ECOLOGICAL ENGINEERING

TESTS OF CONCEPTS AND ASSUMPTIONS ON LEVACK

proposed by

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for discussion with INCO Ltd

on May 10, **1985**

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CONCEPTS OF ECOLOGICAL ENGINEERING

One of the well-known methods for reclaiming tailings is to establish a layer of vegetation. The presence of a vegetation cover provides surface stablilization and prevents wind dispersal of tailings. The stability of introduced covers in the absence of continued maintenance over the long-term, and the effectiveness of this cover in preventing acid generation, are presently unknown.

Waste sites can be considered habitats with extreme environmental conditions which limit the number of species present and give rise to the barren appearance commonly reported in both aquatic and terrestrial areas of tailings sites.

The conventional method in terrestrial reclamation involves the the use of agricultural crop plants, but the ground preparation (neutralization and fertilization) involved and the subsequent maintenance, are prohibitivly expensive and do not offer long-term, cost effective solutions to acid generation from waste materials.

The proposed approach, i.e. ecological engineering, involves the development of economical methods which result in a self-maintaining long-term and stable vegetation cover, that will reduce infiltration of air and water to the tailings, and hence, may curtail acid generation. Ecological engineering is based on the observation that certain plants invade and grow in terrestrial (dry) and aquatic (submerged) areas of tailings sites, if given sufficient time and the appropriate conditions.

To assist these plants which are tolerant to the extreme conditions of the tailings, to colonize and expand, a methodology has to be developed which would potentially lead to cost-effective, stable and self-supporting vegetation covers on acid-generating tailings areas.

Organisms which are present on these wastes, are frequently abundant and have developed protective mechanisms to tolerate the adverse conditions. Their presence, therefore, can potentially play a role in improving the conditions present, and ultimately assist in the recovery of these disturbed areas. It is the basic aim of ecological engineering to encourage such vegetation to "reclaim naturally" their own harsh environment.

2. RELEVANCE OF THE INCO-LEVACK STUDY TO THE RATS PROGRAM

The Reactive Acid Tailings Study (RATS) Program has formulated five major objectives outlined below (under sections 2.1. through 2.5.). The studies proposed by INCO, to be carried out on the Levack site contribute to these objectives in the following aspects.

2.1. Objective - Technology Transfer:

To ensure that information concerning well-established technologies are available to the mining industry (e.g. revegetation, current tailings disposal and effluent control practices).

NO CONTRIBUTION BY INCO-LEVACK STUDY

We attempt instead to develop novel methodologies to establish indigenous vegetation covers on tailings which may reduce acid-generation and are self-maintaining.

2.2. Objective - Prediction Techniques:

To develop those techniques related to the physical and chemical behaviour of tailings.

CONTRIBUTION FROM THE INCO-LEVACK STUDY

We will monitor the physical and chemical properties of indigenous vegetation covers on tailings, quantify the response during precipitation events (hydrology plots) and simulate acid generation-oxygen penetration (static and accelerated lysimeters). Those measurements can be used as input parameters to models used in predicting the physical and chemical behaviour the waste site. Lysimetry will be used in conjuction with basic modeling to predict changes in the long-term, anticipated as a result of the covers developed.

Changes in the physical/chemical properties of tailings with and without vegetation cover can be predicted based on the input parameters.

2.3. Objective - Tailings Disposal Svstems:

To develop more effective methods fur the disposal of tailings.

CONTRIBUTION OF THE INCO-LEVACK STUDY

We will evaluate the physical and chemical properties of the indigenous vegetation covers which have developed on different acid- generating tailings areas, for example at Quirke, Stanleigh - Milliken, Nickel Rim, Nordic, Stanrock, Fecunis and Falconbrige, in order to determine which of the indigenous vegetation covers could be used most effectively on different tailings disposal areas. This will yield information about the effectiveness of the indigenous vegetation covers on different types of acid- generating tailings; this information can then be related to data from areas with introduced vegetation covers as well as to information on various other tailings characteristics.

2.4. Objective - Effluent Control:

To develop methods to inhibit and control the generation of acidity.

CONTRIBUTION OF THE INCO-LEVACK STUDY

We will monitor the effectiveness of the polishing capacity of green filamentous algae on seepages from acid-generating tailings, and determine the effects of separating the acid-generating tailings from oxygen-rich environments with layers of organic matter produced by building an acidic bog or an alkaline wetland. We will also assess the effects of Chara in the ,polishing pond.

2.5. Objective - Revegetation:

To assess the specific benefits and effects of revegetation as an inhibitor of acid generation.

CONTRIBUTION OF THE INCO-LEVACK STUDY

We will attempt to demonstrate the establishment of long-term, maintenance-free vegetation which may reduce oxygen penetration to the tailings. We will develop methodologies which can be used to evaluate the effectiveness of different vegetation covers in preventing oxygen transfer to the tailings i.e. acid generation.

3. PROPOSAL FOR INCO-LEVACK STUDY: A TEST OF THE CONCEPS OF ECOLOGICAL ENGINEERING

INCO contracted Boojum Research Ltd. to assess this taiings site near Sudbury, and to evaluate:

a) the possibility of using the "Chara process" in the mine-water pond to control occasional pulses of acid influxes from the exposed pyrrhotite surface during precipitation events. Chara was tested in bench scale experiments and found to survive and grow in Levack waters;

b) the occurrence of indigenous biota which would indicate that a "potential" exists to encourage these biota as per the concepts of ecological engineering.

The overall concept of the proposed research program has been described in a report submitted to the Department of Energy Mines and Resources, CANMET prepared by Boojum Research Ltd. entitled:

"Close-out Scenarios for Reactive Acid Tailings: a Pilot Demonstration of Ecological Engineering Measures".

This survey lead to the conclusion that several experimental areas are evident at Levack which could be used in further testing of ecological engineering concepts:

1. the small acidic creek on the north end of the tailings could be used to test colonization by filamentous green algae, which were found earlier in an acidic seepage stream;

2. the acidic gravel pit might be converted into an acid bog, with the introduction of an acid-tolerant aquatic moss;

3. the dry acid areas might be "test-colonized" by an acid-tolerant terrestrial moss serving as a cover; different materials will be mixed with broken pyrrotite and then "seeded" with mosses;

4. the areas along the alkaline mine-water creek could be used to test the survival, propagation and expansion of indigenous mosses from neutralized tailings areas as well as those which have been found on-site, in cracks on the tailings surface;

5. the mine-water pond could serve as a test area for the introduction of Chara and other suitable flora from the Conservation Area (Falconbridge).

Laboratory work was carried out and the results suggested that:

1. the organisms are indeed indigenous biota present in acidic and alkaline habitats, but they are not unique to the Levack site;

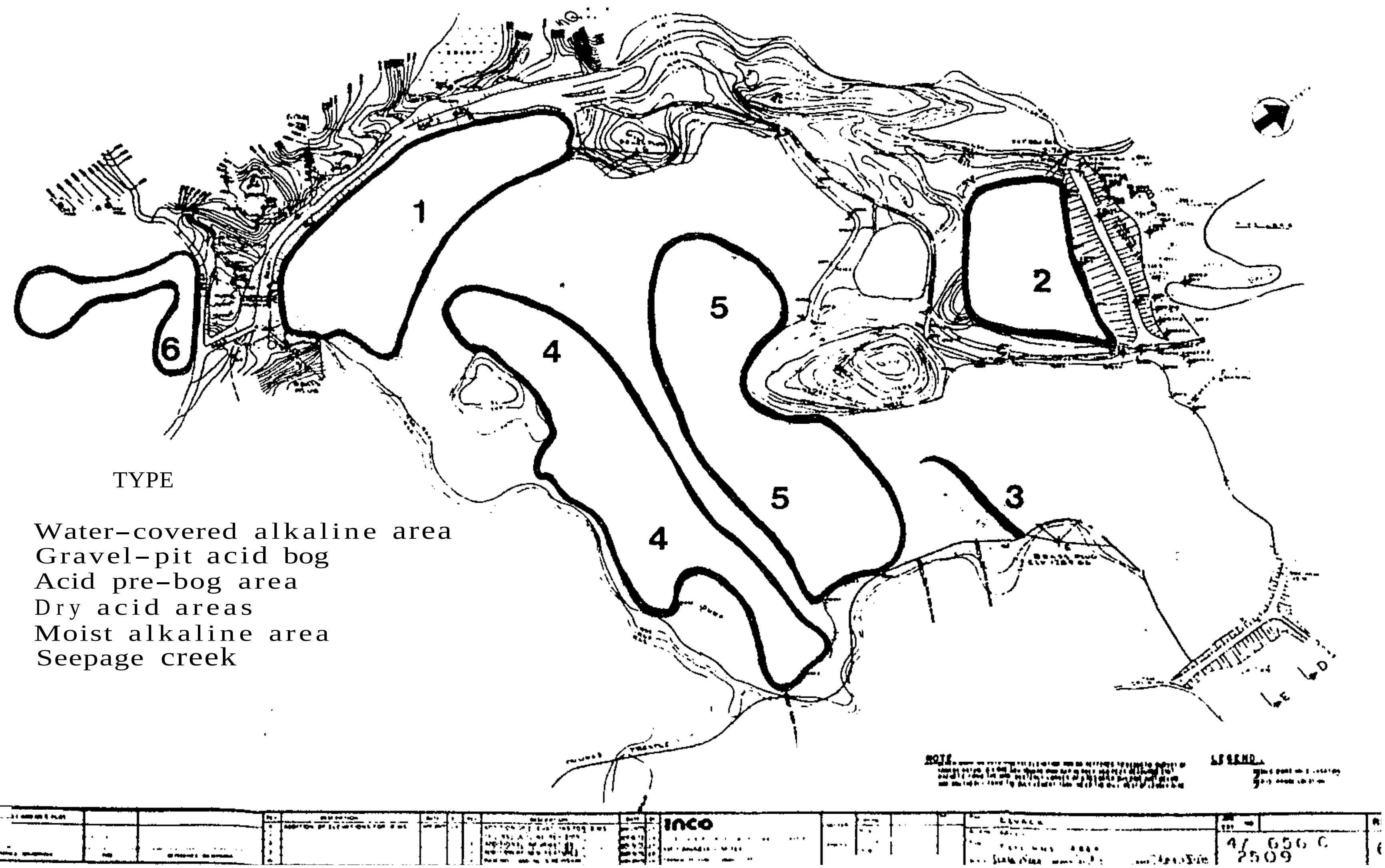
2. these indigenous species can be grown in the laboratory for use in both field and laboratory experiments which are essential for the development of a reclamation methodology with these biota.

This feasibility study lead to the formulation of different study areas (Map 1) which appear to show considerable promise For testing the validity of the ecological engineering concepts and for testing the effectiveness of the Chara process.

The overall concept, if found viable, will produce methods which could lead to a substantial economization of the costs of reclamation and/or treatment of mill effluents, and of the costs of mine close-out.

This proposed study which has the aim of evaluating the ecological engineering approach as a viable methodology for treating and/or reclaiming mine waste areas is outlined in general over a four-year time-frame.

MAP 1. Experimental Areas Outlined on Levack Tailings Site.



AREA	TYPE
1	Water–covered alkaline area
2	Gravel–pit acid bog
3	Acid pre–bog area
4	Dry acid areas
5	Moist alkaline area
6	Seepage creek

The main objectives of the four-year program are:

1. to conduct field studies to establish, enhance and develop the indigenous and tolerant plant communities from other tailings sites, on the experimental wet, dry and seepage sites on the Levack site;

2. to provide experimental proof of the seepage-cleansing effects of the indigenous biota and evidence of the establishment of an oxygen-barrier at the interfaces between the air or water and the unoxidized tailings developed as a result of the introduced and/or promoted ecosystems;

3. to provide a field assessment of the hydrological and hydro-geological conditions resulting from these measures, (i.e. to evaluate the surface water quality on the treated sites).

For such a project a multi-disciplinary team of specialists is required. Experienced experts from Boojum Research Limited, MacLaren Engineers and MacLaren Plansearch Inc., Ontario Research Foundation and Geocon Inc. have been brought together.

Although the ecological engineering approach has not been tested, there is considerable reason to believe it will be successful. From the descriptive ecological work reported in the literature, it is known that many non-vascular plants (e.g. algae, mosses) are early colonizers on tailings sites. From studies of bogs where mosses predominate, and, from areas where extensive algal blooms occur, it has been demonstrated that these organisms can have a considerable cleansing effect on their surroundings.

Some basic experiments oriented toward the development of ecological engineering reclamation measures are outlined which after completion could lead to the implementation of the proposed research program to develop reclamation methods for addressing the long-term problems of acid-generating tailings sites.

The most important requirement of this program, however, is to be able to establish the indigenous or tolerant vegetation covers on-site. As a first crucial step, it is necessary to design a detailed procedure for establishing and encouraging such vegetation communities and to test the assumptions of ecological engineering in the field. The procedures to be used on the Levack site for the first year are outlined in the next section.

4. YEAR 1: TEST METHODOLOGY AND BASIC ASSUMPTIONS OF ECOLOGICAL ENGINEERING CONCEPTS

Succinctly, the project cannot procede as proposed, if the biota cannot be introduced and enhanced, and, the methodology of measuring oxygen behaviour at the cover-tailings interface cannot be developed if the measurements of the surface hydrology are not carried out under field conditions.

Therefore we consider it nessessary to procede with a testing phase in 1985 to develop and test methodologies of all aspects of the program.

Emphasis will be placed on the ecological component, and measurement techniques suitable for a variety of field conditions (e.g. wet, dry, and semiaquatic) will be tested on-site. A preliminary list of experiments to be conducted in the test phase incl use:

1. testing different introduction and expansion methods for establishing indigenous biota in the proposed experimental areas (Map 1);

2. demonstrating the cleansing effect of filamentous green algae on seepage water;

3. demonstrating the development of an oxygen barrier between the indigenous vegetation covers and the tailings;

4. testing the hydrological instrumentation during run-off conditions.

The work proposed for 1985 is, therefore, considered a summer season of test work to determine the feasibility of proceding with the implementation the proposed program. A first assessment of the biological work would be made by the end of the field season in October. If some indication of success can be acertained, the hydrology test plot will be instrumented and a test core to measure oxygen penetration will be obtained .

4.1. Details of Biological Work in Experimental Areas - Boojum

In the ecological areas outlined in the INCO feasibility study, the pH ranged from pH 2.5 at site 11 (acid creek site) up to pH 11.5 at the origin of the mine-water discharge. On the basis of pH alone, the tailings area can be divided into two major areas --- those which are acidic with pH's below 6.0 and those which are alkaline with pH's above 9.0. The conductivity measurements indicated high values at all sites, especially in the surface creeks and seepages.

The records of indigenous flora on the tailings add further separation of areas, since dry, wet and moist (four acidic and two alkaline) areas have to have distinct characteristics in order for the indigenous ecosystems to develop.

Based on these parameters different areas are defined for testing of the proposed program.

4.1.1 Acid seepage treatment

The feasibility study carried out by Kalin (1985) for INCO considered the possibilities that the green alga, Ulothrix, was accumulating significant amounts of Fe, with lesser amounts of Cu, Zn and Ni removed from the seepage stream (Site 17) at Levack. As the pH of the stream drops from 6.5 to 4.7, Fe also precipitates out on the surface of the algae due to the great surface area provided by the filamentous strands and also the mucilaginous cell surface. Calculations indicate that more Fe is "lost" from the water than can be accounted for simply on the basis of the pH decrease and that there may be a significant "bioaccumulation" of Fe, i.e., direct uptake by the algal cells, in addition to the precipitated Fe on the external algal cell walls. It is also not known whether other metals may be co-precipitating with the jarosite on the algal surface.

4.1.1.1. Specific objective

The purpose of the following experiment is to determine the amount of Fe, Cu, Zn and Ni taken up ("bioadsorbed") when laboratory-grown Ulothrix is incubated with seepage stream waters from several sites, and to compare these uptake values with similar elemental concentrations in Ulothrix collected from various seepage stream sites. In the latter case, Ulothrix will be treated ultrasonically to remove iron precipitated on the algal filaments. Elemental analysis will be made on this precipitate and also on the cleansed algae.

4.1.1.2. General experimental methods

Metal uptake experiments

Laboratory-grown Ulothrix will be introduced into a water-jacketed chromatography column (the column is jacketed to maintain the column temperature at that of the site water). Water from the site is pumped through the column-contained Ulothrix at a measured flow rate. After exposure to the site water, the algae are analyzed for metal content (and compared with the initial metal content of the laboratory-grown Ulothrix). Site water metal content is also analyzed and a general picture of the metal uptake rate by the Ulothrix can then be determined.

Metal content of seepage-grown Ulothrix

At identical sites where the uptake experiments are conducted, Ulothrix samples will be collected for elemental analysis and "elemental compartmentation", i.e., determination of the relative proportion of metals precipitated onto a given weight of Ulothrix (i.e. the residue from ultrasonic treatment) versus the metal content resulting from "uptake" or "bioaccumulation" by the alga.

In addition to total iron, Fe^{+2} and Fe^{+3}, Cu, Zn and Ni will be specifically analyzed in the seepage stream waters, the Ulothrix-bound precipitate and the Ulothrix algal matter.

Stream flow rates will also be determined in order to compute the metal-polishing efficiency of Ulothrix currently growing at various sites and stream flow rates in the seepage streams.

Oxygen versus depth profiles alonq seepage stream

Dissolved oxygen determinations at various locations along the seepage stream will be determined (02 electrode) along with stream flow rate estimates and pH in order to get an insight into the "cause(s)" of the decreasing acidity along the seepage stream length.

Expected results

1) The experiments will determine the effectiveness of Ulothrix as a passive-polishing agent in mildly acid seepage stream waters as a function of pH (between ca. 4.5 and 6.5) and stream flow rate.

2) The decrease in seepage stream pH may be correlated with the degree of oxygenation of the water, arising from turbulent stream flow, and may suggest that "lagooning" be introduced to slow down water movement and increase the O_2 gradient between the water surface and the sediment.

4.1.2. Acidic gravel pit

This area will be used to test different introduction methods of aquatic moss, growing presently in Elliot Lake (pH 3.5) and in Moose Lake (Falconbrige) in the active tailings area. Details of these introdcution methods are at present not clear and will be developed on the basis of literature available at Boojum Research.

4.1.3 Acidic dry areas

The small acidic creek will be used as a water source for increasing moisture on dry tailings for the experimental plots on which acid-tolerant moss cover is to be developed. This requires some engineering ingenuity, to produce an irrigation system for the experimental plots. It is anticipated that pipes could be used for the distribution of acid water.

Moss protonemata have been collected from the moist acidic Fecunis and Nickel Rim tailings. Based on experiments designed by B. Michellutti, an extensive moss shrub cover has been developed in the past few years. These covers will be investiqated. and based on the results. experimental plots will be set up on'the Levack site. It is p anned to use these and other moss populations as inocula for exper mental plots.

In the creek itself, experiments will be carried out to introduce filamentous green algae from acidc locations (e.g. Timmins or Elliot Lake). The acid creek is chemically typical of most acidic drainages, but in spite of these extreme conditions several algal taxa were growing. The dominant organism was Euglena mutabilis which is very common species in extremely acidic habitats and is usually one of the early algal colonizers mentioned in acid mine drainage studies.

4.1.4 Moist alkaline sites

Mosses were found in moist alkaline cracks along the creek bed. By altering the flow of the mine-water creek over the area and thereby providing a larger moist area, it is anticipated that the indigenous moss, can cover more extensive areas.

Mosses identified on the limed tailings are either Ceratodon or Pohlia; both species provide extensive moss covers on limed tailings surfaces in Elliot Lake. The existing moss is too young to be identified. The experimental methods will be similar to those used in the acidic areas, by mixing different borrow material into the area kept moist with the mine water. These experimental plots also require some engineering support, to produce a water distribution system. Possibly small berms could be built out of tailings or other availbale material.

4.1.5 Water-covered alkaline areas

Area 1 includes the wet alkaline sites which remain submerged in the mine-water and are conducive to growth of alkalophilous species. The plan for this area is to extend the cattail stands along the beaches, introduce Chara and test other species from the Conservation Area at Falconbridge. Methodologies for Chara introduction are derived from the previous work carried out in the summer 1984 in Elliot Lake. Introduction methods of Falconbridge species have to be developed. All introductions will be made by fastening the plants in experimental plots so that growth evaluations can be carried out.

4.2. Details of the Engineering Aspects, MacLaren Plansearch

Basically very little engineering work will have to be carried out, since all efforts are expended primarily to test the introduction methods. The availability of adequate water supplies for plant growth will be paramount in determining the success of the ecological engineering approach to tailings area reclamation. The rationale for hydrological and hydrogeological investigations have been given in the general proposal and only the main objectives are repeated.

The main objectives are to describe the following:

1. the near-surface water balance of the tailings;

2. the flow patterns of water into and within the tailings deposit.

3. the general geochemistry of the system.

Year 1 - Hydrological Recognaissance

Detailed instrumentation will be installed in the tailings area to permit estimates of the components of the surface water balance including:

- infiltration
- evapotranspiration
- geochemistry
- precipitation

Only one plot will be instrumented, after the evaluation of the ecological work. This is mainly aimed at testing the instrument performance and the plot design during the snowmelt conditions in the following year, since snowmelt is likely an important feature of the hydrology and the vegetation covers to be developed.

The instruments required include:

automatic recording rain gauge
precipitation chemical sampler
20-point snow course
two "twinned" 5 x 5 m runoff plots with measurement devices
1 Ott (OTT) water level meter
13 observation wells for manual measurement
13 piezometer nests (5 levels each nest) entire basin
3 observation wells for continuous recording
5 multi-level samplers, 10 levels in each
3 neutron probe access tubes
5 shallow tray lysimeters
1 Campbell CRF datalogger
single-level windspeed
single-level net shortwave radiation
single-level net allwave radiation
single-level temperature and humidity
10 ground temperature measurements

For planning purposes for the second year, the instrumentation required for detailed water and energy balance is listed. These however are not required until the second year, after the plots have been tested and the vegetation cover has survived the winter.

The equipment required in teh second year includes:

second set of radiometers for treatment plot
(shortwave and allwave)
5 anemometers for vertical profiling of windspeed,
5 psychrometers temperature and humidity
heat flux plates
expansion cards for datalogger
extended soil temperature measurements

All team members will be visiting the site, to assess the instrumentation, determine location and for a general recognaissance of the site. This will not be required before the ecological test plots are set up and some water distribution system is in place.

<u>Water distribution systems</u>

It is the aim of this year's work to test different methods of water distribution on the site and to develop a prototype system for implementation in the second year.

These systems will be tested in the seepage for water containment, and in the acid and alkaline dry areas to support the experimental plots for cover development.

<u>Prediction tools - modelling</u>

Since the entire program aims to improve water quality by reducing acid generation by various methods, it will be necessary to use modelling as a planning tool during development of the methodology. During the first year, only the evaluation and assessment of the appropriate systems model need to be carried out.

4.3. <u>Details of the Oxygen Measurements. ORF</u>

The objectives of the laboratory test program are to:

1) obtain oxygen profiles for various test samples under chosen conditions at different depths;

2) correlate the laboratory test results with field data; and

3) collect data on Eh, pH, temperature, major cations and anions, trace metal concentrations.

Only a prototype core will be constructed in the laboratory in the first year as it is necessary to have full facilities until the field measurements which are also to be carried out in the first year are completed. If the ecological work procedes as proposed field samples that represent one or two dry sites will be obtained as 3" dia. x 6' drill cores.

For the gas sampling, an oxygen "specific ion" probe would be used to determine the oxygen content .Probes would be installed for water sampling measurements either in the opposite end of the sampling tubes, or in a separate tube installed one or two inches below oxygen monitoring probes.

Details of the core layout and the instrument for oxygen measurements were given in the general proposal.

After testing of the performance of the cores and the practicability of the field measurements in the second year, the field samples will be collected and installed under laboratory-simulated climatic and ecological conditions.

5. YEAR 1 : PROJECT SCHEDULE

Technical Component

Activity	JUN. (1985)	JUL.	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN. (1986)	FEB.	MAR.
Ecology Field Work Boojum Research										
TEST PLOTS SET UP	XXX	XXX								
CHARA INTRODUCTION	XXXX									
SEEPAGE EXPERIMENT		XX	XXX							
GROWTH ASSESSMENT				XXX	XXX					
Laboratory Tests - ORF										
DESIGN CORES AND FIELD INSTRUMENTATION		XXX								
TEST FIELD MEASUREMENTS IN BOX ON SITE			XXX							
SET-UP CORE FOR TESTS					XXX					
MONITOR CORE								XXX		
Hydrology - MacLaren										
DESIGN WATER DISTRIBUTI SYSTEMS FOR EXPERIMENTS			XXX							
EVALUATE EXISTING DATA										
Hydrology, hydrogeology, water balance				XXXX	XXX					
SET UP HYDROLOGY PLOT					XXX					
COLLECT CORE					XXX					
DATA ANALYSIS FROM FIELD WORK								XXX		
DESIGN IMPLEMENTATION OF PROTOTYPE WATER DISTRIBUTION										XXX
REPORTING OF ECOLOGY RESULTS					XXX					

5.1. Project Team

The project team selected for the pilot demonstration program is comprised of a number of staff from Boojum Research, ORF, MacLaren Engineers, MacLaren Plansearch and Geocon.

The major team members and their areas of expertise are outlined as follows:

M. Kalin, M.Sc.	- Boojum Research Limited Senior Research Scientist
V. I. Lakshmanan, Ph.D.	- ORF Senior Scientist
L.M. Luckwich	- ORF Research Scientist
D. Charlesworth. Ph.D.	- MacLaren Plansearch Hydrogeology
T. Price, Ph.D.	- Consultant to MacLaren Plansearch Geochemistry
J. Roberts. M.Sc.	- MacLaren Plansearch Water Chemistry
R. Bishop, M.Sc.	- MacLaren Plansearch Hydrology
E.J. Chart, B.Sc.	- MacLaren Engineers Civil Engineering
	- Geocon Inc. - Geotechnical Services

Curricula vitae of the main study team members is contained in Appendix A of the general proposal.

6. ESTIMATED COSTS FOR YEAR 1

A preliminary estimate of the cost of carrying out the Levack reclamation research program in its entirety has been presented in the general proposal.

The costs identified in this submission are preliminary and will be finalized after detailed discussions with INCO and FALCONBRIGE, since some of the costs are presently generalized for this submission. As well, support from both Inco Limited and Falconbridge Limited have to be included, if they are prepared to support the program.

ECOLOGY AND TRANSPORTATION	$ 49,660.--
MACLAREN ENGINEERING	$ 36,340.--
ORF, OXYGEN MEASUREMENTS	$ 31,100.--
TOTAL COST OF PROJECT WITHOUT INCO CONTRIBUTION OF ANALYTICAL AND SUPPORT SERVICES	$ 117,100.--
INCO CONTRIBUTION DISCUSSED	$ 22,420.--
FALCONBRINGE CONTRIBUTION	$ 6,400.--
TOTAL COST OF PROJECT	$ 145,920.--

Detailed cost estimates for the three components are provided below.

6.1. Ecology Cost Estimate - Boojum Research Ltd.

	Labour	Expenses
Growth studies of algae and moss: R. Buggeln -10 days/month for 4 months @ $ 300.--/day	12,000.--	
Materials and equipment		2,000.--
Identification, experimentation and field work: M. Olaveson -15 days/month for 4 months @ $ 206.--/day	12,360.--	
Materials and equipment		1,000.--
Chara Process introduction: M. Smith for 15 days @ $ 190.--/day	2,850.--	
Summer student @ $ 1650.--	1,650.--	
Supervisor: M. Kalin 20 days @ $ 350.--/day	7,000.--	
Total Labour:	$ 35,860.--	
Transportation:		
Air plane (10 round trips 4)		2,500.--
Vehicle for 4 months @ $ 400.--/month		1,600.--
Gasoline estimate		2,000.--
Subsistence in lab $ 10.--/person/day (for 3 persons for 3 months)		2,700.--
Hotel accomodation for engineer @ $ 100.--/day for total of 20 overnights		2,000.--
Total Expenses		$ 13,800.--

TOTAL ESTIMATE (Labour + Expenses) $ 49,660.--

6.2. Engineering Cost Estimate - MacLaren Engineering

	Labour	Expenses
Supervising Engineer: 8 days @ $ 600.--	4,800.--	
Hydrogeology , data review 10 days @ $ 410.--	4,100.--	
Hydrology , data review and evaluation of water balance 20 days @ $ 380.--	7,600.--	
Water distribution /retention systems design 7 days @ $ 380.--	2,660.--	
Experimental plot instrumentation 7 days @ $ 380.--	2,600.--	
Equipment		7,000.--
Core retrieval Equippment supplied by INCO 2 days of Geocon staff @ $ 350.--	700.--	
Data analysis - 8 days @ $ 380.--/day	3,040.--	
Implementation of surface design after testing prototypes for year 2 testing- 8 days @ $ 380.--/day	3,040.--	
Report writing and preparation 10 days @ $ 380.--	3,800.--	
TOTAL ESTIMATE	$ 39,400.--	

6.3. Oxygen Measurements Cost Estimate - ORF

	Labour	Expenses
Construction of prototype core and field box		10,000.--
Monitoring of core 300 hours @ $ 40.--/hour	12,000.--	
Supervision 80 hours @ $ 60.--/hour	4,800.--	
Management of program 50 hours @ $ 66.--/hour	3,300.--	
TOTAL ESTIMATE	$ 30,100.--	

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Project 1:

DEVELOPING A TECHNIQUE FOR RECLAMATION OF HIGH IRON SULPHUR TAILINGS BY ESTABLISHING MARSHLAND.

referred to as

BUILD A BOG OR WETLAND

1. INTRODUCTION

Falconbridge Ltd. has outlined four projects associated with reactive acid tailings, for which they felt support could be given by the company to address problems within the CANMET program. Boojum Research Ltd., in conjunction with Geocon and MacLaren Plansearch, was identified as part of the project team by Falconbridge Ltd.

After further discussions with the parties concerned, it became apparent that priority will be given to Project 1: Developing a technique for reclamation of high iron sulphur tailings by establishing marshland, which is referred to as, "Build-a-bog". Project 4: Investigation of natural removal of nickel from solution by lake ecosystems, may be considered in the future. Both projects are enclosed in the Appendix, as submitted by Falconbirdge Ltd.

Project 2: Developing a long-term treatment strategy upon abandonment of a high sulphur tailings area, was considered of low priority and was dropped from the present project list. Project 3: A comparative study of three methods of reducing acid generation and metals release from waste rock and tailings, will not be considered by Boojum Research Ltd. This submission outlines program details for Project 1 and preparatory work for Project 4.

A preface to the project outlines is required since Project 2 was dropped from the program. Project 2 was intended to address the growth, development and effectiveness of wetland ecosystems as a mill-effluent management tool, i.e. what are the benefits of having a polishing pond with macrophytes, such as the Falconbridge Conservation Area.

This area is considered by Boojum Research as an extremely important component in developing a general methodology for ecological engineering of waste management areas.

The rationale of ecological engineering lies in the effective utilization of biota established in waste management sites. These biota are expected to be tolerant to the harsh environmental conditions present. It follows, therefore, that in part, aspects of the work under Project 1 require utilizing the Conservation Area, the East Mine tailings area and possibly bogs around Nickel Rim.

In the absence of support for the study of the Conservation Area and other tolerant ecosystems, the extent of information which can be determined will be limited.

2. BUILD ing A BOG OR WETLAND: TASK DEFINITION

The general concept was outlined in the Falconbridge submission (Appendix) and hence the ecological task is to establish wetland vegetation onto tailings, fertilized either with sewage or chemical fertilizer, without major additions of original wetland-soil-source material.

Dunn and Best (1983) formulate the objective of ecosystem development very well: "One goal of reclamation should be to design self-maintaining ecosystems in concert with nature, especially native ecosystems." Clearly, tailings are not native ecosystems, however the conditions given in the experimental cells to be constructed, can be viewed as the first stage of invasion (colonization) of an abiotic substrate. The mechanisms of this invasion process are those, which function after a disturbance, ie. drought and flood. The critical role in the recovery after a disturbance of an ecosystem is played by the reproductive capacity of the organisms present, ie. the wetland soil which stores dormant and viable seed as well as different viable root and rhizome forms which can lead to regeneration of the ecosystem. This seed and root bank, therefore, provides the plant community with its means to regenerate from naturally-occuring disturbances, and hence is the material which should be used as introduction material if a self-maintaining ecosystem is to be initiated.

Within this objective, it is apparent that the most important tasks to be considered include:

1) the identification of suitable seed-root material for transplanting;

2) the development of a methodology for the transfer of plant material from the the source sites to the abiotic tailings environment.

These two tasks will be addressed in an experimental fashion involving two components --- a set of small-scale experiments, described below, and a set of large-scale experiments, described in the Falonbridge submission (Appendix).

The experimental design of the small-scale experiments will consist of a large number of smaller containers or cells in which a large number of interactions between substrates, plant responses and transplant methodologies can be tested. This will then allow some assessment on how to approach most effectively the introduction of biomass into the large cells in the large-scale experiments.

The small-scale experiments will be conducted first and the results from these experiments will be evaluated to identify suitable seed and root sources and to indicate the most effective methodology of transfer of these materials. Also the interaction between the source material and the cell lining materials, (substrate types) can be evaluated. Based on the results of these small-scale experiments, the details of the larger-scale experiments can then be planned and implemented (refer to overall project activities on pg 5).

The small-scale experimental approach is required since the following areas are at present undetermined and this information is essential to the effective assessment of the subsequent large-scale experiments.

For transplanting of vegetatively-reproducing species:

1. the chemical balance of the root zone is particularly important to know in order to minimize the damage to plants during the transplant procedures into waste areas;

2. the most effective transplanting time is not known at present, ie. the time in the growth cycle at which senescence starts will determine the sucess of overwintering and subsequent growth in the following year;

3. the physical /chemical conditions specific to the plants which will be transplanted have to be determined in the source ecosystem; those conditions (e.g. acidic lower strata, alkaline upper strata) have to be aligned with conditions in the experimental set-up, and, after overwintering, the conditions have to be evaluated in comparision to those which develop in the large cells in which the plants are to be transplanted.

For seed innoculation:

4. the importance of seed location within the wetland soil strata in relation to ability of the seeds to germinate and establish is not known for the source ecosystems;

5. nothing is known about the seedbank composition in the source ecosystems.

3. SMALL-SCALE EXPERIMENTS

3.1. Detailed Experimental Design

The following experimental design is planned for the small-scale experiments. A series of small containers (e.g. wooden flats or any type of box approximately 0.5 to 1 m^2 in area) which will contain water to a 50-cm depth, will be set up in a suitable location on site. The exact dimensions of the containers and the material to be used in their construction will be determined by the engineers and Falconbridge personnel.

In these small-scale containments, several variables will be tested in order to acertain the optimal treatments for subsequent longer term experiments in the large-scale plots. The variables to be tested are discussed below under the following categories:

1. types of cell-lining materials
2. sources of seeds or transplants
3. methods of seed introduction and transplantation.

3.1.1. Types of Cell-lining Materials

FeOH iron hydroxide

Four cell-lining types (e.g. tailings + sewage, tailings + fertilizer, tailings + jarosite, tailings + natural soils) will be tested in the small-scale experiments to determine the best substrate combination to encourage vegetation survival and growth after seed germination or plant transfer.

3.1.2. Sources of Seeds or Tranplantable Vegetation:

Four types of habitats have been selected as potential sources of native species which would provide a seed bank or supply of transplantable material. The sites include a control area which is not affected by mining activities, the Conservation Area at Falconbridge which has received neutralization treatments, a natural bog unaffected by mining activities and ~~the~~ Nickel Kim bog which is near acidic mine tailings. The combination of control sites which represent natural unstressed habitats and stressed sites which have been influenced to some degree by mining activities should offer a broad spectrum of tolerances to a wide range of environmental conditions.

3.1.3. Methods of Seed Introduction and Transplantation:

Three types of methodologies will be tested during the small-scale experiments --- one involving seed transfer techniques alone, another involving transplantaion techniques alone and the third involving a combination of seed transfer and transplantation methods.

a) seed transfer

At present, it is not known what factors will be important in ensuring the viability and subsequent germination and survival of seeds taken from natural habitats and planted in tailings materials. To attempt to address this problem, two methods of seed transfer will be tried.

Method 1: Cores of soil material containing native seeds will be collected from each of the source sites. The core material will be mixed with the various test lining materials. This approach will give some indication of the viability of a wide variety of seeds in the test materials but will offer little information on where within the soil core the seeds originate or what physical and chemical conditions are required for germination andlor sustained viabi 1ity.

Method 2: Additional cores, which will be collected as in Method 1, will be separated into several strata. The seed density and the viability of seeds within each layer will be determined. The layer(s) which indicate the most promising results in terms of density, variety andlor viability will then be mixed with various test materials in the small-scale experiments. The physical and chemical characterist cs of the individual layers in the source area can also be mea ured and this information can be used subsequently in optimizing the conditions in the test plots to maximize seed germination and growth responses.

The results of these two methods will provide considerable information about the responses of a variety of seeds from several native seed banks to the conditions present in the test tailings mixtures.

b) transplantation of vegetative material

Since relatively little is known about the responses of many indigenous plants to transplantation, it is necessary to test various methods to discern which growth or survival responses are due to the tailings substrate treatment and which are artifacts of the transplantation procedures used. Two methods which will be used in the small-scale experiments are described below.

Method 1: Entire plants (e.g. rootslrhizomes, stems, leaves) will be removed from the source sites and tranplanted in the various test materials. The number of individuals plants transferred will depend on availability at the source sites and the size of the experimental containers. Mixtures of plants will be placed in the test plots so that more realistic conditions (e.g. mixed species communties) can be evaluated.

Method 2: Only the root or rhizome without the emergent portion of the plant will be transplanted. This technique will provide information on the responses of the various plant parts to transplantation as well as to the test conditions.

c) mixed methods

The final tests will examine a combination of the seed transfer and transplant techniques together described above to obtain some idea of responses in natural communities which consist of both mature plants and seedlings.

A summary of the planned experimental design is proyided in the table below.

TYPE of Lining	SOURCE WETLAND TYPE Control Area S.	Control Area T.	Conservation Area S.	Conservation Area T.	Control Bog S.	Control Bog T.	Nickel Rim Bog S.	Nickel Rim Bog T.
Tailings/ sewage	1	2	3	4	5	6	7	8
Tailings/ j a o r s i t e F e 0 H								
Tailings/ fertilizer								
Tailings/ native soil								

S seed bed experiment
T transplant experiment

This experimental set-up 'consisting of 32 cells will be replicated three times for each transplant method resulting in a total of 96 containers for the experiment. The transplanting experiments will be repeated twice to test the effect of ti e of transplant on the survival and growth responses. hese experiments will be carried out in the same experimental ce 1 at two different times of the year. The first experiment wil be set up during the growing season and harvested at the end o the growing season. The second set will be started in the same cells with plants at the end of their growth cycle and left over the winter.

To reduce the number of cells which need to be constructed, for testing the introduction methods, the cells of each lining type could be divided, to allow for testing different ~~physical~~ or ~~chemical~~ factors (e.g. water depth).

(and/or ~~of~~ S/[illegible])

4. TIME SCHEDULE FOR PROJECT 1

Overview of Activities

Falconbridge	Geotech. Engineer. Geocon MacLaren	Boojum Research Limited
Year 1: 1985		
Construction of containments and experimental plots and analysis	Design of containments	Biota sources and transfer methodology
Year 2: 1986		
Adjustments and revisions to containments and analysis	Evaluation of performance of containment	Evaluation of exp. Year 1 and introduction to main containments
Year 3: 1987		
Maintenance of containments, monitoring and analysis	Final design and description	Evaluation of introduction methods based on results of boxes and containments
Year 4: 1988		
Maintenance of containments, monitoring and analysis	--	Introduction on larger scale
Year 5: 1989		
Maintenance of containments, monitoring and analysis	--	Evaluation of results and final method description

Details for Year 1

The experimental set-up for the 1985 season should be ready not later than July, to allow one month for the settling of the containments and for the determination of the chemical conditions. The first transplanting should occur no later than the beginning of August i.e. to transfer during the growing season. At the beginning of October, a second period to transplant is envisaged.

In Year 2, transplanting would be carried out at the beginning of the growing season and the results will be evaluated for implementation in the larger cells.

A report with the details of the experimental set-up for the large-scale experiments will be issued at the end of the year. A second report which will contain the results from the overwintering experiments will be available by late May, 1986.

5. COST ESTIMATE FOR YEAR 1

FIELD WORK - SET-UP OF EXPERIMENTS

The costs are estimated based on the assumption that the project in Levack (Inco) is proceeding in 1985, since no allowance has been made for a second field trip which is required for the introductions at the end of October. The costs for the evaluations of the results in May, 1986 will be estimated in the Year 2 budget, since the funding is assumed to be within federal fiscal year constraints.

In essence, Boojum's costs are estimated for the identification of the source wetlands and the transplant material for the experiments. For the actual set up of the experiments, it is anticipated that Falconbidge would provide assistance for approximately 4 days. Also, it may be possible that a truck would be required from Falconbridge for the transportation of the material from the source wetland to the experimental plots.

Furthermore, it is assumed that the laboratory at Levack will be available for accomodations at no cost to Boojum Research Ltd. and if at all possible the storage room could be converted into a second usable room as discussed.

LABOUR:	
M. Kalin, Principal Investigator 15 days @ $ 350./day	$ 5250.--
M. Olaveson Technician 20 days @ S 206 /day	4120.--
SUPPORT COSTS	
<u>Miscellaneous:</u> Consumables, film, reports, Secreterial etc.	800.--
<u>Transportation:</u> To site and on site: Vehicle and gas	900.--
Subsistence: 20 days a $ 50.- / day for 2 persons	1000.-- ---------
Total Estimate for Biology	$ 12070.--
<u>Subcontract:</u>	
Engineering MacLaren Plansearch/ Geocon Allow sum	5000.-- ----------
Total costs of Year 1	$ 17070.-- ==========

Project 4:

6. INVESTIGATION OF NATURAL REMOVAL OF NICKEL FROM SOLUTION BY LAKE ECOSYSTEMS

PRELIMINARY DATA ANALYSIS BY BOOJUM RESEARCH LTD.

The complexities which are associated with the described phenomenon of nickel removal in lower Moose Lake are rather extensive, based on the available information. Some of these complex problems are outlined below. For example,

1) after plotting total Ni concentrations for each sampling station for the years 1980 (original graph, Fig. 1.), and 1984 and 1985 (Fig. 2 and 3), it appears that the magnitude of the removal is about 0.5 ppm of Nickel regardless of the original Ni concentration (Tables 1 and 2);

2) after plotting pH, and total Fe and SO4 concentrations for the same time period, it was observed that, during the depression in Ni concentrations (around day 200) at the Discharge, the sulphate concentrations increased and that the iron concentrations remained relatively constant; the dynamics of iron and sulphate were quite different at the Neutralization Dam. This suggests a strictly chemical phenomenon is involved.

3) the biological processes, i.e. population dynamics within lower Moose Lake, can be observed as a series of population peaks (Fig.4) varying with time of year which occur partly, or entirely, in response to the seasonal fluctuations in the physical-chemical conditions in the lake (Fig.5).

A brief phytoplankton scan of water samples collected in May 1985 by Boojum Research indicated, that the species at the sampling station of the Neutralization Dam are typical of very acidic waters. Diatoms (e.g Eunotia), cryptomonads and small flagellated chlorophytes and chrysophytes are the dominat biota at this site. The sample from the Discharge, on the other hand, has a higher species variety, dominated by Dinobryon, Tabellaria, Peridinium, and Asterionella as well as smaller algal species. These identifications reflect the typical phytoplankton composition of Precambrian Shield lakes which' are usually oligotrophic. This observation corresponds to the reported bacterial counts (ref. Falconbridge) which also indicated a nutrient poor system.

Higher biomass quantities were observed (although not quantified) at the Neutralization Dam. Frequently in acidic conditions, the population density of acid-tolerant species is high since resource competition is reduced wheras the conditions at the Discharge would reflect closer those of a natural lakes in which biomass fluctuations are expected to be larger during the seasonal cycle.

It follows therefore, that if the removal phenomenon is biological, it could be controlled either by the acid system or the more natural lake biomass dynamics. These two systems will respond differently to the factors schematically presented in Fig 3 and 4. The seasonal dynamics of both phytoplankton communities would have to be addressed in a rigorous fashion to formulate the biological basis of the removal phenomenon.

These three major problem areas are intended to demonstrate that before a study program can be determined, the background information needs to be evaluated in more detail since the removal phenomenen requires a definition within this background.

Boojum Research Ltd. is interested in providing limited background analysis in 1985/1986 within the manpower allocations for Project 1: Build-a-bog, with the cooperation of falconbridge Ltd. This aspect should be discussed further with Falconbridge.

Mg

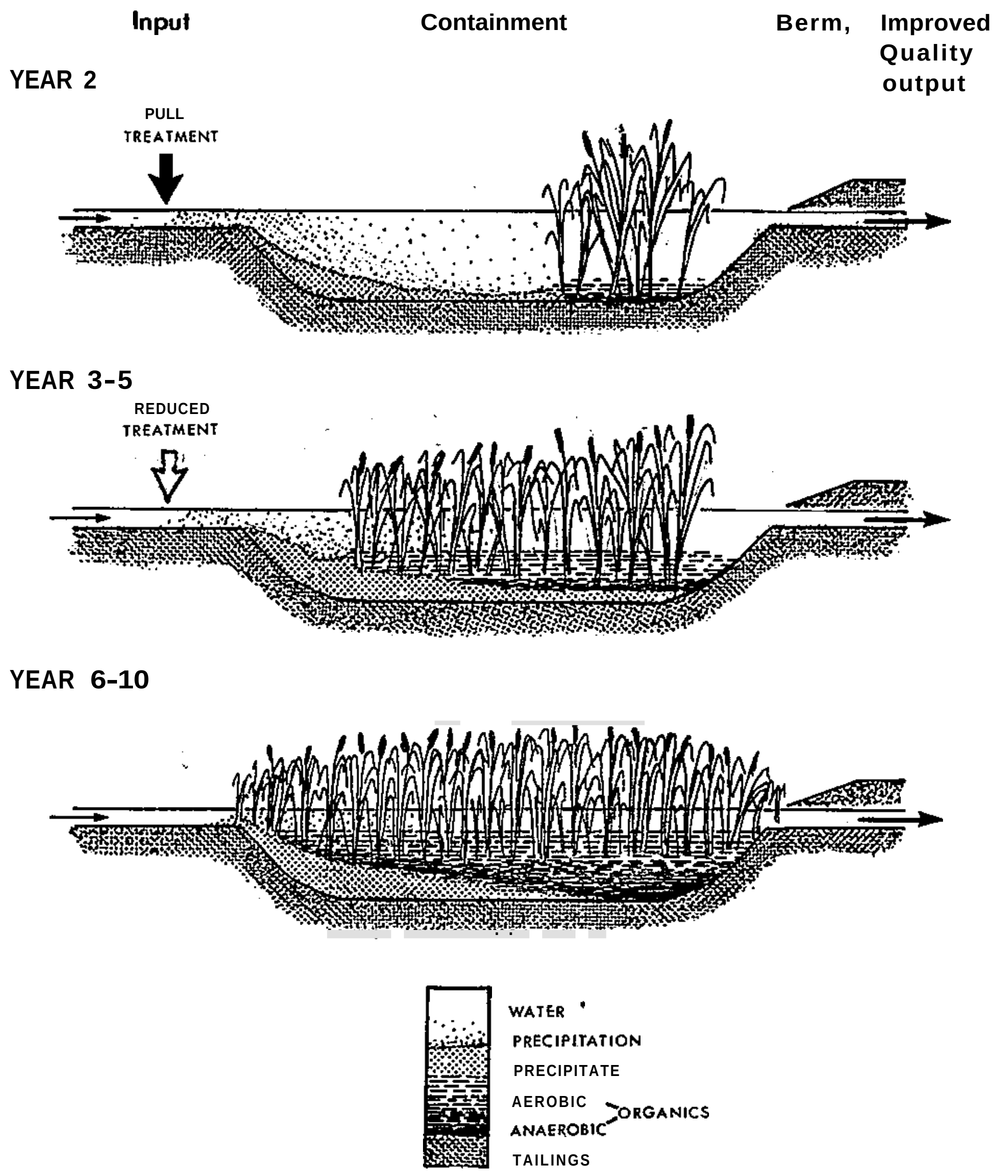
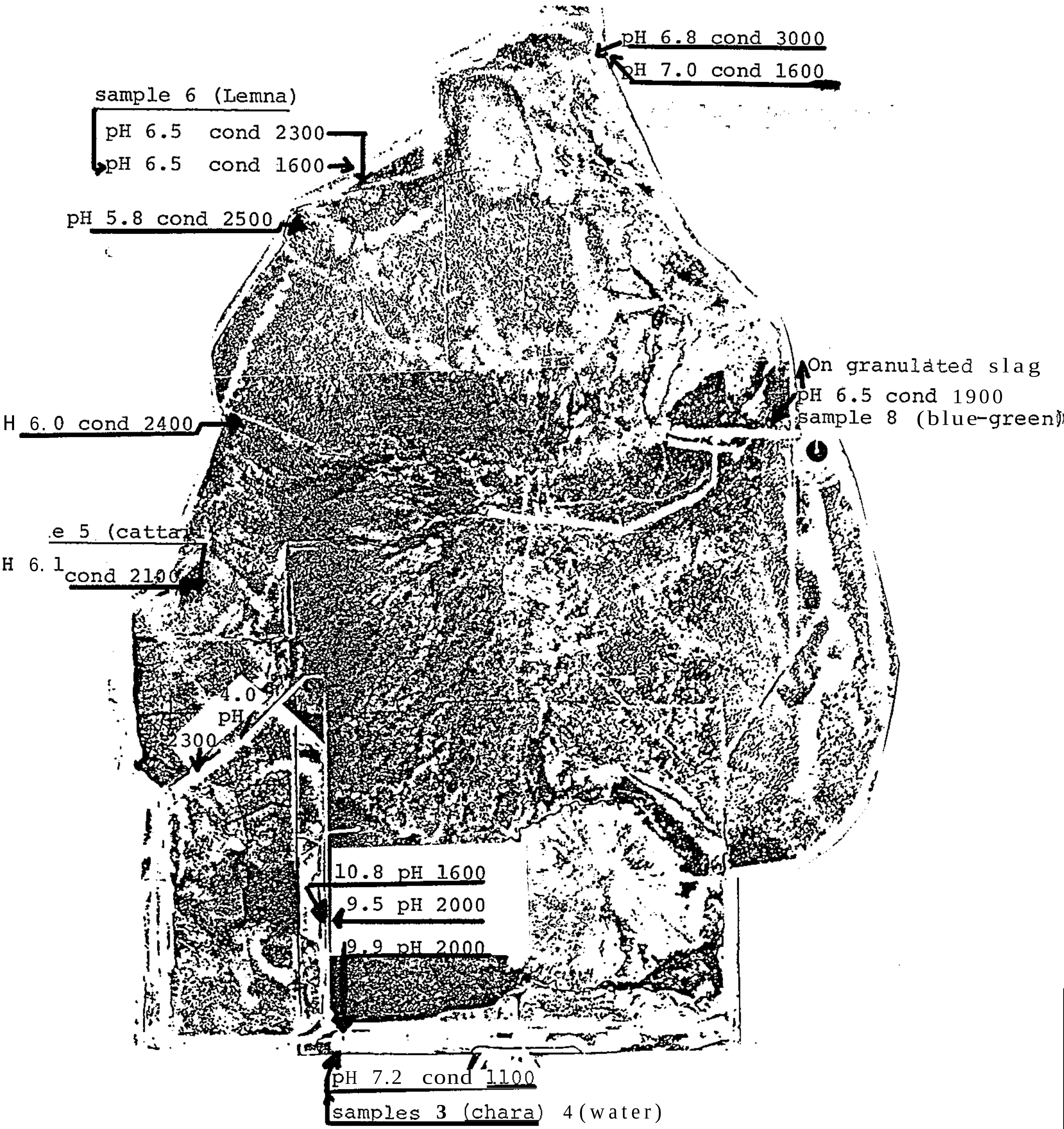
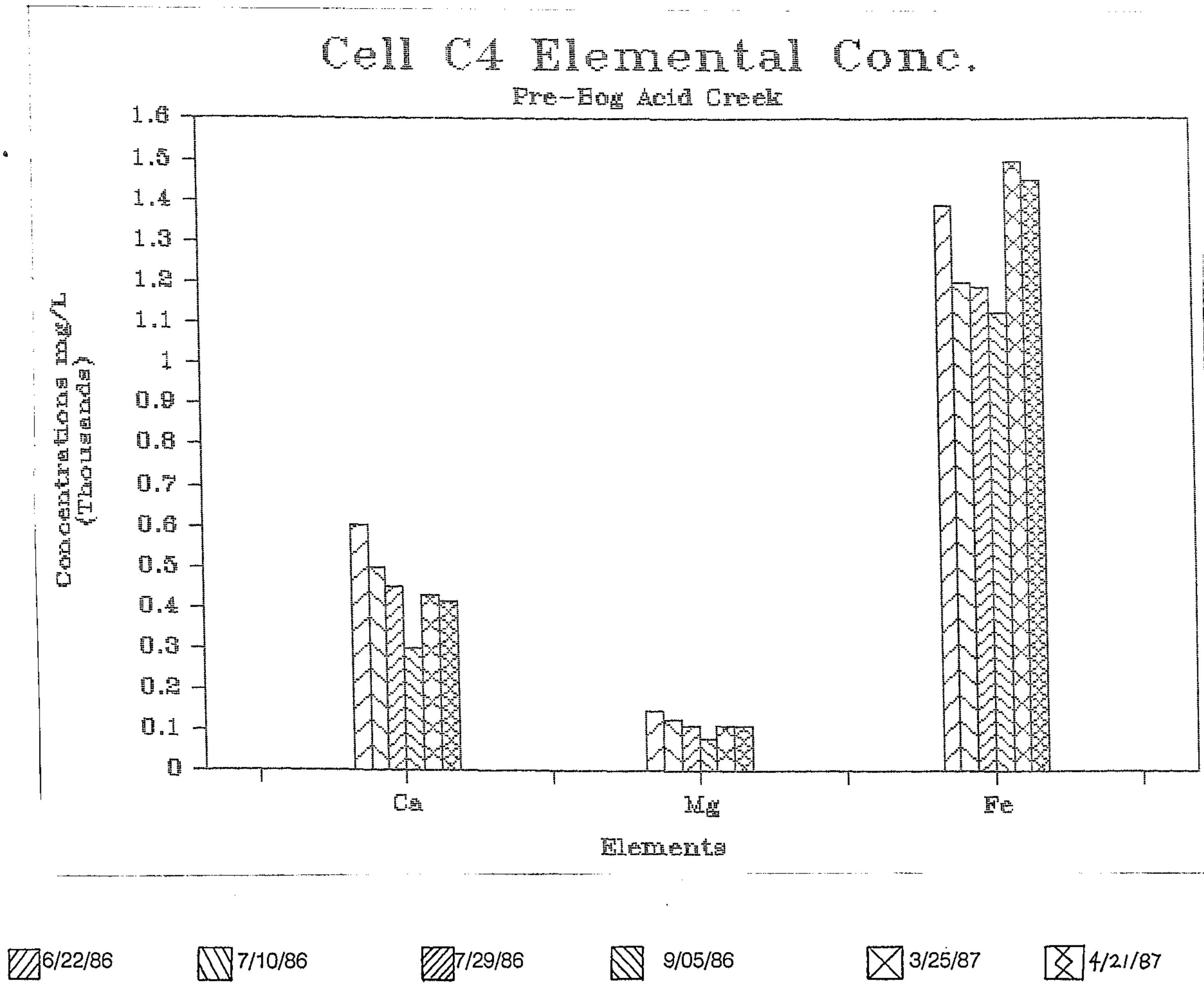


FIGURE 2: ACIDIC WETLAND SYSTEM



KIDD **CREEK** ; **MET** SITE SURVEY



Cell C4 Elemental Conc.
Pre-Bog Acid Creek
Concentrations mg/L (Thousands)
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Ca
Mg
Fe
Elements
6/22/86
7/10/86
7/29/86
9/05/86
3/25/87
4/21/87

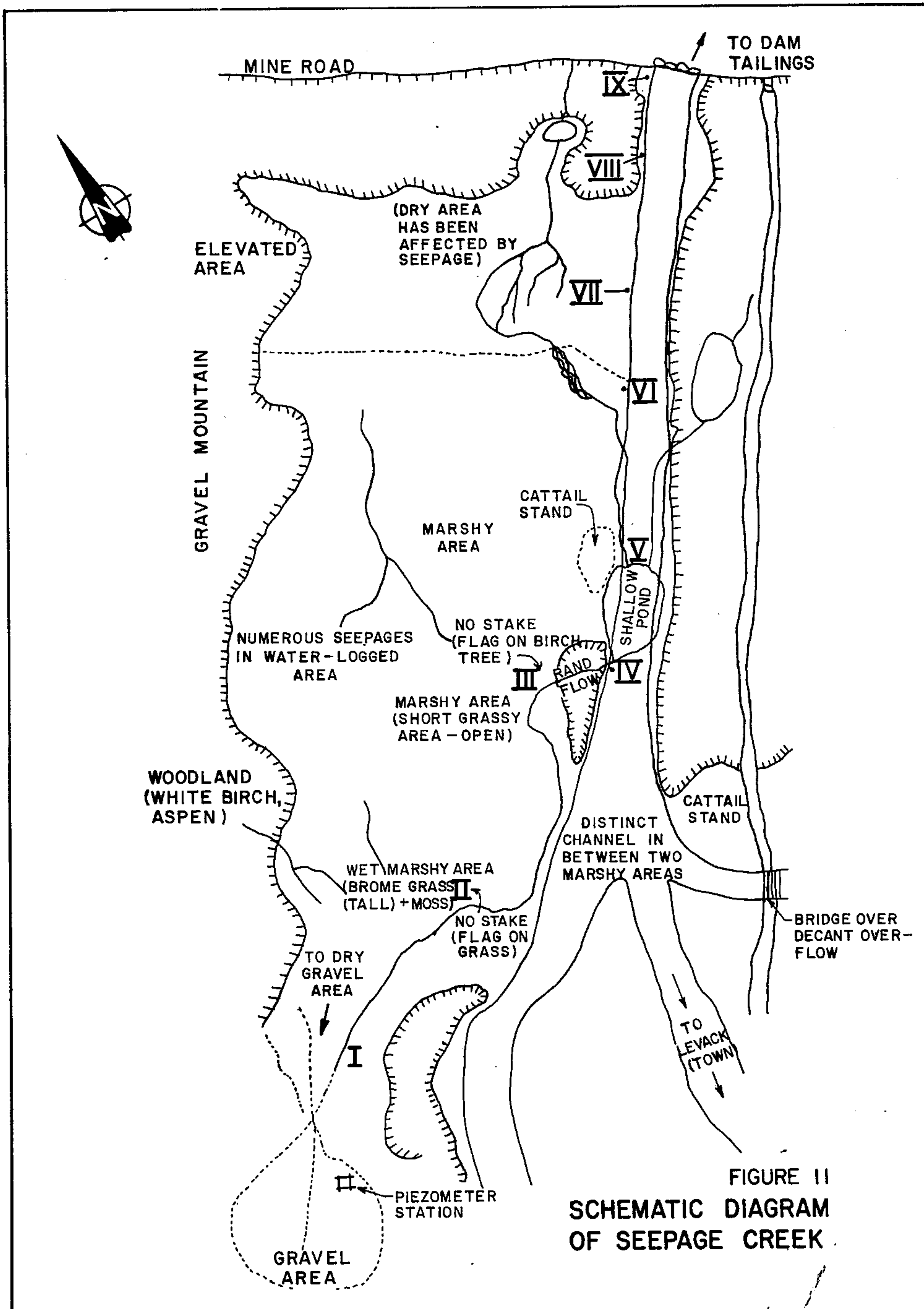


FIGURE 11
SCHEMATIC DIAGRAM OF SEEPAGE CREEK

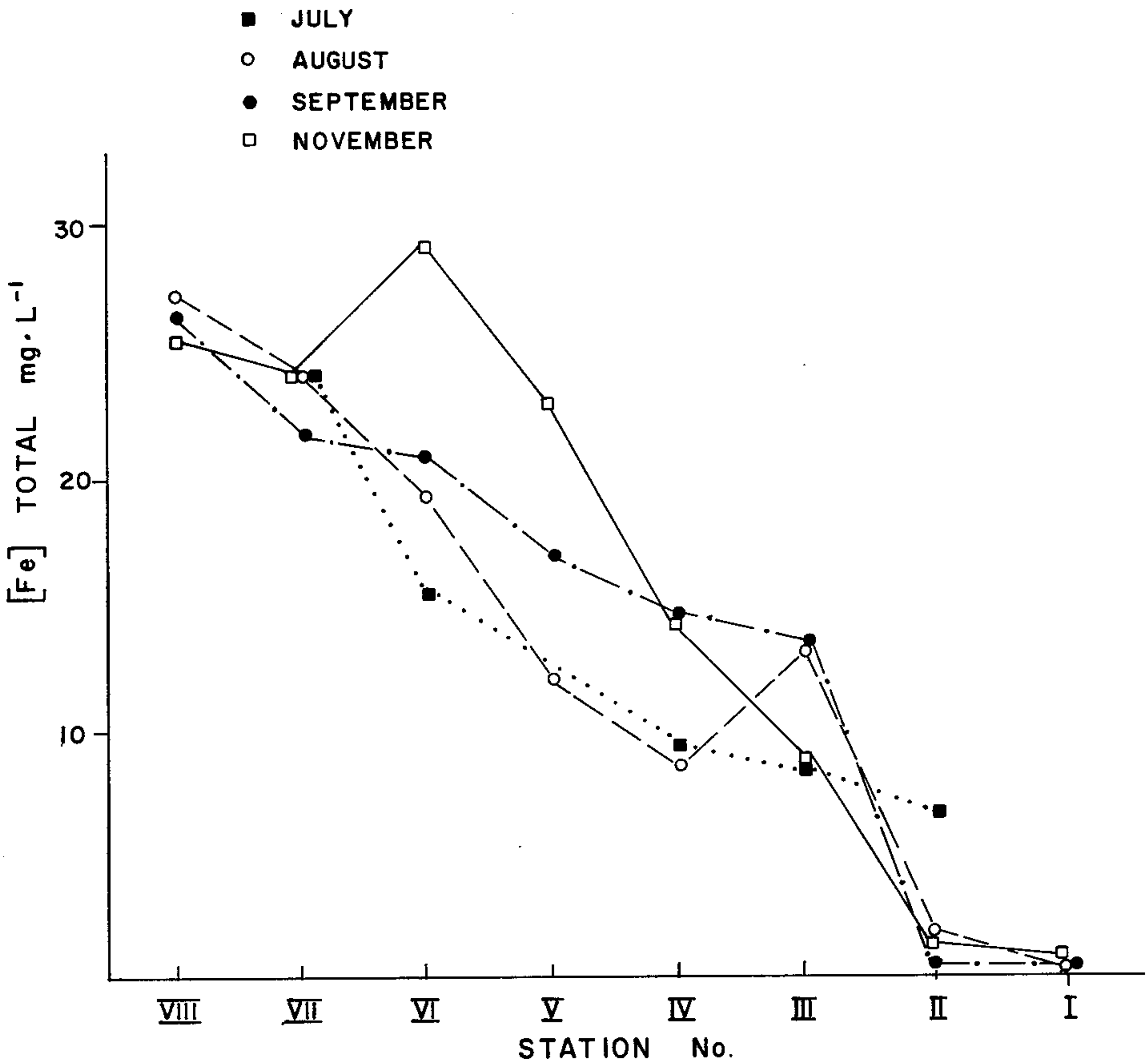


FIGURE 15

SEASONAL CHANGES IN TOTAL IRON ALONG THE SEEPAGE CREEK

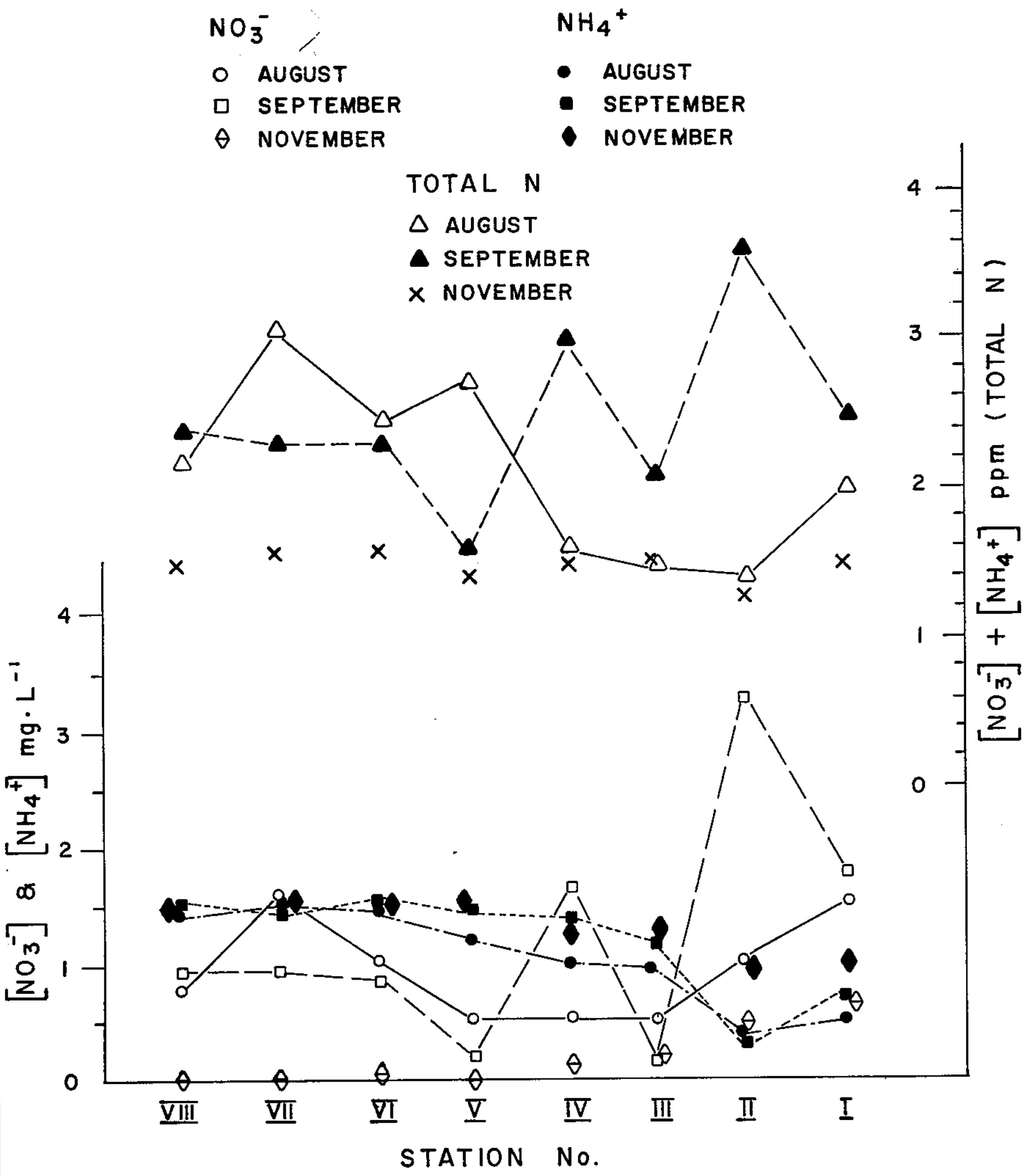


FIGURE 17

$[NO_3^-]$, $[NH_4^+]$ and TOTAL NITROGEN IN SEEPAGE CREEK WATER

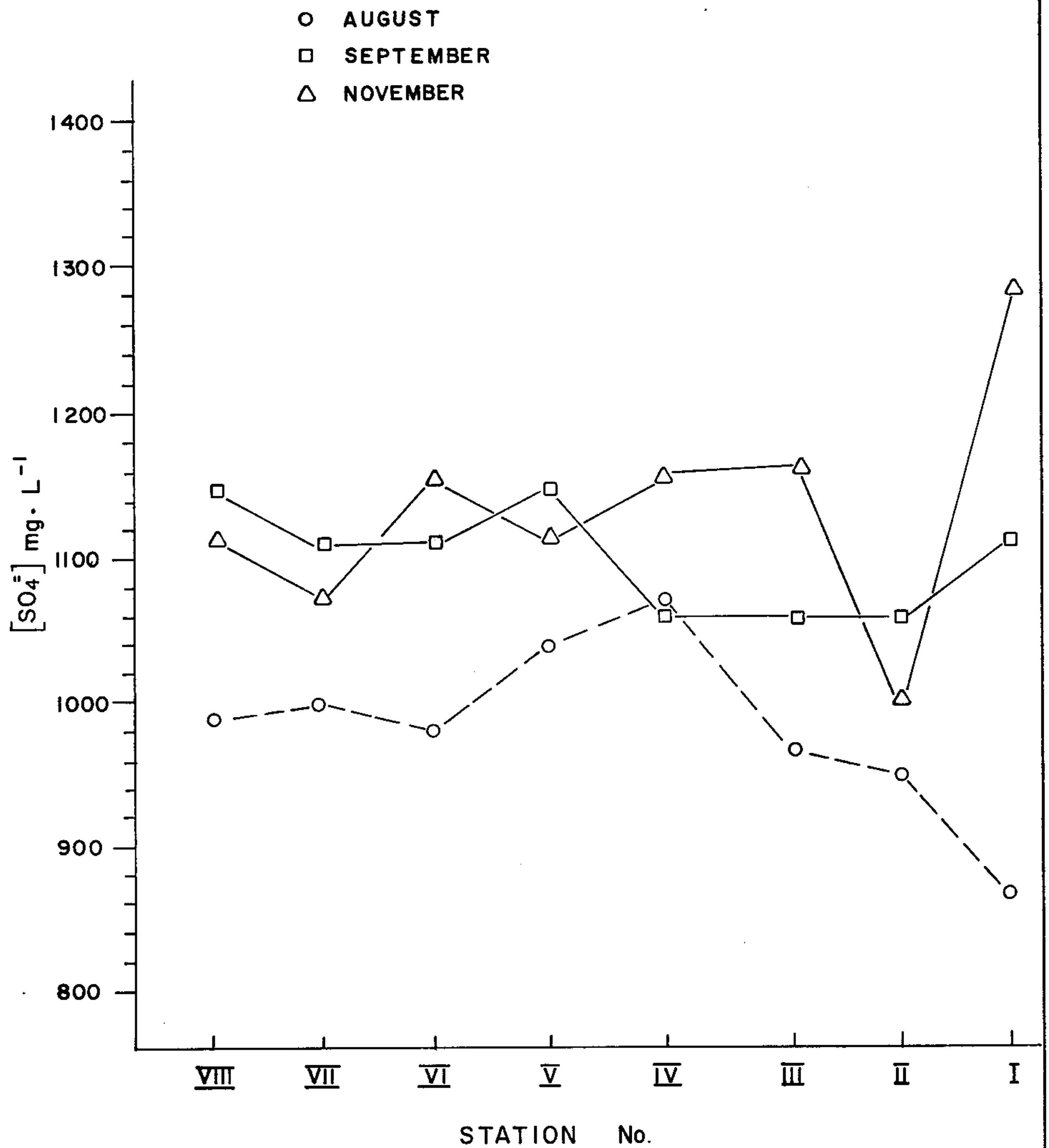


FIGURE 16

CONCENTRATION OF $SO_4^{=}$ IN WATER AT SEEPAGE CREEK STATIONS