC6	21-May-89	13	60			Control	22-May-89
	OEP Curtain	Jun-90	500	750			15,125(Sawdust)	26-May-90
							Alder Brush	26-Jul-90
							840 (Alfalfa)	22-Aug-90
FIRST MEADOW			29,000					
	Polishing Pond 1	17-Jun-89	57	36	0.14	3.0	110 x 7' Alders	07-Sep-89
	Polishing Pond 2	17-Jun-89	89	54	0.12	5.2	110 x 7' Alders	07-Sep-89
	Polishing Pond 3	17-Jun-89	66	40	0.11	4.3	110 x 7' Alders	07-Sep-89
	Polishing Pond 4	17-Jun-89	64	48	0.09	6.5	110 x 7' Alders	07-Sep-89
	Polishing Pond 5	17-Jun-89	57	24	0.07	3.8	110 x 7' Alders	07-Sep-89
	Polishing Pond 6	17-Jun-89	66	41	0.07	7.1	130 x 7' Alders	07-Sep-89
SECOND MEADOW			56,500					
WASTE ROCK PILE								
	Pond 7	08-Jul-89	24	16	0.68	0.27	371 (Hay)	09-Aug-89
	Pond 8	08-Jul-89	20	12	0.35	0.40	371 (Hay)	09-Aug-89
	Pond 9	08-Jul-89	36	25	0.10	2.89	349 (Hay)	09-Aug-89
DRAINAGE TUNNEL					6.8 - 7.6			
TAILINGS POND 2		29-Apr-88	343,740	1,047,720	7.63	1,589		
	Boom Enclosure	Oct-91	2,133	1600			4,832 x 5' Alders	Oct-91
							40 Kg NPK Fertilizer	

Fig. 4.1-1a Limno 123 pH
Sawdust, Peat, Control

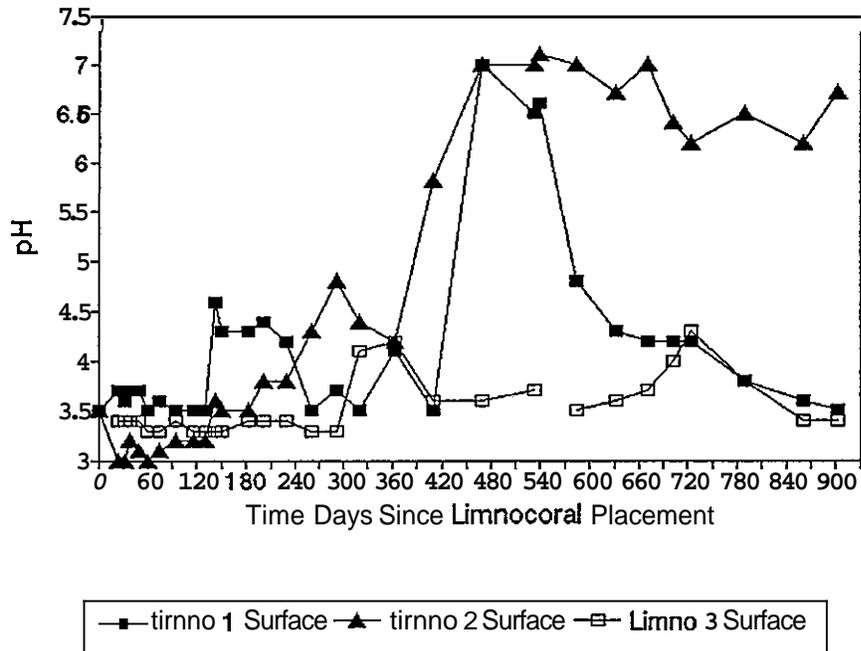


Fig. 4.1-1b Limno 123 pH
Sawdust, Peat, Control

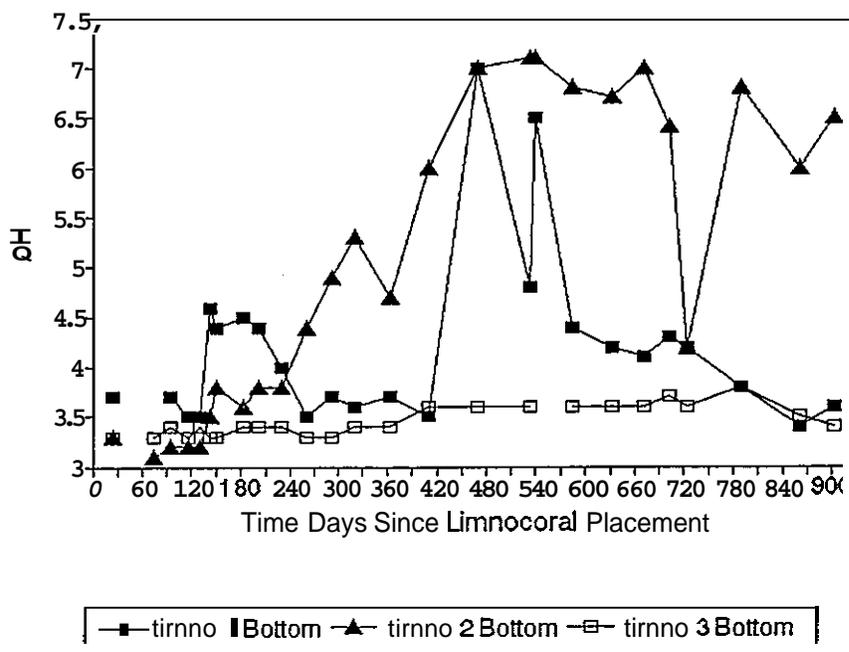


Fig. 4.1-2a Limno 123 Conductivity
Sawdust, Peat, Control

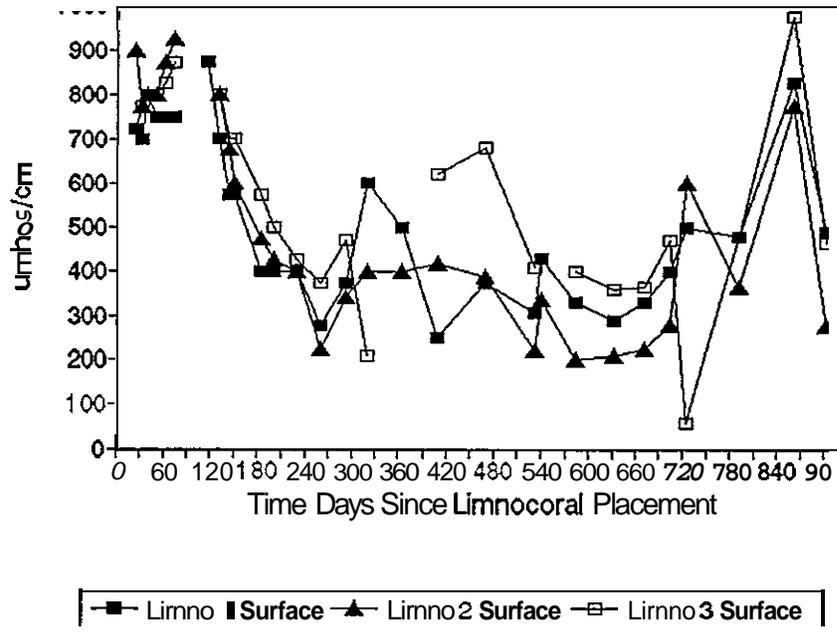
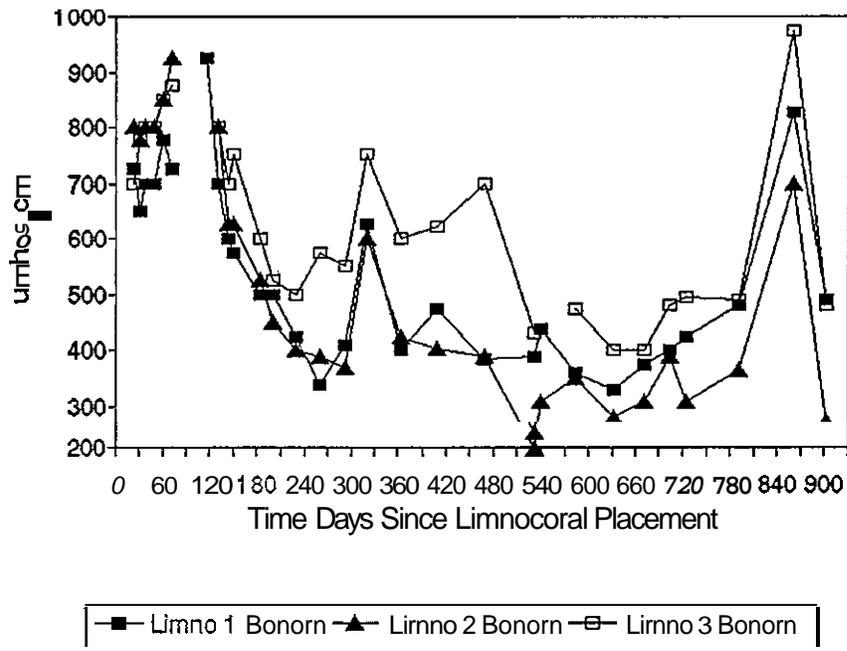
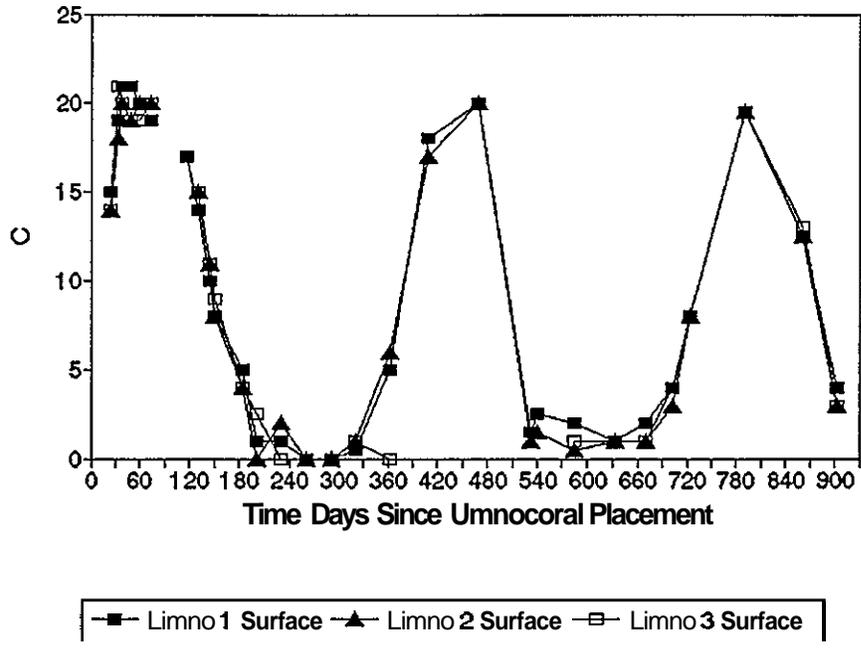


Fig. 4.1-2b Limno 123 Conductivity
Sawdust, Peat, Control



**Fig. 4.1-3a Limno 123 Temperature
Sawdust, Peat, Control**



**Fig. 4.1-3b Limno 123 Temperature
Sawdust, Peat, Control**

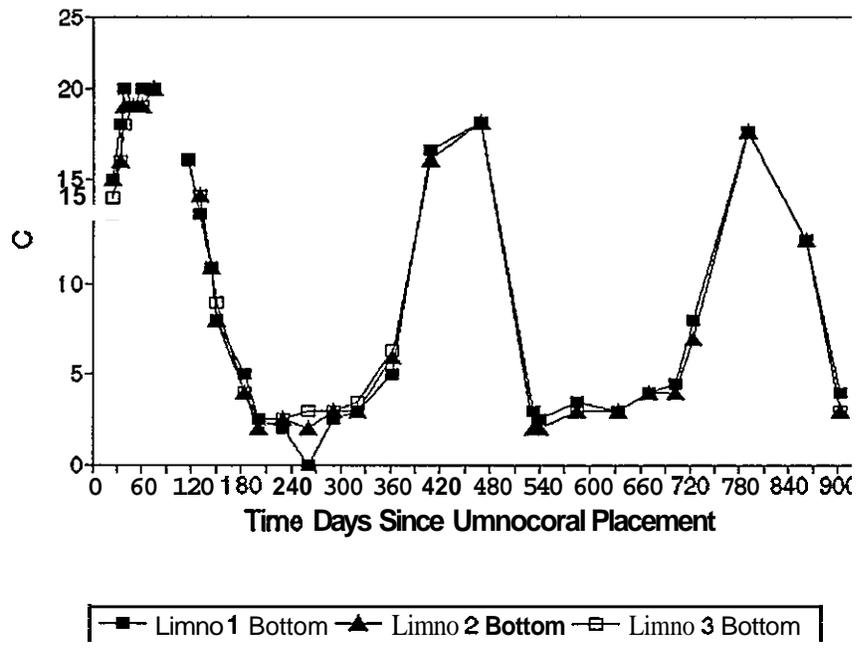


Fig. 4.1-4a Limno 123 Copper
Sawdust, Peat, Control

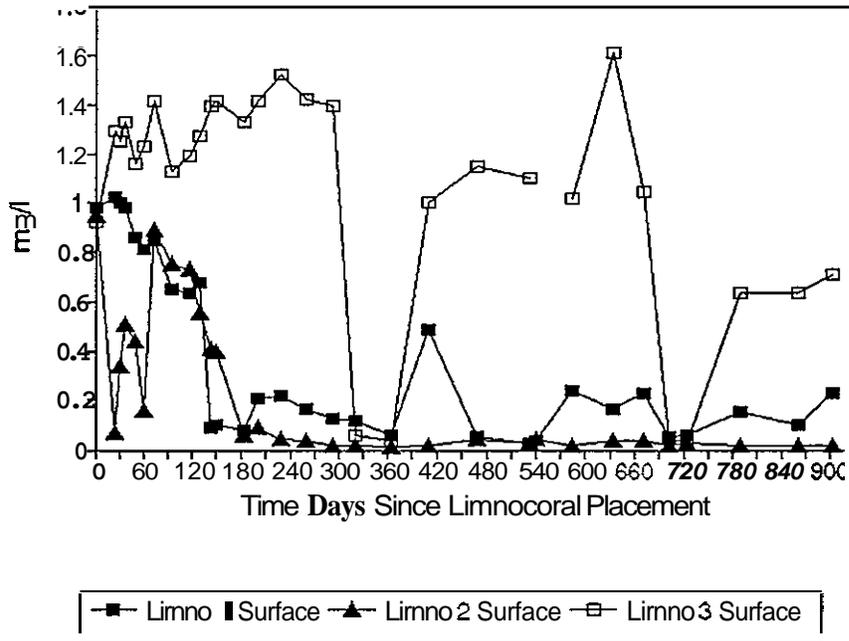


Fig. 4.1-4b Limno 123 Copper
Sawdust, Peat, Control

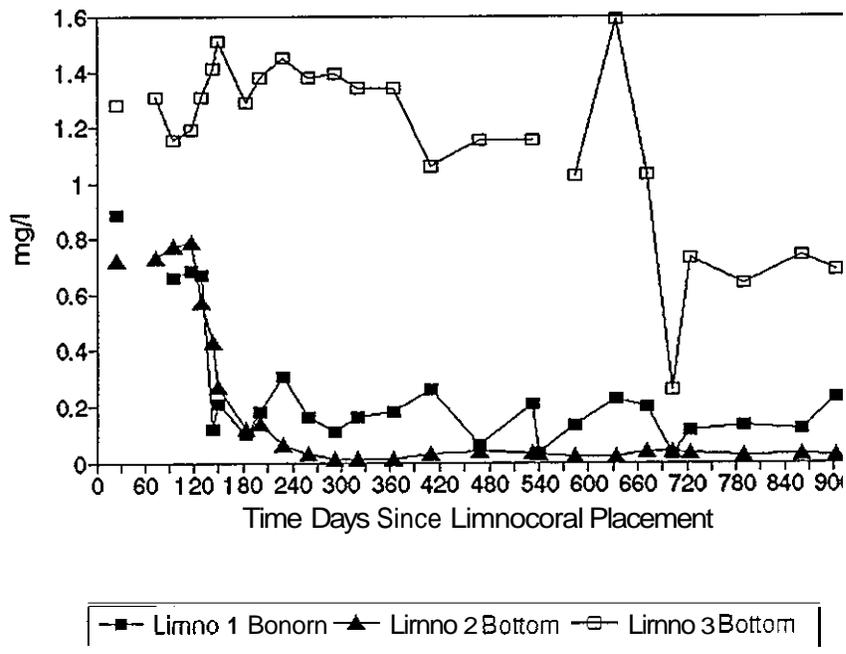


Fig. 4.1-5a Limno 123 Zinc
Sawdust, Peat, Control

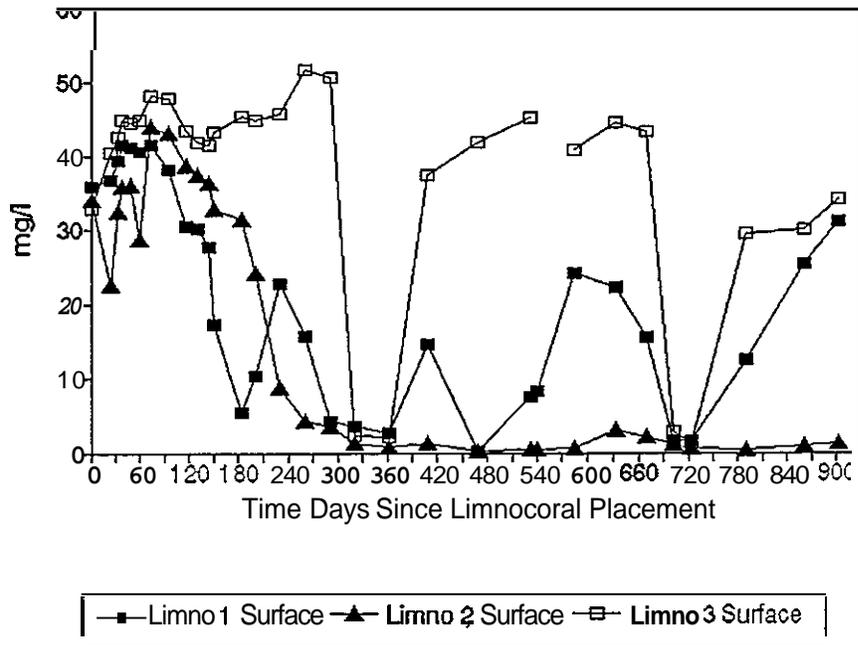


Fig. 4.1-5b Limno 123 Zinc
Sawdust, Peat, Control

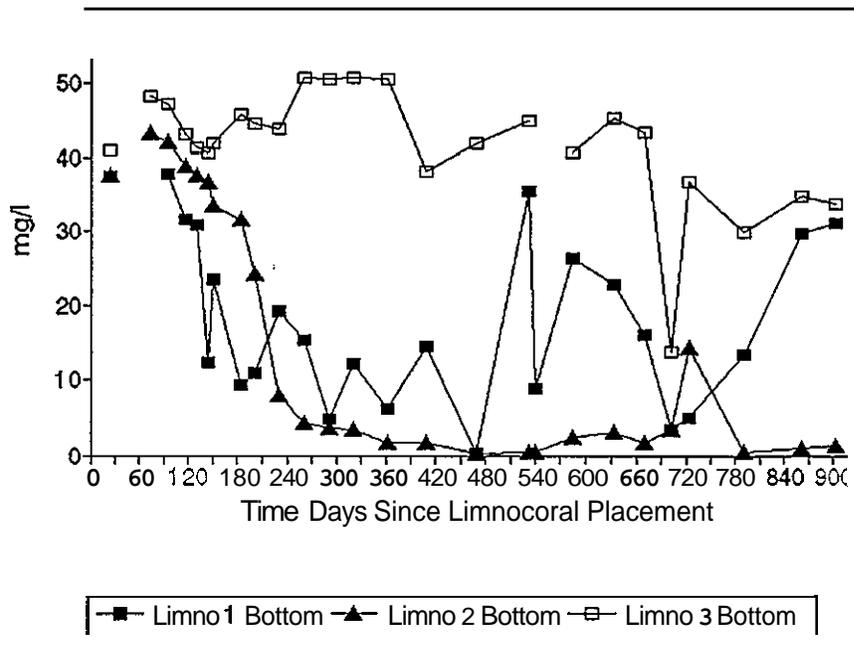


Fig. 4.1-6a Limno 456 pH
Sawdust Peat Control

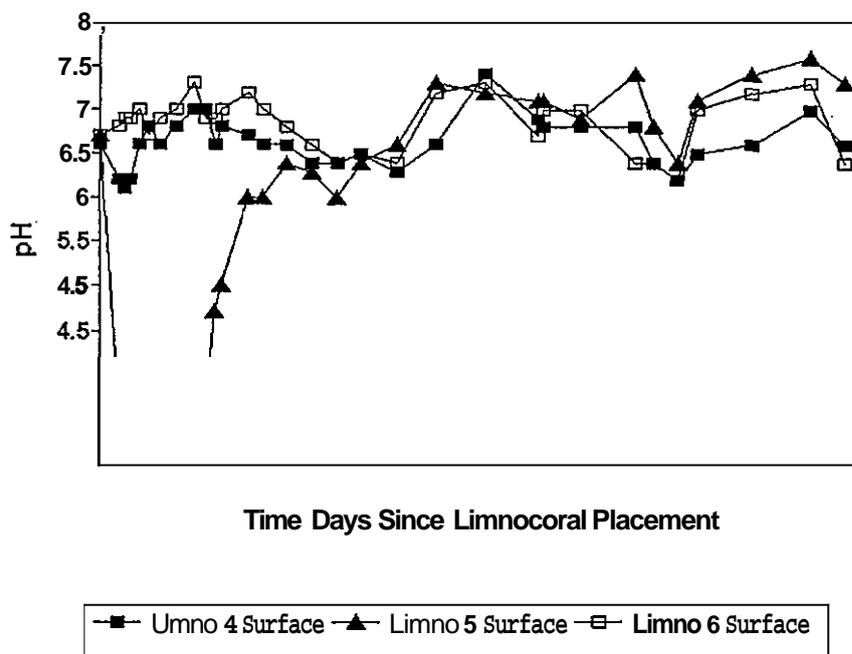


Fig. 4.1-6b Limno 456 pH
Sawdust Peat Control

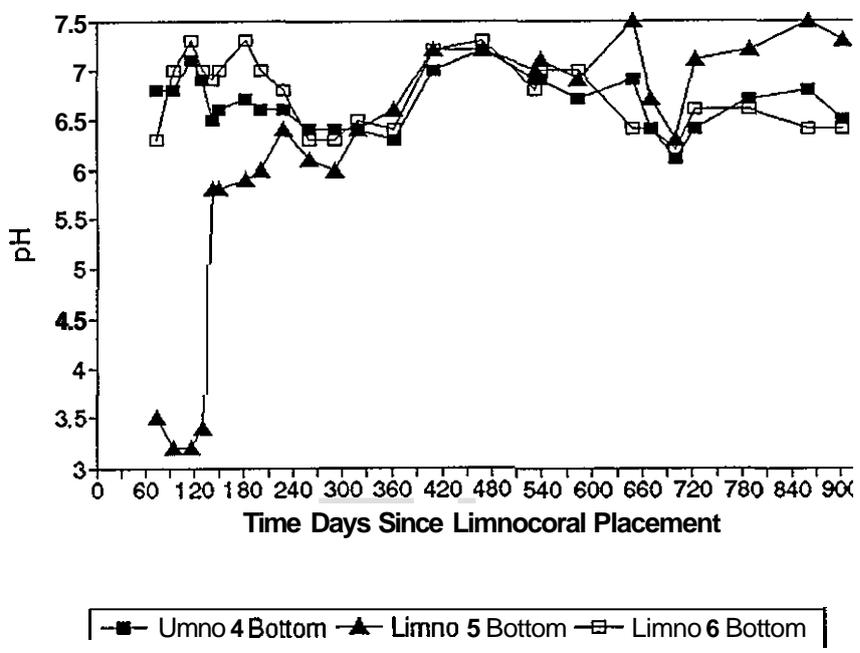


Fig. 4.1-7a Limno 456 Conductivity
Sawdust, Peat, Control

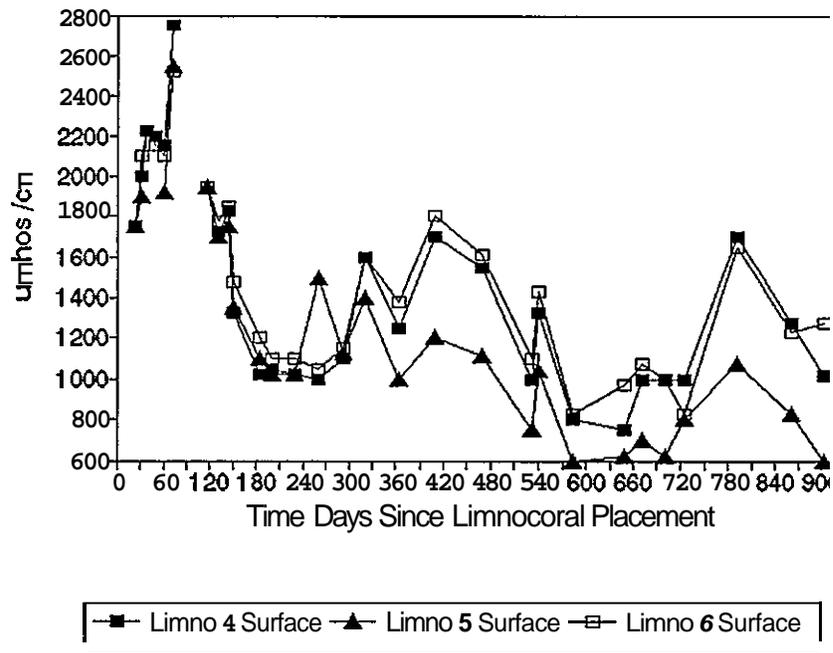


Fig. 4.1-7b Limno 456 Conductivity
Sawdust, Peat, Control

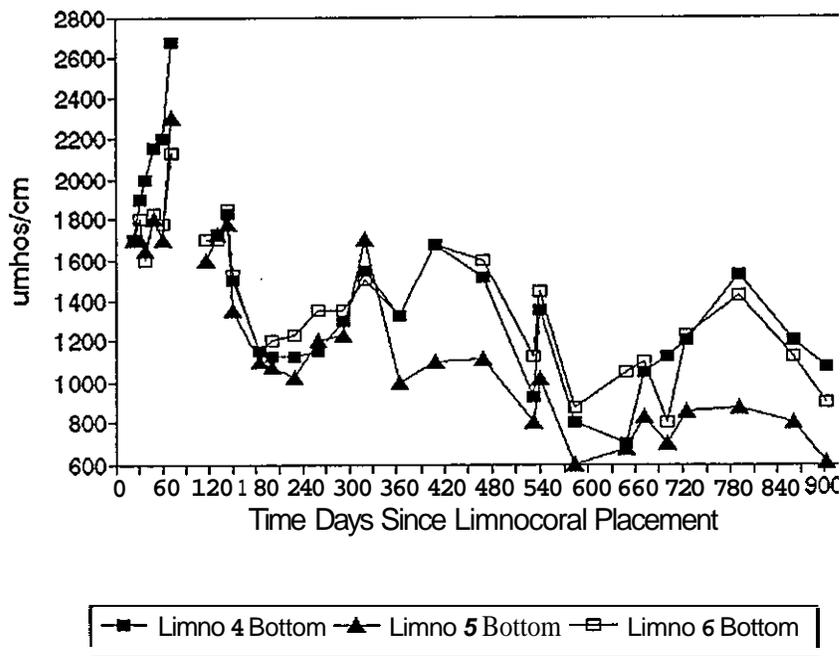


Fig. 4.1-8a Limno 456 Temperature
Sawdust, Peat, Control

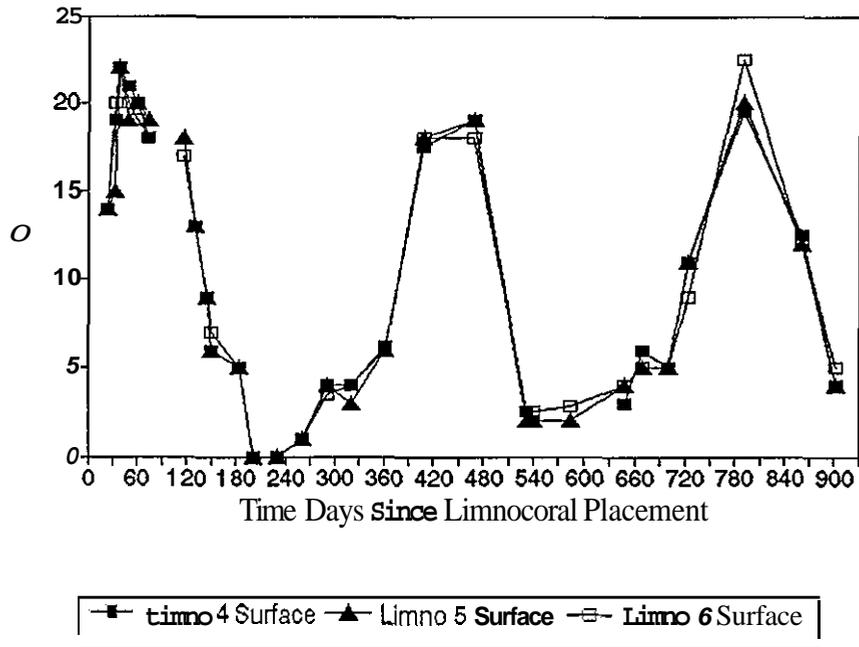


Fig. 4.1-8b Limno 456 Temperature
Sawdust, Peat, Control

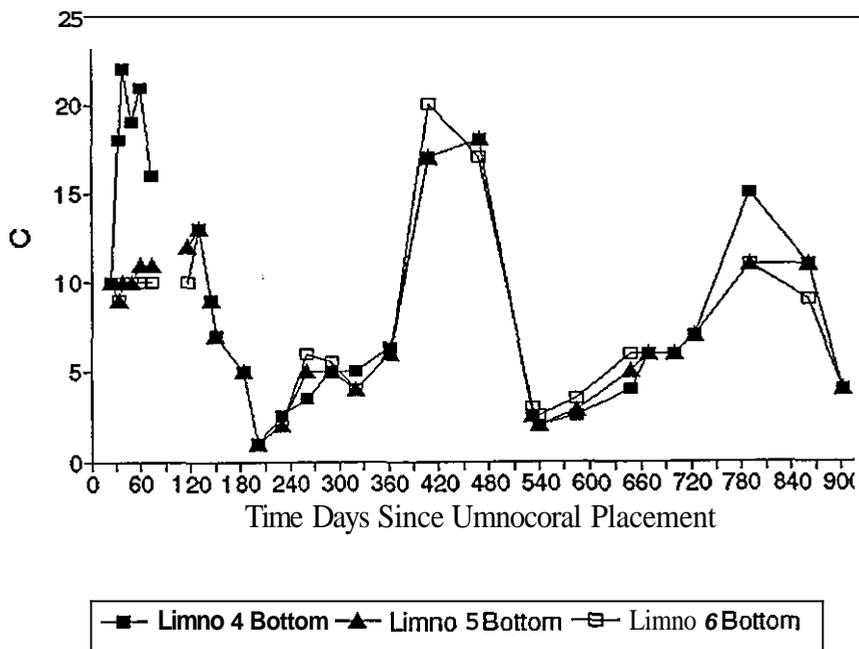


Fig. 4.1-10a Limno 456 Zinc
Sawdust, Peat, Control

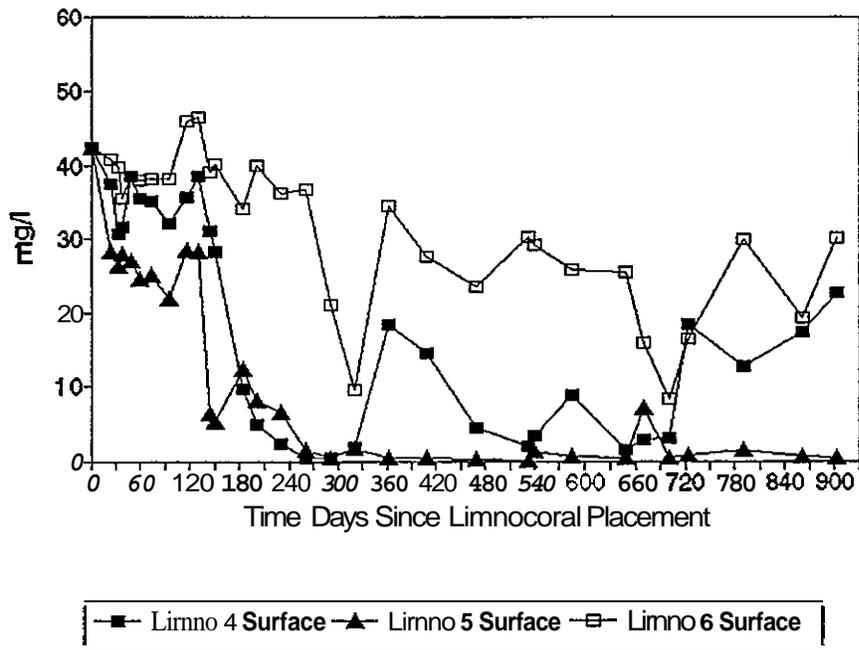


Fig. 4.1-10b Limno 456 Zinc
Sawdust, Peat, Control

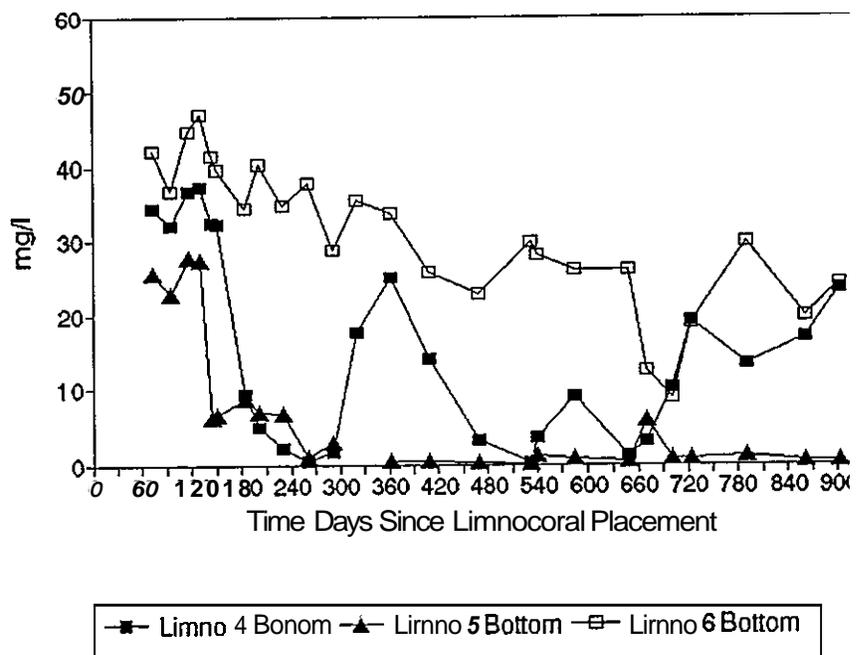


Fig. 4.1-9a Limno 456 Copper
Sawdust, Peat, Control

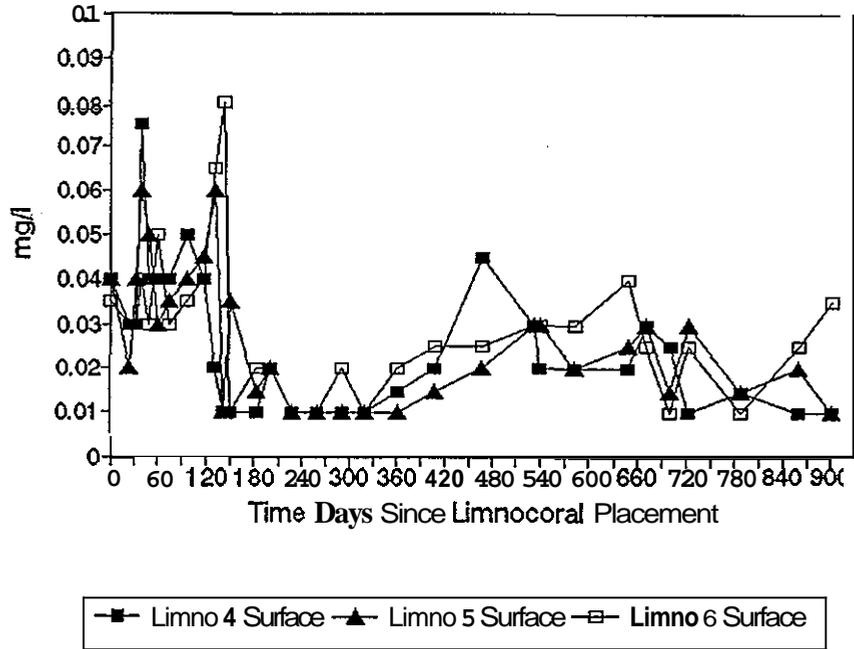


Fig. 4.1-9b Limno 456 Copper
Sawdust, Peat, Control

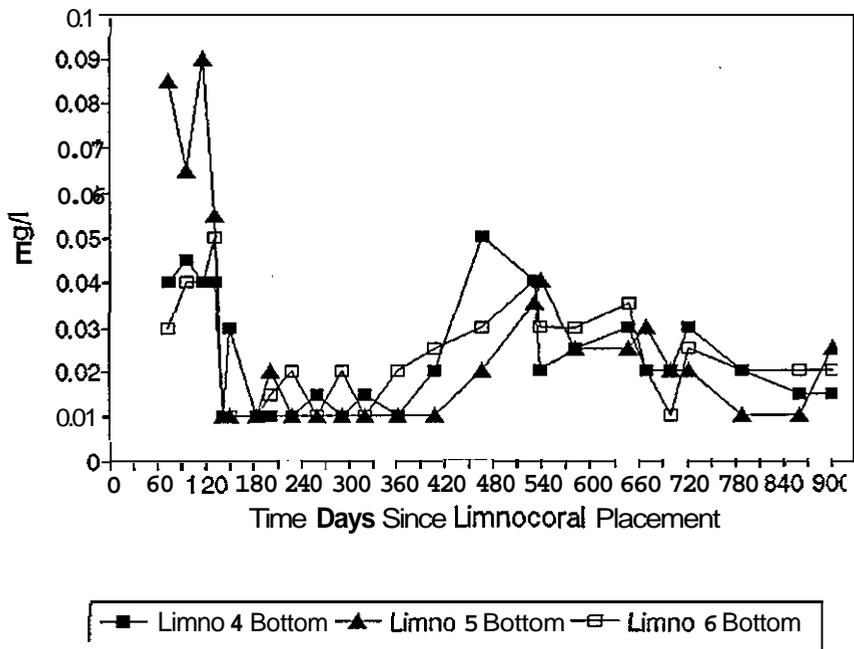


Fig. 4.1-11a Oxygen and Eh Profiles
LCs and OWP, October 1990

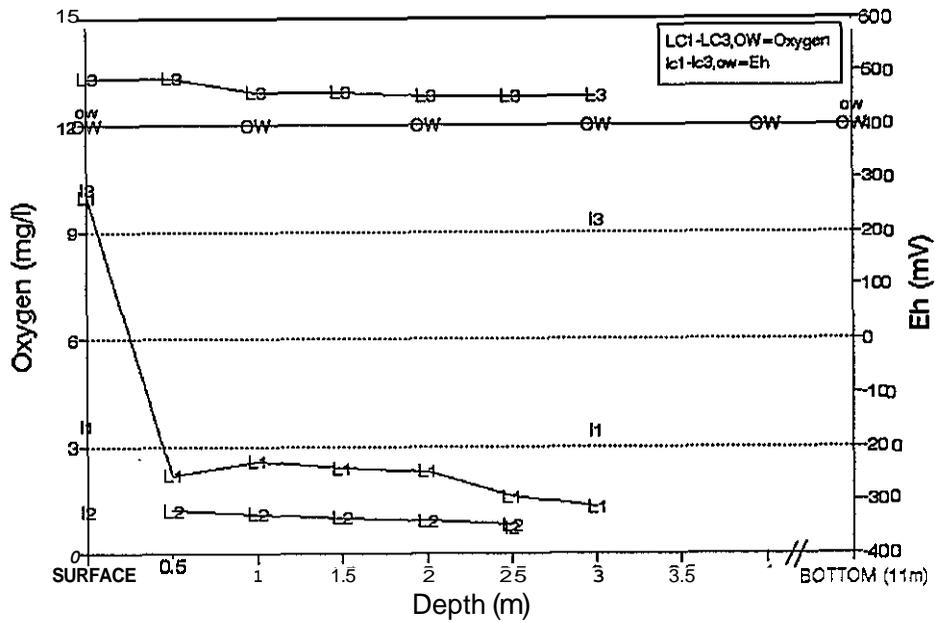


Fig. 4.1-11b Oxygen and Eh Profiles
LCs and OWP, October 1991

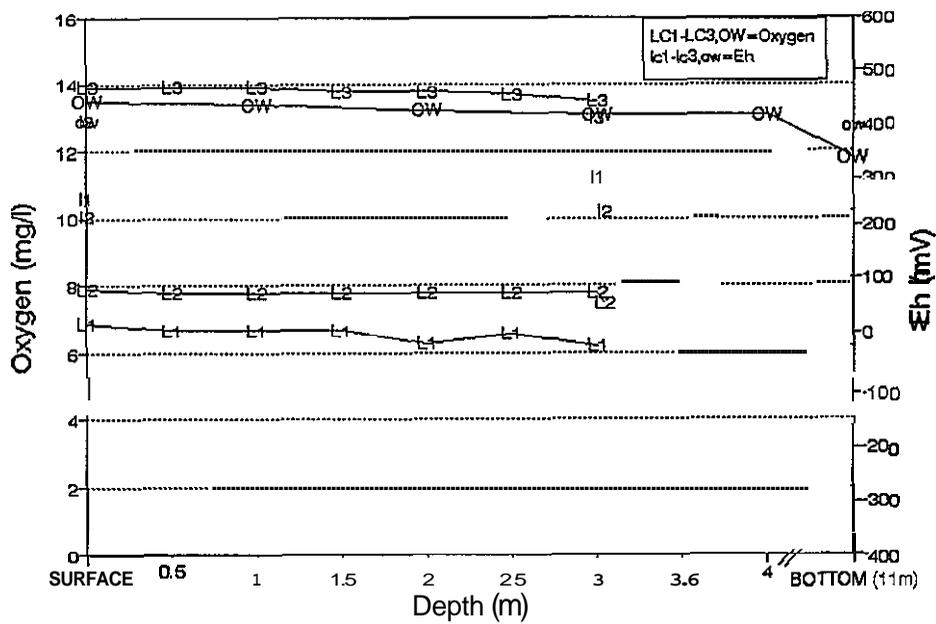


Fig. 4.1-11a Oxygen and Eh Profiles
LCs and OWP, October 1990

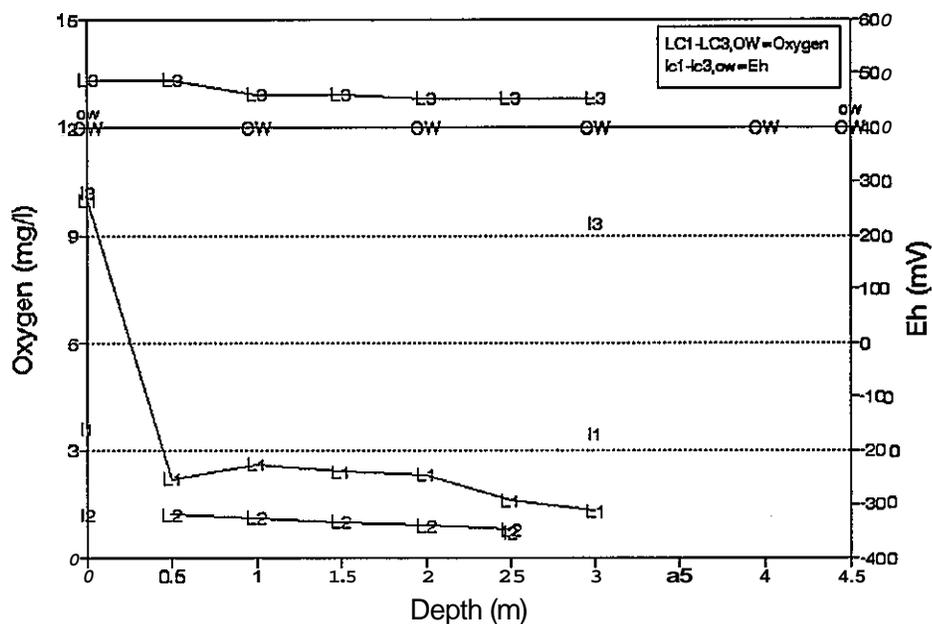


Fig. 4.1-11b Oxygen and Eh Profiles
LCs and OWP, October 1991

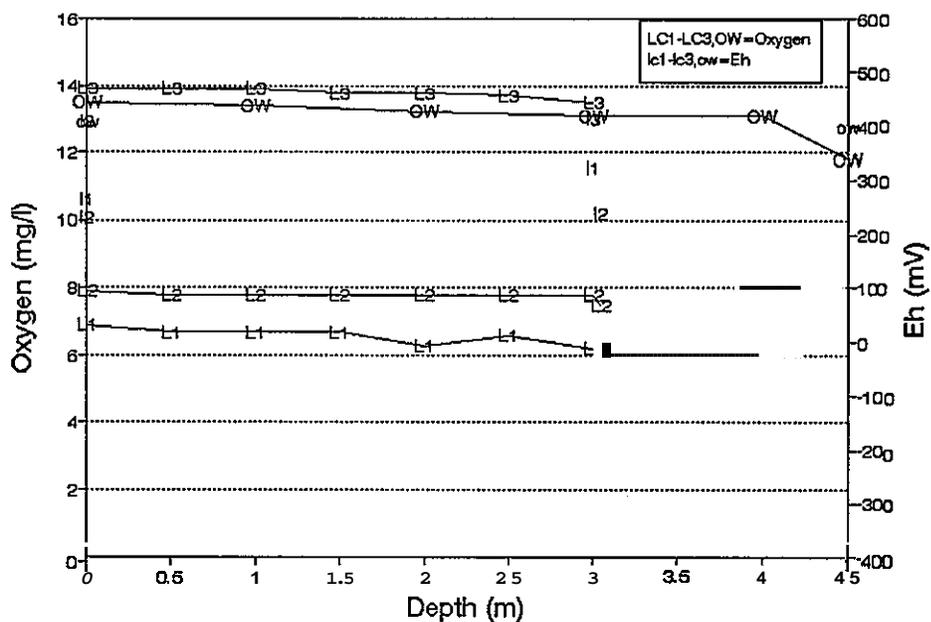


Fig. 4.1-12 Oxygen and Eh Profiles
LCs and OEP, October 1990

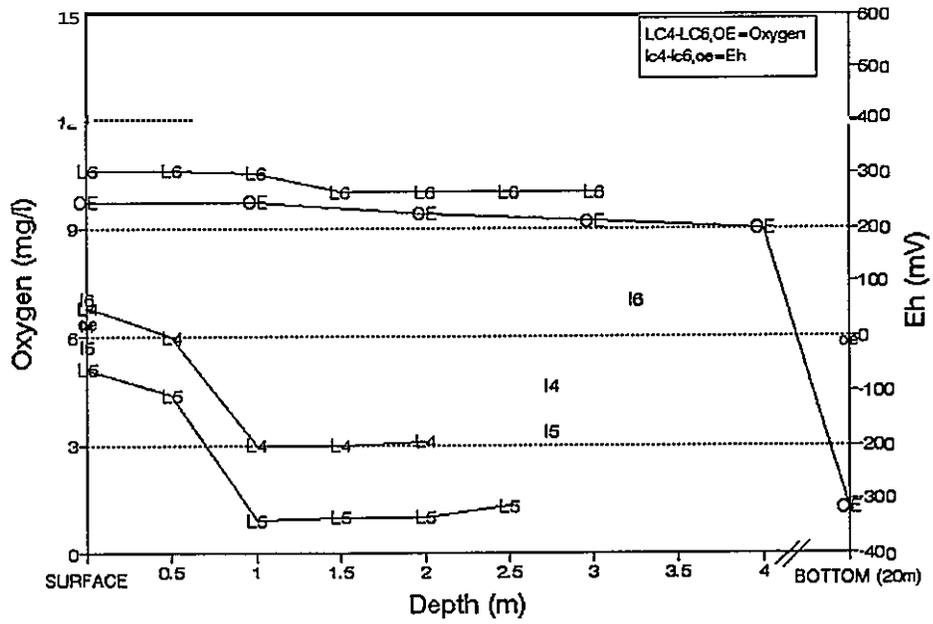


Fig. 4.1-13 Oxygen and Eh Profiles
LCs and OEP, October 1991

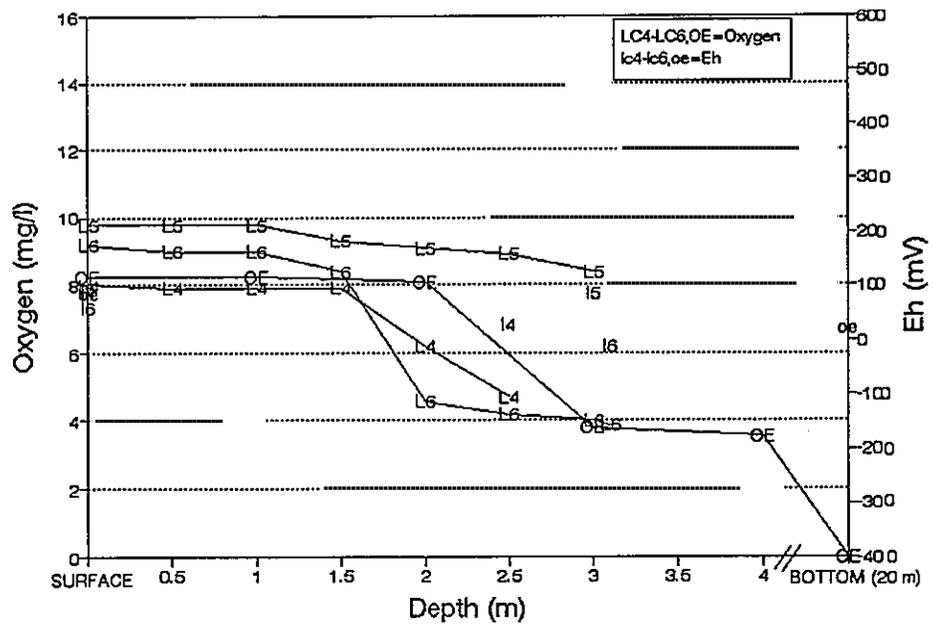


Fig. 4.1-14a Eh profile of OEP curtain
August 1991

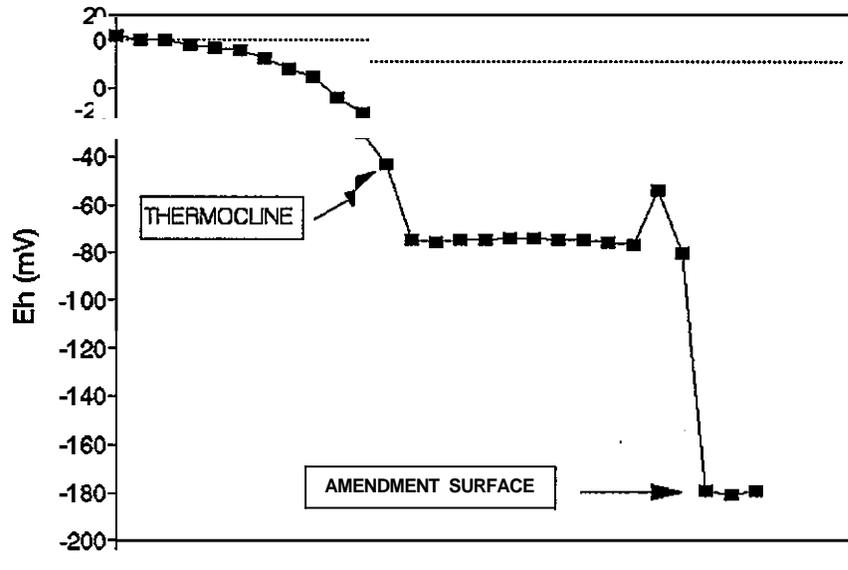


Fig. 4.1-14b Eh profile of OWP curtain
August 1991

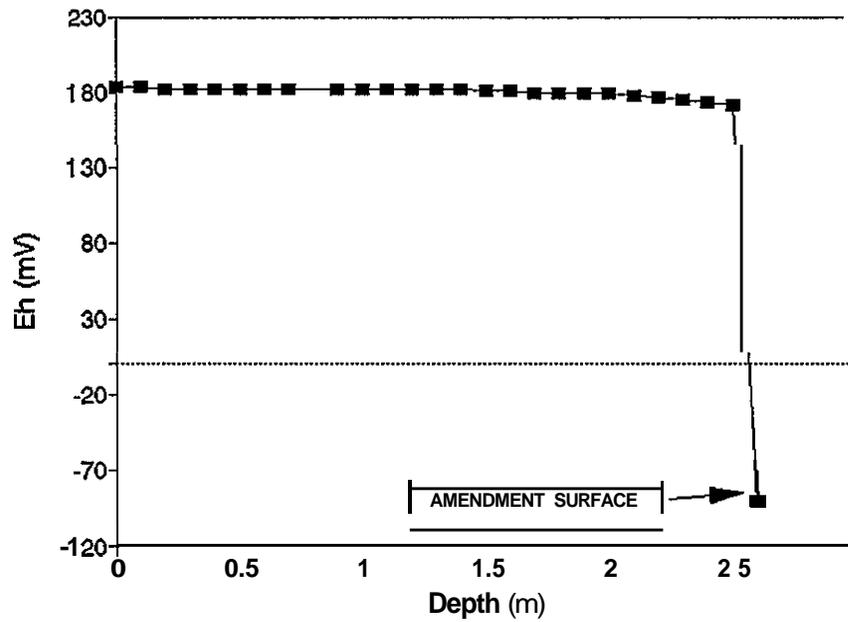


Fig. 4.1-15a Buchans
Cells 7-9 Zinc

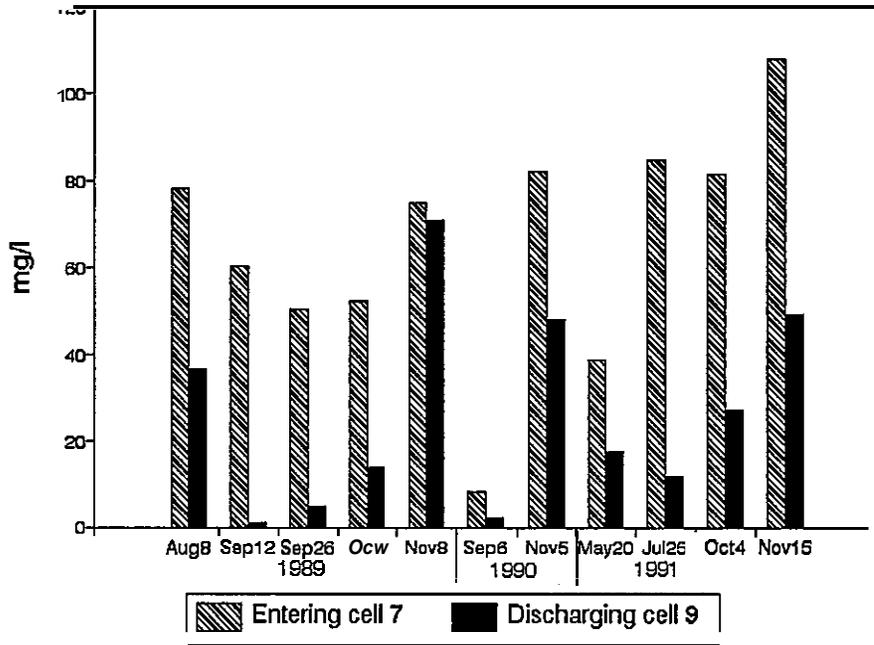


Fig. 4.1-15b Buchans
Cells 7-9 Copper

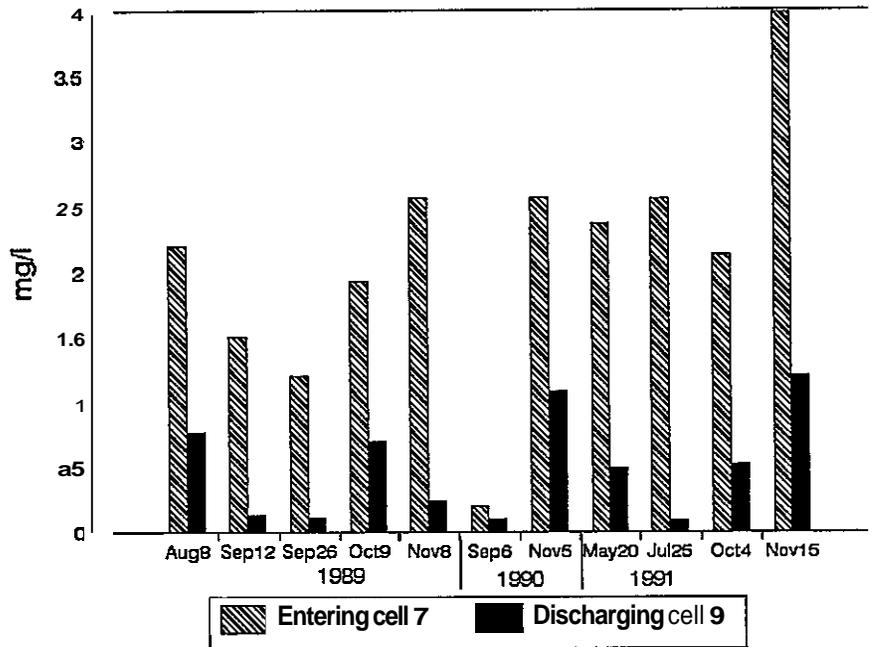


Fig. 4.1-15c Buchans
Cells 7-9 pH

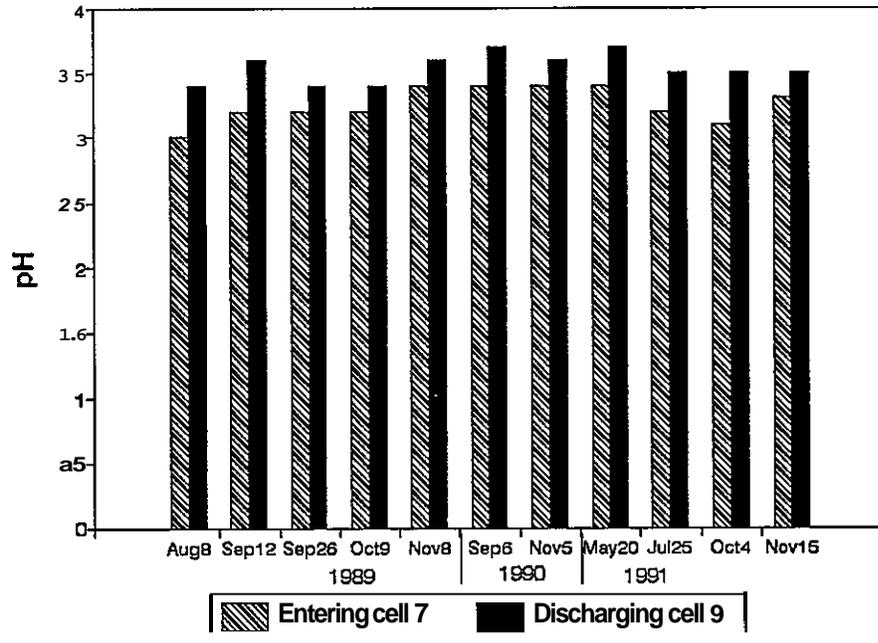


Fig. 4.1-16 First Meadow - Cells 7-9
Chemistry 23/9/91

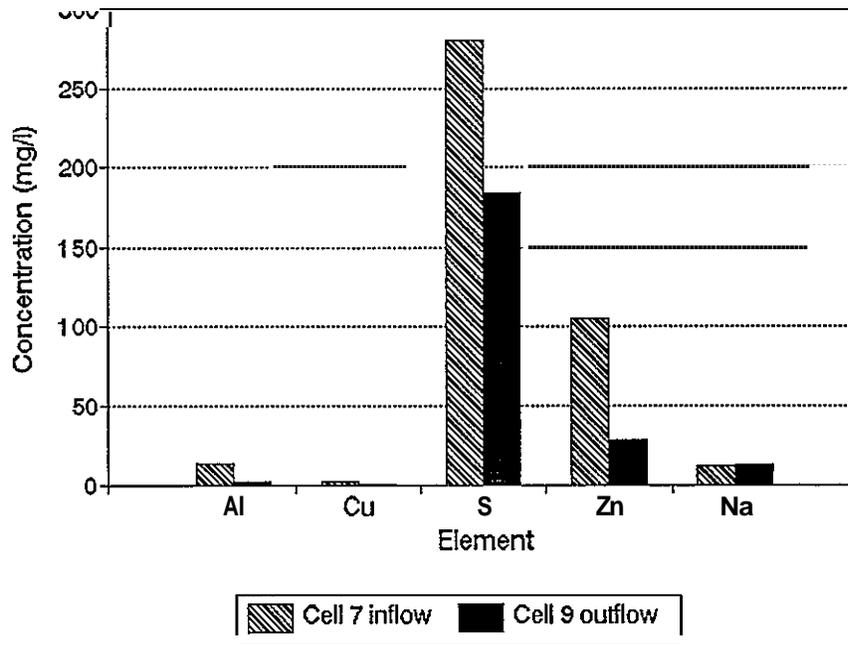


Table 4.1-2
First meadow-Cells 7-9
Chemistry 23/9/91

Factor	Cell 7 inflow	Cell 9 outflow
pH	3.54	3.80
Cond (umhos/c	990	780
Eh (mV)	300	245
		147

TABLE 1:

CHEMICAL AND MICROBIOLOGICAL PROFILE OF BUCHANS 1991 AMENDMENT SAMPLES

Sample inIdentification	pH	ATP (ng/mL)	Total Soluble Carbohydrate (ppm)	Total Volatile Fatty Acids (ppm)	Total Sulphates (ppm)	SRB/mL (Rapidchek®)	SRB/mL (Postgate B)	SRB/mL (Postgate F)
Oriental West Pit - curtain (Rapidchek®)	5.46	93	38	150	340	$10^4 - 10^5$	10^4	10^3
Oriental West Pit LC 1	4.81	100	23	<100	270	10^6	$\geq 10^5$	10^2
Oriental West Pit LC 2 (Rapidchek®)	4.00	94	30	<100	190	$10^4 - 10^5$	$\geq 10^5$	10^3
Oriental East LC 4	6.46	29	12	<100	880	10^6	$\geq 10^5$	10^3
Oriental East LC 5	6.58	45	13	<100	250	10^6	$\geq 10^5$	10^4
Oriental East Pit Alfalfa curtain	6.40	7.0	12	<100	880	$10^5 - 10^6$	$\geq 10^5$	10^4
LC 2 Peat	3.80	21	75	<100	90	$10^3 - 10^4$	10^4	10^2
Oriental West Pit LC 1 (rec 7/11/91)	5.40		15	<100				

TABLE 2A:

BUCHANS - PICOCOSM TESTS ALL AMENDMENTS EXCEPT OMP LIMNOCORRAL 1 & 2

Amendment Condition	pH			
	Day 0	Day 14	Day 30	Day 37
1	3.90	5.40*	6.62*	6.83*
2	3.77	5.82*	6.52*	6.94*
3	6.71	6.72*	6.42*	6.97*
4	6.89	6.73*	6.55*	6.96*
5	7.05	6.54*	6.10*	7.65*
6	7.14	6.80*	6.23*	7.62*
7	7.10	6.70	6.05	7.40
8	7.20	6.80	6.21	7.50
9	6.13	6.20	4.93	4.50
10	6.07	6.00	4.95	4.56

* Indicates appearance of sulphide production

TABLE 2B:

CHEMICAL PROFILES ON DAY 14

Amendment Condition	pH	Total Sulphates (ppm)	Zinc (ppm)	Copper (ppm)
3	6.72*	930	<0.10	4.05
4	6.73*	880	<0.10	0.05
5	6.54*	1200	<0.10	4.05
6	6.80*	910	<0.10	<0.05
7	6.70	1000	<0.10	<0.05
8	6.80	1030	<0.10	<0.05
9	6.20	1200	9.6	4.05
10	6.00	1080	10.8	<0.05

* Indicates appearance of sulphide production

Amendment Conditions

- 3 and 4: 3 g of Oriental East LC 4 amendment and indigenous microbial seed
 5 and 6: 3 g of Oriental East LC 5 amendment and indigenous microbial seed
 7 and 8: 3 g of Oriental East Pit alfalfa curtain amendment and indigenous microbial seed
 9 and 10: 3 g of LC 2 Peat amendment

Test Conditions:

Buchans Oriental East Pit water.

Comments:

- Indigenous microbial seed was prepared by shaking the container in which the field test amendment was stored 30 times and collecting the supernatant. 1 mL inoculum was added to each test condition. Conditions 9 and 10 received no seed since the sample of amendment had no aqueous phase.
- Concentration of zinc and copper in CEP water was 7.69 and 4.004 ppm, respectively.

TABLE 3A:

BUCHANS 1551 - OWP LIMNOCORRAL 1
pH PROFILES OF PICOCOSM TESTS (FIRST SERIES)

Amendment Condition	Day 0	Day 14	Addition To Vial on Day 14	Day 30	Day 37	Day 44	Addition on Day 44	Day 45
1	3.42	3.83		3.87	3.96	3.87		
2	3.44	3.80	BOD nutrients	3.85	3.95	4.00	0.1 g steel wool 200 ppm Na ₂ S	7.65
3	3.40	3.82	BOD nutrients	3.86	3.97	4.00	0.1 g steel wool	4.50
4	3.47	3.84	BOD nutrients + 1000 ppm glucose	5.25	6.26	6.62*		
5	3.46	4.20		4.09	4.26	4.31		
6	3.39	4.10	BOD nutrients	4.16	4.24	4.30	0.1 g steel wool + 200 ppm Na ₂ S	8.00
7	3.40	4.11	BOD nutrients	4.20	4.21	4.31	0.1 g steel wool	5.36
8	3.39	4.13	BOD nutrients + 1000 ppm glucose	4.10	5.46	6.34*		

* Initiation appearance of sulphide production

Amendment Conditions:

1 to 8: 3 g of Oriental West Pit LC 1 amendment sample

Test Conditions:

- Buchans oriental West Pit water

Comments:

1. Amendment-conditions 5 to 8 received microbial seed obtained from Buchans Oriental East Limnocorral site F which was known to contain 10^5 sulphate reducing bacteria per mL.
2. Picocosms were set up one week after receiving the amendment sample.
3. Analyses on Day 14 were conducted before addition of glucose and BOD nutrient?
4. Amendment conditions 1 and 4 were analyzed for the presence of sulphate reducing bacteria and volatile fatty acid producers on day 59 (see Table 3C).

TABLE 3B:

CHEMICAL PROFILES

Amendment Conditions	DAY 14			DAY 30			
	PH	Total Sulphates (ppm)	Total Soluble Carbohydrates (ppm)	Total Volatile Fatty Acids (ppm)	pH	Total Soluble Carbohydrates (ppm)	Total Volatile Fatty Acids (ppm)
1	3.83	540	18	<100			
2	3.80	510	20	<100			
3	3.82	510					
4	3.84	650			5.25	18	360
5	4.20	660	23	<100			
6	4.10	490	28	<100			
7	4.11	570					
8					3.54	23	340

- indicates analysis not done

Amendment Conditions:

1 to 8: 3 g Oriental West Pit LC 1 amendment

Test Conditions:

Buchans OLP water

Comments:

1. Amendment conditions 5 to 8 received microbial seed obtained from Buchans OE Limnocorral F site.
2. Sulphate concentration in Oriental West Pit water was 530 ppm.
3. Amendment conditions 1 and 4 were analyzed for the presence of sulphate reducing bacteria and volatile fatty acid producers on day 59 (see Table 3C).

TABLE 3C: CHEMICAL AND MICROBIOLOGICAL PROFILES ON DAY 59

Amendment Condition	pH	Redox potential (mV)	Sulphate Reducing Bacteria per mL (Pastorate R Media)	Volatile Fatty Acid Producers per mL
1	6.02	360	10	10 ²
4*	6.60	25	10 ⁵	10 ²

*Indicates appearance of sulphide production

Amendment Conditions:

- 1 and 4: 3 g of Oriental West Pit LC 1 sediment

Test Conditions:

- Buchans Oriental West Pit water

Comments:

- Amendment condition 4 received 800 nutrients and 1000 ppm glucose on day 10

TABLE 4A:

BUCHANS 1991 - OWP LIMNOCORRAL 1
pH PROFILES OF PICOCOSM TESTS (SECOND SERIES)

Test Condition	Amendment	Day 0	Day 14	Day 21	Day 28	Addition Day 28	Day 29
1		3.52	3.97	3.92	4.00		
2	BOD nutrients	3.55	3.94	3.75	3.93	0.1 g steel wool + 200 ppm Na ₂ S + 1000 ppm glucose	7.73
3	BOD nutrients	3.50	4.00	3.76	3.91		
4	1000 ppm glucose	3.42	5.75	6.90*	6.83*		
5	1000 ppm glucose	3.41	6.16	6.10*	6.30*		
6		3.47	4.53	4.10	4.23		
7	BOD nutrients	3.60	4.36	4.10	4.24	0.1 g steel wool + 200 ppm Na ₂ S + 1000 ppm glucose	9.15
8	BOD nutrients	3.61	4.20	4.10	4.20		
9	1000 ppm glucose	3.56	4.06	6.38*	6.61*		
10	1000 ppm glucose	3.53	3.90	4.86	5.62*		

* Initiation appearance of sulphide production

Test condition common to all vials:

3.0 g Oriental West Pit LC 1 amendment
Buchans Oriental West Pit water

Comments:

1. Test Conditions 6 to 10 received microbial seed obtained from Buchans Oriental East Limnocorral site F which contained 10^5 sulphate reducing bacteria per mL.
2. Picocosms were set up three weeks after receiving the amendment samples.
3. Tests for the presence of Thiobacillus ferrooxidans in amendment condition 1 were performed on day 52. Negative results were obtained.

TABLE 46:

CHEMICAL PROFILES ON DAY 14

Amendment Condition	pH	Total Soluble Carbohydrates (ppm)	Total Volatile Fatty Acids (ppm)
4	5.75	550	180
5	6.16	375	300
9	4.06	18	230
10	3.90	23	320

Amendment Conditions:

4 and 5: 3 g Oriental West Pit LC 1 amendment and 1000 ppm glucose.

9 and 10: 3 g Oriental West Pit LC 1 amendment and microbial seed and 1000 ppm glucose.

Comments:

1. Microbial seed was obtained from Buchans Oriental East Limnocorral site F which contained 10^5 sulphate reducing bacteria per mL.

TABLE 5A:

BUCHANS 1991- OWP LIMNOCORRAL
 pH PROFILES OF PICOCOSM TESTS (FIRST SERIES)

AmendmentCondition	pH								
	Day 0	Day 14	Addition on Day 14	Day 30	Day 37	Day 44	Addition on Day 44	Day 45	Day 68
1	3.50	3.48		3.45	3.40	3.56			3.55
2	3.52	3.42	BOD nutrients	3.50	3.51	3.53	0.1 g steel wool + 200 ppm Na ₂ S	8.17	5.90
3	3.48	3.50	BOD nutrients	3.50	3.45	3.49	0.1 g steel wool	6.52	4.65
4	3.54	3.45	BOD nutrients + 1000	3.48	3.48	3.49	0.1 g steel wool +	5.41	6.70
5	3.60	3.88		3.81	3.71	3.71			3.75
6	3.52	3.75	BOD nutrients	3.80	3.80	3.78	0.1 g steel wool + 200 ppm Na ₂ S	8.63	6.40
7	3.51	3.77	BOD nutrients	3.83	3.83	3.80	0.1 g steel wool	5.45	4.93
8	3.49	3.80	BOD nutrients + 1000 ppm glucose	3.54	3.56	3.61	0.1 g steel wool + 200 ppm Na ₂ S	6.15	7.20

TABLE 5B:

CHEMICAL PROFILES

Amendment Condition	DAY 14			DAY 30			
	pH	Total Sulphates (ppm)	Total Soluble Carbohydrates (ppm)	Total Volatile Fatty Acids (ppm)	pH	Total Soluble Carbohydrates (ppm)	Total Volatile Fatty Acids (ppm)
1	3.48	670	18	<100			
2	3.42	660	21	<100			
3	3.50	630					
4	3.45	670			3.48	280	360
5	3.88	570	18	<100			
6	3.75	510	13	<100			
7	3.77	500			3.54	32	340

- Indicates analysis not performed

Amendment Conditions:

1 to 8: 3 g Oriental West Pit LC 2 amendment

Test Conditions:

- Buchans OWP water

Comments:

1. Amendment conditions 5 to 8 received microbial seed obtained from Buchans Oriental East Limnocorral F site which contained 10^5 sulphate reducing bacteria per mL.
2. sulphate concentration in OWP water was 530 ppm.
3. Chemical analyses on day 14 were conducted before addition of glucose and BOD nutrients.

TABLE 5C:

CHEWICAL AND MICROBIOLOGICAL PROFILES ON DAY 59

Test	Amendment Condition	
	1	5
pH	3.56	3.69
Redox Potential (mV)	+154	+193
Sulphate reducing bacteria per mL (Postgate B)	$<10^0$	10^3
Volatile Fatty Acid Producers per mL	10^1	10^3

Amendment Conditions:

ALL vials contained 3.0 g OWP LC 2 amendment and Buchans OWP water

Comments:

1. Amendment Condition 5 received a microbial seed obtained from Buchans Oriental East Limnocorral site F which contained 10^5 sulphate reducing bacteria per mL.

TABLE 6A:

BUCHANS 1591 - OWP LIMNOCORRAL 2
pH PROFILES OF PICOCOSM TESTS (SECOND SERIES)

Test Condition	Amendment	Day 0	Day 14	Day 21	Day 28	Addition on Day 28	Day 29
1		3.67	3.64	3.52	3.62		
2	BOD nutrients	3.60	3.58	3.55	3.59	0.1 g steel wool/200 ppm Na ₂ S/1000 ppm glucose	8.88
3	BOD nutrients	3.63	3.60	3.57	3.58		
4	1000 ppm glucose	3.49	3.50	3.47	3.48		
5	1000 ppm glucose	3.53	3.57	3.56	3.56		
6		3.57	3.83	3.67	3.65		
7	BOD nutrient	3.60	3.73	3.73	3.74		
8	BOD nutrients	3.57	3.80	3.80	3.78		
9	1000 ppm glucose	3.53	3.52	3.58	3.63		
10	1000 ppm glucose	3.51	3.60	3.62	3.85		

Test conditions common to all vials:

- 3.0 g Oriental West Pit LC 2 amendment
- Buchans Oriental West Pit water

Comments:

1. Test conditions 6 to 10 received microbial seed obtained from Buchans Oriental East Limnocorral site F which contained 10^5 sulphate reducing bacteria per mL.
2. Picocosms were set up three weeks after receiving the amendment samples.
3. Amendment conditions 4, 5, 9 and 10 were analyzed for the presence of sulphate reducing bacteria and volatile fatty acid producers on day 42 (see Table 6C).
4. Tests for the presence of Thiobacillus ferrooxidans on day 52 were performed in amendment condition 1. Negative results were obtained.

TABLE 68:

CHEMICAL PROFILES ON DAY 14

Amendment Condition	pH	Total Soluble Carbohydrates (ppm)	Total Volatile Fatty Acids (ppm)
4	3.50	>1000	120
5	3.57	>1000	120
9	3.52	19	360

Amendment Conditions:

4 and 5: 3 g Oriental West Pit LC 2 amendment and 1000 ppm glucose

9 and 10: 3 g Oriental West Pit LC 2 amendment and microbial seed and 1000 ppm glucose

Comments:

1. Microbial seed was obtained from Buchans Oriental East Linnocorral site F which contained 10^5 sulphate reducing bacteria per mL.

TABLE 6C: CHEMICAL AND MICROBIOLOGICAL PROFILE ON DAY 42

Amendment Condition	pH	Redox.Potential (mv)	Sulphate reducing bacteria per mL (Dactinosa B)	Volatile Fatty acid producers per mL
4	3.45	+200	<10 ⁰	<10 ⁰
5	3.51	+195	10 ²	<10 ⁰
9	3.90	+60	10 ⁵	10 ²
10	4.73	+86	10 ⁴	10 ²

Amendment Conditions:

All vials contained 3.0 g Oriental West Pit LC 2 Amendment

water

Comments:

1. Amendment Conditions 9 and 10 received a microbial seed obtained from Buchans Oriental East Limnocorral Site F which contained 10⁵ SRB per mL
2. Amendment conditions 4, 5, 9 and 10 received 1000 ppm glucose on day 0.

TABLE 7A:

BUCHANS 1991 AEROBIC GROWTH pH PROFILES

Amendment Condition	pH			
	Day 0	Day 14	Day 30	Day 37
1	4.28	4.25	4.17	4.12
2	3.96	4.20	4.11	3.97
3	3.84	3.75	3.64	3.28
4	3.70	3.56	3.60	3.25
5	5.33	4.33	5.90	6.69
6	5.38	4.55	6.08	6.71
7	6.57	5.65	5.32	4.18

Amendment Condition:

- 1 and 2: 15 g Oriental West LC 1 amendment
 3 and 4: 15 g Oriental West LC amendment
 5 and 6: 15 g Oriental West Pit curtain amendment
 7 and 8: 15 g Oriental East LC 4 amendment

Comments:

- Amendment conditions 1 through 6 received Oriental West Pit water.
- Amendment condition 7 and 8 received Oriental East Pit water.
- Conditions were set up in 250 mL Erlenmeyer flasks with the addition of 100 mL of water.
- Amendment conditions 1 through 4 were analyzed for the presence of soluble carbohydrates on day 14 and 68 (see Table 7B).
- Tests for the presence of Thiobacillus ferrooxidans in amendment condition 7 and 8 were set up on day 68. Condition 8 tested positive for Thiobacillus ferrooxidans.

Amendment Condition	Day 14		Day 68	
	pH	Total Soluble Carbohydrates (ppm)	pH	Total Soluble Carbohydrates (ppm)
1	4.25	<10	4.31	13
2	4.20	20	4.20	10
3	3.75	<10	3.66	18
4	3.56	10	3.58	21

Comments:

1. Amendment conditions 1 to 4 received 100 mL of OWP Hater.
2. Conditions Here set up in 250 mL Erlenmyer flasks

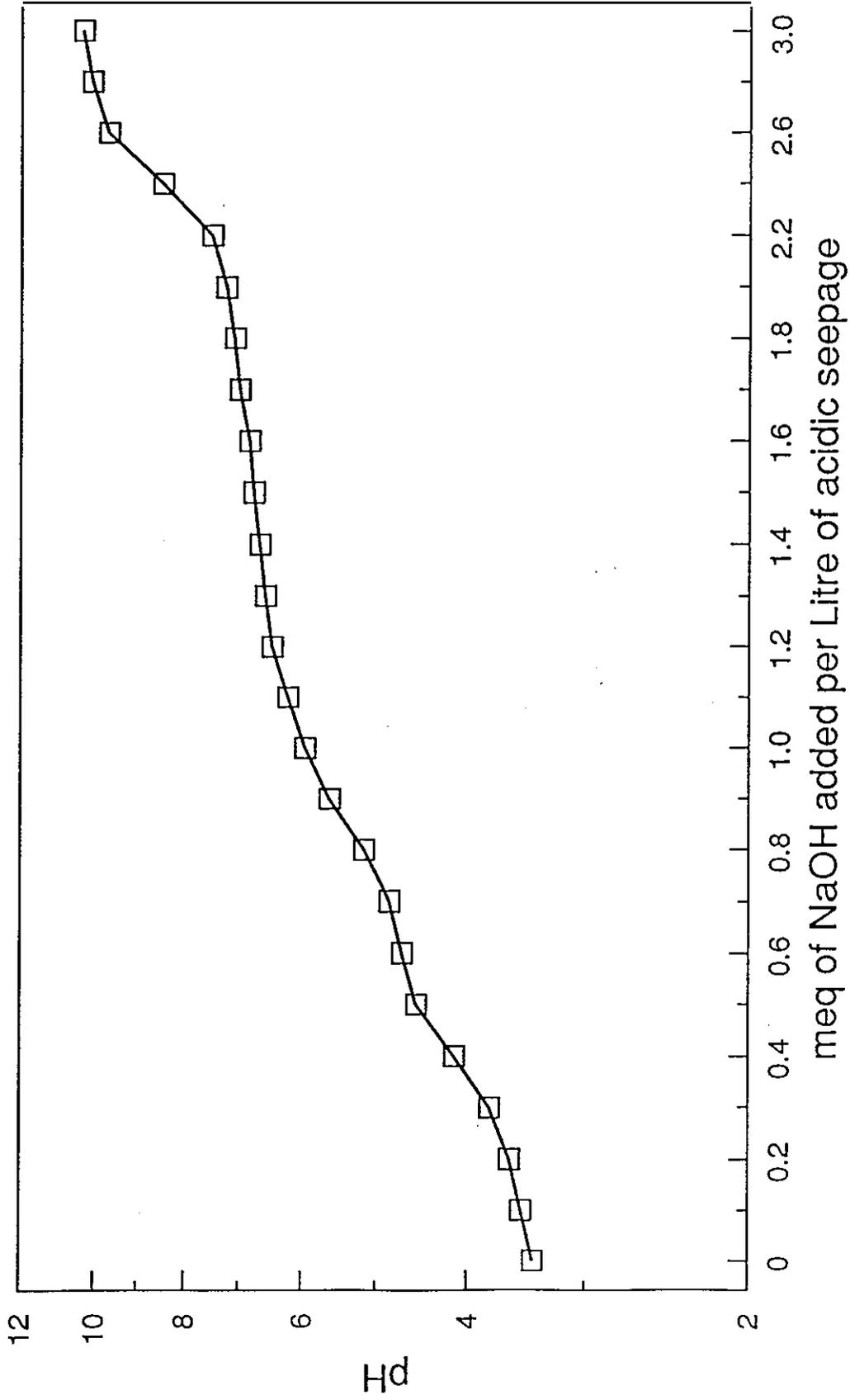
TABLE 8

ZINC AND COPPER ANALYSES OF BUCHANS AMENDMENT SAHPLES

Amendment Sample	Sample Identification	Zinc mg/kg Dry Amendment	Copper mg/kg Dry Amendment
2	Oriental West Pit LC 1 (June/91)	7,900	<0.5
3	Oriental West Pit LC 2 (June/91)	1,500	<0.5
10	Oriental West Pit LC 1 (July/91)	7.000	<0.5

Comments:

1. Zinc and Copper concentrations of Oriental West Pit water were 53.5 and 1.60 ppm respectively.
2. Zinc and Copper concentrations of Oriental East Pit water were 7.69 and <0.004 pp, respectively.



H:GUCZ 1: BUCHANS ORIENTAL WEST PIT, (JUNE 6/91)
TITRATION CURVE

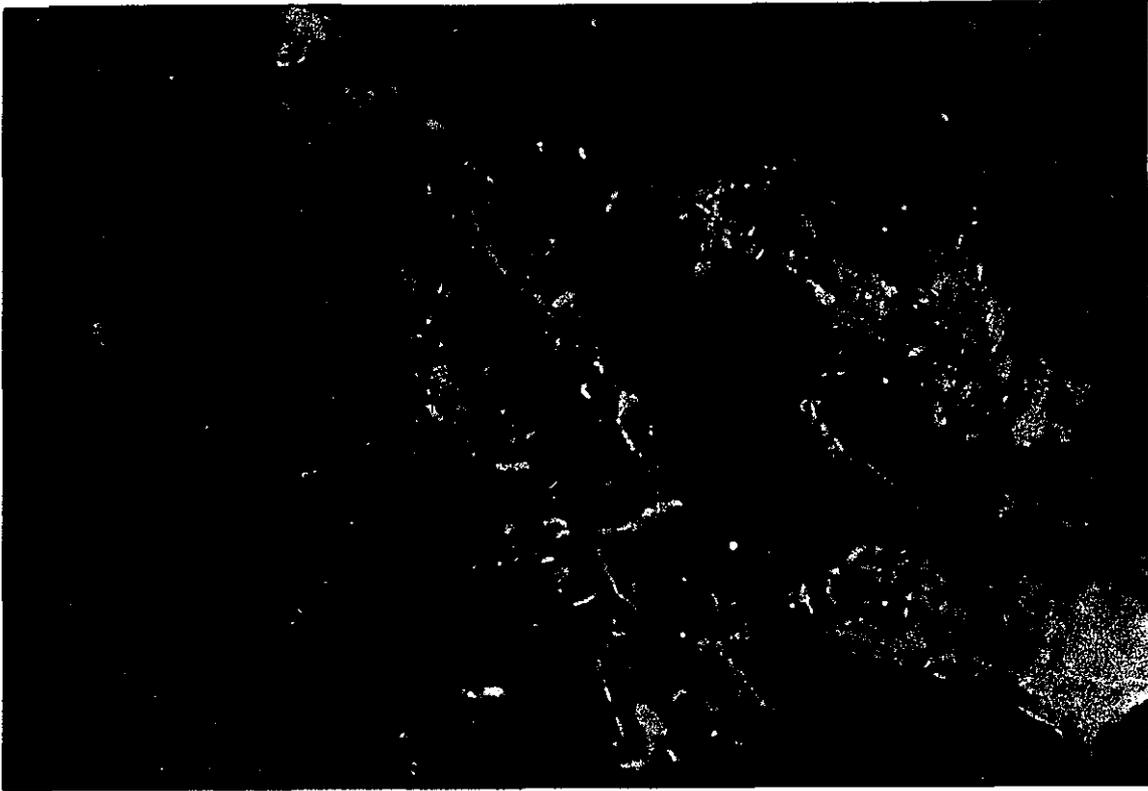


Figure 2 Buchans limnocorral #1, Straw Amendment Sample, June 1991. ARUM in this sample required glucose to be activated. The bacterial colonization of the amendment as shown microscopically is sparse. Magnification: 1700x.



Figure 3: Buchans Linnocorral #3, Peat Amendment Sample, June 1991. ARUM in this sample could not be activated even after a glucose supplement. The bacterial colonization of the amendment was very sparse as the photograph illustrates.

Table 4.1 -3 Glucose/Osmocote and Limnocorral waters/amendments
Baseline chemistry- 2-3 h after set-up, and after 80 days

reatment	Jar	H		h iV		ond mhos/cm		Acidity mg/l CaCO ₃		Zn mg/l	
		days	80 day	days	80 day	days	80 day	0 days	80 day	0 days	80 day
imnocorral 1	1	4.19	3.51	252	473	550	790	139	162	21	2
	2	4.15	3.48	252	471	550	720	133	180	21	45
imnocorrai 1 † lucose	1	4.14	3.54	251	474	530	650	131	240	21	10.5
	2	4.05	3.57	257	472	550	660	133	200	21	8
imnocorral 1 † ismocote	1	4.1	3.47	251	380	540	880	142	297	21	3.5
	2 + air	4.18	3.35	253	445	530	1290	135	706	21	84
imnocorral 2	1	5.8	4.51	91	416	395	490	64	124	<1	9.5
	2	5.88	4.52	92	426	400	510	57	121	<1	10
imnocorral 2 † lucose	1	5.43	4.53	92	400	395	430	68	136	<1	4.5
	2	5.53	4.53	91	408	398	410	72	144	<1	4
imnocorral 2 † ismocote	1 + air	5.68	4.29	88	353	400	730	59	176	<1	34
	2	5.32	4.27	128	320	400	730	60	193	<1	33
imnocorral 4	1	6.39	6.54	80	261	1770	1820	80	110	23	c0.5
	2	6.49	6.61	80	253	1720	1940	82	139	23	c0.5
imnocorral 4 † lucose	1	6.53	6.69	82	247	1820	1780	91	122	23	c0.5
	2	6.54	6.72	82	243	1800	1810	90	79	23	c0.5
imnocorral 5	1	6.8	6.57	-99	-236	1100	1110	80	104	1	<0.5
	2	6.84	6.6	-129	-140	1100	1150	80	100	1	c0.5
imnocorral 5 † iucose	1	6.88	6.56	-141	-200	1120	1240	99	100	1	<0.5
	2	6.91	6.66	-127	-173	1100	1180	79	94	1	<0.5

Jars contain water and amendment from limnocorrals collected in late August, 1991.

Table 4.1-4 Potato waste-OWP jar experiment
Chemistry-75 days after set-up

Treatment	Ja	pH	Eh mV	Cond umhos/cm	C	Acidity mg/L CaCO ₃	Alkalinity mg/L CaCO ₃	H ₂ S	Zn mg/L
Peat	1	3.23	292	700	22.1	146			16
	2	3.19	295	710		158			15.5
Peat + potato-layer	1	3.73	224	208	21.8	81		+	<0.5
	2	3.6	324	260		127		+	<0.5
Peat + potato-mixer	1	3.34	317	346		105		+	<0.5
	2	3.66	308	191		115		+	<0.5
LC2 peat	1	4.4	238	600		140			27.5
	2	4.35	247	600		136			24.5
LC2 peat + potato-mixer	1	4.82	222	271		54	10		1.5
	2	5.19	197	273		49	8		1
Potato only	1	4.85	144	1280		480	367	+	<0.5
	2	5	160	1200		1110	328	+	<0.5

Zn concentration of OWP water used was 65 mg/l (Taylor test)

Fig. 4.1-17a LC2 Peat vs. New Peat Jar Experiment

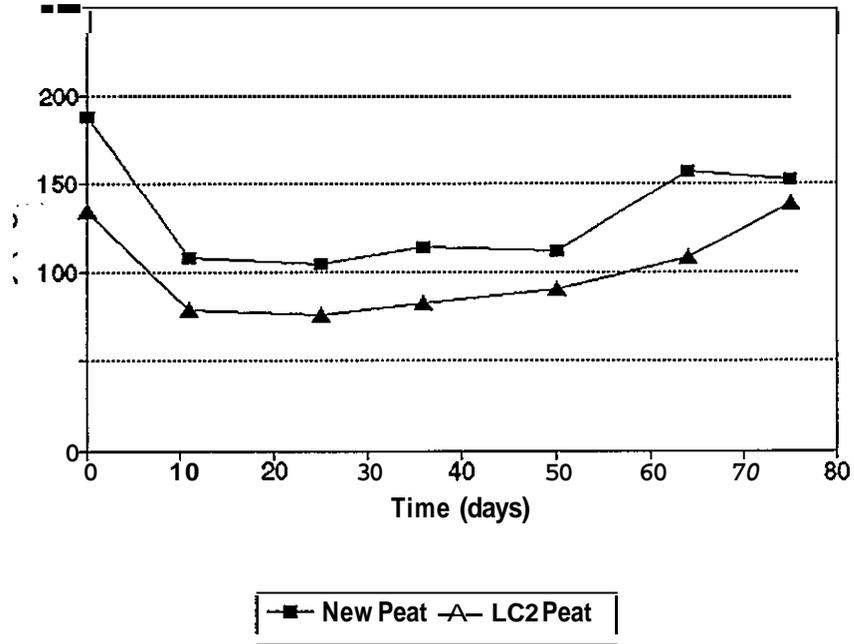


Fig. 4.1-17b Peat+Potato Waste Jar Experiment

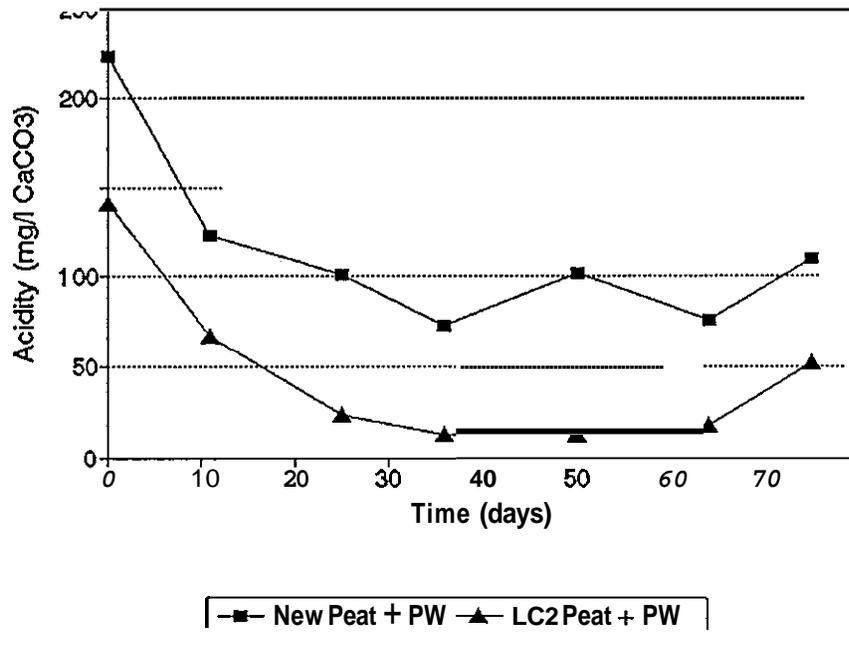


Fig. 4.1-18 Amendment Comparisons
Jar Experiment

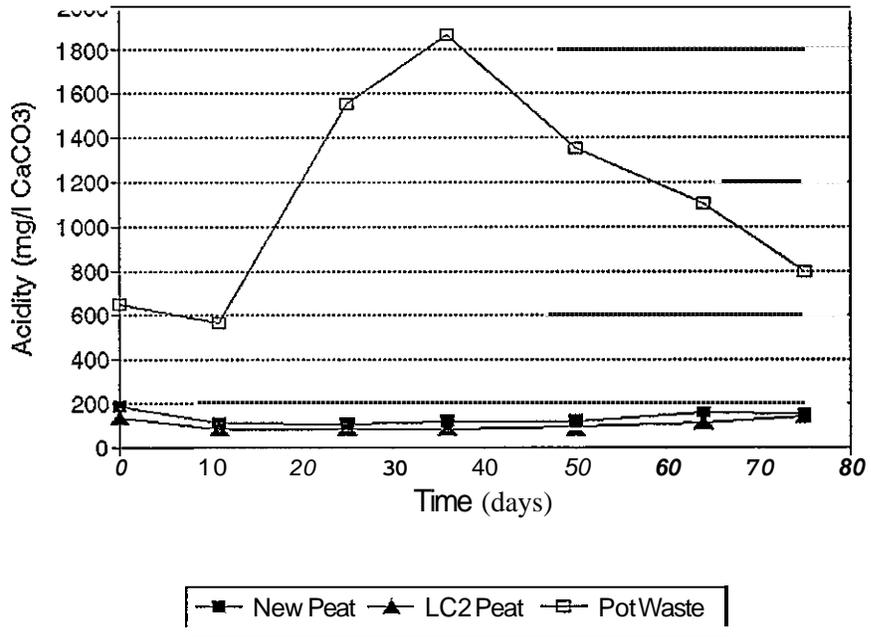


Fig. 4.1-19a Potato Waste in OWP Water
experiment on Dec.9,1991

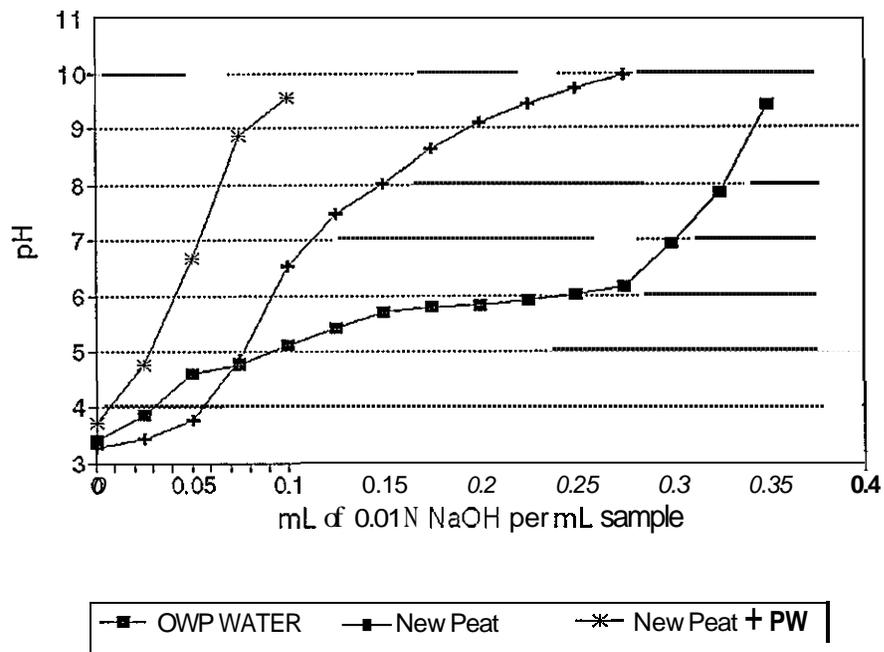


Fig. 4.1-19b Acidity Change - OWP Water

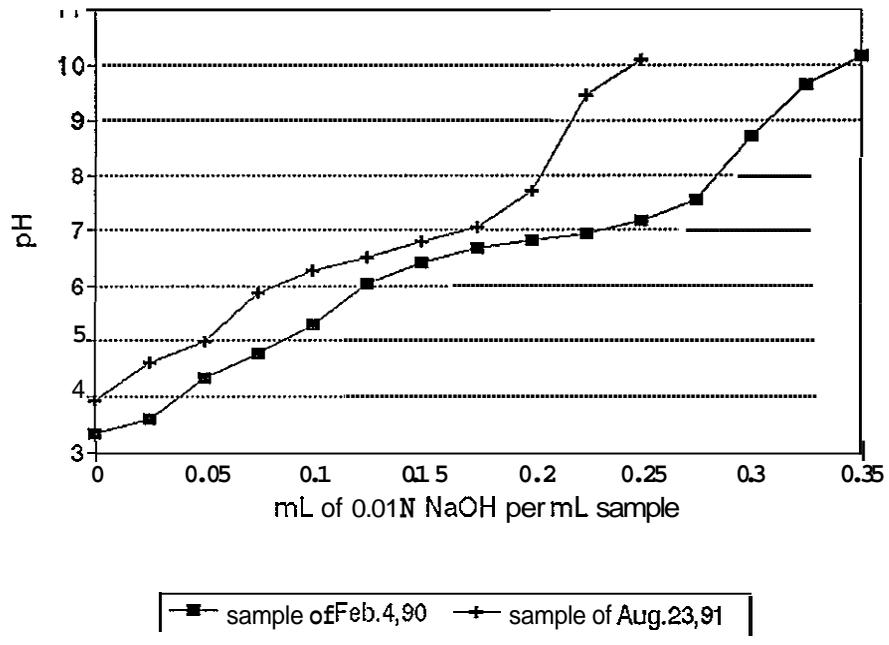




Plate 4.1-1: Jar Experiment. Left jar contains 11 OWP water + 19g of new peat. Jar on the right contains the above with 1g potato waste, after 55 days.

Fig. 4.1-20 Weight Loss Experiment
By Pit, Amendment, % Loss

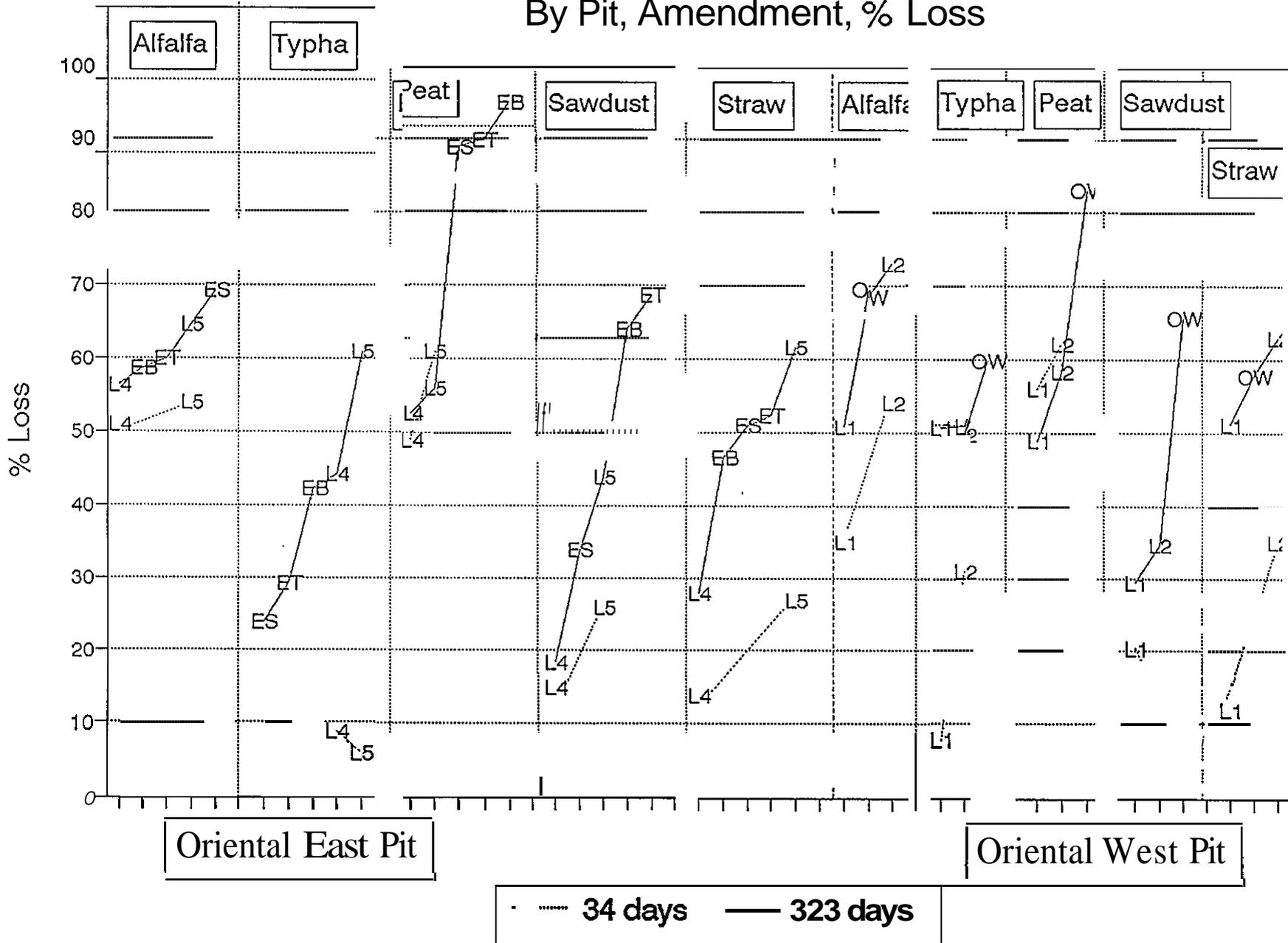


Fig. 4.1 :21a Sequential Analysis
Sawdust 323 days

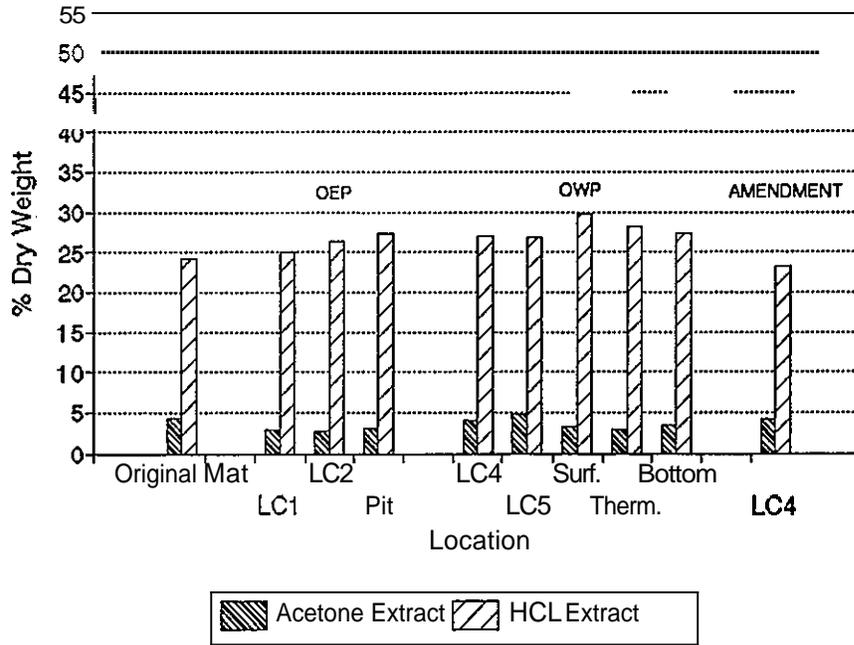


Fig. 4.1-21 b Sequential Analysis
Peat 323 days

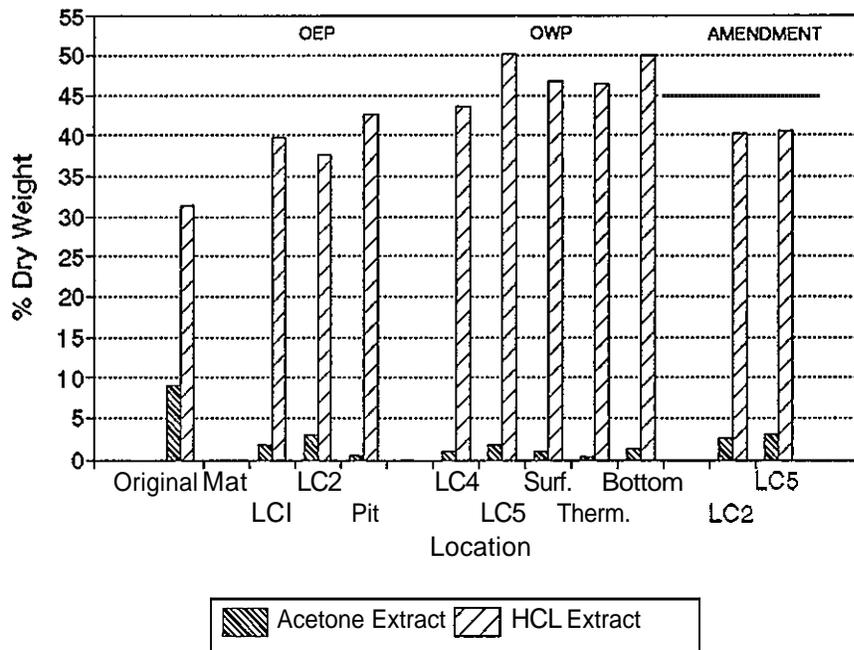


Fig. 4.1-21c Sequential Analysis
Straw 323 days

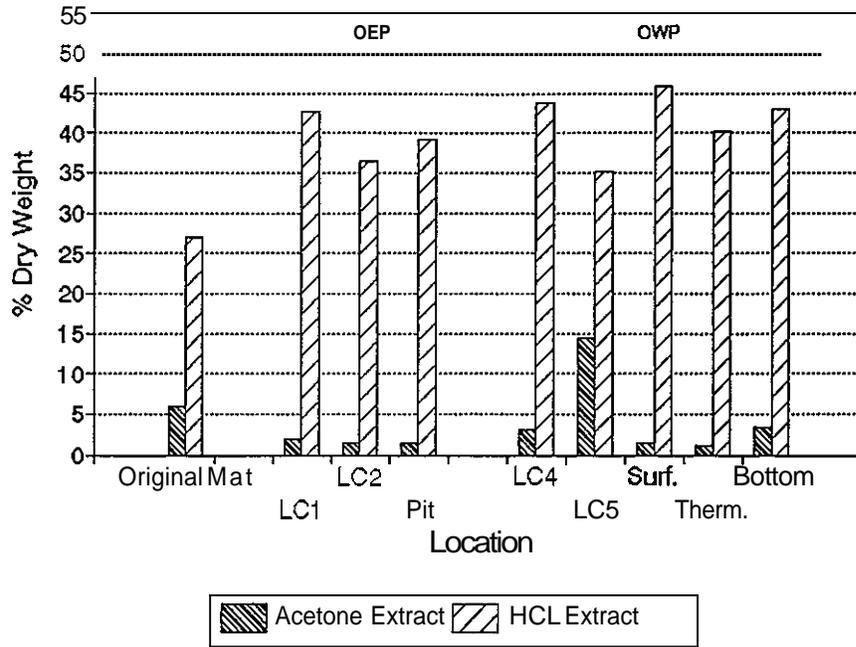
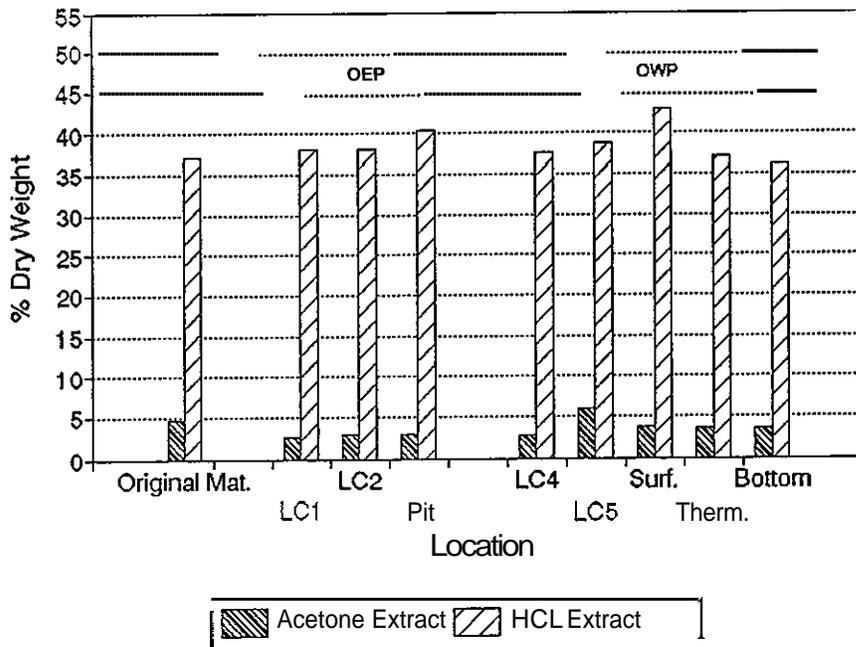


Fig 4.1-21d Sequential Analysis
Cattails 323 days



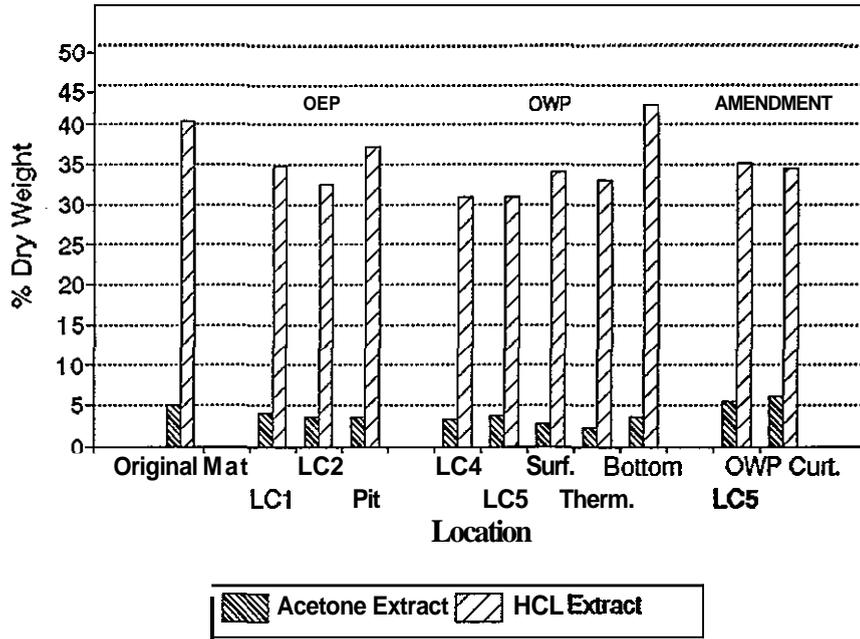
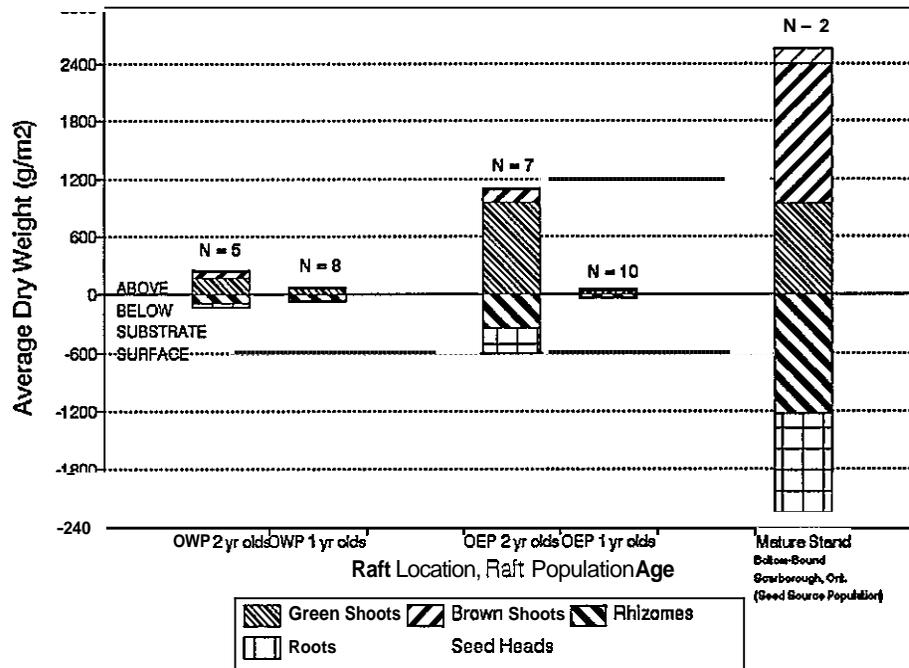


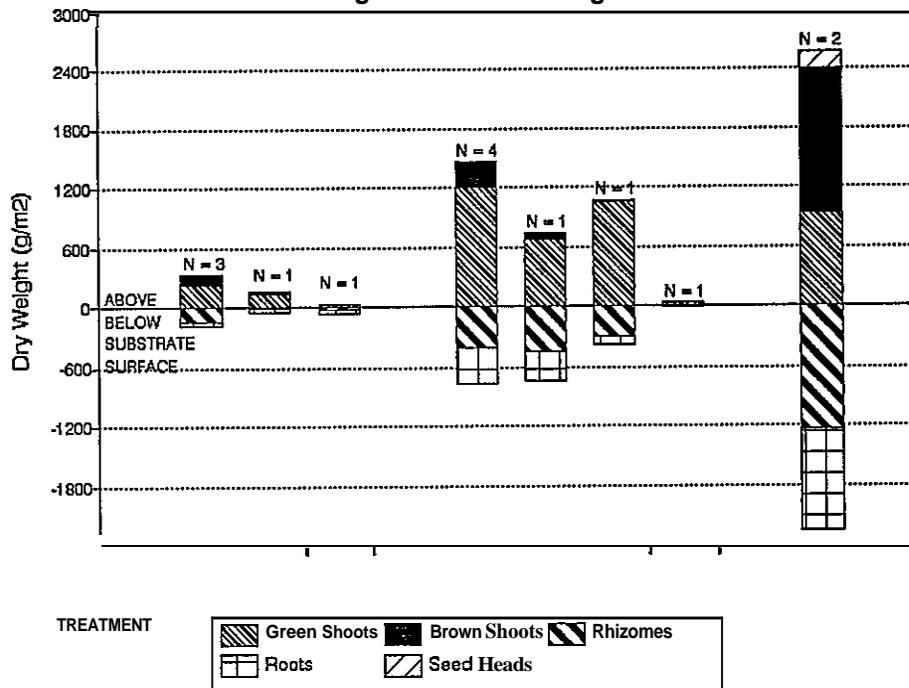
Table 4.1-5 Eh survey of cattail rafts, August 1991
Mean values

Location	Raft type	Sphagnum enc	Straw end
		Eh (mV)	Eh (mV)
OWP	Old/mature	71	-134
	Old/seedlings	122	44
	New/burlap	-238	
	New/lattice	-229	
OEP	Old/mature	-75	-163
	Old/seedlings	-63	-145
	New/burlap	-81	
	New/lattice	-229	

**Fig. 4.1-22a Buchans Typha Rafts
Standing Biomass: Oct 17, 1991**



**Fig. 4.1-22b Buchans Typha Raft
Standing Biomass According to Additives**



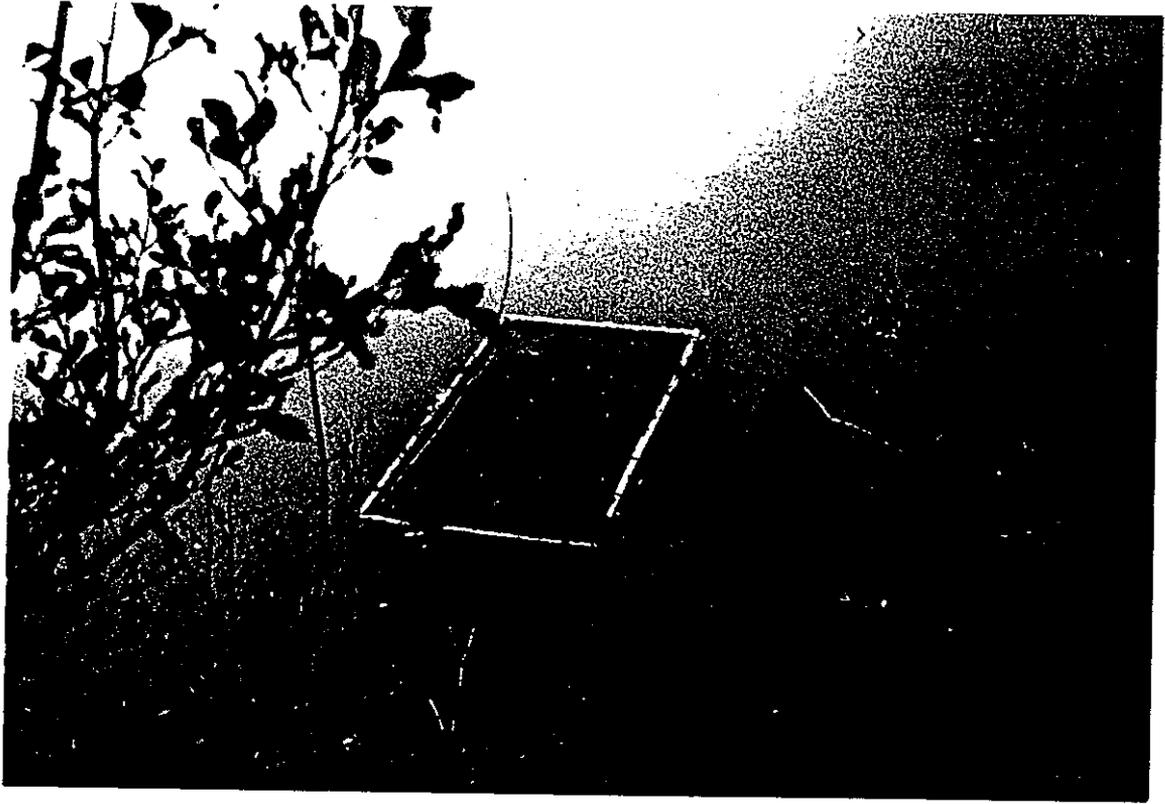


Plate 4.1-2 Cattail seedlings (*Typha latifolia*) germinated *in situ* on a raft in the OEP.

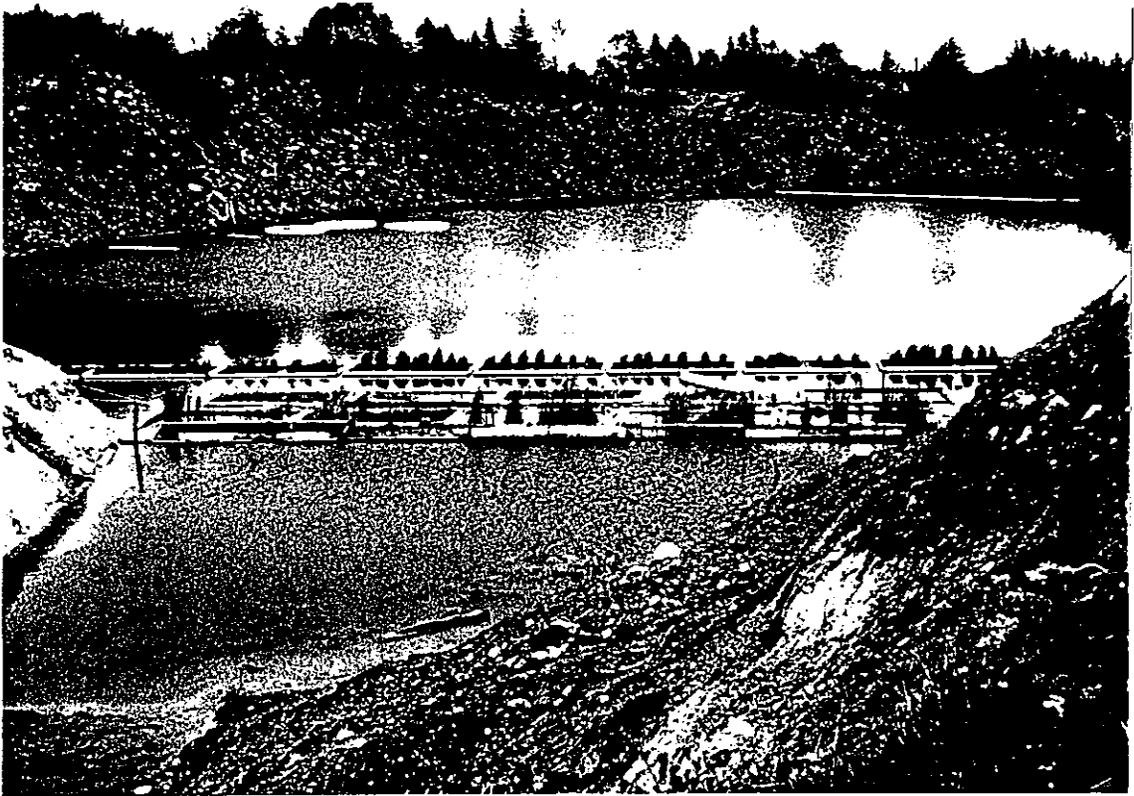


Plate 4.1-3: Cattails (*Typha*) planted on rafts in the OWP in 1990 and 1991.

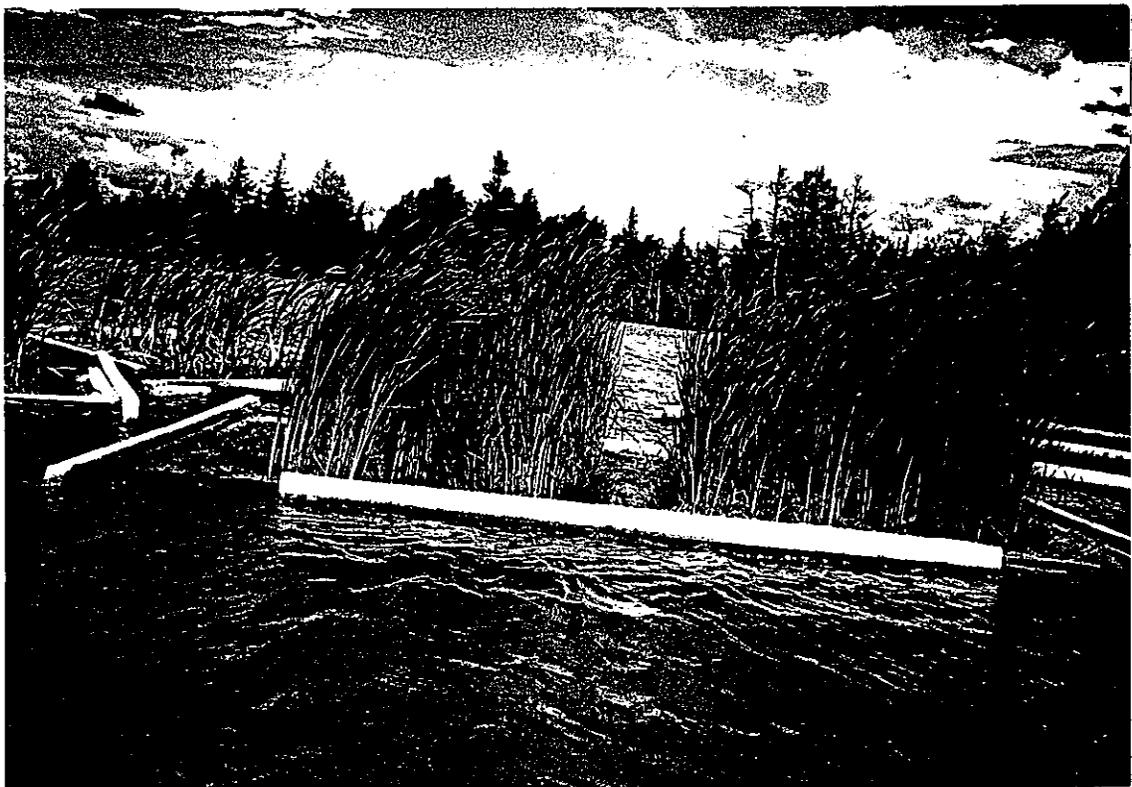


Plate 4.1.4: *Typha angustifolia* planted as seedlings on rafts in the OEP in 1990 (foreground). *Typha latifolia* transplanted as mature plants (rear, left).

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4.2 BIOLOGICAL POLISHING

4.2.1. Introduction

Several communities of algae and moss are evolving in the Oriental East outflow system. Each of these communities removes dissolved zinc and precipitated zinc from water flowing over them. The objective of this year's work was to address some of the fundamental questions relating to the removal of zinc from water by these populations. In addition, zinc removal rates were to be quantified, and parameters established to scale-up the process in the Meadows.

Three periphyton communities been identified in the OEP effluent system: a *Ulothrix* community which inhabits seepages and pop-ups in the first meadow; a *Microsporu* and moss community which is proliferating in the OEP and outflow streams; and a *Microsporu*, moss, and *Achnanthes* community in the polishing ponds. The location of the different communities is given in SECTION 1.

Zinc removal from waste water occurs by several processes. Zinc precipitates or colloids can be sieved from the water by periphyton populations. Dissolved zinc can be sequestered by periphyton, either extra- or intra-cellularly. A fourth mechanism operates in carbonate/bicarbonate waters such as the OEP. The process of precipitate enhancement occurs when photosynthesis in the periphyton Communities rapidly elevates the pH of the water locally during the day. In the range of pHs between 6 and 7.5, this pH elevation, will selectively enhance the precipitation of iron, zinc, manganese and aluminum. The biologically-induced precipitates are then biosieved by the periphyton communities.

The interactions between chemical and biological systems operating in OEP outflow waters are complex. Chemical precipitation processes mix with biological sequestration to effect a removal of zinc from OEP waters. Chemical precipitation processes are discussed in SECTION 3.

Biomass growth and zinc content were analyzed from two separate systems. In Section 4.2.2.2 periphyton populations were monitored growing on natural substrates. Actual rates of growth cannot be measured with these populations, since no starting point can be defined. Therefore, in Section 4.2.2.3, an artificial substrate system was employed. These systems were cleaned on each field trip providing a zero starting point from which to measure growth rates.

Section 4.2.3 discusses the interaction between metal precipitates and the periphyton populations. Section 4.2.4 focuses on the specific relationship with zinc. Section 4.2.5 provides the background for field scale-up, giving results of laboratory experiments. Biological polishing performance as growth in the ponds is tied together in section 4.2.6, while performance as zinc removal is presented in section 4.2.7. Finally section 4.2.8 uses these performance numbers to extrapolate growth and zinc removal to a scale encompassing the entire OEP outflow.

4.2.2. *The* Polishing Ponds

In June of 1989 ~~six~~ serial ponds were excavated in the first meadow to act as biological polishing ponds (SCHEMATIC 4.2-1). Water was diverted from the main Oriental East outflow stream into the 6 ponds, Between August and September 1989, 110 alders were placed in each of the pools (130 in pond 6) to act as additional surface area for biological polishers. The ponds are, on average, about 0.6 m deep, with a diameter of 9.2 m. This gives pond volumes that range from 24 cubic meters (pond 5) to 54 cubic meters (pond 2). The average volume is 40 cubic meters.

4.2.2.1 Flow and residence times

Throughout 1991, flows through the polishing ponds varied from 0.035 l/sec in July to 0.174 Vsec in August. The average flow was 0.122 Vsec. If we assume that the flow through the ponds is diffuse, then residence times vary from 80 days (July) to 16 days (August). The average residence time for the summer was 23 days. Short-circuiting within the ponds was undoubtedly occurring, as actual residence times calculated in 1990 were on the order of hours rather than days.

4.2.2.2. Periphyton colonization on natural substrates

Alders were added to the ponds to provide a surface on which periphyton could grow. These periphyton populations were monitored by clipping the end of a branch, cleaning off

periphyton, drying both branch and periphyton. Production was recorded as dry weight of periphyton (jelly) per dry weight of branch. The term "jelly" comes from the large amounts of polysaccharides produced by the periphyton.

By June of 1990 colonization of the alders by periphyton had begun. There appeared to be an initial period of one to several months depending on the time of year in which the surfaces became conditioned. Conditioning involved leaching of phenolics from the trees, followed by bacterial colonization. Once bacterial populations coated the surfaces, periphyton colonization could begin.

Sampling of the ponds began rigorously in 1991. Water passing through the ponds was monitored several times each year since installation. These data indicate that zinc (FIGURE 4.2-1a) is being removed. Copper, on the other hand, seems to pass through the system (FIGURE 4.2-1b). Periphyton samples were collected between May and October. FIGURE 4.2-1c shows the development of biological polishing capacity (biomass) in the polishing ponds from inception through 1991.

Populations of periphyton start growing on natural (conditioned) substrates early in the spring, probably at the time of ice breakup. Populations accumulate on the substrates (i.e. grow) until mid summer, at which time some of the material begins to slough off. Sloughing increases throughout the late summer. The effect of this sloughing, along with decreasing growth rates, is that "jelly" accumulations become smaller towards the end of summer. Sloughed material sediments to the pond floor.

In 1991, biomass accumulations on branches peaked in August in ponds 1, 2 and 5, and peaked in **July** in ponds 3, 4 and 6. During **July**, a comparison of algal zinc concentrations, water zinc concentrations, and biomass per branch were made (FIGURE 4.2-2). On this date in July, about 94% of the zinc was removed from the water between entering pond 1 and leaving pond 6. Concentrations of zinc in periphyton varied from 3.7 to 9.3% of the dry weight.

Natural periphyton communities on branches begin to slough in mid summer. Estimating total biomass production for the summer, or year, is therefore difficult. However, if a starting date at ice **breakup** (late April) is used, then accumulation rates (change in biomass accumulations with time) can be calculated (see FIGURE 4.2-3). Accumulation rates increase from April to July. That is, accumulations of periphyton on branches were larger with each successive sampling. After July, however, accumulation rates decreased as sloughing increased. By middle September (day 260), sloughing rates became greater than accumulation rates, causing the accumulation rate to fall through zero.

4.2.2.3. Periphyton colonization on netting

Actual periphyton growth measurements using "jellies" are estimates only. Accumulation rates can be considered growth rates, but only when no sloughing occurs. Actual sloughing rates cannot be measured with the jelly method. To estimate growth and sloughing processes separately, special "peritraps" were installed at various sites in the area of the Oriental pits. In SCHEMATIC 4.2-2, the configuration of a peritrap is shown.

Peritraps were designed to answer several questions. The first question was how to separate growth from sloughing. The second question dealt with estimating the amount of "conditioning" that was required before colonization could occur. The third question involved estimating the effects of fertilizer on periphyton growth. Fertilizer was added directly to the trap, or placed on floats in the pools.

The traps consisted of an artificial netting structure which housed natural substrates (alder branches; **PLATE** 4.2 -1). Below the netting was a plastic bag which collected any periphyton falling from the netting or substrates. Periphyton growth rates could therefore be determined on both the netting and alder branches. The same sized netting frame was used at several mine sites for comparative purposes. Substrates (branches), however, were site specific. Periphyton growth was cleaned off the nets and branches, dried and weighed. Total growth was determined by adding algal weights on nets and branches to that which had fallen into the bag. The cleaned traps were put back into the polishing ponds for further colonization.

Peritraps were placed in polishing ponds 1, 3, and 6 in late May 1991. Some of the traps were cleaned on each successive field trip, others were left for 2 or three months before cleaning. Growth of periphyton and accumulation of precipitate added mass to the traps over the period the traps were submerged in the ponds. Collection and cleaning of traps 3 times over the summer, gave 3 growth periods, June, July-August, and September-October.

4.23. Precipitate formation/algal interactions

Biomass on nets and branches was comprised not only of periphyton, but precipitate as well. In some cases, most of the dry weight measured was precipitate. This precipitate should not be included in algal growth measurements. The data were therefore corrected for precipitate content by using LOI data. Dried samples were ashed in a muffle furnace. The loss of weight after 30 min. at 500 C is the **LOI**. This weight loss is due to combustion of organic carbon, carbonates and hydroxides in the sample. **An** estimate of the organic carbon content can be made if the LOI of a sample is compared to an LOI of a "clean" alga (85%; FIGURE 4.2-4). However, the relationship between precipitate and algae is complex. Separating the growth of algae from the growth of precipitates is difficult. In PLATES 4.2-2 and 4.2-3 the differences between "clean" and precipitate-collecting periphyton can be seen.

A number of Periphyton Precipitate Complexes (PPCs) from the OEP outflow have been collected and processed in 1991. These PPCs have the following characteristics. When the precipitate is cleaned off the periphyton, or when an alga occurs in an area without noticeable precipitate (2nd Meadow), LOI is greater than **85%**. Precipitates collected from sediment traps, First Meadow, and from cleaned algae all have LOIs less than 30%.

A relationship for periphyton and precipitate complexes was defined based on LOIs for clean algae and precipitates (FIGURE 4.2-4). Using this relationship, precipitate and periphyton proportions can be assigned for each PPC.

4.24. Zinc-algae

When PPCs from a variety of study sites around Buchans were analyzed in this way for zinc, the relationship shown in FIGURE 4.2-5 was found. From these data several things became apparent. A zero-percent precipitate is a clean alga (by definition). Clean algae, adapted to water in the OEP outflow appear to have about 1% zinc (on a dry weight basis; 10,000 $\mu\text{g/g}$). The precipitate fraction continues, as expected, even more zinc to the mixture. Clean precipitates can have as little as 2% or as much as 25 % zinc. The amount of zinc in the precipitate is dependent on the location of the sample, and indirectly on phosphate or carbonate concentrations in the water (see SECTION 3).

These data suggest that a cleaned alga will contain about 1% zinc on a dry weight basis, and they further indicate that the precipitate will contain a minimum of 1.5 % zinc. OEP precipitates from sediment traps are about 1.9% zinc. The effect of the chemical environment and physical environment (location) on PPC composition can be analyzed by grouping the PPCs by location. The following graph shows the distribution of zinc (FIGURE 4.2-6) in Buchans PPCs. DT = Drainage Tunnel; WRP = Acid pools 7-9; TP2 = Tailings Pond 2; MDW = 2nd Meadow; OW = Oriental West Pit; PP = Polishing Ponds; OEP = Oriental East Pit ppte samples; OEW = Oriental East Pit, algal-ppte mixtures; OEC = Oriental East Pit, cleaned algae.

The chemical environment seems to play a large role in the zinc distribution in Buchans PPCs. Samples from sites other than the OEP outflow contain little zinc. The polishing

pond algae contain the most zinc, and algae from the pit itself contain an intermediate amount of zinc. Our current working hypothesis about why the polishing ponds excel as zinc collectors, is that the carbon dioxide produced by the algae during photosynthesis increases the pH of the ponds slightly - enough to precipitate zinc carbonates on the surface of the algae (see SECTION 3). Also, enriched phosphate concentrations in the lower ponds due to fertilizer may be enhancing the precipitation of zinc phosphate (see SECTION 3). From FIGURE 4.2-5, it can be seen that clean algae, e.g. Second Meadow algae, can contain up to 1% zinc on dry weight basis. This zinc is either bound to cell surfaces or taken up internally. A number of laboratory experiments were carried out to further elucidate the interactions of zinc and algal growth.

4.2.5 Laboratory Experiments

Laboratory experiments were designed to define the relationship between dissolved zinc and clean OEP algae. In these experiments, dissolved zinc concentrations were monitored over time both with and without algae. Dissolved zinc was removed from OEP water, culture media and bubbled distilled water (see SECTION 3). Short-term uptake (hours) indicated that periphyton could remove zinc at a rate faster than the rate of precipitation. Over longer period experiments, dissolved zinc was removed from OEP water and growth media at rates in excess of precipitation rates.

4.2.5.1. Zn uptake in the laboratory

The removal of dissolved zinc appears to have two phases. The first, rapid, phase is related to zinc adsorption and ionic exchange with periphyton cell walls. The second phase is much slower, and is linear over the rest of the experiment (several weeks). This pattern is constant regardless of the initial dissolved zinc concentration (FIGURE 4.2-7).

The amount of zinc removed from solution (represented as g Zn/gdw algae) can be plotted against the initial dissolved zinc concentration in the water (from FIGURE 4.2-8). The linear relationship can be translated to mean that with a water zinc concentration of **15 mg/l**, periphyton should contain at least **1.5% zinc (15000 µg/gdw)**. The thousand fold concentration factor is similar to that found in other periphyton samples from other mine sites.

After the initial cation exchange process has reached a steady state, there is still significant, though slower, zinc removing capability. Steady-state uptake rates are also dependent on bulk water zinc concentrations. The relationship appears to be hyperbolic, meaning that zinc removal rates gradually slow as concentrations increase. This relationship is characteristic of a physiological process, rather than an "exchange" or other physical process. It further suggests that in the OEP outflow, this process is saturated (i.e. will not increase further) at external concentrations in excess of **25 mg/l**. At this concentration, the process is capable of removing up to **300 µg Zn/gdw/day**.

4.2.5.2. Model development and predictions

A general model simulating the polishing system for general application is being developed, however not complete. Progress this year was limited to setting up the overall framework, and collection of the data for the model. Some of the model subroutines are briefly outlined below.

- Environment Module - Predicts water temperature and sunlight conditions. Based on Buchans records, water temperature in the first meadow has been programmed. Sunlight, however, requires records from Environment Canada, sunlight records from Buchans, and some guesswork. These estimates are being programmed.
- Nutrient Module - Predicts nitrogen, phosphorus, carbon dioxide, residence time.
- Geochemistry Module - Predicts carbon dioxide, phosphorus, and oxygen concentrations based on interactions with precipitates and saturating metals.
- Biomass Module - Predicts the growth and productivity of periphyton based on inputs from the above three modules. Biomass production can, in turn, alter geochemistry, and hydrology, and zinc concentrations.
- Zinc Module - The output of the biomass module will primarily affect the zinc module which will predict the zinc concentration in water. The output is dependent on zinc sequestration rates, uptake rates, precipitation rates, and loss rates.

It will now be possible to utilize the data collected during the summer season for predictions to scale up from ponds 1 to 6.

4.2.6 Biological polishing performance

4.2.6.1 Growth rates of periphyton in the ponds

FIGURE 4.2-9 shows the LOI-corrected periphyton growth rates found on peritraps during the summer of 1991. Growth was recorded for three periods. From May 30 to July 5, from July 6 to Aug 23, and from Aug 24 to Oct 15. During June, the growth rates were the lowest of the summer. **This** is due to an initial period required for the traps to become colonized, especially since accumulation rates for "jellies" are high in June. Growth (corrected) averaged around $0.15 \text{ gdw/m}^2 \text{ (substrate)/day}$.

Major differences between trap locations started to show up in Jul-August period. During this period, the greatest production of algae was in polishing pond 3. The marked differences shown during this period are, at present, attributed to differences in nutrients.

In September-October, the growth rates between ponds was similar, averaging $0.4 \text{ gdw/m}^2 \text{ (substrate)/day}$. The similarity between pond periphyton growth in all three ponds indicates that some outside factor, common to all locations is limiting production.

When growth rates from Buchans peritraps are compared to growth rates at another zinc/lead mine in N. Ontario (FIGURE 4.2-10), it becomes clear that periphyton growth (except in the OWP) is comparable between mine sites and within mine sites. This indicates further, that dissolved zinc concentrations and pH are not severely limiting periphyton

production. Periphyton growing in Boomerang Lake (*MPO* and *OUTF*) at pH 3.5 and zinc levels around 7 mgil have very **similar** growth rates during the second growth period (July-August). The population labelled *DECP* was primarily blue-green algae growing in a tailings pond (pH 7, [Zn]- 2 mgil).

4.2.6.2. Other biomass/growth estimates

As discussed in the previous section, growth of periphyton can be measured by collecting the biomass over the growing season and determining the dry weight produced. **As** the biomass also accumulates large fractions of precipitate, as expressed by *LOI*, growth quantified in this manner will result in an overestimate of the significance of periphyton in the biological polishing process.

One way to circumvent this problem, is to measure metabolic rates over short periods of time. The accumulation of carbon by periphyton (growth) is proportional to the release of oxygen. By measuring the release of oxygen, short-term growth rates can be estimated.

Photosynthetic rates of periphyton from polishing ponds, Drainage Tunnel, Tailings Pond 2, the *OWP* and *OEP* were measured in August using an oxygen probe. Rates were also measured in the lab, under controlled conditions of temperature and light. Field measurements ranged between **0.38** to 1.4 mgO₂/gdw/h. Laboratory measurements ranged between 0.24 and 0.49 mg O₂/gdw/h for roughly the same temperature range.

Carbon dioxide removal rates (photosynthesis and precipitation) can be estimated by the change in pH and alkalinity in carbonate-buffered waters. On August 23, 1991 pH and alkalinity of water entering and leaving the polishing ponds was measured. Total carbon dioxide concentrations were estimated, and removal rates calculated. Based on these parameters the calculated photosynthetic rate was **0.03** mg O₂/gdw/h. Growth rates of periphyton on branches and nets can also be "backtracked" to the same units. By assuming that an **LOI** corrected, dried biomass sample is **30 %** carbon, and this carbon is assimilated through photosynthesis. Using this approach, **0.5-1.5** mg O₂/gdw/h is a value which applies for the entire season. Growth rate measurements estimated by several methods all give similar results. Therefore, it can be concluded that LOI-based corrections give a reasonable estimate of biomass and therefore growth rates.

4.2.6.3. Growth enhancement in the ponds

In May of **1991**, slow-release fertilizer bags were hung in ponds **3** and **5**; pond **3** received **2** bags (**1** kg each), pond **5** only one bag. This fertilizer, Osmocote (**NPK 19612**) was designed to provide an release rate over **3** to **4** months at **20** C. Fertilizer dramatically increased periphyton production in the ponds in which it was placed. In July-August, the growth rates of periphyton in pond **3** were over twice that in pond **1**. Periphyton growth in pond **6** were also higher, than in pond **1**. Visually, the differences in algal colour and floating biomass between ponds with fertilizer and without fertilizer were also striking.

4.2.7. Zinc removal by periphyton in the ponds

The amount of zinc removed by periphyton can be estimated by analyzing dried samples of PPCs from peritraps and "jellies". To do this, PPC weights were multiplied by the closest matching ICP-determined zinc concentrations. Not every peritrap sample was sent in for ICP analysis. But, at least one sample from each set of traps was analyzed by ICP. The results are expressed as mg zinc removed/m² of substrate/day. Total zinc removal data (i.e. bags+ substrate+ net) are presented (FIGURE 4.2-11).

Zinc removal rates are highly correlated with periphyton growth rates, within a growth period. The higher the growth, the greater the zinc concentration of the PPC. There are several possible explanations for these results. High zinc concentrations could be linked to faster growth rates through higher photosynthetic rates, which in turn means a greater increase in pH (due to carbon dioxide removal). The elevated pH will cause more zinc to precipitate in the area around the periphyton.

NPK fertilizer in ponds 3 and 5 is elevating the phosphate concentrations in the ponds. Increased phosphate concentrations will cause zinc to precipitate out as zinc phosphate. The precipitate would be sieved by the periphyton communities.

The third explanation deals with the ability of periphyton to store zinc intracellularly. It has been shown that the presence of phosphate as polyphosphate bodies in algae enhances the ability algae to take up zinc, as well as allowing the plants to store excess phosphate.

Regardless of the explanation, zinc is removed from the waste stream. Calculations from data on Aug **25**, and periphyton data from the preceding **2** months are shown in FIGURE 4.2-12. These data indicate that at under the conditions of: 1) 16 day residence time; 2) 20 mg/l incoming Zn, and 3) **6.75** pH, **88%** of the dissolved zinc was removed. Up to 40% of that zinc can be accounted for by PPCs in the ponds. In July, over **93%** of the zinc was removed with a residence time of 80 days (FIGURE **4.2-12**).

4.2.8. Proposed Scale-up for First Meadow

In the previous sections the background work for biological polishing processes has been presented. Factors controlling periphyton growth and zinc removal were determined. Although the interactions between periphyton, water, and chemistry are extremely complex from a process control point of view, estimates for a scale-up to larger ponds can be derived.

The primary factor in scale-up is the provision of surface area for periphyton growth. This can be provided either with natural (e.g. alder) or artificial surfaces (netting). Since surface area in the polishing ponds is currently provided by alder, some scale factors are needed for alder.

4.2.8.1. The standard tree

In order to quantify the surface area present in the polishing ponds, it was necessary to quantify the surface area of the alder trees which were placed into them. A "standard" tree

could be estimated, and scaled up to the surface area of the **110** trees submerged in each polishing pond. Thus, a standard tree provides total surface area of **0.95 m²** and **all** of the trees in a pond provide about **105 m²**. If the bottom and sides of the ponds are included, the total surface areas are about **156 m²**. If this is divided by the volume of the ponds, then there is approximately **3.8 m²** of surface area per cubic meter of pond.

Total PPC production for the whole summer (based on peritrap netting+branches+bag) was **82 gdw/m²** (substrate) for polishing pond **#1**, **149 gdw/m²** (substrate) for **#3**, and **125 gdw/m²** (substrate) for **#6**, for the period from May **30** to October **15**. This averages to **119 gdw/m²** (substrate)/summer. **Since** part of the growing season extends beyond the summer period, some fraction of the periphyton growth is missed. If it is assumed that **1/3** of the annual growth **occurs** outside this summer period, the extrapolated growth is **159 gdw/m²** (substrate)/yr. The average zinc content of the PPC is **8.2%** (see FIGURE 4.2-6). Therefore, average amount of zinc removed was **13.0 g Zn/m²** (substrate)/yr.

Based on the data in FIGURE 4.2-12, an average of only **27%** of the zinc removed from the polishing ponds is found in PPCs. Therefore, indirect processes are removing **73%** of the zinc. Regardless, directly and indirectly periphyton are responsible for the removal of about **48 g Zn/m²** (substrate)/yr. Multiplying the result by the relation **3.8 m²** (substrate)/m³ (pond), gives, on average about **183 g Zn/m³** (pond)/yr.

Assuming that we **can** build a holding pond the size of the first meadow, the proposed area of the pond would be approximately **29000 m²**. If this pond can be filled to an average of about **1 m** deep, the volume would be **29000 m³**. Average estimates for the OEP outflow

volumes are around 1000 cubic meters per day. **This** translates into an average residence time of about **30** days. Multiplying the volume of the proposed pond by the surface area required/volume, gives us the surface area required. This is approximately **110,000 m²**.

With a residence time of **30** days and **3-4 m²/m³** (substrate surface area per pond volume), we can reasonably expect to remove about **1.4** tonnes of zinc per year directly into the PPCs and an additional **3.9** tonnes indirectly. The annual zinc loading to the first meadow is about **7.8** tonnes. Since the conservative estimate of zinc removal capabilities by periphyton is about **1.4** tonnes, without further enhancement, about **18.3%** of the **OEP** outflow zinc can be removed directly by periphyton.

4.2.9 Conclusions

From the data collected during the summer the most important aspect was to arrive at an understanding of the capacity of the algae as a polishing agent. Although the processes which are involved in the removal of zinc are complex, as discussed in the previous sections, the fact remains that zinc is removed from the water. Design criteria are shown below for scale-up of the polishing ponds to any size. To do this, numbers are shown on a cubic meter of pond basis. Residence time - **16-80** days (avg. **50** days); Substrate surface area required - **3-4 m²** per m³ (pond); Zinc content of PPC - **8.2%**; PPC accumulate - **119** gdw/m² (substrate)/summer; PPC accumulate directly - **49** g Zn/ m³/yr; PPC directly+indirectly accumulate - **183** Zn/ m³ (pond)/yr. It is concluded that these criteria can be utilized for the entire Buchans area, where biological polishing capacity is needed.

Fig. 4.2-1a Buchans
Pond 1 - 6 Zinc

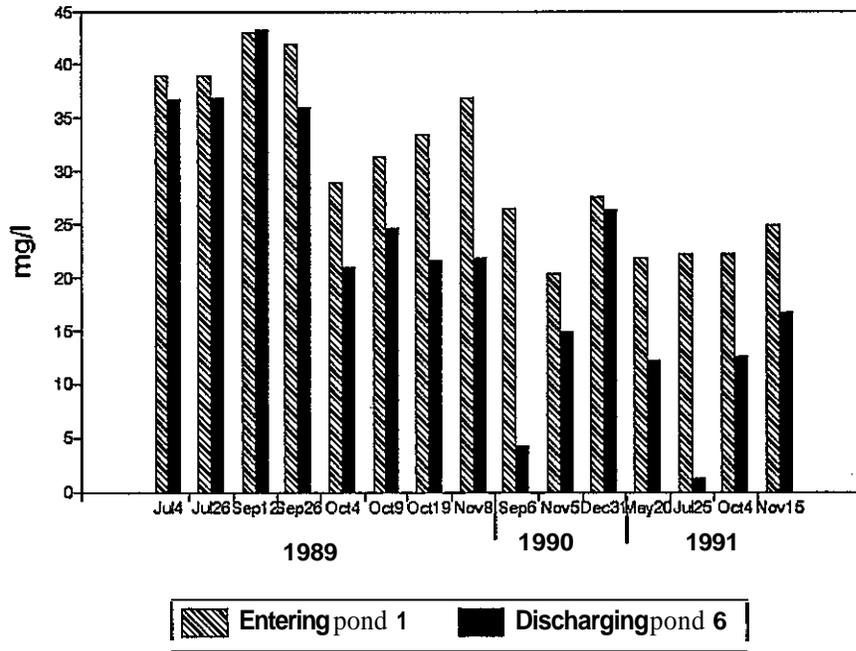


Fig. 4.2-1b Buchans
Pond 1 - 6 Copper

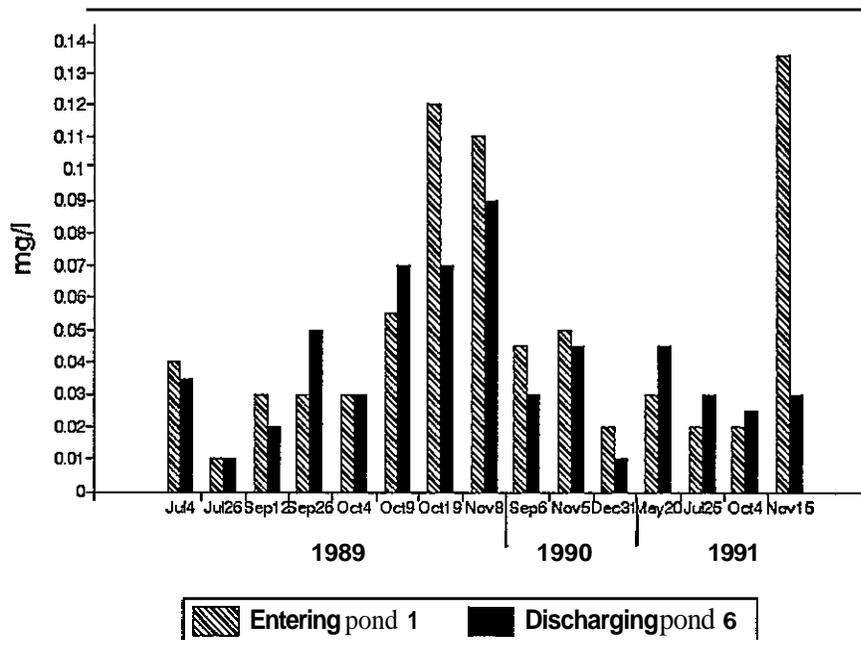


Fig. 4.2-1c Buchans - Periphyton Polishing Ponds Jelly Biomass

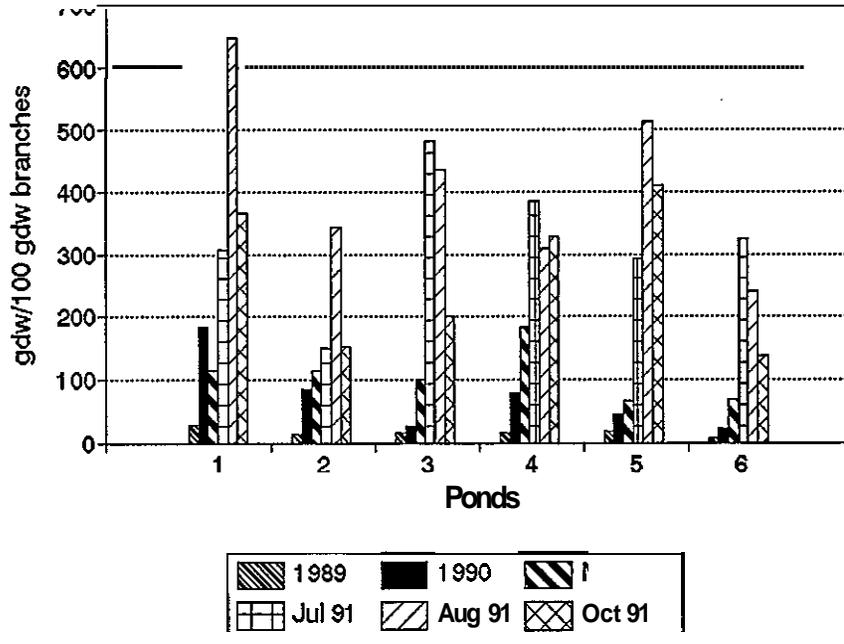
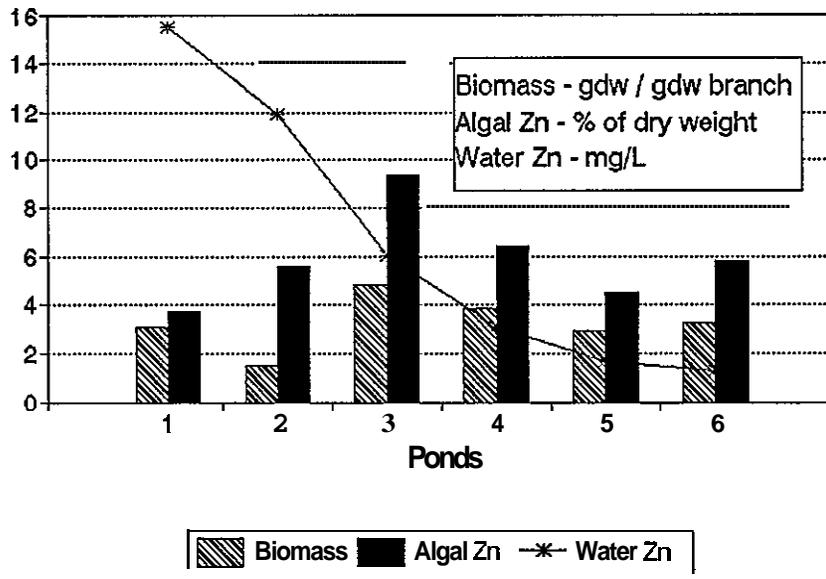
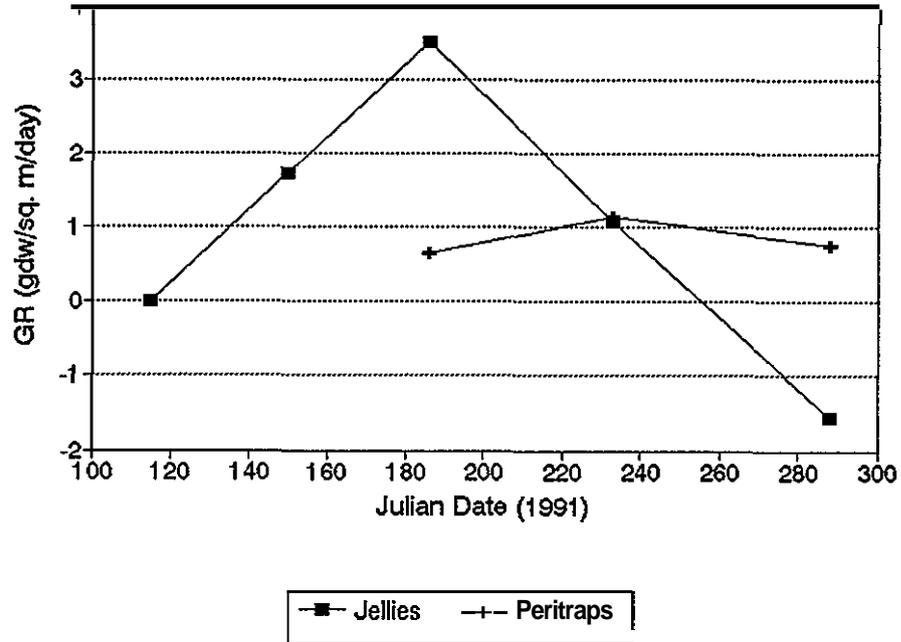


Fig. 4.2-2 Periphyton Biomass and Zinc Buchans - Microspora



**Fig. 4.2-3 Periphyton Growth Rates
Polishing Ponds**



**Fig. 4.2-4 Buchans - PPTE vs LOI
Data from 1991**

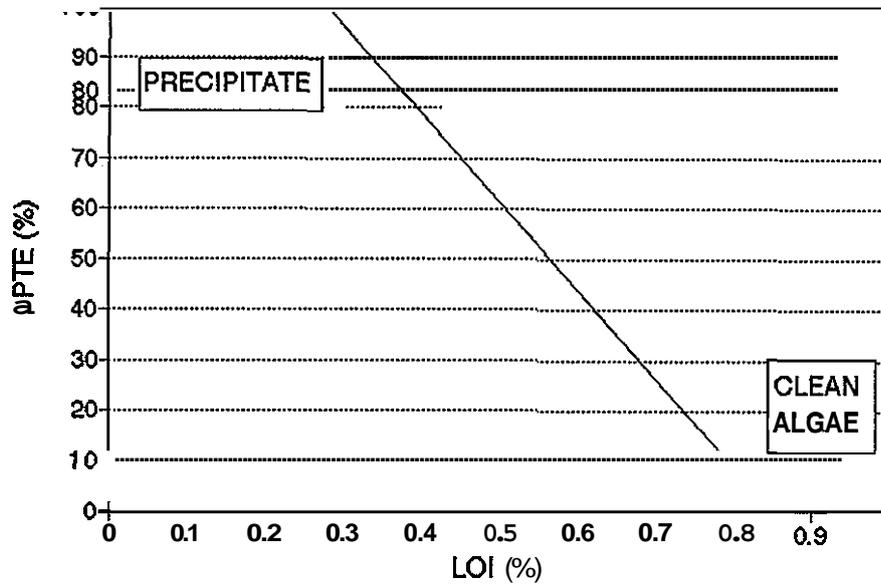


Fig. 4.2-5 Zn Content of Precip/algae
Buchans 1991

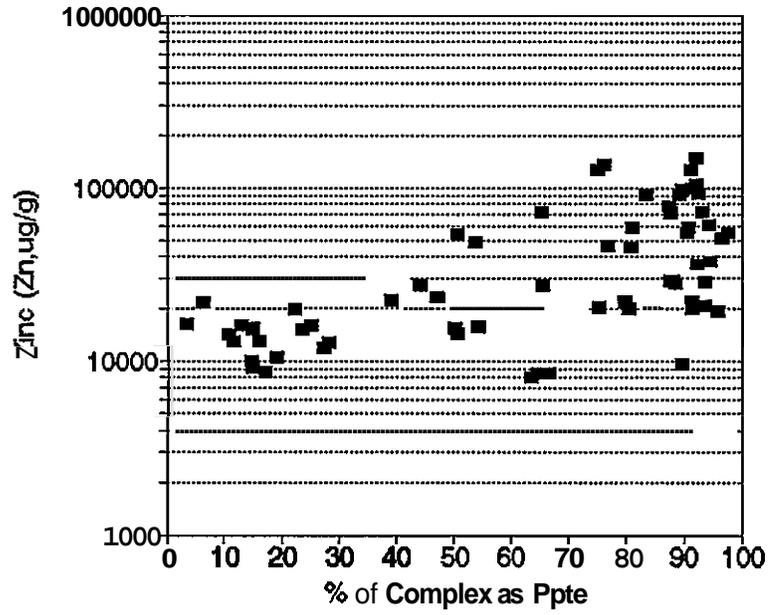


Fig. 4.2-6 Buchans Algal Composition
Zinc

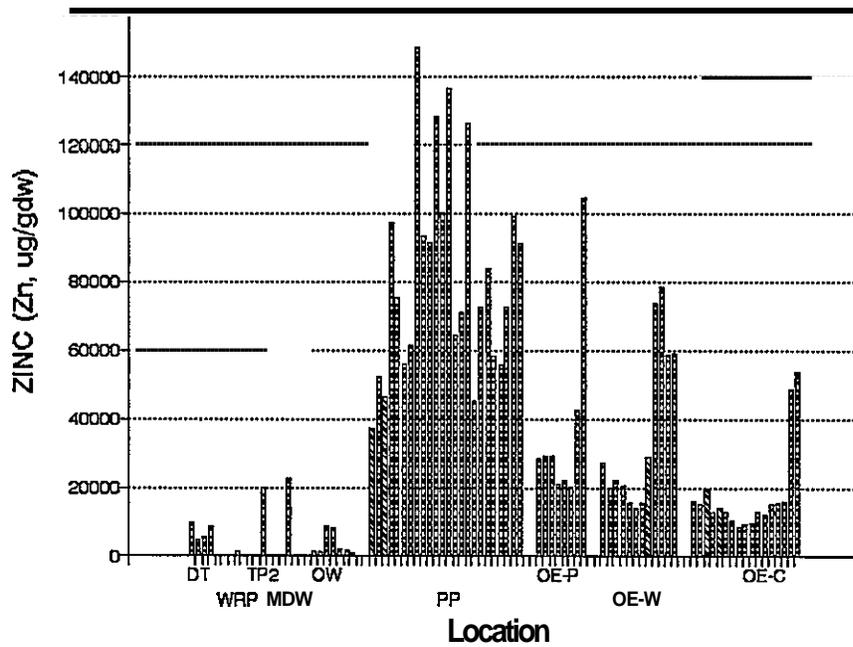


Fig. 4.2-7 Zn uptake experiment
August 1991

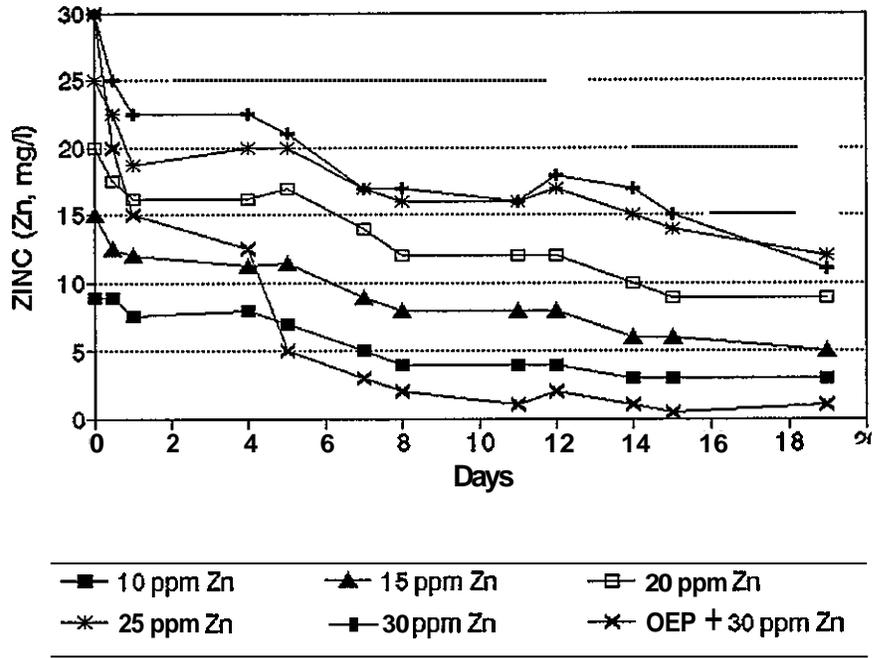


Fig. 4.2-8 Zinc Uptake
Loss from water

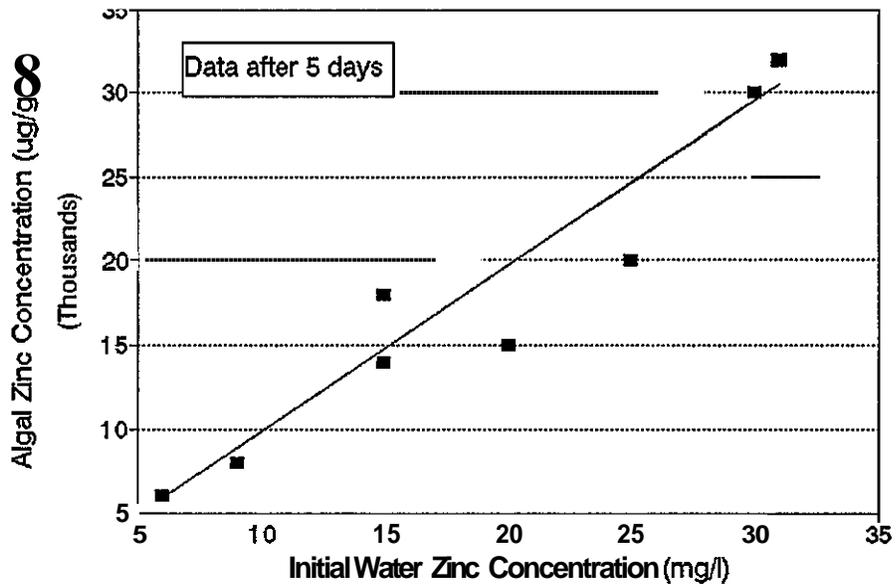


Fig. 4.2-9 Periphyton Growth Rates
Polishing Ponds 1, 3, 6

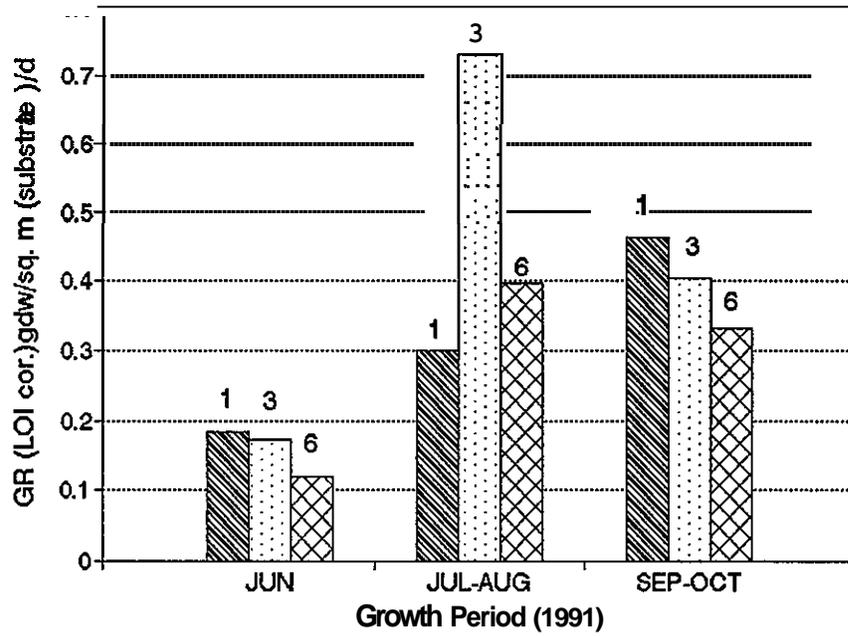


Fig. 4.2-10 Growth Rates - Periphyton
Net Growth - Summer 1991

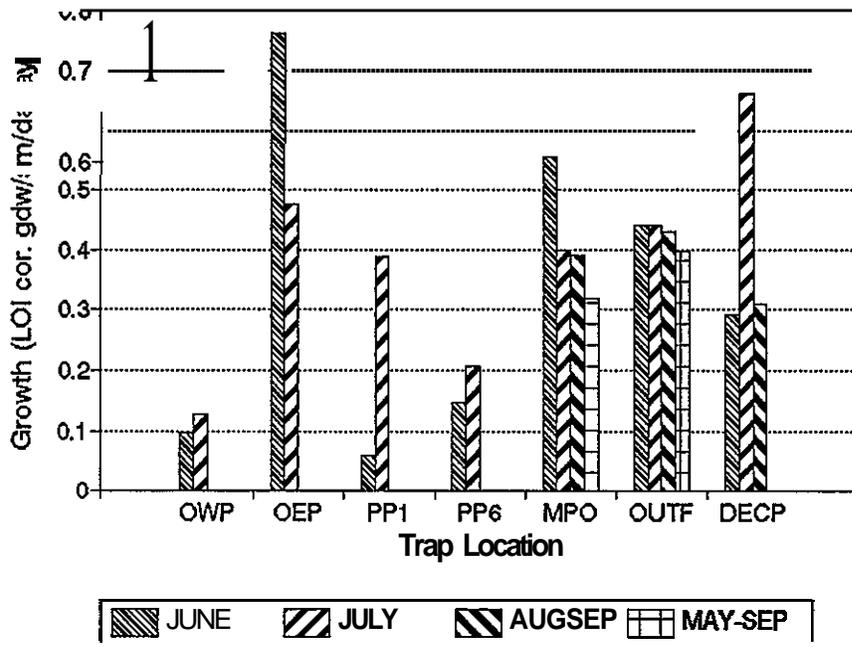


Fig. 4.2-11 Periphyton Growth Rates
Polishing Ponds 1, 3, 6

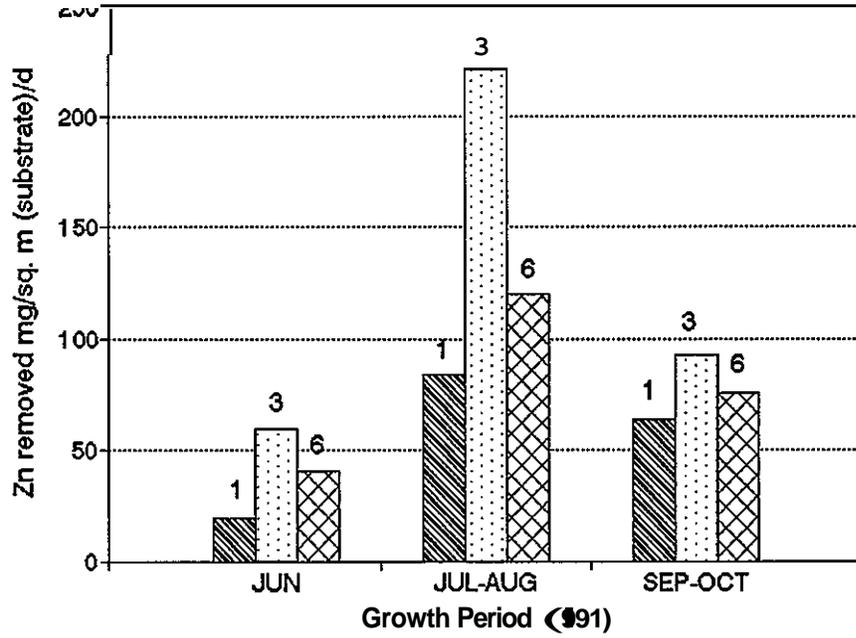


Fig. 4.2-12 Zinc Removal
Loadings vs. Algal Removal

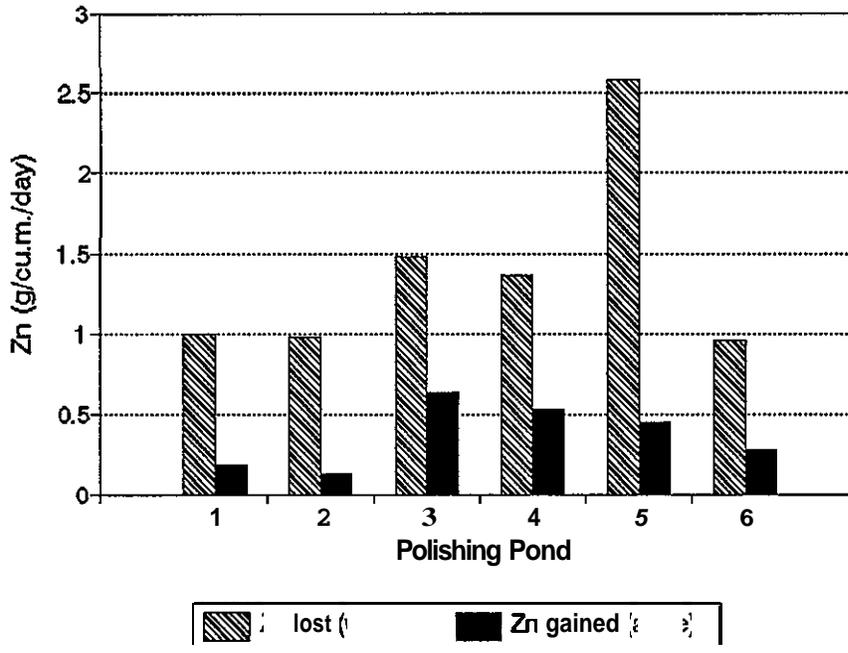
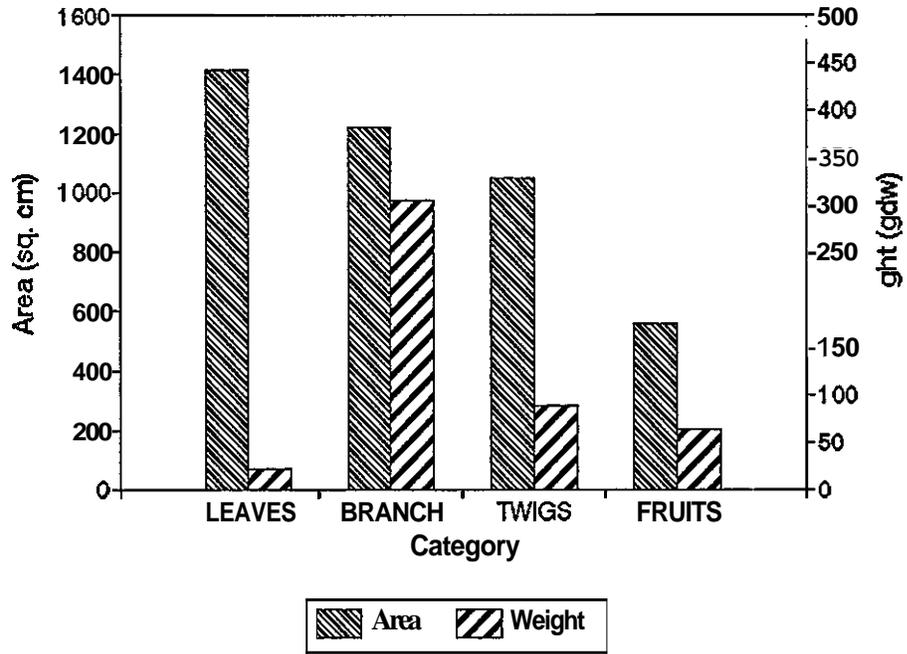


Fig. 4.2-13 Buchans Standard Tree Weights and Areas



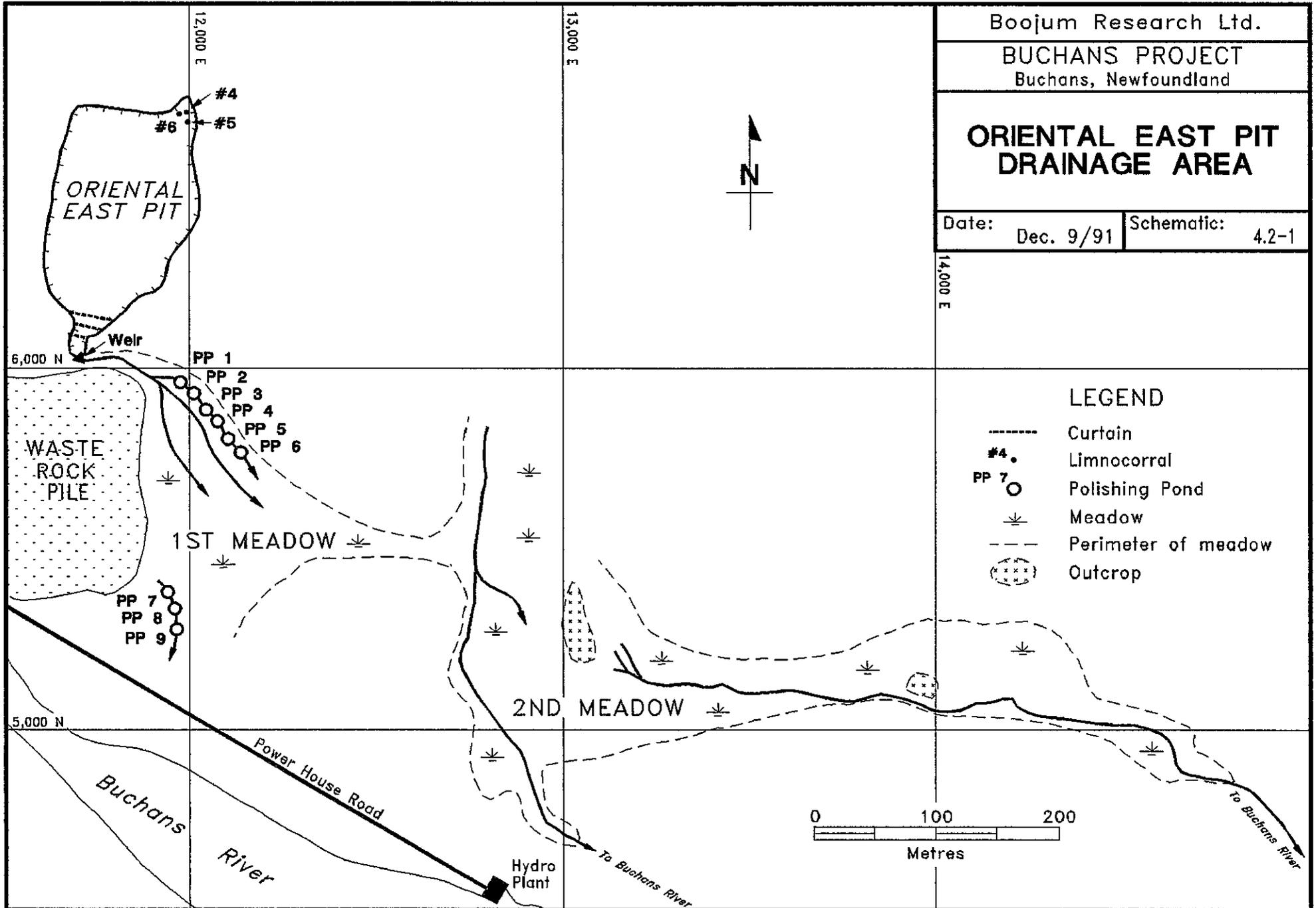
Boojum Research Ltd.

BUCHANS PROJECT

Buchans, Newfoundland

ORIENTAL EAST PIT DRAINAGE AREA

Date: Dec. 9/91 Schematic: 4.2-1



SCHEMATIC OF PERITRAP

Substrates
(enclosed by netting)

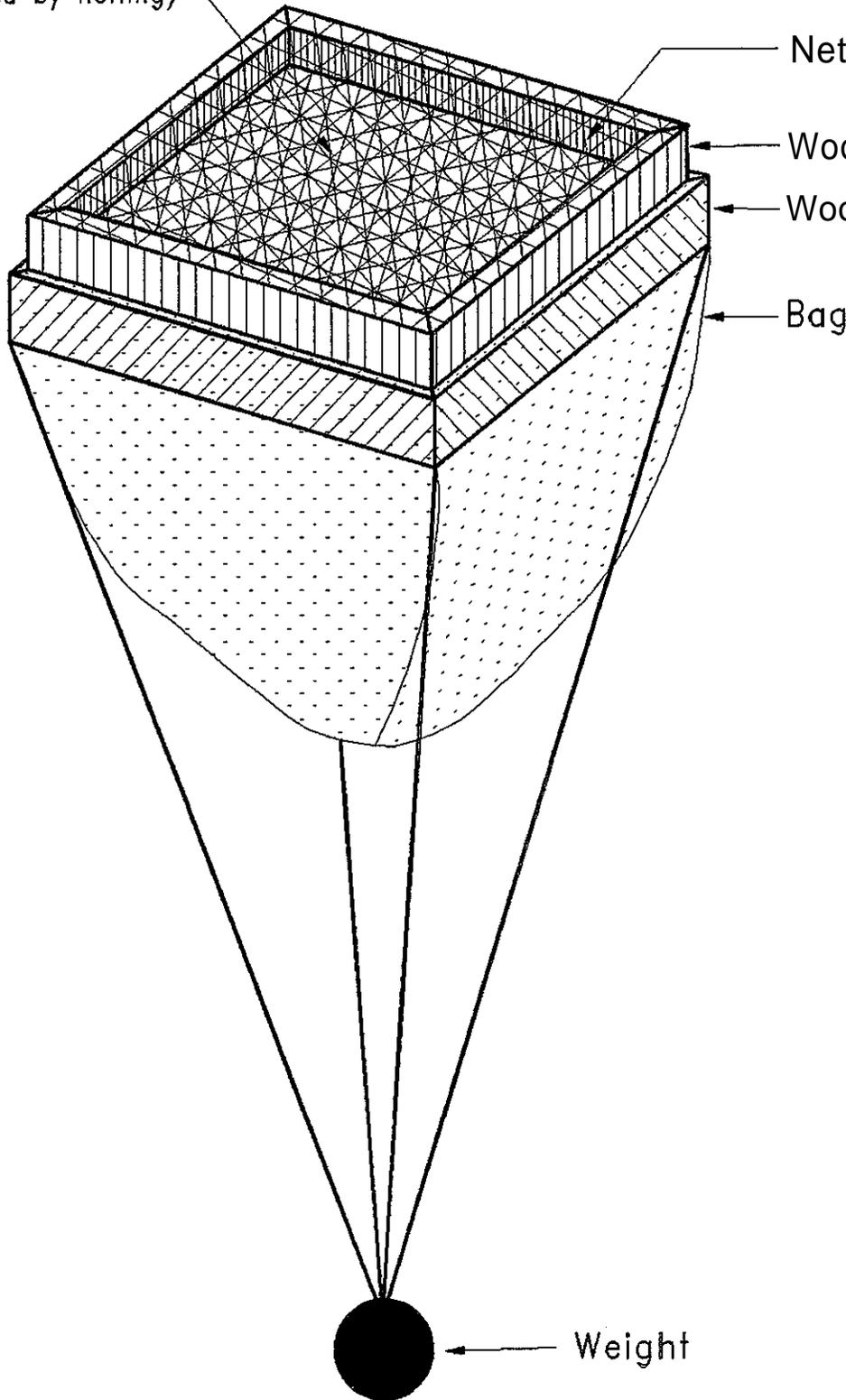
Netting

Wood Frame

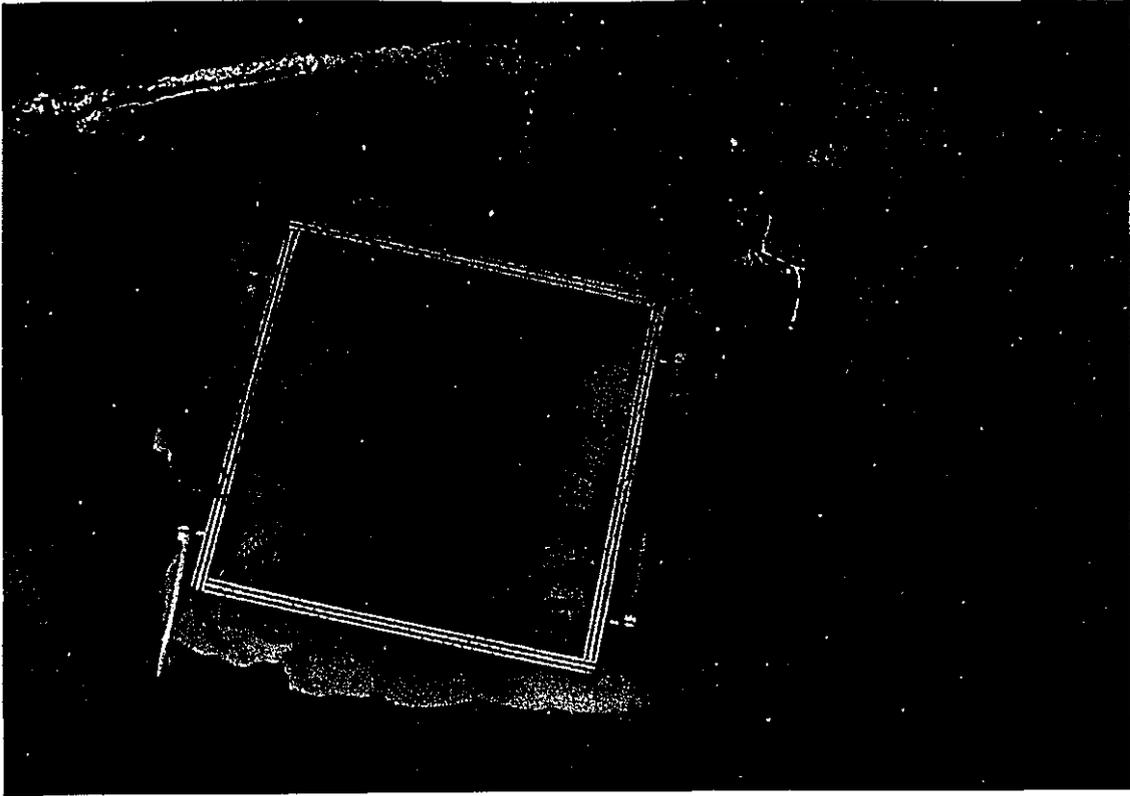
Wood Frame

Bag

Weight

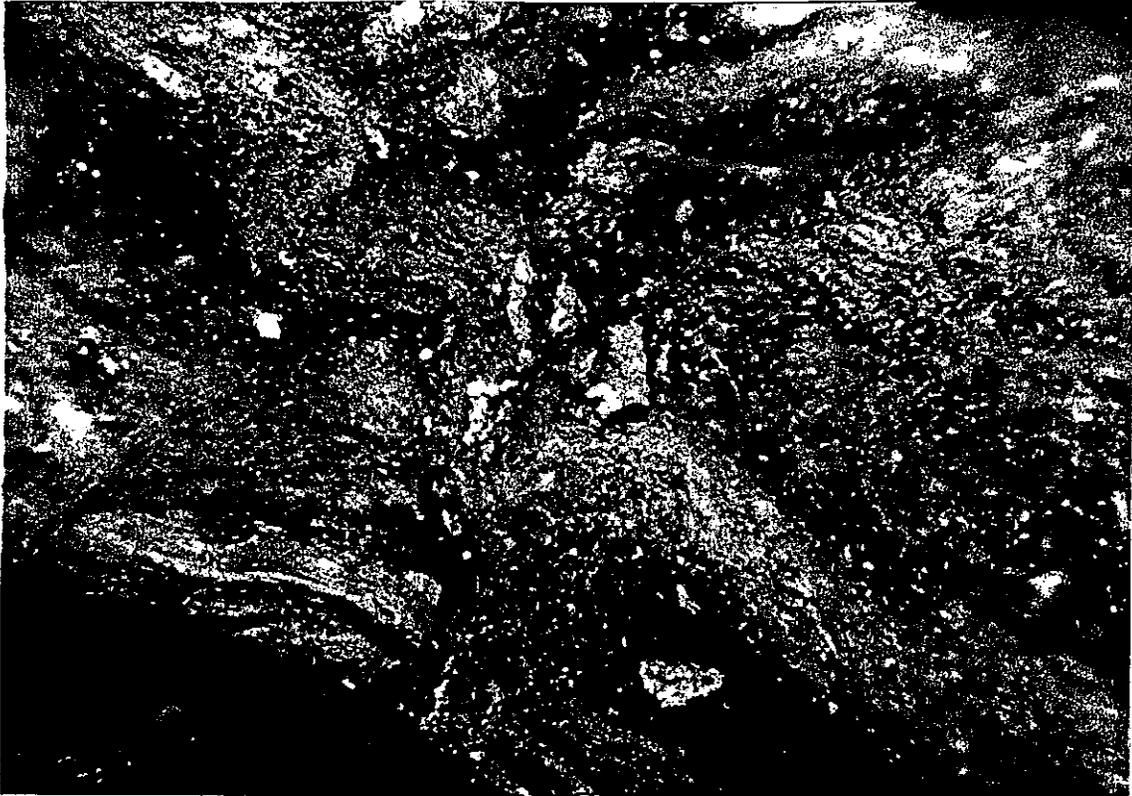


Schematic 4.2-2



4.2-1

Plate 4.1-5: Peritraps (netting and branches for periphyton growth and senescence measurement) in a polishing pond. Sloughed periphyton will fall into bag.



4.2-2

Plate 4.1-6 Microphotograph of OEP periphyton with iron precipitates.

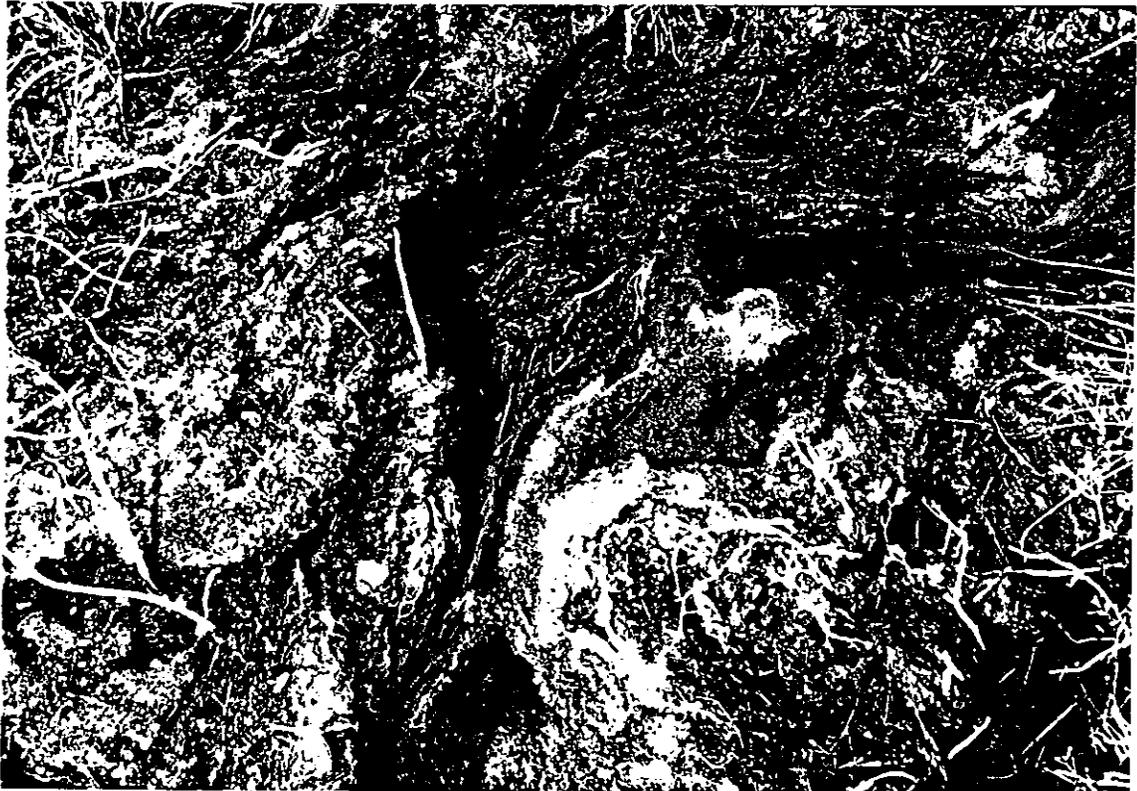


Plate 4.1-7: "Clean" periphyton from seepages in the First Meadow.

4.2-3

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5.0 ECOLOGICAL ENGINEERING CLOSE-OUT CONCLUSIONS

5.1 The Orientals

The work since 1989 has concentrated on developing Ecological Engineering close-out measures for these two water bodies. In Section 4, the details of the work on ARUM - the microbial system which would precipitate ZnS through the production of hydrogen sulphide - have been presented: Section 25 brings together the hydrological and geochemical aspects of the work as they relate to the sources of zinc in the different effluents.

It is evident that zinc sources in the OWP differ from those in the OEP. Geochemical simulations were again used to identify, through water mixtures, the sources of zinc that have produced existing effluent characteristics. Simulation of OEP water as a mixture of pure water (i.e. rain, snowmelt, Sandfill Spring) with OWP water generally resulted in unrealistic mixing ratios. In principle, these findings support the conclusion, drawn earlier, that it is unlikely a large fraction of OWP water contributes to the zinc and copper concentrations in the OEP. This can further be substantiated when the general chemical characteristics of the OEP and the OWP are compared. The available data are separated into two groups - those samples collected from the bottom of each pit and those collected at the surface (Table 5.1-1). Five elements, including iron, aluminium, zinc, sulphur, and silicon, are used for this comparison since they are likely to differ between the two pits due to different dissolution and precipitation processes.

The concentrations of iron in the OWP in both bottom and surface samples ranged from less

than 1 mg/l to 3.6 mg/l. In the OEP, however, bottom water samples displayed increased iron concentrations ranging from 21 mg/l to 88 mg/l. It is clear that the source of iron in the OEP can not be from the OWP, unless the water is redissolving significant levels as it passes through the ground and workings. If OWP water was moving through a zone where pyritic material was dissolved, then one would expect to find an increase in both iron and sulphur, thus reflecting those observed molar ratios. However, from Figure 5.1-1 it can be seen that the iron and sulphur ratios do not support this possibility. The geochemical simulations carried out in Section 2.3.4 suggest that some of the sulphur could have been precipitated as gypsum.

The conclusion, then, that very little water from the OWP contributes to the zinc concentrations in the OEP is strongly supported by evidence from three different approaches to data analysis: (1) long term trends as indicators for sources of Cu and Zn; (2) geochemical mixing of waters to arrive at pit water characteristics; and (3), comparisons of surface and bottom chemistries in both pits. Therefore, it follows that by reducing the zinc concentrations in the OWP, as can be expected to occur due to ARUM introduction, little effect will take place in the OEP. It makes sense, then, to treat the OEP effluent with the use of an enlarged ARUM limnocorral installed in the upper part of the water column. It is expected that such an installation could work at least as effectively as the existing limnocorrals with peat. In the first meadow, a scaled-up version of the biological polishing ponds is envisaged, as per the conceptual outline given in Schematic 5.1-1. Details of the limnocorral ring in the upper portion of the OEP have not been developed.

5.2 Drainage Tunnel and Lucky Strike

When the monitoring data from Lucky Strike and Drainage Tunnel are compared in detail, as discussed in Section 2.3, it is evident that the Lucky Strike and Drainage Tunnel waters have different chemistries.

It was also concluded, and discussed in detail in Section **2.5**, that the Drainage Tunnel effluent is the result of acid mine drainage, probably from either the mineslimes and/or the ore exposed to oxygen above the Drainage Tunnel. Through the analysis of the water levels in the accessible drill holes, it was concluded that the Drainage Tunnel discharge was not "driven" by the water level in Lucky Strike, but due to the generally higher (recharge-driven) water levels **in** the ground overlying and surrounding the Tunnel.

Water level contours around the Drainage Tunnel were developed through ground water flow simulations in the drainage basin of the Tunnel. The climatic (precipitation) records should account for the recharge-driven water levels in the ground overlying the Drainage Tunnel. The required recharge rates represented **50%** of the mine's estimated precipitation/evaporation regime. This, however, is quite unreasonable so it was suspected that flows in the Drainage Tunnel were also influenced by fault zones. Such fault zones have been identified in the conceptual ground water flow field model discussed in detail in Section 2.2.6; the fault zones have an estimated hydraulic conductivity one order of magnitude larger than other hydraulic units potentially present in the basin of the Drainage Tunnel.

Both the geochemical simulations and the conceptual model development had the aim of arriving at some understanding of what the effluent characteristics of the Drainage Tunnel could be at the time the Lucky Strike pit reaches its final water level. The steady state hydrology model was used to predict the filling time to the 900 ft level; Lucky Strike is expected to reach that level in early 2005. However, due to uncertainty associated with some variables used in the input of the model, these predictions are only educated estimates. From the same model, it is predicted that it is possible the Drainage Tunnel discharge will **increase** by about 7 to 10 % (see Section 2.3 for details).

The work on developing a conceptual ground water flow field model for the Lucky Strike and the Orientals (**Section 2.2**) indicates, based on the physical and structural conditions, that extensive hydrological investigations need to be undertaken to increase the certainty of final Drainage Tunnel flows and their characteristics. Similarly, to increase the reliability of the geochemical and hydrological models, extensive monitoring programs are required.

The work carried out to date, however, provides sufficient evidence that major increases in the flows of the Drainage Tunnel are unlikely to occur as the water level rises in Lucky Strike. In addition, the strong evidence that acid generation is taking place (producing existing effluent characteristics of the Tunnel), suggests that raising the water level of Lucky Strike could potentially result in reduced oxygen access to the acid generating material. Therefore, controlled flooding of Lucky Strike should produce hydrological and geochemical conditions that *can* be utilized to complete the decommissioning options for the Drainage Tunnel.

In principle, the decommissioning plans encompass the use of phosphate rock and biological polishing. Some preliminary assessment of the biological conditions has been carried out during **1991**. Drainage Tunnel was visited twice in the summer of **1991**. The first time, in July, water samples and algae were collected for chemical analysis. The general layout of the area was assessed and the data for the August investigations are presented in Schematic **5.2-1**.

In the marshy area near the weir, extensive beds of *Ulothrix* (Chlorophyta) were found primarily in the faster moving stream. In the back water areas, *Agrostis* (Poaceae; grass) and *Scirpus* (Cyperaceae; sedge) dominated the vegetation (see Plate **5.21**). The algae (*Ulothrix*) were collected from the weir area and the area just south of the Buchans River. Samples taken in July contained between **0.46** and **0.96 %** zinc on a dry weight basis. Samples in August contained between **0.51** and **0.86 %** zinc on a dry weight basis. Significant differences in metal content occurred between algae collected at the weir and at the river.

Algal productivity (photosynthesis) was measured over one day in August. The weather was particularly bad (rain) so photosynthetic rates, affected by ambient light levels, were around **0.47 mg/gdw/h**. This rate is definitely low when compared to measurements made in the polishing ponds. Nevertheless, algal growth occurs and those rates which were derived for the polishing ponds will be applicable to the area below the Drainage Tunnel.

Using rhodamine, which stains the water red, the flow path from the Drainage Tunnel weir

was elucidated. The water "fans out" away from the weir, with some portions flowing westward into the marsh taking several minutes to cross. Most of the water, however, moved along the east channel straight to the river within 25 minutes. These observations suggest that the retention time for the effluents from the Drainage Tunnel is extremely low and, thus, does not make biological polishing feasible.

As the raising of the Lucky Stike water level is expected to take place during 1992, the Drainage Tunnel discharge rate may increase, and **new** discharge points may become evident; **an** experimental area is proposed below the Drainage Tunnel where phosphate rock **can** be used in a meander system, **as** outlined in Schematic 5.2-2. Such a meander would provide information on the effectiveness of phosphate rock together with biological polishing.

Alternatives for discharging the Drainage Tunnel water to the Oriental West or East pit have been evaluated. In principle, these alternatives would alter the conditions significantly with respect to these effluents, as discussed in detail in Section 2.3.4. Although a beneficial effect on OWP water **can** be predicted if Drainage Tunnel discharge is mixed with this water, the addition of oxygen, however, is undesirable. The effects on OEP water mixing with Drainage Tunnel effluent would reduce the precipitation, likely affect the thermocline, and generally result in water in which mineral precipitation would be more difficult than is presently the case. Given the higher flow rates which would have to be accommodated in the first meadow by the biological polishing system, this option does not appear attractive.

5.3 Tailings

In 1988, TP-1 and TP-2 were investigated during the initial assessment of all Buchans effluents to determine if Ecological Engineering measures could be utilized as a decommissioning approach for both tailings areas. Data for water leaving the tailings ponds in the drainage basin suggested that a potential source of heavy metals existed below both tailings ponds. Therefore in 1991, the drainage was resampled in more detail by assessing a total of 10 stations (Schematic 5.3-1). Zinc concentrations along this gradient are plotted in Figure 5.3-1; concentrations range from less than 1 mg/l to close to 2 mg/l (range determined by zinc-carbonate dissolution and precipitation). The mixing simulations using samples of TP-1 and TP-2 collected in July 1991 (discussed in Section 2.4), indicate that the waters are undersaturated and could dissolve Smithsonite if present (from previous deposition).

At different times of the season it can be expected that conditions which promote evaporation will exist, followed by rainy periods when flushing occurs. Therefore, it can be expected that when the meadow is flushed, zinc and copper will not be released at the same rate. The adsorption affinities for copper on organic matter are somewhat higher than those for zinc, although they remain dependent on pH and Eh. It is concluded that the copper and zinc sources in the tailings drainage basin are the result of differential precipitation and dissolution rates occurring in the meadow. If loadings from the tailings ponds are reduced, then one could expect a long-term improvement of copper and zinc concentrations in the drainage below the tailings area, as the meadow gets flushed out.

Seasonal fluctuations in zinc concentrations were noted for **TP-2**, based on the monitoring data, with slight increases in zinc at the end of the season. This was suspected to be the result of acid generation in the exposed tailings beaches. A static leach experiment was set up in the laboratory and **run** for 8 months to determine those elements which were likely to be leached from both barite-free and barite-rich tailings. A detailed discussion of the experiments, along with monitoring data from both tailings ponds and the Simms Brook drainage basin has been presented in Section **2.4**. Based on the findings, it was concluded that a more detailed assessment of the tailings pond **2** should be carried out to **confirm** that, indeed, the exposed tailings beaches are the source of zinc.

The static leach experiment indicated that only 5 to 6 % of the metals was solubilized. If some of the beaches have potentially completed the leaching, then it is possible to explain the long-term downward trend noted for zinc and copper in **TP-2** since 1976 (Figure **5.3-2**). In Schematic **5.3-2**, an overview of exposed beaches in **TP-2** is given, with details of sampling locations on beach #1. To determine the acid generating spots, several test pits were dug about **0.5 m** deep and their pH and conductivity measured. For beaches #1 and #2, the conductivities in the test pits were generally low, from **200** to **2400** umhos/cm, whereas in test pit #s 7 to 10 on beach #1, the conductivities ranged from 4400 to 11800 umhos/cm. With the exception of samples from beach #1, zinc concentrations were all around 1 to 2 mg/l in the collected porewater. Dissolved zinc concentrations in porewater from the test pits on beach #1, with the associated high conductivity, ranged from **142** to **2250** mg/l.

The test pits on beach #1 are presented along a cross section of the beach in Schematic **5.3-**

3, with subsurface water levels indicated. Results **from** holes 1 through 6 in Table 5.3-1 show that zinc concentrations are significantly lower at the shoreline, with concentrations of **44 mg/L** to **63 mg/l**, compared with the upper part of the exposed beach. When the test pits were inspected along this gradient, it appeared that dilution was **taking** place, as indicated for pit **#s 11 to 3** on the cross section. Given the relatively **high** hydraulic conductivity of the tailings, estimated at **2.7 to 2.9 x 10⁵ m/s** based on particle size (see Section 2.4), it is evident that the exposed part of the beach is the major supplier of dissolved zinc to the tailings pond water. Due to the fluctuating water table in the tailings pond, iron precipitation generates horizontal strata of hardpan (Plate 5.3-1).

In Table 5.3-2 descriptions of the test pits are given, along with pH, conductivity, and acidity determinations. Again, a distinct gradient is evident **as** one moves from test pit #1 at the beach to the test pits which are farthest away **from** the shoreline. Most distinct is the increase in acidity, though not immediately reflected in the pH value (in test pit #10, for example). Titration curves for some of the porewaters along the transect are given in Figure 5.3-3. Old (aged) and new (fresh) samples differ according to aging time, permitting the oxidation of ferrous iron to ferric **iron** to occur. **As** was discussed in Section 3, this process is accompanied by significant acid production; the acid then continues to leach the tailings. When test pit **#s 1 or 3** are reached, virtually no acidity remains because it is neutralized by either TP-2 water or the residual neutralization capacity of the tailings themselves. **As** expected, the titration of porewater **from** test pit **#s 5 and 6** indicated intermediate acidity.

5.3.1 Proposed Remedial Actions for TP-2

It is clear that the acidity generated in the upper part of beach #1 represents a significant source of zinc. It is therefore proposed that a ditch about 4 feet deep be dug along the contour between tests pit #s 5 and 7 to cover the range of pond level fluctuations. This would facilitate porewater exposure to air and subsequent oxidation. A second ditch below the oxidizing ditch would be filled with phosphate rock to the same depth; this would facilitate neutralization of the acidity and, potentially, the formation of a vertical hardpan to reduce the permeability for contaminated water from the upper portion of the tailings to the tailings beach. A vegetation cover over the upper portion of the tailings would increase transpiration during the ice-free season and reduce infiltration of precipitation.

For the pond at large, it is proposed that consideration be given to biological polishing with algae, utilizing the information available from investigations of the pools below the OEP effluent. This recommendation is based on the investigations of the currents in **TP-2** which suggest very active mixing and potentially good contact of the water with biological polishing substrates.

The open water of Tailings Pond 2 is approximately 1000 m long from west to east and 400 m at its widest. The **maximum** depth of the pond is 6 m, but generally the depth is between 1.5 and 4.5 m. Given its large volume (1,047,720 m³) and an average outflow of 7.63 l/s, the calculated retention time is 4.35 years.

The velocity of wind-driven water circulation in the tailings pond was examined in order to assess the likelihood of short-circuiting the zinc to the decant tower. Measurements of water

velocities near the shoreline were performed using Rhodamine colour tracer on August **21, 1991**, when west wind velocities were between 15 and 25 km per hour. Drogues were used to examine water movement in the middle of the pond when wind velocities, estimated at 20 km per hour, were from the south-west.

Results of these measurements are presented in Schematic **5.3-4**. It can be concluded that the tailings pond surface water generally moves in the direction of the wind, while at those shores perpendicular to the wind direction (north and south), water movement is in the opposite direction to the wind. In addition, at the west end of the tailings pond, water below 30 cm is upwelling in a westward direction from the deeper parts of the pond, replacing surface waters moving eastward.

On average, water velocities were 3.8 meters per minute. If it is assumed that a 300 m wide swath of the upper 0.3 m of the tailings pond is moving at this velocity (August **21, 1991** wind conditions), then 90 m³/min is moving eastward, and another 90 m³/min is moving westward.

At this rate, the tailings pond would completely circulate in 8 days. As this period is much lower than the retention time of the pond according to outflow rates, short-circuiting of water from the beaches to the decant tower is very unlikely.

Taking some of the essential parameters for **TP-2** and those derived from the polishing pools, such as **TP-2** volume = 1.048×10^6 m³, total volume leaving the pond = 755 m³/d with

a residence time of 4.35 yrs, and zinc concentration of algae collected in TP 2 drainage (Ass.# 3404) = 19402 $\mu\text{g/g}$, the following estimates can be made. Artificial peritraps can produce **Periphyton-Precipitate-Complexes** (PPC) at a rate of about 1.0 gdw/m^2 (substrate)/day throughout the summer. Rates are somewhat higher during sunny periods in mid-summer, and somewhat lower during cloudy days or days early and late in summer. If a minimum growth rate of about 1.0 gdw/m^2 (substrate)/day for the months of May through October (180 days) is expected, then we can achieve about 180 gdw/m^2 (substrate)/yr.

From calculations on pond surface area and tree surface area, we know that there is about 3 m^2 of substrate surface area per cubic metre of pond. If these criteria are applied to the tailings pond, then 180 gdw/m^2 (substrate)/yr multiplied by 3 m^2 of surface area per cubic metre of water with an algal zinc concentration of 19.4 mg/gdw , would produce a biological polishing capacity of 11.0 tonnes of zinc removed per year. Annual zinc loading to the **TP-2** outflow is about 0.7 tonnes. Given that the extrapolated zinc removals are over 10times the loadings, we can probably cut down the amount of surface area required.

An experimental area has been installed in 1991 as outlined in Schematic 5.3-4 where the wind-driven currents were presented. Brush has been placed to represent the above stated density per cubic metre of water. Given the results of the 1991 growing season, it can then be determined which size of scale-up is necessary to remove zinc to the desired regulatory limits. A conceptual outline of the scale-up is given in Schematic 5.3-5.

Table 5.1-1

Elements Distribution in Oriental East Pit

Date	Assayer#		Iron (Fe)		Aluminum (Al)		Zinc (Zn)		Sulphur (S)		Silicon (Si)	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
Jul-88	545	544	0.08	58	0.3	0.3	47	61	398	508	5.6	9.4
Dec-88		727				0.09		33		443		6.8
Mar-89	* 924		0.01		0.01		31		380		8.5	
Jun-89	CHEMEX	CHEMEX	0.6	21.8	<0.2	<0.2	>10	>10				
Aug-89		1269		36		0.01		45		875		11
Sep-89	1361		0.01		0.03		37		825		8.3	
Oct-89	1381	1383	2.8		0.3	0.1	37	38	366	386	8.7	9.1
Oct-89	1382		8.7		0.3		36		373		8.7	
Jun-90	1741		0.02		0.08		29		432		5.1	
Jun-90	# 1734		0.02		0.04		27		427		4.6	
Jul-90	1808	@ 1809	6.1	56	<0.01	<0.01	30	40	312	383	6.1	7.3
Jul-90		& 1810		42		<0.01		38		378		7.1
Jul-90	1947	@ 1949	4.4	68	0.03	0.1	30	41	329	400	5.7	7.4
Jul-90	1950	& 1951	0.3	46	0.06	0.1	28	39	339	407	5.1	7.1
May-91	2775	2758	2.2	61.2	0.31	0.05	24	35.1	277	419	7.6	11.8
Aug-91	3243	3244	1	60	8	12	19	30	303	415	7	11
Oct-91	3557	3558	1.5	88.9	9.9	12.4	20	33.2	297	479	6.8	10.8

Elements Distribution in Oriental West Pit

Date	Assayer#		Iron (Fe)		Aluminum (Al)		Zinc (Zn)		Sulphur (S)		Silicon (Si)	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
Jul-88	551	554	1.3	3.6	3.8	4.9	53	75	170	230	6.3	8.3
Jul-88	552	553	1.4	2.7	3.9	4.7	54	70	176	220	6.5	8
Dec-88		726		0.05		<0.01		55		195		7.5
Mar-89	* 925		0.1		3.6		48		169		9.5	
Jun-89	CHEMEX		1.2		4.4		>10					
Aug-89		1268		0.7		4.1		53		291		8.5
Sep-89	1360		1.2		4.7		58		362		8.9	
Jul-90	1968		1.2		3.8		39		120		4.4	
May-91	2748	2749	1.3	2.1	2.44	4.96	23.5	52.3	73.3	146	3.8	7.1
Aug-91	3239	3240	<1	1	7	6	33	33	107	107	7	7
Oct-91	3563	3564	1.5	1.3	7.4	7.2	39	37.3	119	105	6	5.7

* - Precipitation experiment, # - OE Outflow, @ - with precipitation, & - without precipitation

SAMPLE DATE	17-Oct-91	17-Oct-91	17-Oct-91	16-Oct-91	17-Oct-91	17-Oct-91	15-Oct-91	15-Oct-91	15-Oct-91	15-Oct-91	16-Oct-91
SAMPLE VOLUME	100	100	25	100	100	100	100	100	100	100	100
ASSAYERS CODE	3507/3512	3508/3513	3509	3575	3510/3514	3511/3515	3570	3571	3572	3574	3573
SAMPLING LOCATION	BUCHANS Hole# 1 Beach1	BUCHANS Hole# 6 Beach1	BUCHANS Hole# 7 Beach1 Repeat	BUCHANS Hole#7 Beach 1 Original	BUCHANS Hole# 9 Beach 1	BUCHANS Hole# 10 Beach1	BUCHANS TP2 Beach 1 40 cm	BUCHANS TP 2 Beaoh2 40 cm	BUCHANS TP 2 Beach3 40 cm	BUCHANS TP 2 Beach 4 40 cm	BUCHANS TP2 WestDam SEEPAGE Surface Flow

pH	6.45	6.03	5.36	5.2	2.62	5.46	6.86	7.12	7.05	6.4	6.26
Cond. (umhos/cm)	390	2000	3000	11800	7200	4400	200	200	300	2400	1600
Eh (mV)				-36			215	36	16	255	41
mg/l	18	17	14	11.9	1540	26	0.9	1.5	1.3	13.6	6.7
As	< 1	< 1	< 1	0.08	< 1	< 1	< 0.03	< 0.03	< 0.03	< 0.03	0.03
B	1	2	5	1.56	19	35	0.06	0.03	0.02	1.3	0.06
Ba	< 1	< 1	< 1	0.09	< 1	< 1	0.14	0.05	0.55	0.06	0.06
Ca	414	422	357	353	470	480	16.9	35.3	34.9	527	261
cu	< 1	< 1	< 1	< 0.01	156	< 1	< 0.01	0.04	0.03	0.07	0.04
Fe	1	402	3700	4170	13700	6500	< 0.1	0.1	< 0.1	1	16.6
K	6	10	7	24	1	6	< 1	6	2	6	14
Mg	15	1200	1030	1100	1440	1280	1.1	1.2	1	17.2	46.6
Mn	5	15	52	45.4	53	132	0.16	0.22	0.26	7.16	31
Na	12	14	11	12.6	16	13	1.4	1.7	1.7	11.7	9.7
Ni	< 1	< 1	1	1.15	2	2	< 0.01	0.03	c 0.01	0.06	0.02
P	< 1	< 1	1	< 0.1	1	< 1	< 0.1	< 0.1	< 0.1	< 0.1	0.1
Pb	< 1	< 1	< 1	0.36	< 1	c 1	< 0.02	< 0.02	c 0.02	0.31	0.03
S	351	2170	3670	4490	13100	6380	11	16.3	19.7	502	266
Si	4	8	12	10.2	158	17	0.3	0.8	0.7	4.3	5.4
Sr	< 1	1	2	2	< 1	2	0.07	0.27	0.15	0.58	0.26
Zn	44	56	142	162	694	2250	1.95	1.42	1.55	39.2	1.59
Chloride	0.5	3	c 100	< 100	c 100	100					
Acidity, CaCO3 equiv., mg/	100	1250	7500	6500	29500	11500					
Sulphate	920	5700	12600		52600	25200					

Table 5.3-2:
Description of test pits in Tailings Pond-2

Hole No.	Tailings Colour	pH	Cond. (umhos)	Acidity (mg/L CaCO ₃)
1	grey coarse	6.45	390	100
2	grey coarse	6.48	900	
3	grey coarse	6.33	1000	50
4	grey coarse	6.30	1950	
5	red strata, grey coarse	6.02	1600	550
6	grey coarse	6.03	2000	450
7	red strata distribution	5.36	3000	3500
8	red hardpan	dry		
9	yellow, beige strata	2.82	7200	30000
10	grey coarse, red strata	5.48	4400	11000
11	yellow, orange strata, hardpan	2.83	5400	16000
12	grey coarse	6.65	1200	

Fig.5.1-1 Sulphur versus Iron

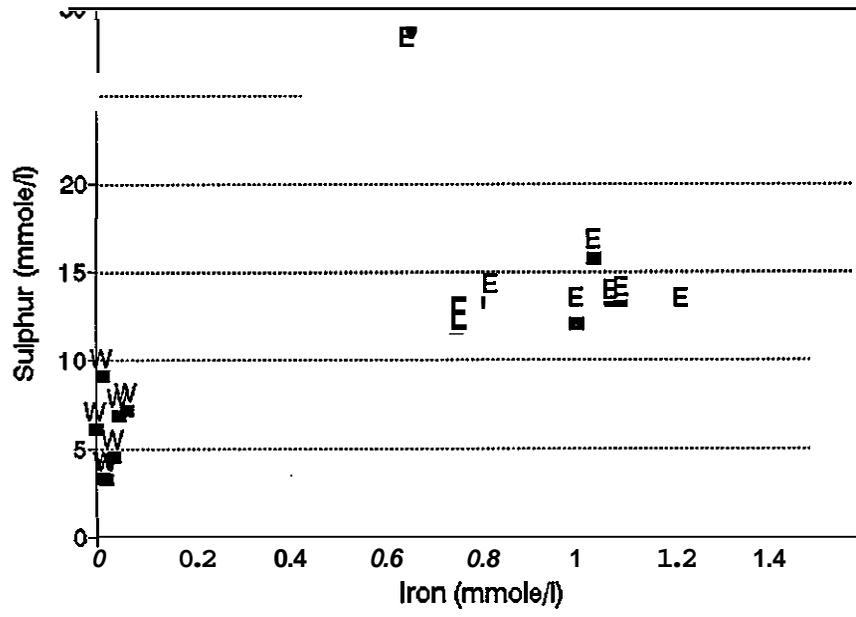


Fig.5.3-1 Dissolved [Zn],TP2 Outflow

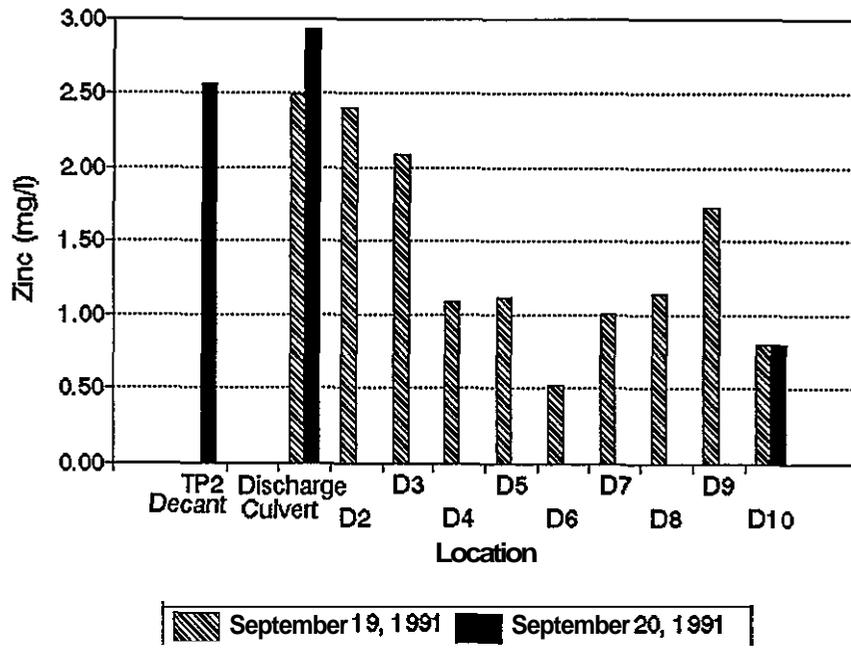


Fig.5.3-2 TP2: Zinc & Copper Annual trends

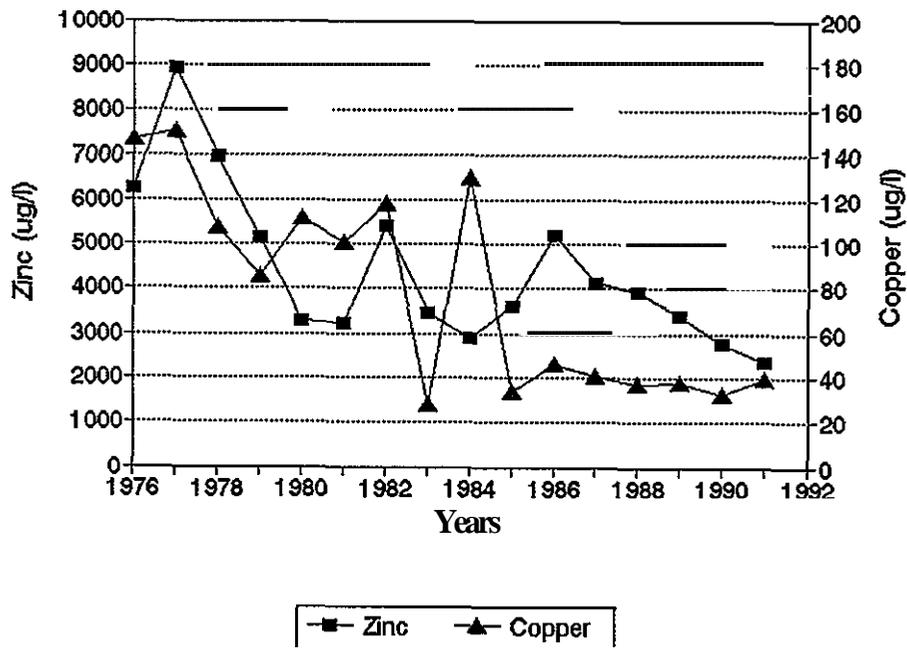
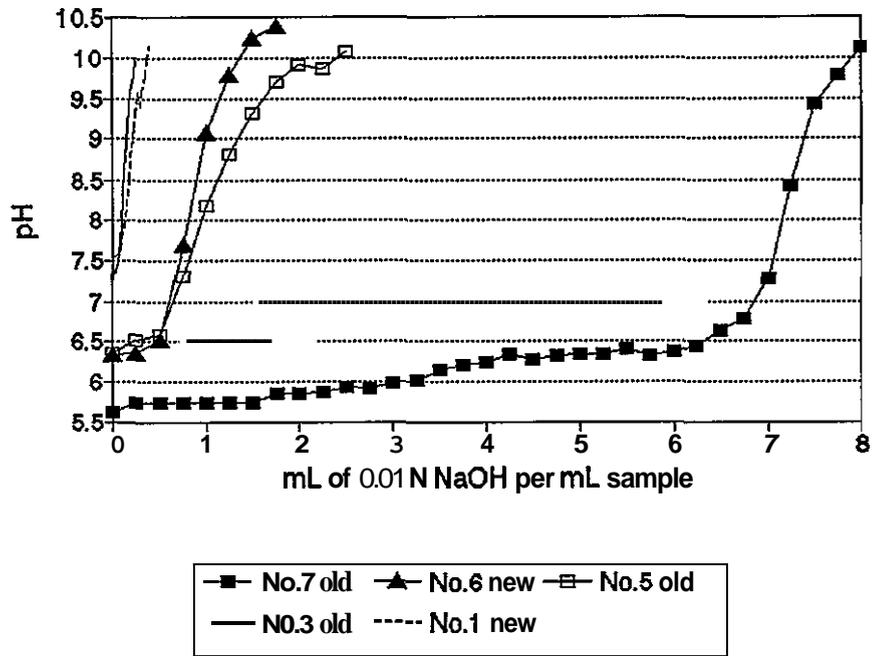
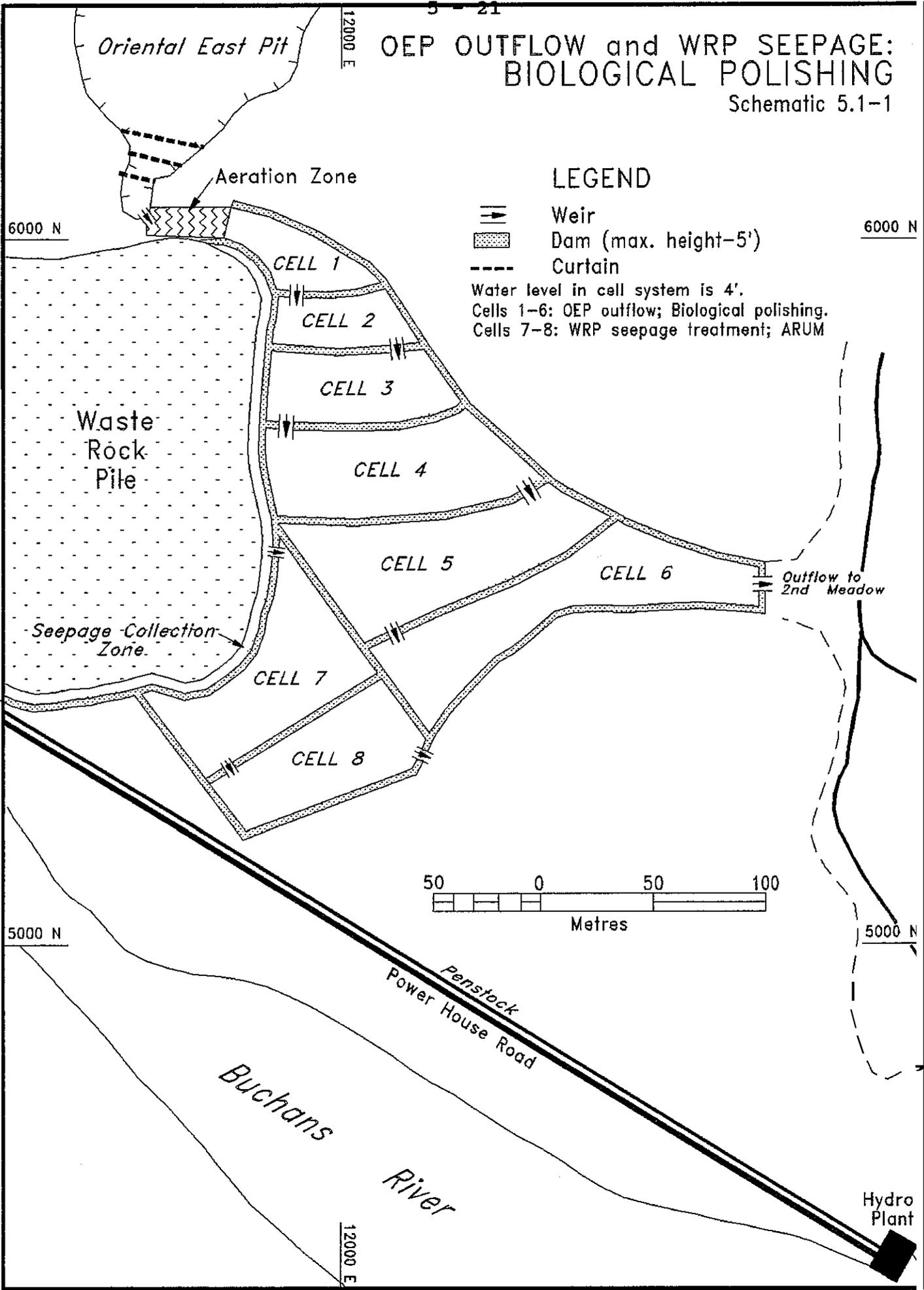


Fig. 5.3-3 TP-2 Test Pits Titration
sampled in October 1991



OEP OUTFLOW and WRP SEEPAGE: BIOLOGICAL POLISHING

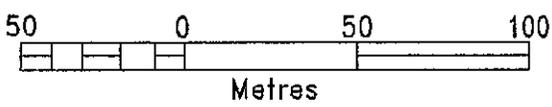
Schematic 5.1-1



LEGEND

-  Weir
-  Dam (max. height-5')
-  Curtain

Water level in cell system is 4'.
 Cells 1-6: OEP outflow; Biological polishing.
 Cells 7-8: WRP seepage treatment; ARUM



6000 N

6000 N

5000 N

5000 N

12000 E

12000 E

Oriental East Pit

Aeration Zone

Waste Rock Pile

Seepage Collection Zone

CELL 1

CELL 2

CELL 3

CELL 4

CELL 5

CELL 6

CELL 7

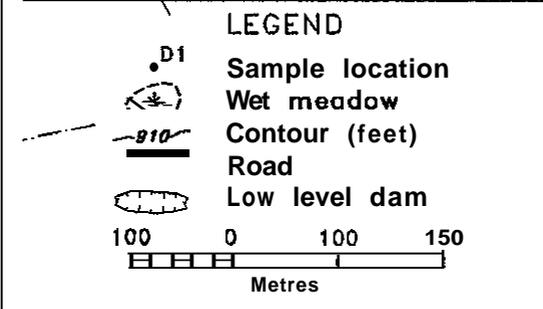
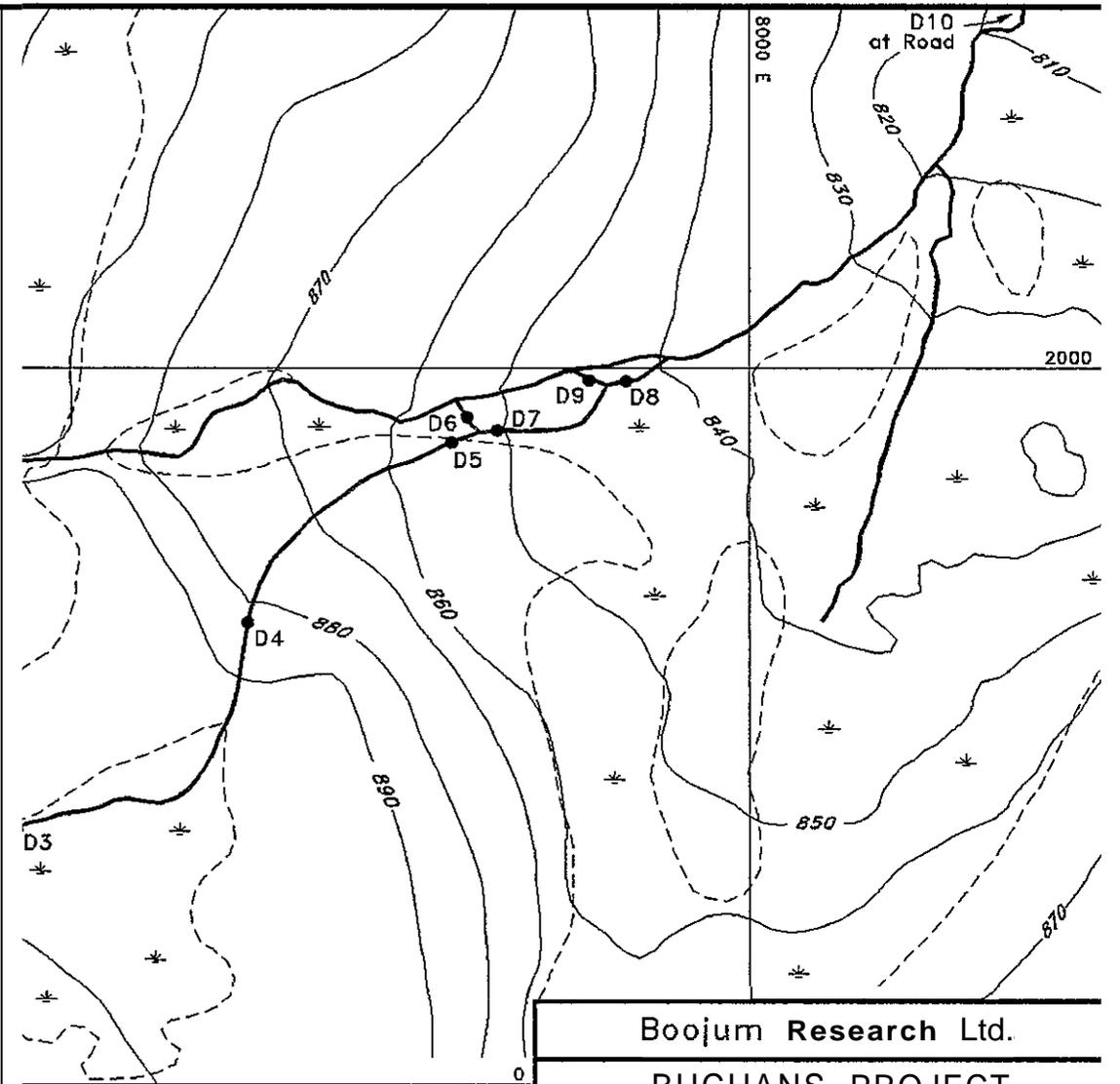
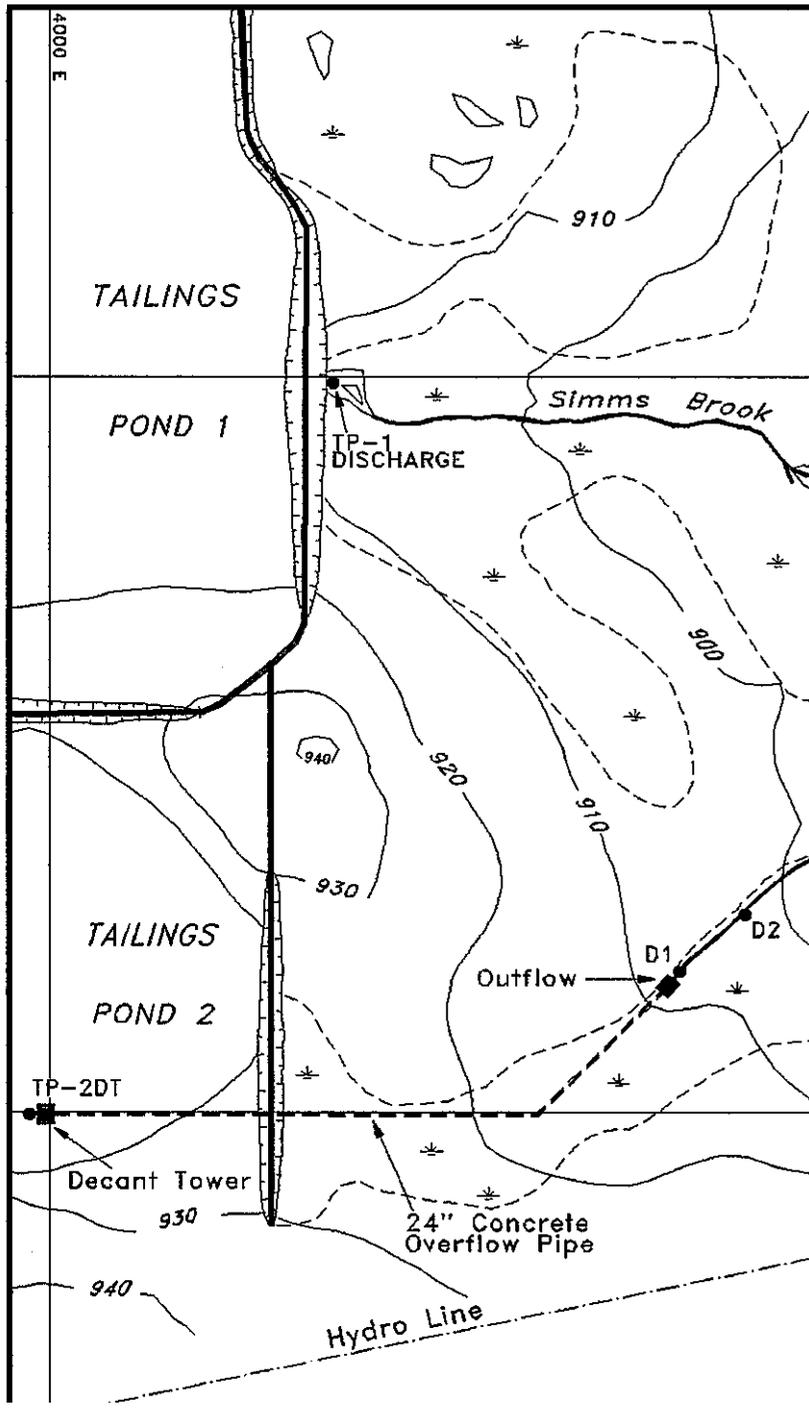
CELL 8

Outflow to 2nd Meadow

Penstock Power House Road

Buchans River

Hydro Plant

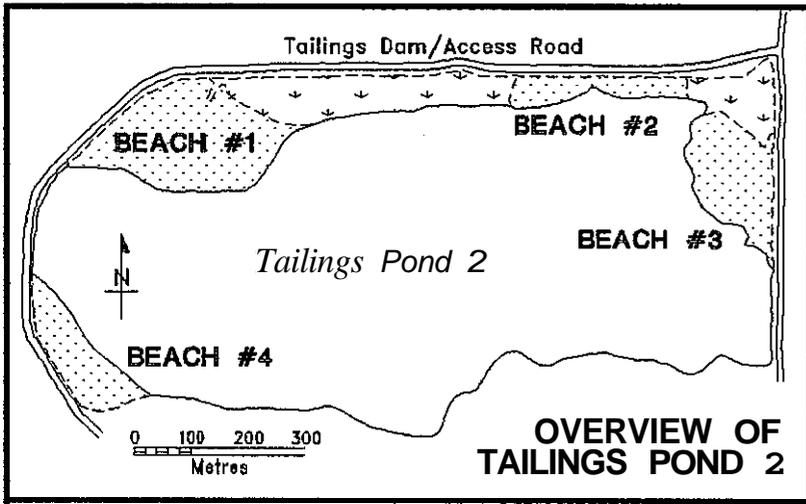


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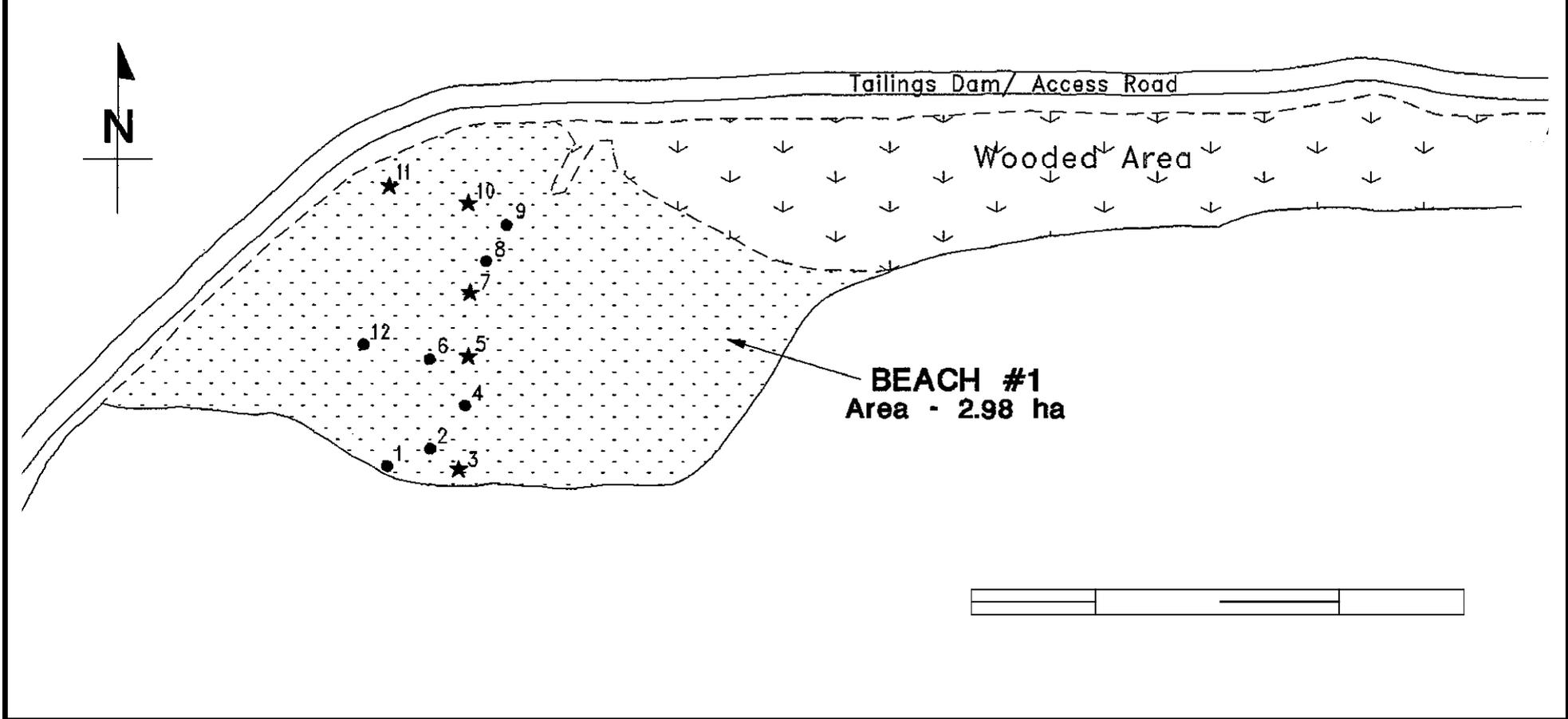
BUCHANS PROJECT
Buchans, Newfoundland

**SAMPLING LOCATIONS
OF TAILINGS PONDS
AND DRAINAGE PATHS**

late: Aug. 19-22/91 Schematic: 5.3-1



Boojum Research Ltd.	
BUCHANS PROJECT	
Buchans, Newfoundland	
TAILINGS POND 2	
BEACH #1	
Date:	Oct./91
Schematic:	5.3-2

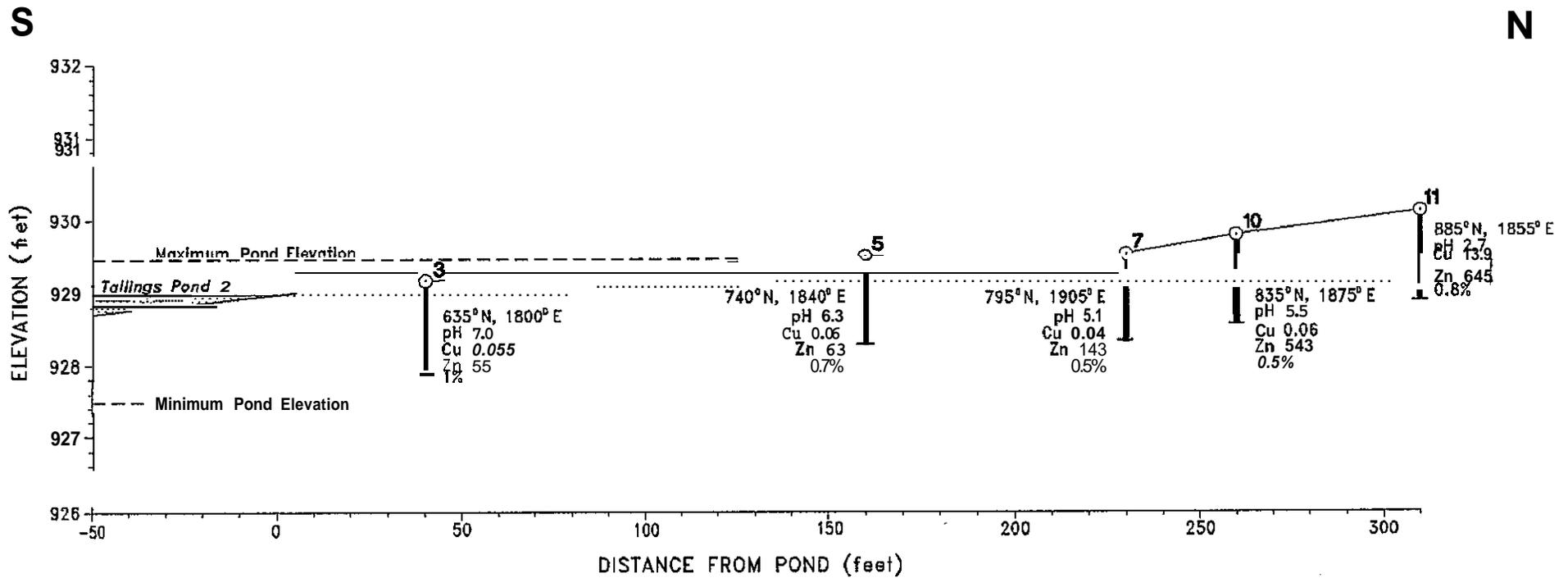


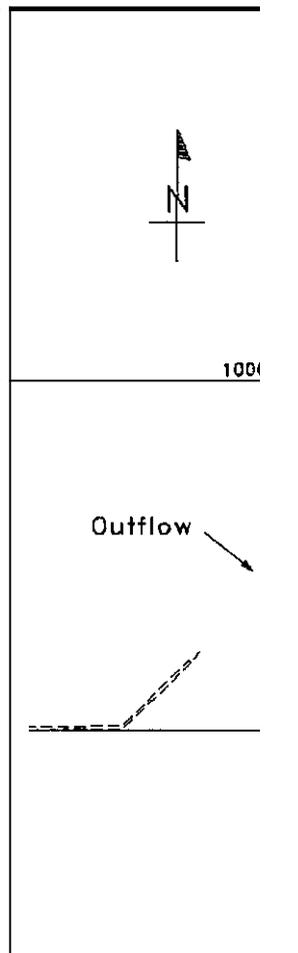
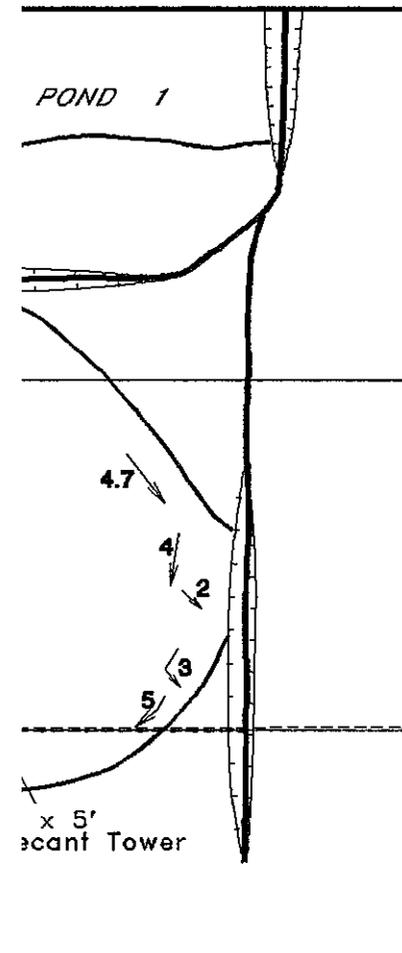
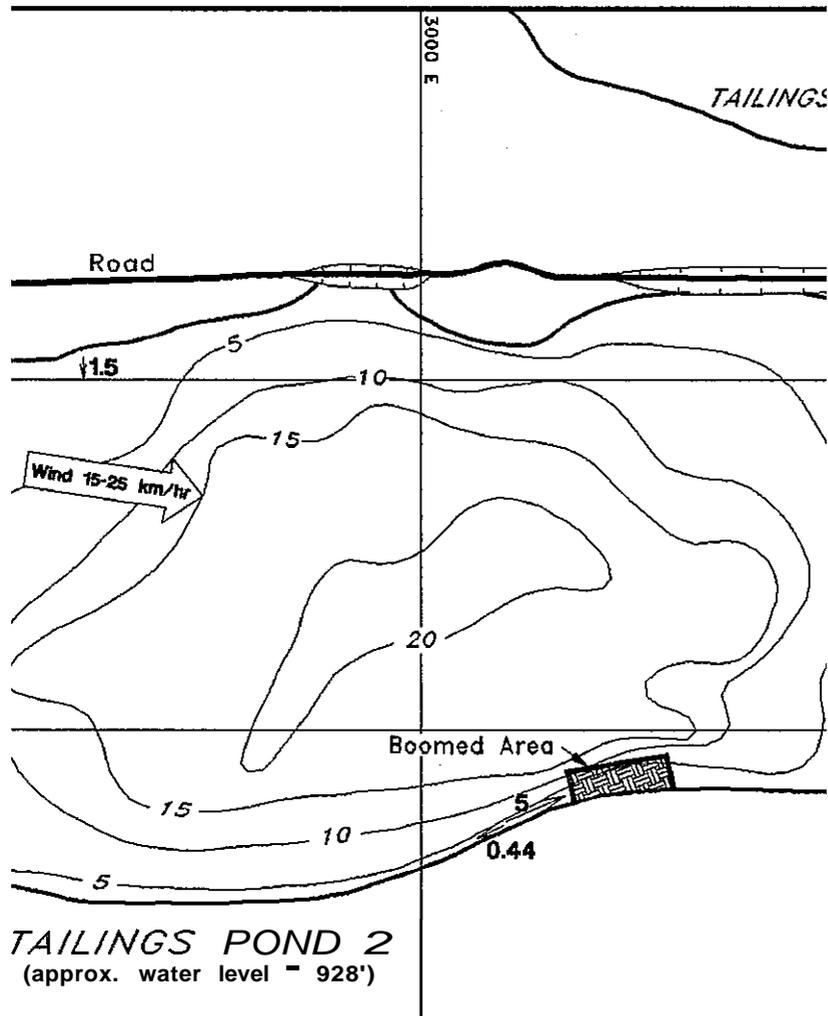
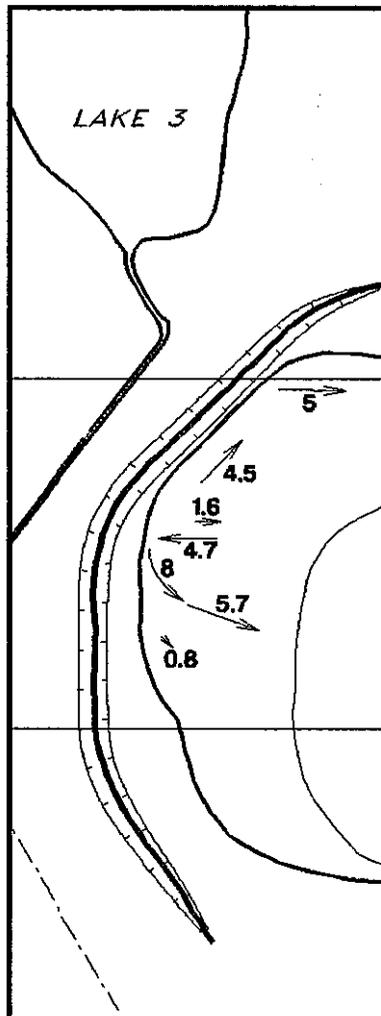
TAILINGS POND 2 CROSS-SECTION OF BEACH #1 SHOWING EXPLORATORY HOLES

October 16, 1991

Schematic 5.3-3

3 ← Hole number
 635°N, 1800°E ← Hole coordinates
 pH 7.0 ← pH
 Cu 0.055 ← Concentration of Cu (ppm)
 Zn 55 ← Concentration of Zn (ppm)
 1% ← Slope to shoreline
 Water table

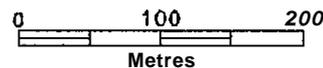




LEGEND

- Water velocity (metres/minute)
- Water direction
- Depth (feet)
- Low level dam
- Concrete overflow pipe

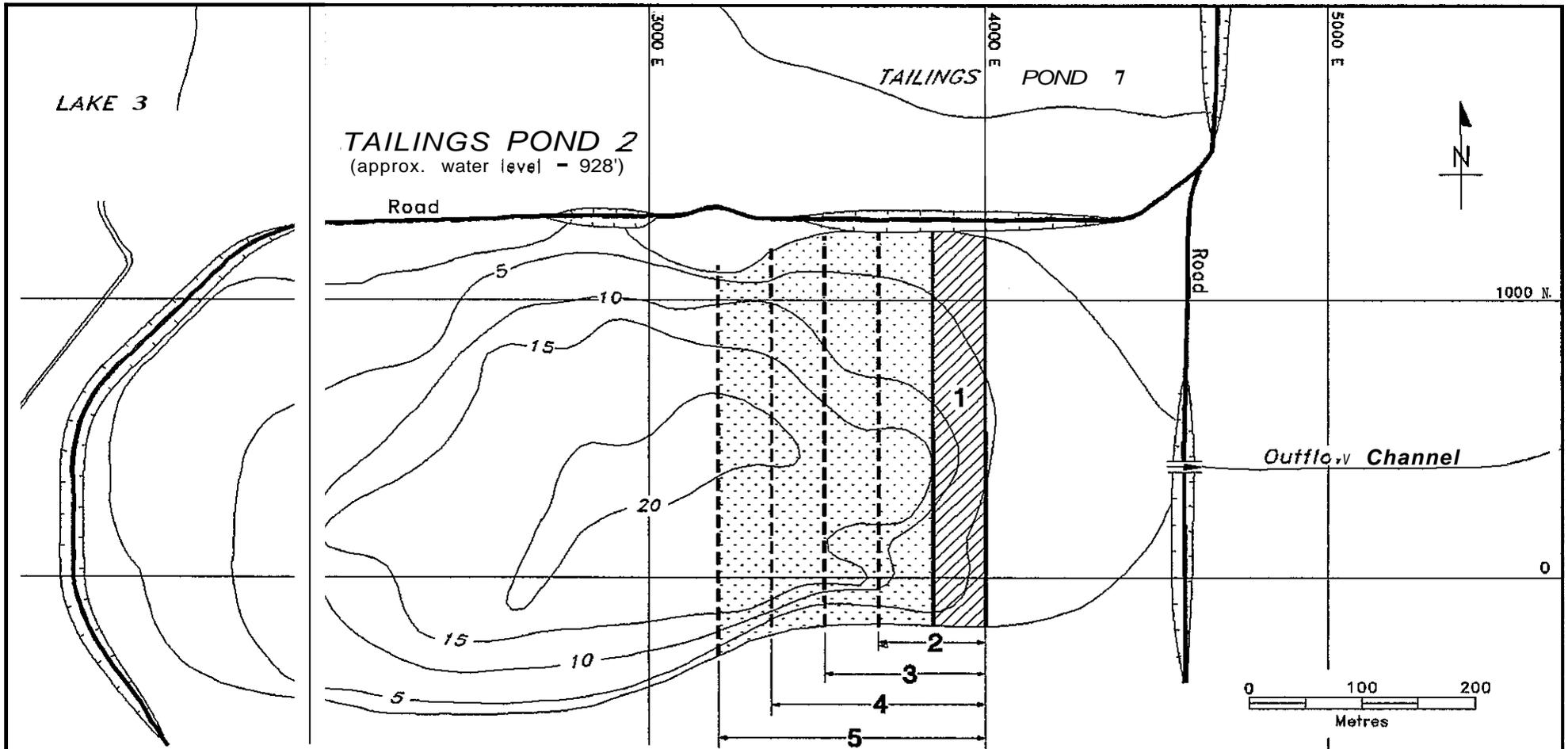
NOTE: Average water velocity - 3.8 m/min.
n = 15



Boojum Research Ltd.
BUCHANS PROJECT
 Buchans, Newfoundland

TAILINGS POND 2
WIND DRIVEN SURFACE
WATER

Date: Aug. 21/91 Schematic: 5.3.



ANNUAL OUTFLOW OF ZINC - 700 kg.

-  Volume of water needed to remove 100% of Zn using biological polishing - $6.6 \times 10^4 \text{ m}^3$
-  Volume of water needed to remove 200% of Zn using biological polishing - $13 \times 10^4 \text{ m}^3$
-  Volume of water needed to remove 300% of Zn using biological polishing - $20 \times 10^4 \text{ m}^3$
-  Volume of water needed to remove 400% of Zn using biological polishing - $27 \times 10^4 \text{ m}^3$
-  Volume of water needed to remove 500% of Zn using biological polishing - $33 \times 10^4 \text{ m}^3$

-  Outflow: flume
-  Depth (feet)
-  Low level dam

Boojum Research Ltd.
 BUCHANS PROJECT
 Buchans, Newfoundland

**TAILINGS POND 2
 POND VOLUMES
 REQUIRED FOR
 BIOLOGICAL POLISHING**

Date: Dec./91 Schematic: 5.3-5



Plate 5.2-1

Outflow zone of the Drainage Tunnel. A wide angle photograph shot from the weir looking out over the marshy area to the west. Buchans River at the top right.



ii: **Plate 5.3-1** Tailings Pond 2 Beach 1. Hole shows oxidation of subsurface tailings.