Boojum Research Limited

A RESEARCH APPROACH TO THE LONG TERM MANAGEMENT OF ACID MINE DRAINAGE AT LA MINE DOYON

by

M. Kalin

for

B. Morrison

LAC Minerals Ltd.

<u>in fulfillment of P.O. #15212</u>

November 30, 1987

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SUMMARY

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Acid mine drainage from mining wastes presents an economic and environmental liability at present and for the future. It is therefore a problem which requires a concerted research and management effort in order to arrive at an economically and environmentally acceptable solution.

It is proposed that through an integration of waste management and research remedial measures can be determined which will ameliorate the waste water problem in the short and long term. All essential aspects of acid generation and treatment of waste water are addressed in this proposal with a focus specifically on conditions encountered at La Mine Doyon. Through the application of a hydrological model for all components of the waste management area, remedial actions are evaluated with respect to their effects on the environment.

The waste management system incorporates research on the fundamental processes which may lead to the reduction of acid mine drainage. The chemical reaction rates of oxidation are addressed which determine the time-frame in which these waste materials are reactive. Methods of acid mine treatment are evaluated with the objective to optimize water quality of effluent and recycle water for extraction. Options for sludge disposal are considered in the short and long term.

The first year of the program concentrates on extensive site investigations of the North and South waste rock piles and their drainage ditches and

treatment plants; the settling and polishing ponds; the tailings area and its seepages; the Ancien Reservoir and Le Chemin Bousquet. A hydrological assessment of the area bordered by Lac Chassignolle and La Riviere Bousquet including the sub-drainage basins within the waste management area will be carried out. Existing background information on water monitoring data will be evaluated prior to the field investigations to narrow and focus the data collection during the year.

Experiments will be implemented in year two, based on the findings and hypothesis formulated in the first year to determine the most appropriate remedial measures for the waste management system. After several years of monitoring and evaluation of the remedial measures taken, a compendium describing all important aspects in the management of acid generating wastes will be produced to serve as a manual to allow plant personnel to independently operate the system and use in future operations.

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1.0 INTRODUCTION

1.1 Why a Long Term Waste Management Approach?

Mining produces wastes and the management of these wastes is both an environmental and economic hazard. The environmental control that must be exercised is expensive with seemingly little tangible return on a required investment. Over the lifetime of a mine, waste management costs might fluctuate considerably, with environmental costs increasing drastically towards the end of the operation when reclamation measures for abandonment are mandatory. With the present state of technology, acid generating wastes demand maintenance in perpetuity.

It is possible today, as the result of past experience and an understanding of the problem of acid mine drainage, to implement measures during operation of the mine to curtail acid generation, thereby reducing both short and long term costs. However, a long term waste management strategy has to be devised which must be based on the practical experiences gained from other operations, together with intensive ongoing research. Ideally, what is sought is a treatment method which can be incorporated into the mine during operation and capsulized with a close-out factor which protects the environment over the long term at a cost which is not prohibitive to the industry at large.

1.2 Definition of Objectives

Lac Minerals requested that **Boojum Research Limited** develop a long term waste management strategy specifically for La Mine Doyon. **Boojum**'s first task therefore, was to define the objectives following a brief on-site investigation. The extensive list of objectives given below reflects the magnitude of the waste management area and its many components:

(i) Determine the reclamation measures for the abandonment of the tailings area, including final cover type, water quality and seepages.

(ii) Determine measures to improve recycle water quality from the tailings and from polishing pond Reservoir A.

(iii) Optimize and economize treatment of drainage water from waste rock piles both in the short and long term.

(iv) Address short and long term sludge disposal systems.

(v) Determine reliable estimates for acid generation rates in the North and South waste rock piles to arrive at realistic scenarios for the short and long term treatment options.

(vi) Determine remedial actions for the Chemin Bousquet and the Ancien Reservoir, addressing surface water and final close-out conditions.

(vii) Develop several configurations for the entire waste management area which would lead to a low maintenance or walk-away situation at the time of shut-down and close-out of operations in two to three decades.

At this stage, the objectives are broadly defined. After the first year of the proposed investigation, detailed information will be available on all components of the waste management area, the chemical and physical characteristics, together with the operational parameters. At that time it is possible that the list of objectives will be quite different in specific format and content.

1.3 How to Achieve the Objectives?

Defining the objectives within the problem area of acid mine drainage is much like creating a 'wish list'. The more complex problems arise in the identification of those problems inherent in each objective and the creation of a tool for use in solving same. It is important to bear in mind that the overall objective is that of managing the waste materials in a cost effective manner, both short and long term, i.e. during operation and following shut-down. It was decided that the most effective tool, to provide a framework for defining and analysing the various components of waste management system, would be a waste management model - one that would be capable of evaluating the short and long term effects of the proposed measures, while simulating the entire system and each of its components.

Each component of the site has to be described within the context of the problem(s) it presents. Problem areas have to be defined specifically for the site, and these should be presented in the context of up-to-date technology. From a technical point of view, therefore, the following areas have to be addressed:

Reduction of the acid mine drainage produced

- reduction of water oxygen contact
- reduction of microbial acid generation
- reduction of available surfaces for oxidation

Acid mine treatment methods

- chemical neutralization of acid
- biological reduction of acid

Sludge production

- chemical stability of sludge
- sludge disposal methods

Chemical reaction rates

- oxidation rates of pyrite/pyrrhotite
- acid base balance of waste material
- retention and release of contaminants

These technical aspects are all part and parcel of the acid mine drainage problem for which there is at present no simple or easy solution. The nature of the acid mine drainage process is so technically and scientifically complex that its management requires a multi-disciplinary approach.

1.4 The Company - BOOJUM RESEARCH LIMITED

During six years of research on uranium mill tailings at the University of Toronto, **M. Kalin** recognized, through her exposure to environmental problems in mining, that focused research was needed to develop methods which would lead to a self-maintaining walk-away situation for waste management areas. With the support of the mining industry (Rio Algom, Denison, Falconbridge, Inco, Alcan, BP-Selco, Kidd Creek, and others), and government agencies such as CANMET Biotechnology and the National Research Council, the company has been able to pursue focused research in this area over the past 4 years.

Experiments have been carried out on various mining properties. These have led to the development of Ecological Engineering and Biological Polishing methods, presently being implemented as the abandonment measure on an acid generating lead/zinc concentrator. A detailed description of these methods and the objectives can be found in **Appendix A.** The work is carried out by a research team under the supervision of **M. Kalin**, Research Director. The other members of the team include **Dr. Robert van Everdingen**, who specializes in geochemistry of sulphur products and hydrology; **Dr. Tom Peters**, the father of reclamation technology in Canada, who has been instrumental in assisting **Boojum Research** in areas of reclamation and in focusing the direction of the research; **Dr. Alex Buchnea**, with expertise in physics, computer modelling, mathematics, system analyses and their application to waste management; and **Tim Edwards**, mill operator and metallurgist, who provides an understanding of mining and milling processes and their associated chemistry, making it possible to determine the precise characteristics of the wastes.

The work is carried out with the help of a small staff of fulltime research assistants, M.P. Smith and R. Chan, and on the mine sites, summer students and mining company personnel provide important backup. A review of the company profile, in **Appendix A**, will highlight **Boojum**'s almost exclusive focus on waste management problems associated with hard rock mining. **Boojum** has combined the experience of senior persons in reclamation with the experience gathered from other mining operations and workers in the field. It has been possible, because of the determined single-mindedness of the company's research goals, to integrate the technologies presently under development in each of the defined problem areas. In this way, the remedial measures to be undertaken can be determined and implemented in a geochemical context, i.e. at the very root of the problem.

2.0 WASTE MANAGEMENT OBJECTIVES AND THEIR RESPECTIVE RESEARCH TASKS

It was recognized that finding a solution to the problem of acid generating waste material, focusing on the site specific needs of La Mine Doyon, would be a challenging undertaking, particularly when the ultimate objective of the research program was an effective final close-out many decades in the future.

The approach finally decided upon involved a technical review of the state of the art of the problem areas of acid mine drainage, with an emphasis on the available site specific information. In short order it became apparent that the problems encountered bore an intimate relationship to one another. It was decided therefore, for the sake of clarity, to identify the objectives to be achieved, delineate the tasks to be performed in connection with each, and then to present the technical background for each problem area.

This section, therefore, is a brief overview of the seven objectives defined in the introduction, and an association to each of the tasks to be performed. The section following presents the technical details which led to the task definitions.

(i) Determine the reclamation measures for the abandonment of the tailings area, including final cover type, water quality and seepages.

Investigate the causes leading to acid generation on the west side of the tailings, compared to the conditions on the east side.

Assess the potential for development of biological polishing systems for the seepages from the tailings area.

(ii) **Determine measures to improve recycle water quality from the tailings and from polishing pond Reservoir A.**

Evaluate the existing monitoring data of both waste waters in detail, to determine the relationships which affect water characteristics. Carry out detailed field investigation of North Treatment system particularly Reservoir A. Following these analyses, formulate a testable hypothesis in light of extraction requirements and confirm the results by way of experimentation.

Evaluate the potential applications of the "*Chara* process" as a polishing step and close-out scenario for the tailings area.

(iii) **Optimize and economize treatment of drainage water from waste rock piles both in the short and long term.**

Carry out a systematic seepage survey through one full season for the North and South waste rock pile ditch system to identify the locations at which acid generation is most active. Based on this information, design a test program to reduce fluctuations in the water characteristics of the water to be treated.

Investigate the physical conditions of the waste rock piles in detail and determine the locations where focused experimentation can be carried out to determine the acid generation processes in these waste rock piles (sulfur and oxygen isotope abundances, temperature measurements, groundwater and pore water) in the years to follow.

Investigate the chemical parameters which control the effectiveness of the waste water treatment process through analysis of monitoring data and evaluation of the North and South treatment plant operations. This investigation will lead to a practical test program in which the treatment of acid mine drainage water is controlled by those parameters which determine waste water quality.

(iv) Address short and long term sludge disposal systems.

Carry out an evaluation of the sludge disposal options including sludge ponds on waste rock piles, disposal in open pit, disposal in ditch systems, dewatering and the production of products from the sludge with a useful end use (neutralization of AMD, fertilizers or soil amendments). Determine the chemical and physical characteristics of the existing sludge and its behaviour. Based on this evaluation, recommend measures to improve sludge characteristics and reduce the sludge volume produced.

(v) **Determine reliable estimates for acid generation rates in the North and South waste rock piles to arrive at realistic scenarios for the short and long term treatment options.**

Evaluate acid generation rates and their theoretical assumptions for the temperate climate. Assess oxidation rate controlling parameters of the process from a geochemical dynamics point of view. Evaluate sulphate fluxes which might be predicted for the waste rock piles, and relate those to the results obtained from the seepage survey of the ditches for both waste rock piles and the Chemin Bousquet.

Utilize all available information in waste rock research, e.g. that carried out by Equity Silver, to interpret the acid generation process in waste rock, based on the analysis of existing temperature measurements and thermography.

Investigate locations on the Chemin Bousquet which appear to be non-acid generating, compared to acid generating locations, to formulate reasons for the differences. These differences could be extremely useful in elucidating the ongoing processes.

A conceptual evaluation of thermography as a predictive tool for active areas of acid generation in waste rock piles and the open pit should be carried out prior to any application of the method. It is sought to accomplish this by way of discussions with experts in various agencies.

Based on the scientific and empirical data synthesis, develop options for the control of acid generation which are to be tested on site, both on Chemin Bousquet and the waste rock piles.

(vi) **Determine remedial actions for the Chemin Bousquet and the Ancien Reservoir, addressing surface water and final close-out conditions.**

Carry out a feasibility study for the use of ecological engineering methods at Le Chemin Bousquet and in the Ancien Reservoir to develop an environmentally acceptable self-sustaining close-out condition for these areas.

Determine the potential of utilizing microbiological processes resulting in acid reduction, which are presently being tested by Boojum at other mining operations, with respect to their applicability to the Ancien Reservoir and Chemin Bousquet.

(vii) **Develop several configurations for the entire waste management area which would lead to a low maintenance or walk-away situation at the time of shut-down and close-out of operations in two to three decades.**

The CHINTEX model will be used to examine and systemize all available data influencing the environmental impact and obtain an understanding of the interaction of the various components of the mine/waste management/environment system.

Further, the model will be used to focus the data gathering activities by identifying the data gaps and the environmentally sensitive parameters.

3.0 THE SITE INVESTIGATION AND REVIEW OF BACKGROUND INFORMATION

3.1 Site History

In February, 1984, the first phase of underground development was started at the Doyon joint venture which, by the end of the year, resulted in stockpiles of about 22,000 tons of high grade ore (0.145 oz/t), and 635,000 tons of low grade ore. By 1985, 52 million tons of ore and waste were mined, producing 860,000 ounces of gold. Ore from Doyon was also processed at East Malartic and Terrains Auriferes. In April, 1986, expansion of the open pit was undertaken and production started. In 1987, a new shaft was completed to 2,050 feet for mining the west zone. The mill will be expanded from 1,650 tpd to 3,300 tpd by late 1987.

Two types of acid generating wastes have been accumulated on site waste rock and tailings. Their mineral composition can be said to contain about 3.5% pyrite with a minor amount of chalcopyrite. The host rock is composed of quartz, felsphathoids, micas, chlorite and carbonates. Some magnetite is reported. This mineralogy indicates some neutralization potential in the waste material. Based on the mineralogy, the acid generation from the pyrite appears to be the major long-term environmental problem.

3.2 Field Investigation

Two days were allocated for the site investigation by **M. Kalin**, assisted by a technician. The magnitude of the site, together with the intricate nature of the treatment system, only allowed for a superficial assessment. The overview produced by **B. Morrison** was very helpful in determining the focus of the field investigation. The concentration was on the collection of as many measurements of pH and electrical conductivity as possible so that an approach to waste management could be formulated for the various components of La Mine Doyon.

3.2.1 Environmental Aspects of Tailings

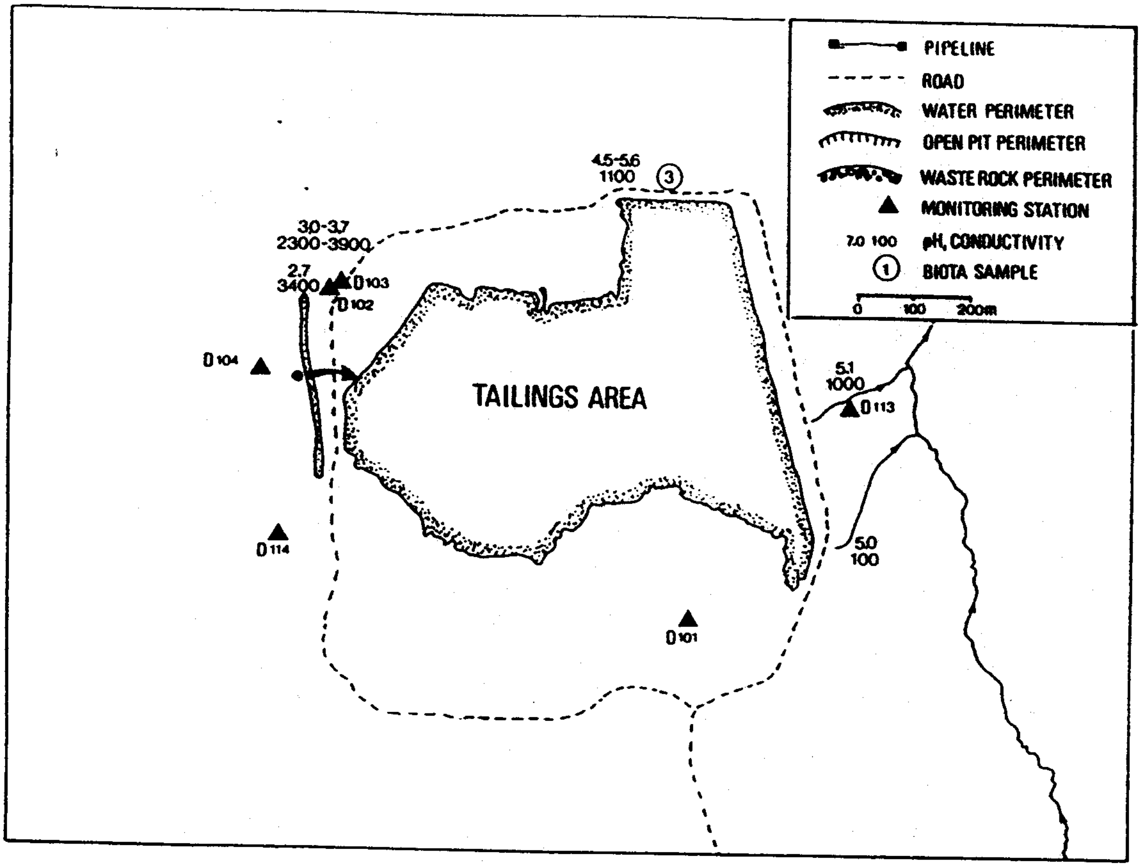
The perimeter of the tailings was described and pH and electrical conductivity measurements taken in water associated with these areas. The ranges of values, given in **Map 1**, are placed in approximately the areas in which they were measured. A detailed listing of the measurements is given in **Table 1**.

LOCATION Date: Sept 1-2, 1987	pH	cond umhos/cm	temp deg. C
SEEPAGE AREA 1 (north-west corner of tailings)			
Ditch near D102	2.70	3400	13
Same, further north	2.95	3900	13
Another seepage near D102	3.25	2300	12
Ditch by Final Effluent	3.70	2700	12
Same, green puddle	3.65	3100	12
SEEPAGE AREA 2 (center of north side of dyke)			
Flow from foot of dyke	5.60	1000	12
Flow into large pool	4.50	1100	11
Far side of pool	4.65	-	-
Pump Station D113	5.05	1000	11
Large flooded area	*5	102	-

* pH meter acting up

Table 1. Tailings area seepages.

The water which emerges from the west dam is acidic, whereas, on the other sides, the water is only slightly acidic to neutral. The seepage from the west dam emerges at pH 2.7 to 3.7, with conductivity ranging from 2,700 to 3,900 umhos/cm. The seepage around the corner, i.e. of the north side of the dam has a strong flow, with pH 5.6 with a conductivity of only 1,000 mhos/cm. The waters remain in this more neutral range with lower conductivities for all other seepages found during the investigation around the remaining sections of the tailings dam (**Table 1, Map 1**).



Map 1. Sampling areas around the tailings perimeter with pH and conductivity ranges.

Based on a summary of the monitoring data available from 1986 and 1987, the observations made during the field investigation are in concert with the chemical composition of D104 and D113. It is assumed that D113 is sampled as indicated on the blueprint map which was received and reviewed and is not the water originating from the small creek (Table 2) running at a distance parallel to the dam. The mean value and the range of both Fe and SO_4 are much larger for the east side of the dam than for the seepage on the west side.

	Sample Number: D104 West Dike					Sample Number: D113 East Dike				
	MIN	MAX	MEAN	STD	N	MIN	MAX	MEAN	STD	N
pH	2.70	3.92	3.17	0.33	9	4.74	7.48	6.29	0.91	9
Fe (mg/l)	3.54	420	103.61	124.82	8	1.27	25	7.39	7.26	8
SO4 (mg/l)	650	3000	1220	893.08	5	260	500	397	86.81	5

Table 2. Comparisons of sampling stations D104 and D113 for concentration ranges of iron and sulphate and ranges of pH.

Time trends in pH and Fe concentrations in these two stations are given based on the monitoring data in **Figures 1 and 2**. Although the data points are sparse, the seasonal behaviour of the two stations is quite different. The pH has been decreasing steadily in Station 104, whereas in Station D113, the seasonal pattern appears to reflect run-off in autumn and recovery during the summer. In Station D113, no increases of iron are noted over the two years, whereas it is clear that in Station D104, the iron concentrations are increasing somewhat (**Figure 2**). This suggests that acid generation is occurring on one side of the tailings and not on the other.

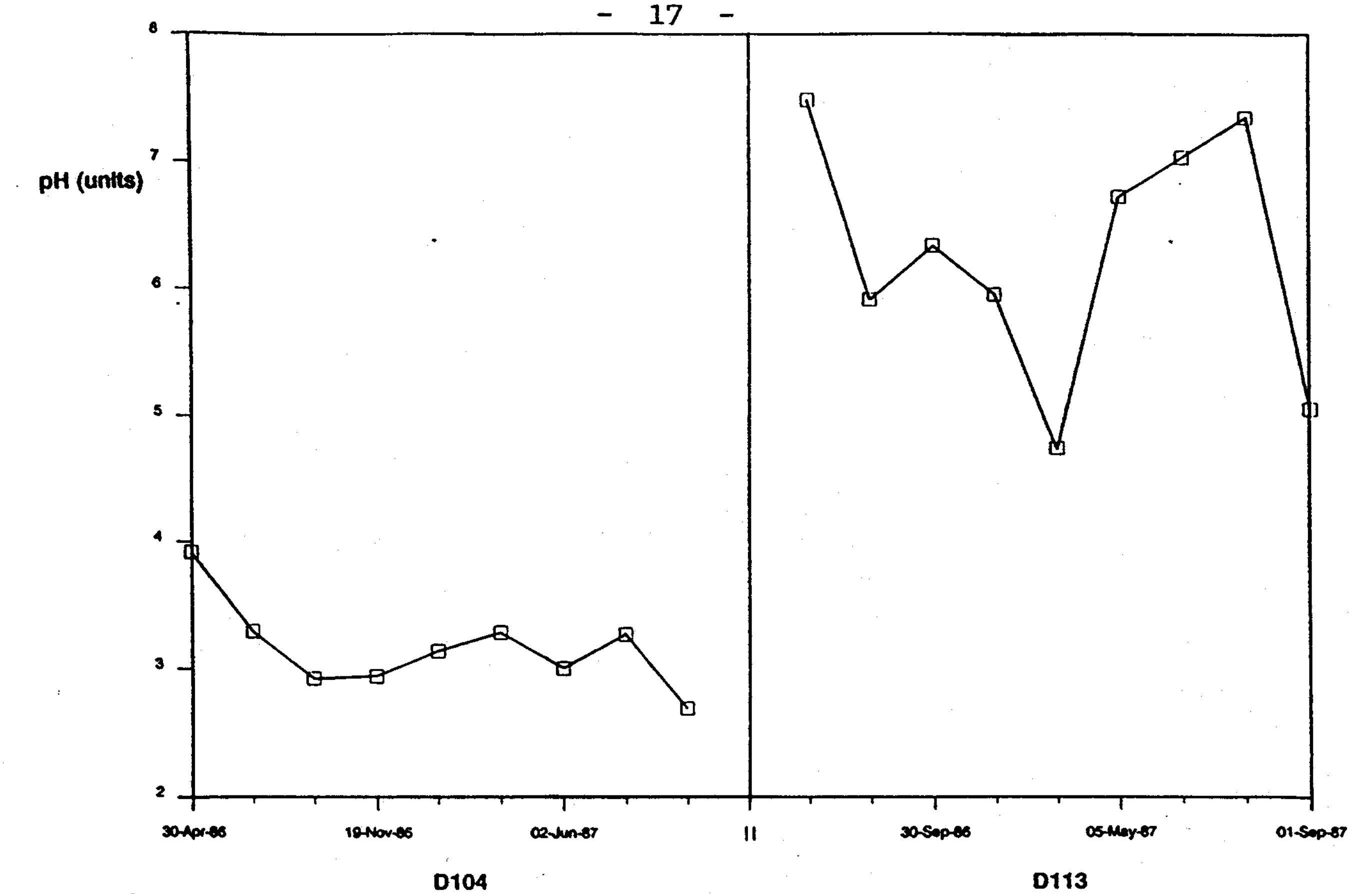


Fig. 1. Tailings (D104 and D113) pH values for 1986-1987.

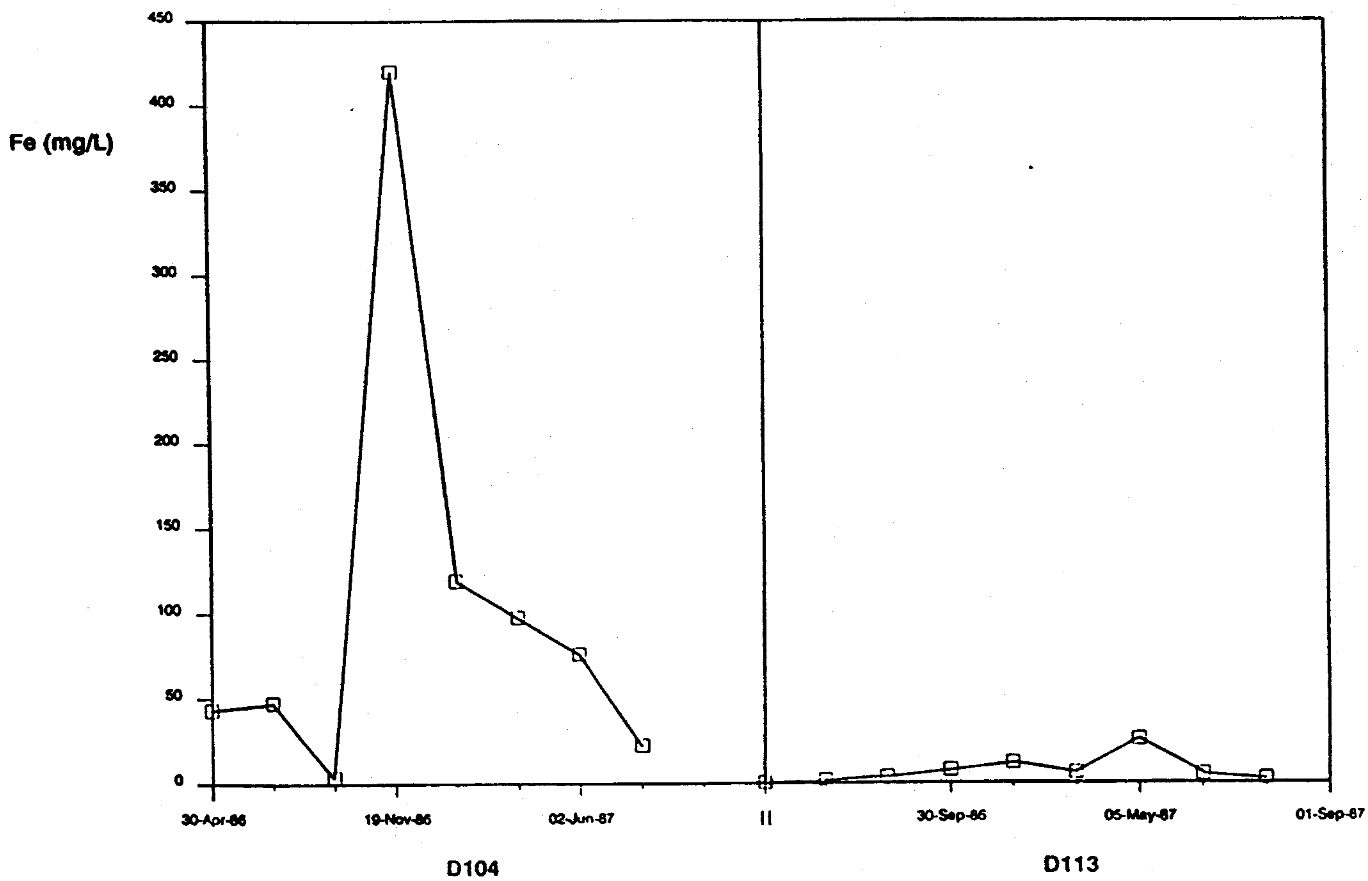


Fig. 2. Tailings Fe concentration for 1986-1987.

By approaching the site from a systematic, analytical point of view, remedial actions can be planned on a sound basis when placed in a research context. For example, it is generally believed that water covered tailings produce considerably less acid, and some people consider under water disposal or ponding a solution to acid mine drainage. Most of the tailings area at Doyon is covered by water which is retained for natural degradation of cyanide, and is to be recycled. This water is, according to the annual report, around pH 9-11. Clearly, in this case, even though the retained water on the tailings is very alkaline, acid generation is noted from the East side of the water covered tailings.

These seepage characteristics suggest that the general belief that water cover on tailings curtails acid mine drainage is not entirely correct.

From the recent work on oxygen and isotope composition of the product sulphate, there is reason to believe that ground water carrying oxygen moving through the tailings can result in acid generation, despite a water cover (**Kalin and van Everdingen**, 1987, and **van Everdingen and Krouse**, 1987). This might be the case on the east side of the tailings site and not on the west side, thus providing the cause of the difference in the seepages.

These conditions and causes behind the seepages have to be addressed within the proposed waste management program. This will lead to remedial measures for close-out of the tailings area and scientifically founded design of the new tailings area.

Most dams, no matter how efficient their design, start seeping at some point in time. Seepages are ideal places for the development of a biological polishing system to improve water quality leaving the site. Work aimed at developing such systems is underway on INCO and BP-Selco properties.

The survey of the dam perimeter included a search for the biota which can be used as biological polishing agents. Their presence was a primary requirement for the development of such systems for La Mine Doyon. Suitable organisms were found at a location identified with biota Sample 3 on Map 1. The most abundant algal type in this periphytic attached algal jelly was the diatom *Navicula* spp. The clumps of precipitate and amorphus organic material also contained relatively abundant *Oscillatoria limnetica* and *Microsposa*. Some tychoplankton was present in the form of *Euglena, Chlamydomonas* and *Nitzschia*. Those species belong to the same group as those used in our present experiments and which have been found in many other locations.

Although only one site was located where these biota were present, their presence is a good indicator of the possibility of developing a polishing system with these indigenous species for seepages from the existing tailings area.

3.2.2 Recycle water quality

A tailings area in a gold operation has not only to function as a waste disposal site, but often also as a treatment plant for cyanide degradation. Most operations are required to recycle water from the tailings retention, the quality of which is important for the extraction process. Although at this stage we are not familiar with the process water requirements for the mill, the monitoring data indicate potential extraction problems in the future. Similar problems have been highlighted by **Hope (1984)** in relation to recovery of gold.

In **Table 3**, the ranges of pH, iron and total cyanide are given for 1986 to 1987. The ranges are clearly quite large, indicating large fluctuations. Since natural degradation is controlled by pH and other factors, a time trend analysis of these parameters might disclose some aspects which might be at the source of the problem. A comparison of the trends of pH and total cyanide over time, presented in **Figures 3 and 4**, suggests that as the pH increases, the total cyanide concentrations increase. This relationship is expected from the dissociation behaviour of cyanic acid. However, it appears that iron concentrations are increasing in 1987 (**Figure 5**). Although the concentrations of iron are more erratic, that correlation is less clearly expressed. Nevertheless, from February on, as the total cyanide concentration dropped drastically, the pH started to decrease, as did the iron concentrations. The formation of metal complexes of cyanide are possibly involved in the changing water characteristics of the pond.

Further analysis of the data is suggested in approaching this problem to lead to methods which provide better treatment of the retained water, thus providing better recycled water and improved effluent characteristics.

	Sample Number: D103 Recycle water				
	MIN	MAX	MEAN	STD	N
pH	7.93	12.90	10.51	1.17	62
Fe (mg/l)	0.07	9.11	1.19	1.88	61
CN Total	0.8	246	89.01	64.47	67

Table 3. Comparisons of iron, cyanide (total) and pH for recycle water.

Boojum Research has been working on the development of the "*Chara* process" with NRC and CANMET. One of its applications is intended for the improvement of water quality in retention ponds for natural degradation in gold mines with high alkaline pH (Kalin and Smith, 1986, Kalin and Smith, 1985). Thus, some experience has been gained with water quality in these ponds, which might be useful to the situation at La Mine Doyon and in future tailings pond design.

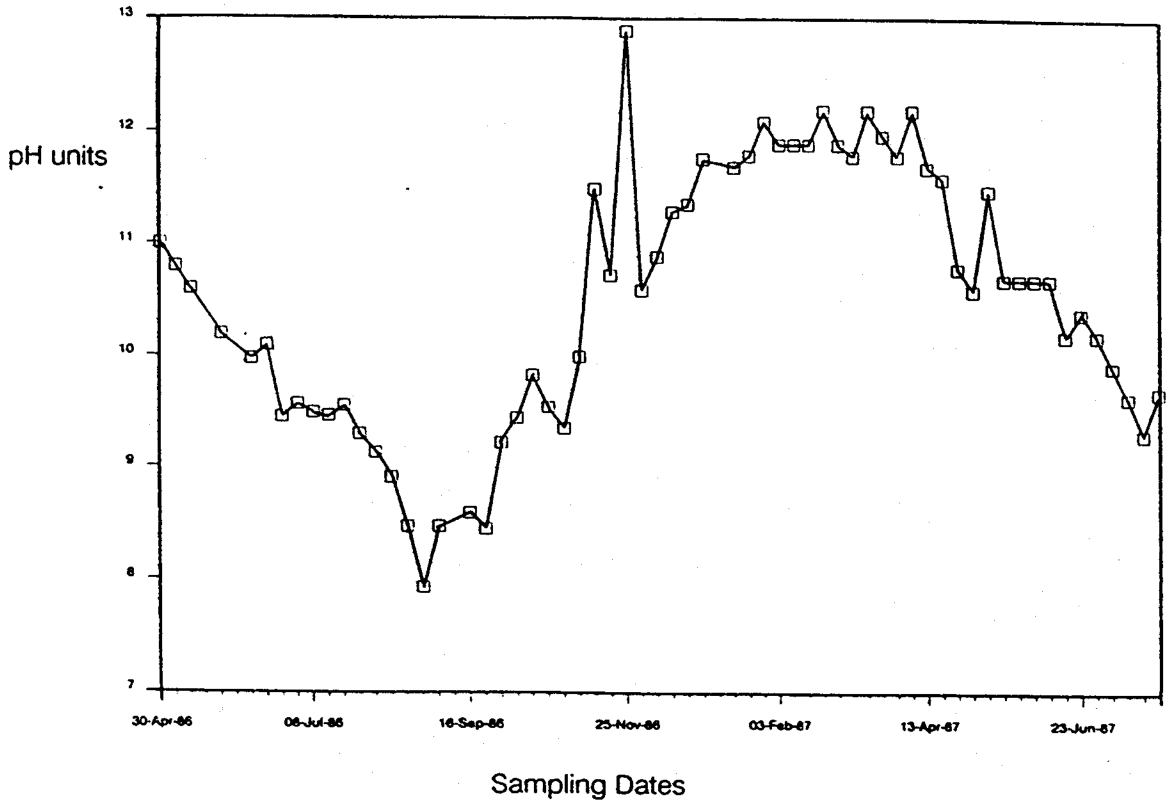


Fig. 3. Recycle water (D103) pH values for 1986-1987.

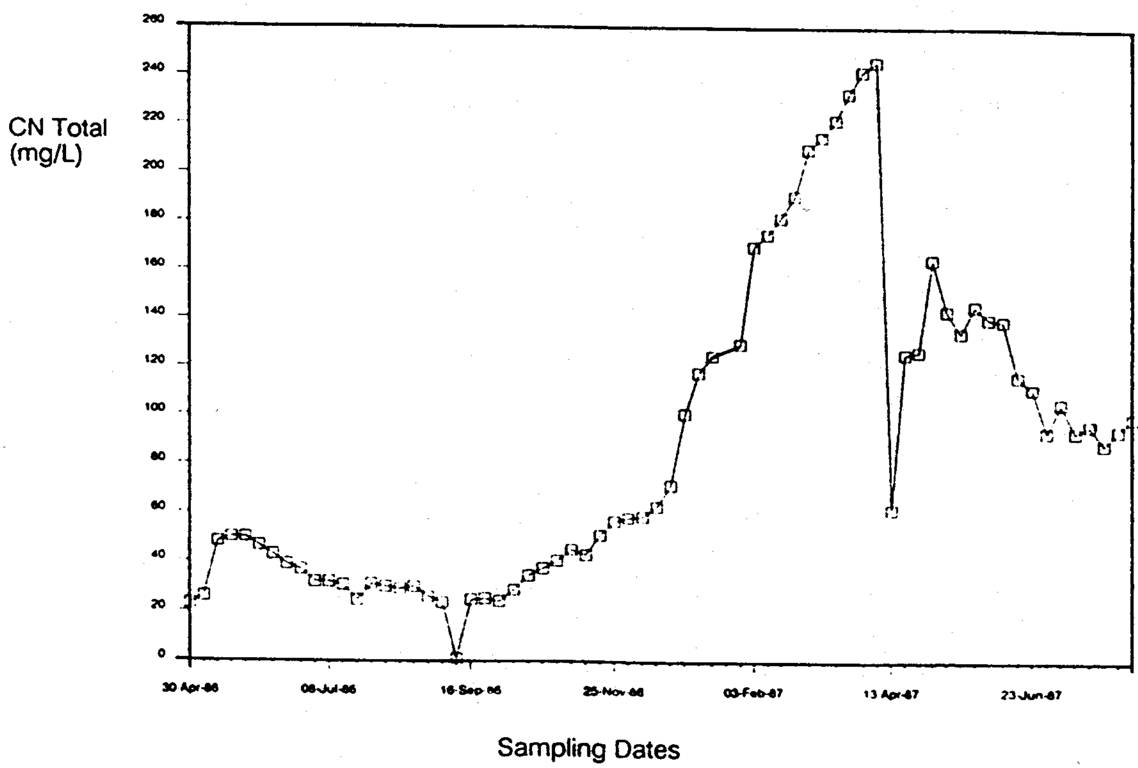


Fig. 4. Recycle water total CN concentration for 1986-1987.

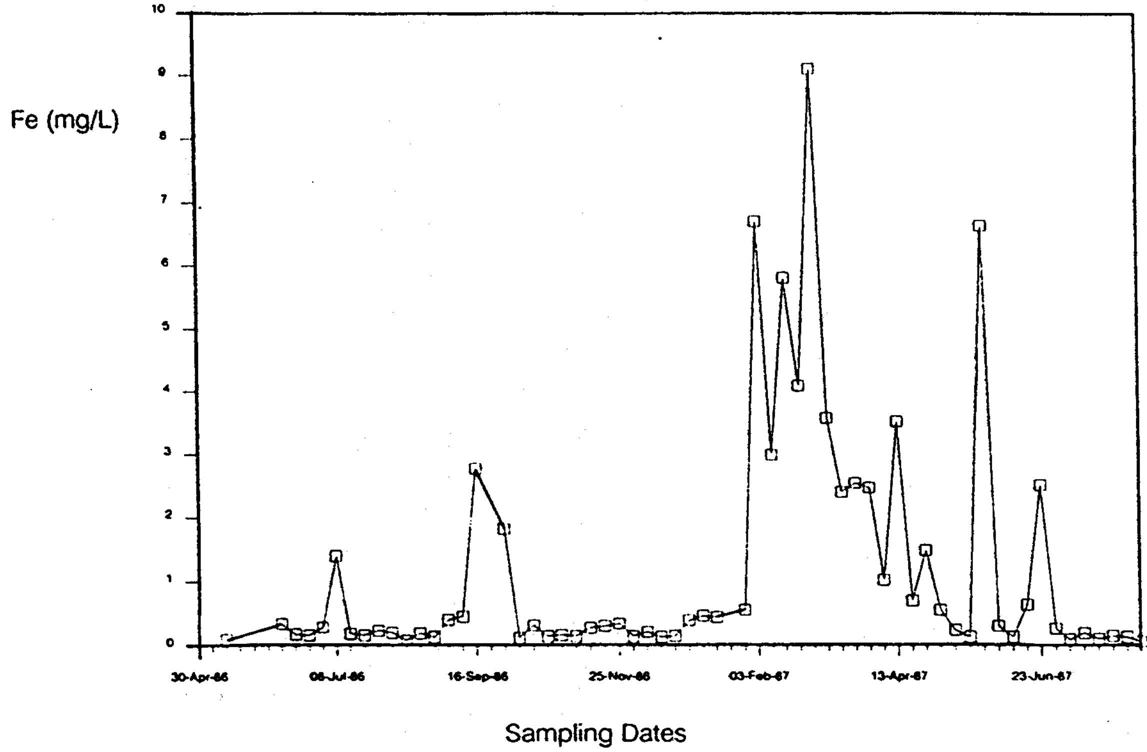
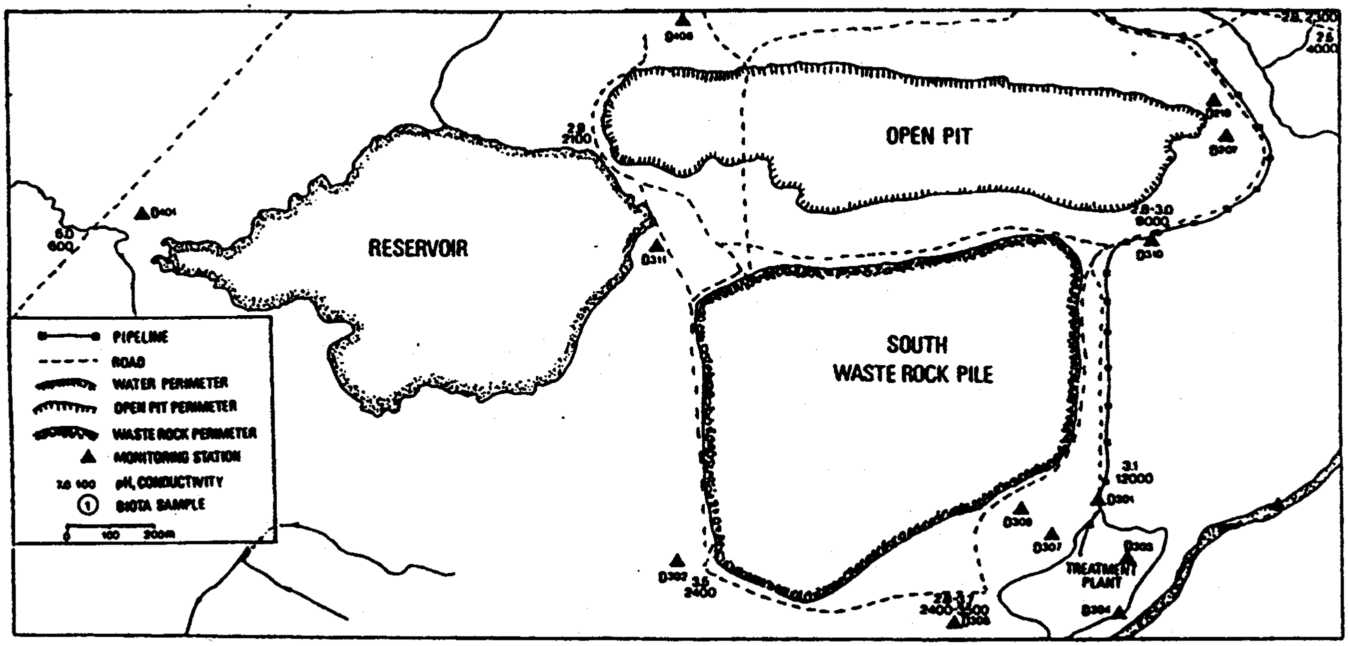


Fig. 5. Recycle water Fe concentration for 1986-1987.

3.3 TREATMENT PLANTS NORTH/SOUTH

3.3.1 South treatment plant

During the field investigation, pH and conductivity were measured in the ditch system around the South waste rock pile to describe the water which is treated in the South treatment plant. In Map 2, the general location at which the measurements were taken is indicated by giving the range of values obtained. The striking feature of these measurements is the difference in electrical conductivity between the values on the east and the west side of the waste rock pile. A detailed listing of the values is given in Table 4, where it can be noted that although the pH on both sides is generally the same, ranging between 2.75 to 3.5, the west side exhibits much higher conductivity ranges with 9,000 to 12,000 umhos/cm^2 compared to the east side with ranges from 2,100 to 3,500 umhos/cm^2. This observation suggests that the characteristics of the sampling stations D301 and D302 should be compared, as both represent the water treated at the South treatment plant. In **Table 5**, these two stations are compared for the key characteristics of acid mine drainage. As expected, the iron and sulphate concentrations are indeed drastically different by an order of magnitude. From the field investigation, it appeared that the flows at these two sampling stations are also not in the same order of magnitude. In fact, these two streams appear to have a different seasonal behaviour when the data are plotted over time (**Figures** 6 and 7). At D301, the drainage ditch on the west side, iron appears to be relatively constant from April to August, and remains lower during the winter months, increasing again as the warmer summer months approach. For station D302 however, the iron concentrations are constantly low throughout the year (**Figure** 6). That the ongoing processes of acid mine drainage are not reflected by the pH values of the water is demonstrated by **Figure** 7, where pH is plotted for the same two waste streams. The pH is slightly higher in station D302 than D301, but no large seasonal changes are noted.



Map 2. Drainage system around the South Waste Rock Pile with Openpit and Old Reservoir.

LOCATION	pH	cond umhos/cm	temp deg. C
WEST SIDE:			
NEAR D310			
Before puddle, running H2O	2.75	9000	13
In large puddle	2.95	9000	12
NEAR D301	3.05	12000	12
EAST SIDE:			
NEAR D308			
In freshly worked earth	3.40	2800	12
NEAR D308			
Resevoir H2O, after pumping	2.75	2400	13.5
Culvert	3.65	3500	12
D302	3.45	2400	13
RESEVOIR			
Red seep. into lake	2.75	-	-
Lake	2.90	2100	12

Table 4. pH and conductivity measurements around the South Waste Rock Pile.

	Sample Number: D301 Acid Water before Liming Station					Sample Number: D302 Old Processed Water Reservoir and Drainage Ditch					Sample Number: D303 Settling Pond E Overflow					Sample Number: D304 Final Effluent - Polishing Pond D Overflow				
	MIN	MAX	MEAN	STD	N	MIN	MAX	MEAN	STD	N	MIN	MAX	MEAN	STD	N	MIN	MAX	MEAN	STD	N
pH	2.16	2.51	2.33	0.09	11	2.68	4.16	3.11	0.40	12	3.65	12.00	8.45	3.23	20	3.13	6.81	3.99	0.79	36
Fe (mg/l)	100	14869	7690	4950	11	2.57	183	71	56	12	<0.1	250	21	56	20	0.45	70	10	13	36
SO4 (mg/l)	9000	58000	41657	15285	11	200	4000	1268	1051	12	1600	9250	2895	1537	20	1700	3750	2208	464	16

Table 5. Concentration ranges of iron and sulphate and ranges of pH for the South Treatment Plant.

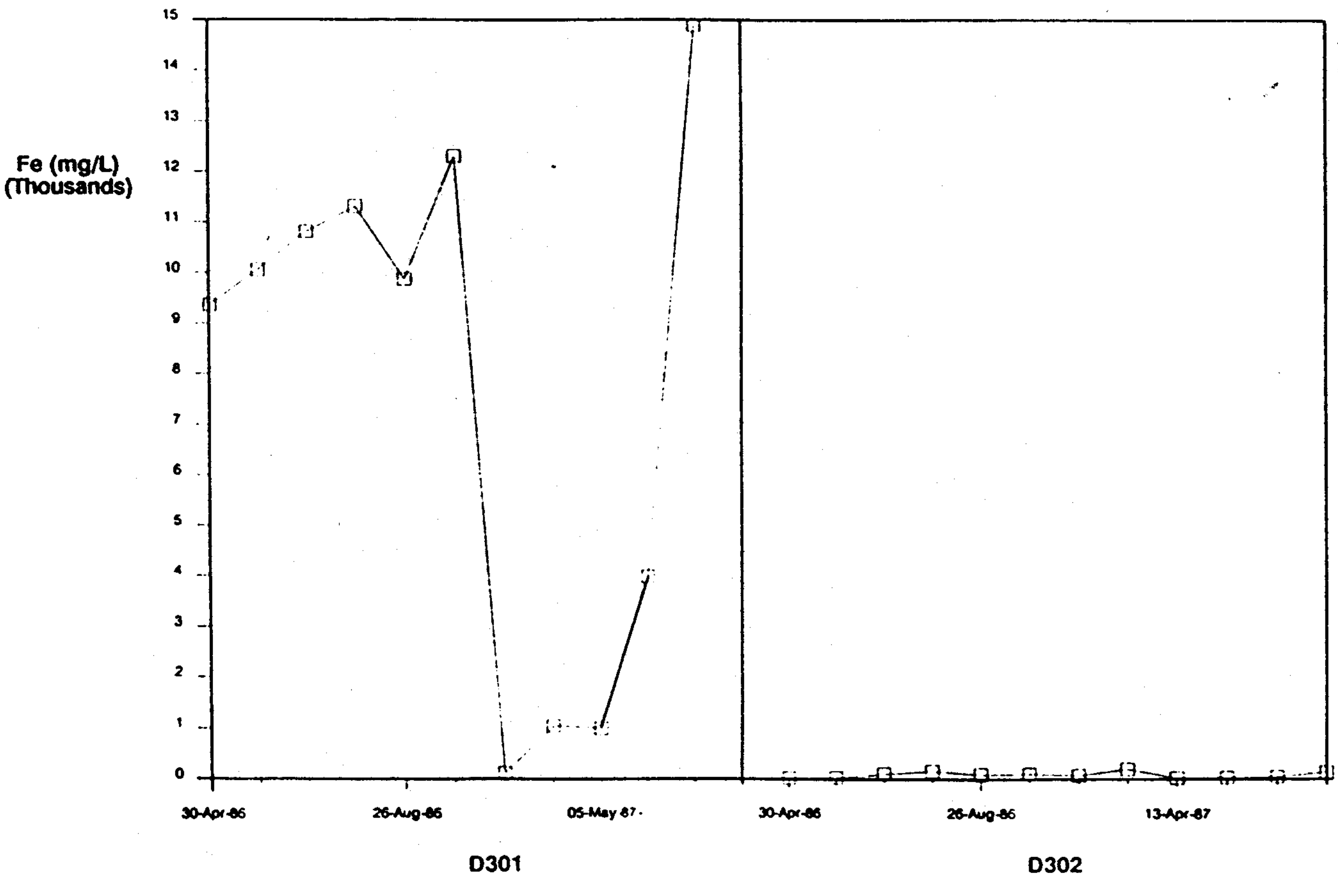


Fig. 6. Fe concentration of the South Treatment Plant (D301 - D302).

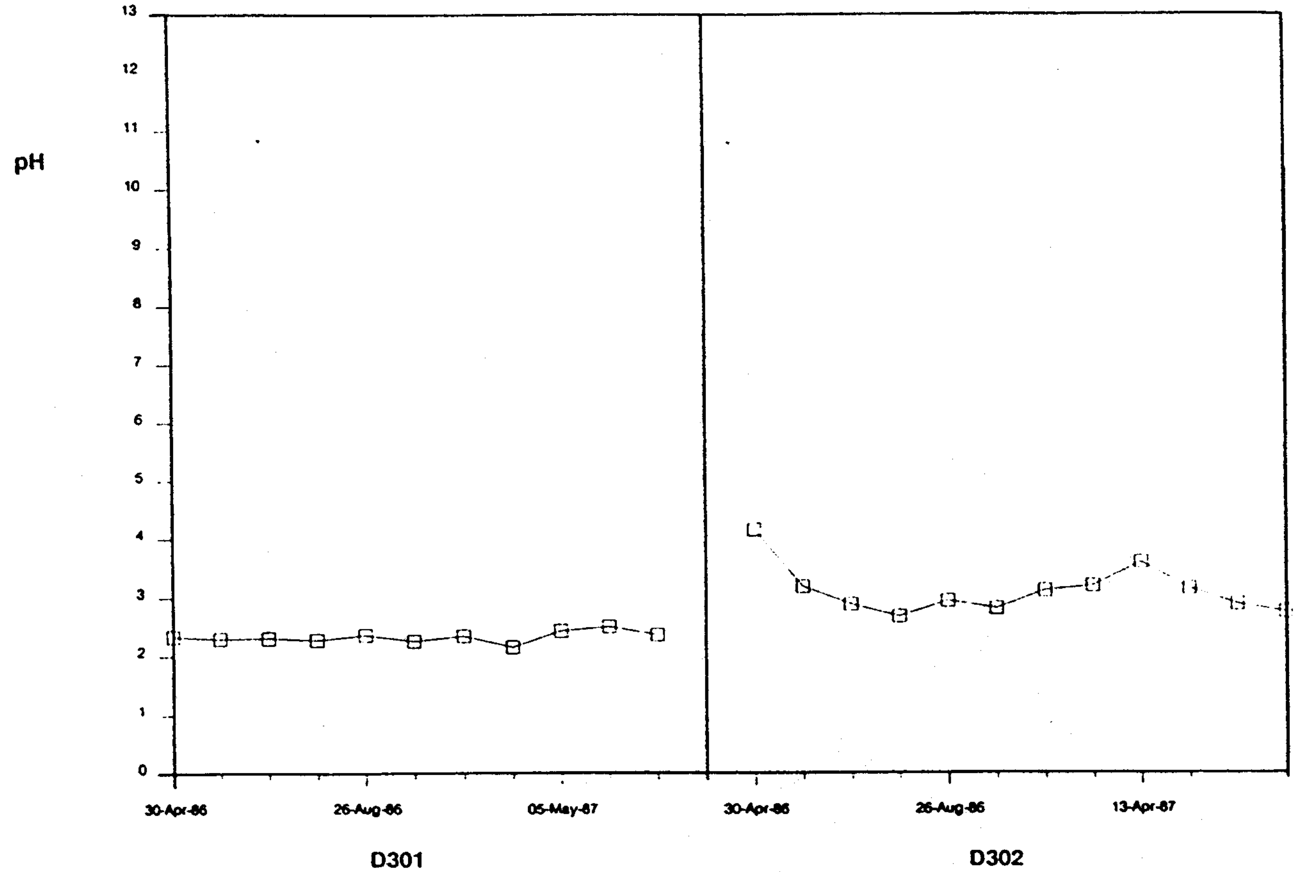


Fig. 7. **pH values of the South Treatment Plant (D301 - D302)**

From these considerations of the monitoring data alone, it is anticipated that the treatment plant treating both waste streams will have difficulty producing a consistent effluent quality (Table 5, Stations D303 and D304). The activity of the treatment system is evident in the pH behaviour exhibited in **Figure 8**. The polishing performance of the pond (station D304) in **Figure 9** is not reflected in the effluent characteristics. Comparing the iron concentrations for the same stations, presented in **Figure 9**, indicates that although the iron is removed after treatment in the polishing pond, iron fluctuations in the two ponds are not related.

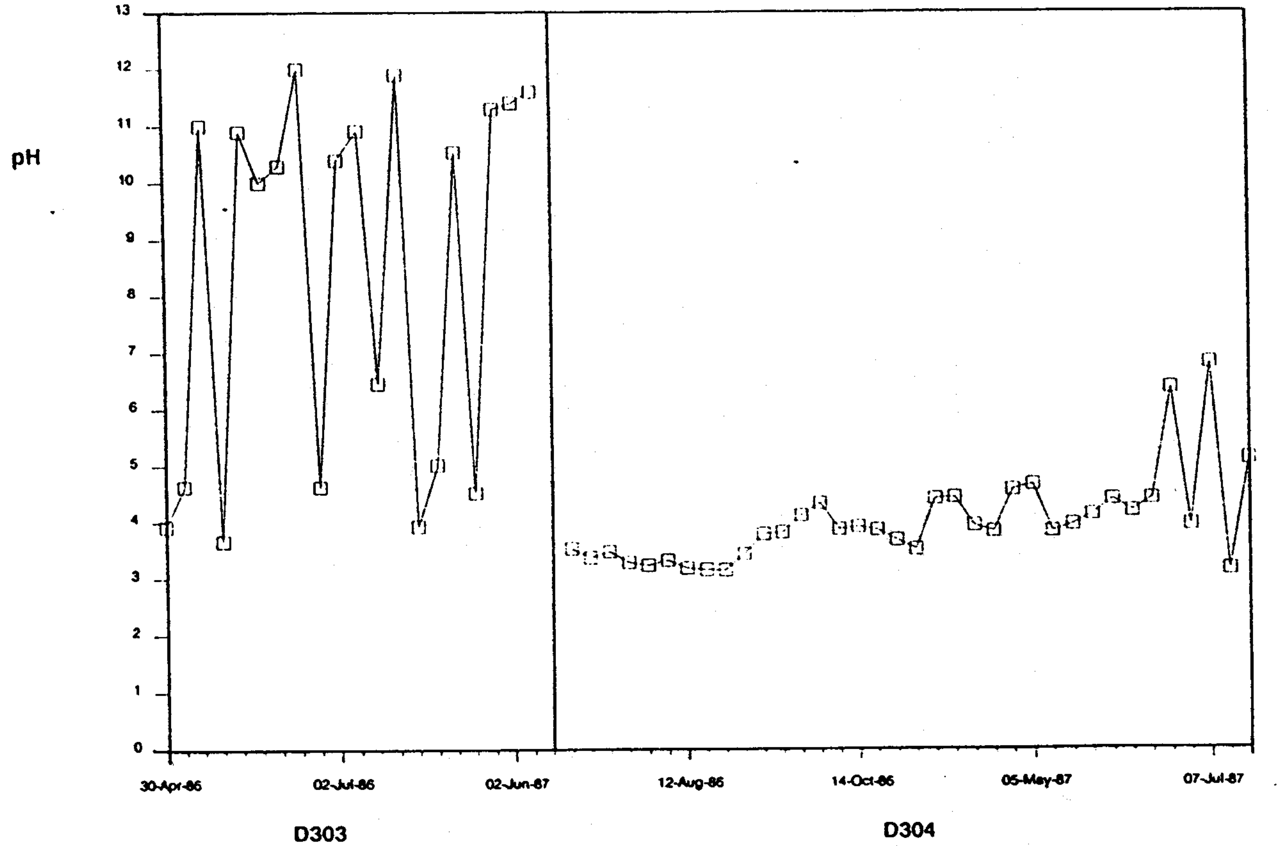


Fig. 8. pH values of the South Treatment Plant (D303 - D304)

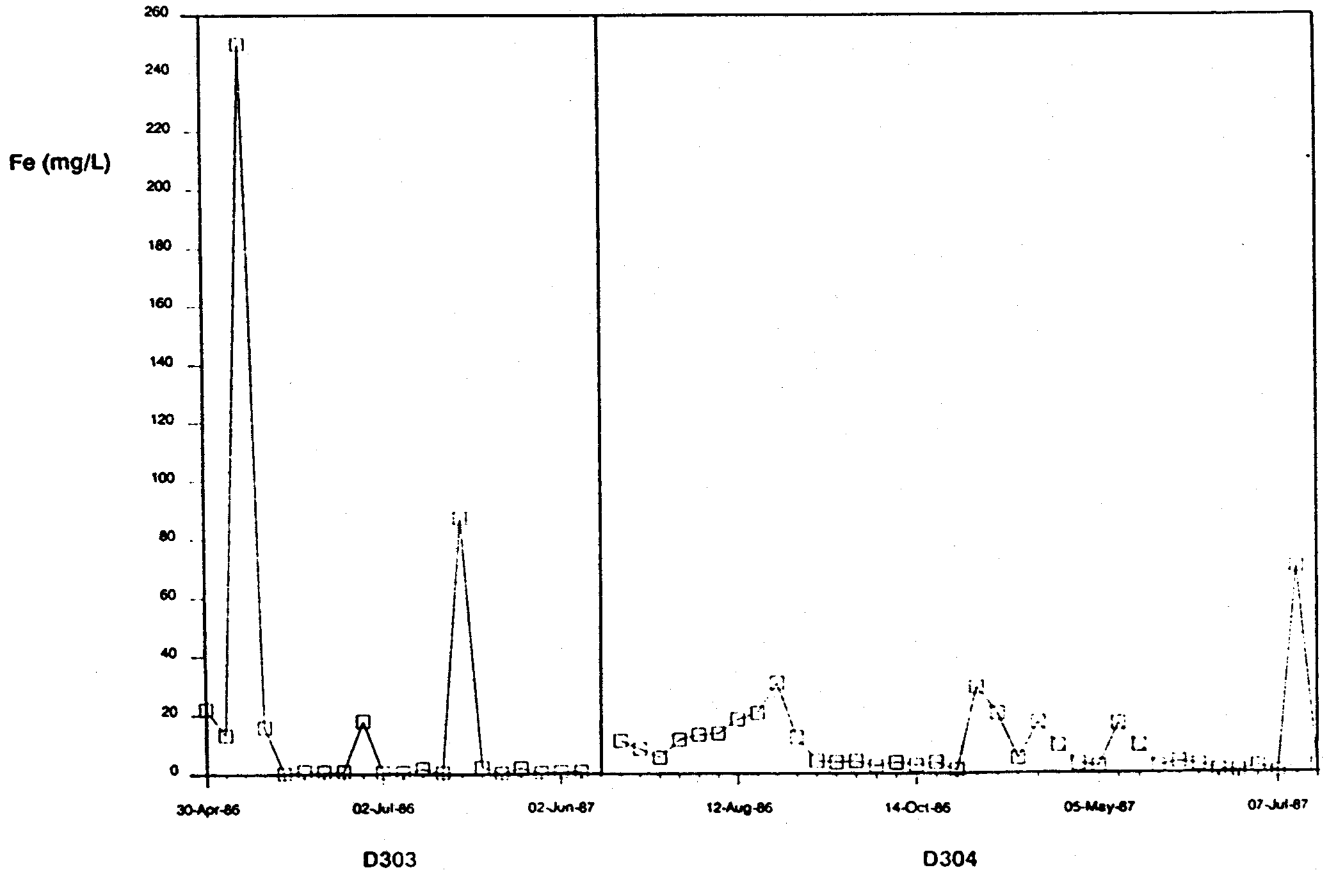


Fig. 9. Fe concentrations of the South Treatment Plant (D303 - D304).

It follows that an understanding of the processes which occur is fundamental to the effective treatment of these waters. Two principal areas of investigation emerge: (i) the origin of the difference between the two waste streams to be treated (D301 and D302) which are related to the waste rock, the open pit and the Ancien Reservoir; and (ii) the effectiveness of the neutralization of the water, followed by the polishing steps at stations D303 and D304.

3.3.2 North treatment plant

The understanding gained during the field visit about this system was limited because the investigation was limited due to time constraints. From discussions we understood that the water in Reservoir A represents final effluent, as well as water pumped from the tailings for retention for use in the mill. Acidification had been noted in Reservoir A from a ground water source. This is of concern to the overall operation of the treatment system as well as to milling.

To demonstrate the usefulness of the scientific, systematic approach proposed in a waste management strategy, a brief analysis of the monitoring data available from 1986 and 1987 was carried out. In Table 6, the same parameters as previously used (iron, sulphate and pH) for the South treatment plant are summarized for the North treatment plant. From a comparison of the ranges of these values of the water to be treated, station D201 and the resultant treated water in Reservoir A (station D203), it is indicated that although pH and iron concentrations are changed in the treatment system, the sulphate concentrations are relatively unchanged. An interesting fact emerges from a comparison of the pH behaviour of the treated and untreated water (**Figure 10**), i.e. the incoming water is around pH 3, while the pH in the treated water fluctuates. Hydrogen ion concentrations affect the solubility of many compounds and it follows, therefore, that the water quality in Reservoir A will change as a result of these fluctuations. This leads to changes in the recycle water quality. The iron input into the treatment system however, is varied, which variation is more likely related more to the seasonable activity of the acid generation process than to the treatment (**Figure 11**).

	Sample Number: D201 Combined Acid Water before N. Liming Station					Sample Number: D203 Reservoir A Overflow				
	MIN	MAX	MEAN	STD	N	MIN	MAX	MEAN	STD	N
pH	2.65	3.33	2.85	0.17	12	3.75	11.70	8.29	1.43	65
Fe (mg/l)	123	1025	495	283	12	<0.05	36.70	1	5	65
SO4 (mg/l)	850	3800	2704	855	12	675	1800	1179	290	29

Table 6. Comparisons between stations D201 and D203 of the North Treatment Plant for ranges of iron, sulphate and pH.

This demonstrates that although the treatment of acid mine drainage water is generally based on pH values, the parameters which drive or control effective treatment of the water are not related to pH.

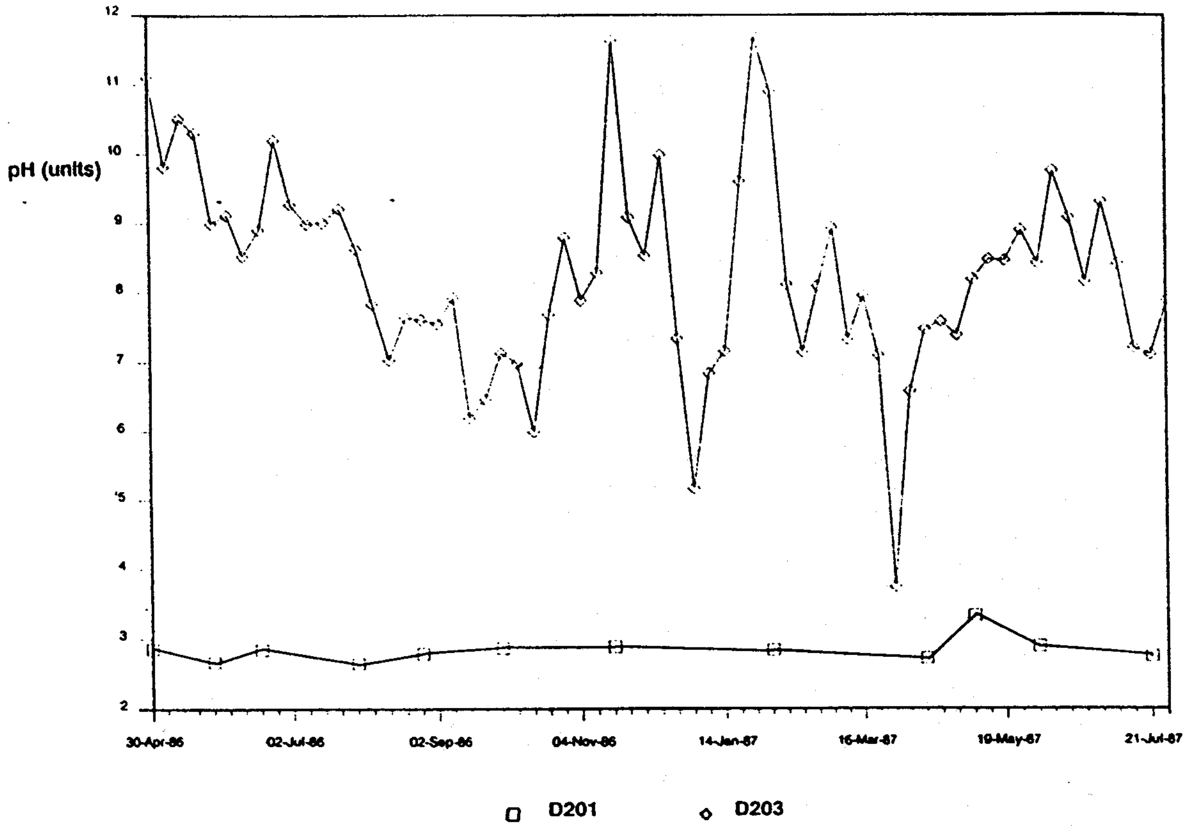


Fig. 10. pH values of the North Treatment Plant (D201, D203).

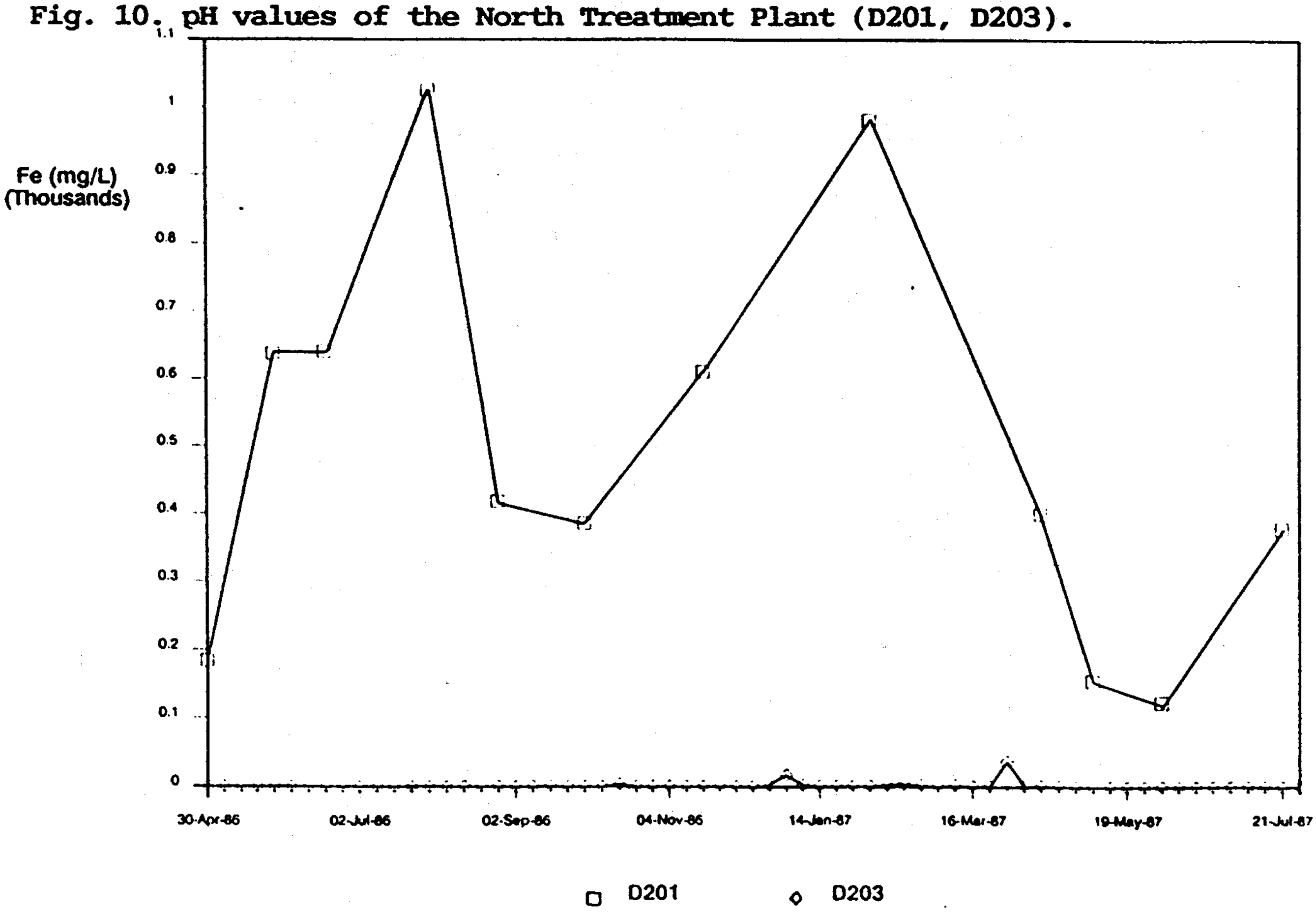


Fig. 11. Fe concentration of the North Treatment Plant (D201, D203).

To determine which parameters do control the water quality, particularly that required for the milling process, linear correlations of some of the important parameters might be a useful analytical tool. In **Figures 12** and 13, sulphate concentrations and pH values for these waters are correlated. A weak correlation is indicated at the lower hydrogen ion concentrations (treated water) (**Figure 12**) but this is not the case in the high range (untreated water) (**Figure 13**).

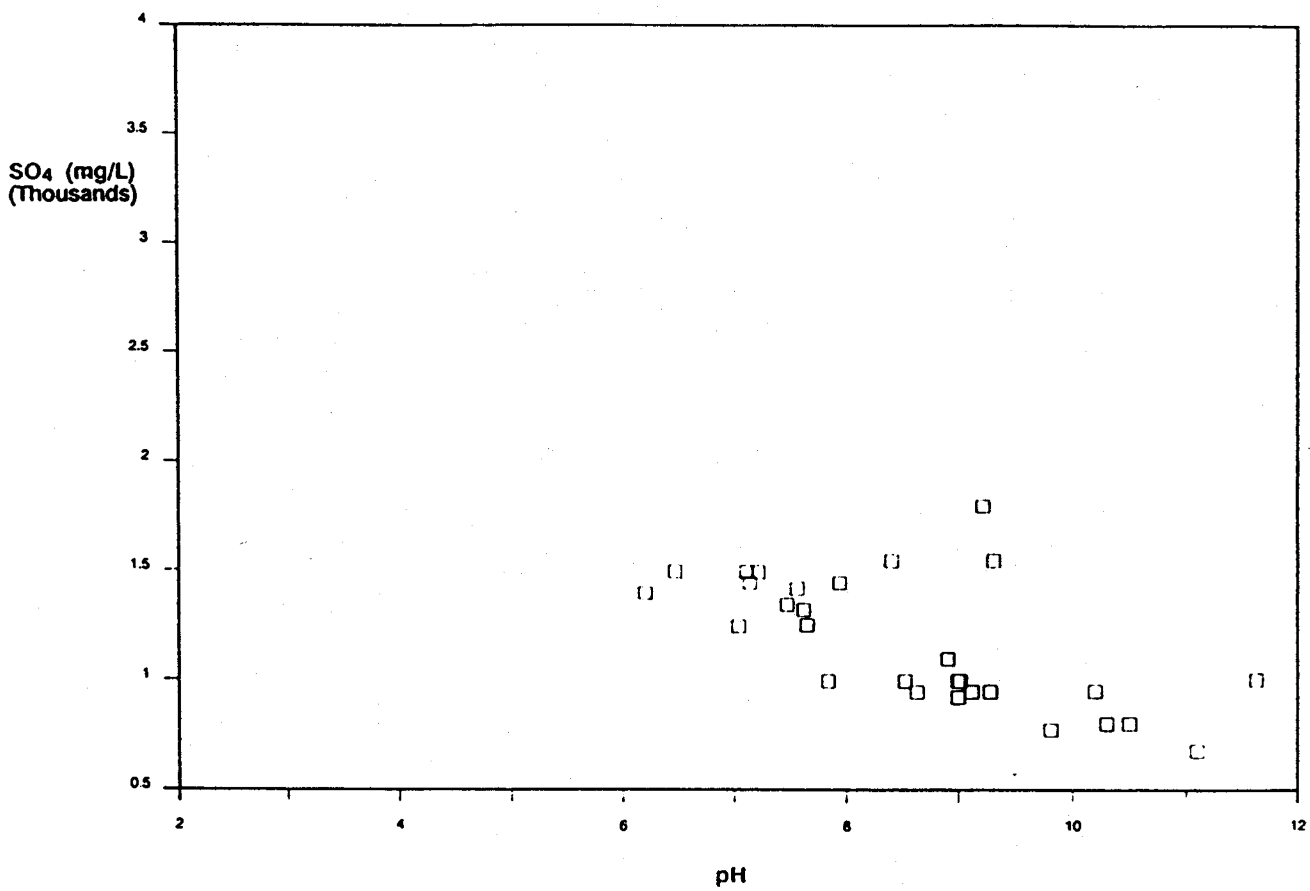


Fig. 12. Correlations of SO_4 and pH in the North Treatment Plant D203.

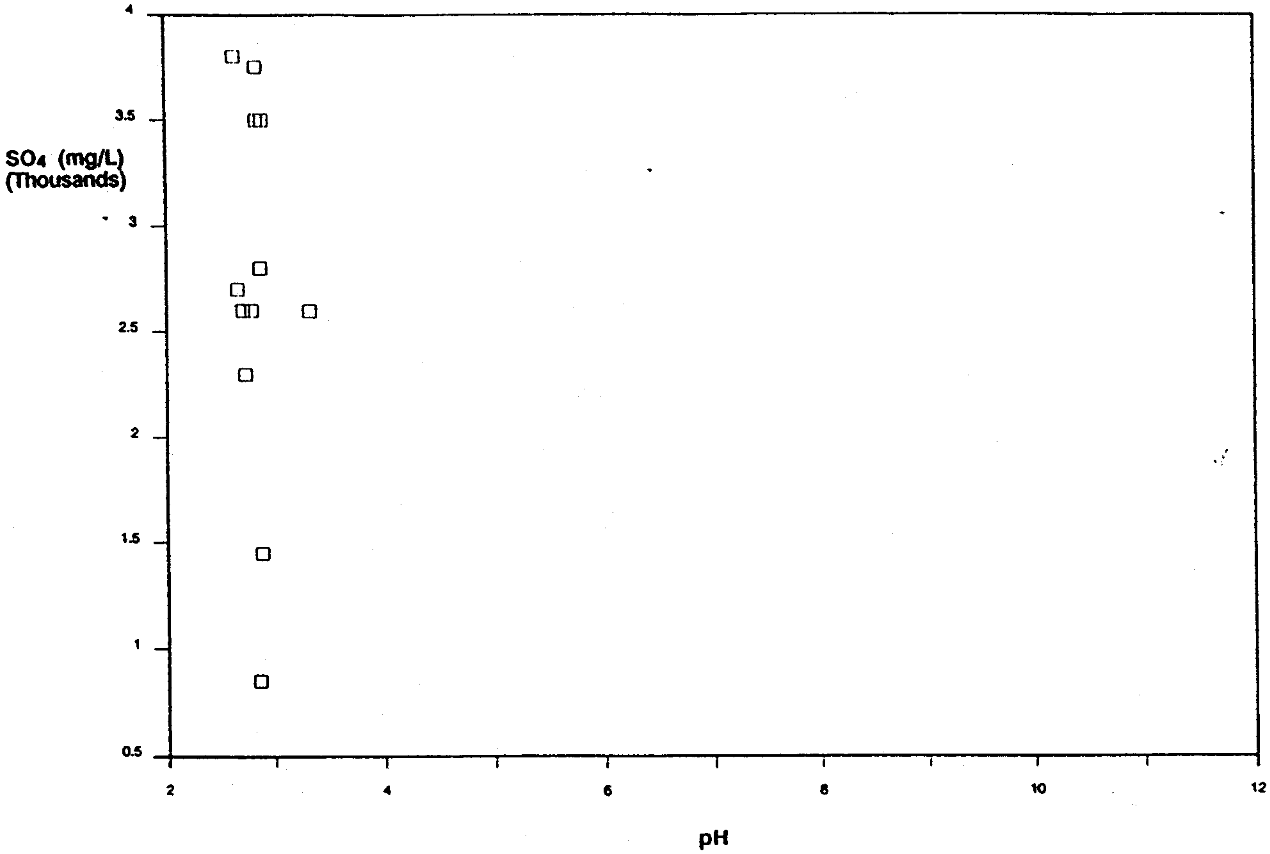


Fig. 13. Correlations of SO_4 and pH in the North Treatment Plant D201.

The iron concentrations and pH are not linearly correlated (Figures 14 and 15) as was noted previously. However, the concentrations of sulphate and iron correlate very well in the acid mine drainage water (Figure 16) though they do not appear to be correlated in the treated water (Figure 17). This analysis of the data is by no means complete. For example, log transformations of the pH values to their hydrogen ion concentrations may reveal other parameters of the chemical dynamics of the treatment system.

The pH value is used as one of the main criteria by which the treatment process is regulated. Clearly, the criteria used for water quality in waste water treatment and, to some degree in the milling process, appears to be a poor indicator of the water quality in these circumstances.

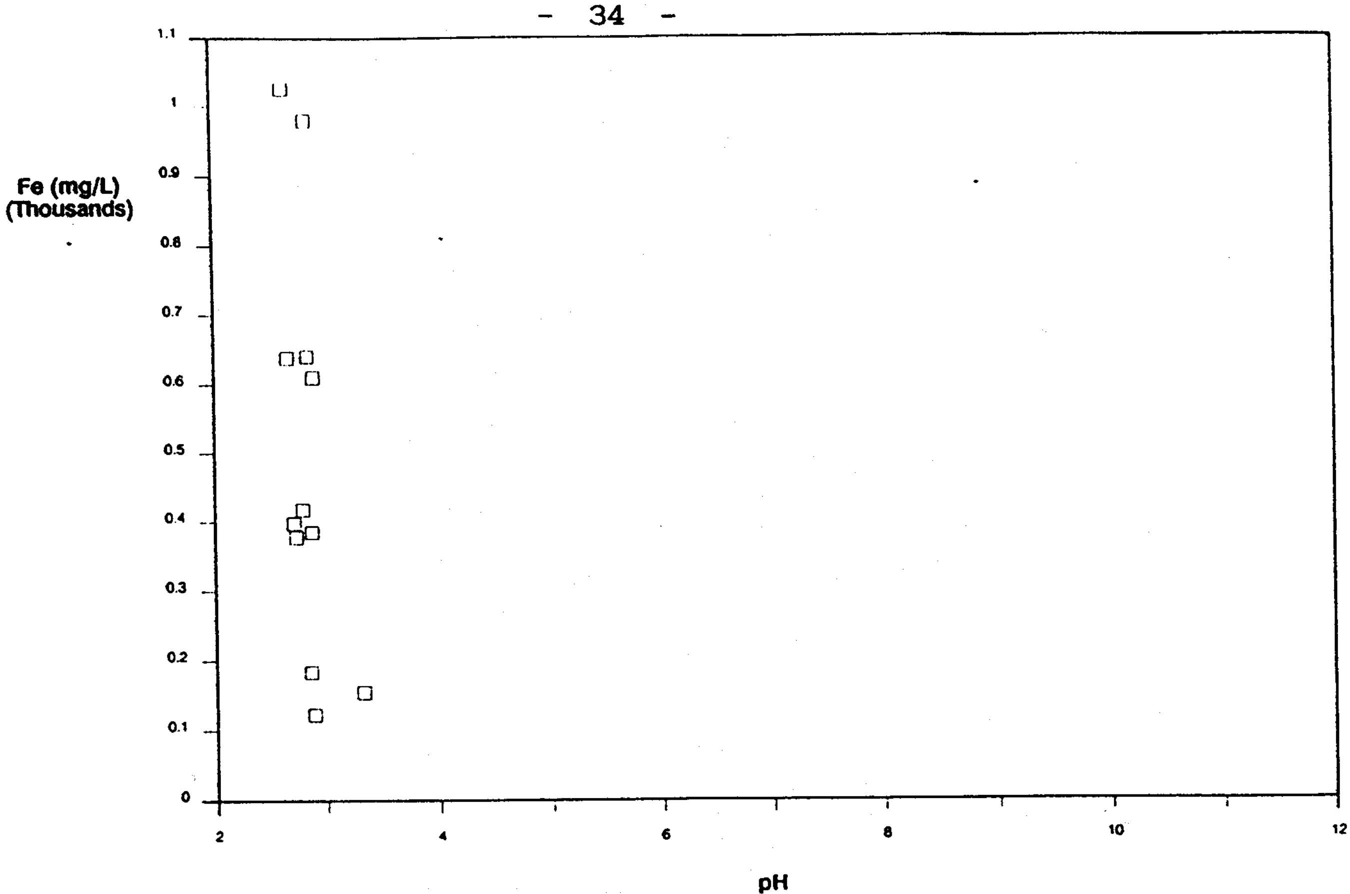


Fig. 14. Correlations of Fe and pH in the North Treatment Plant D201.

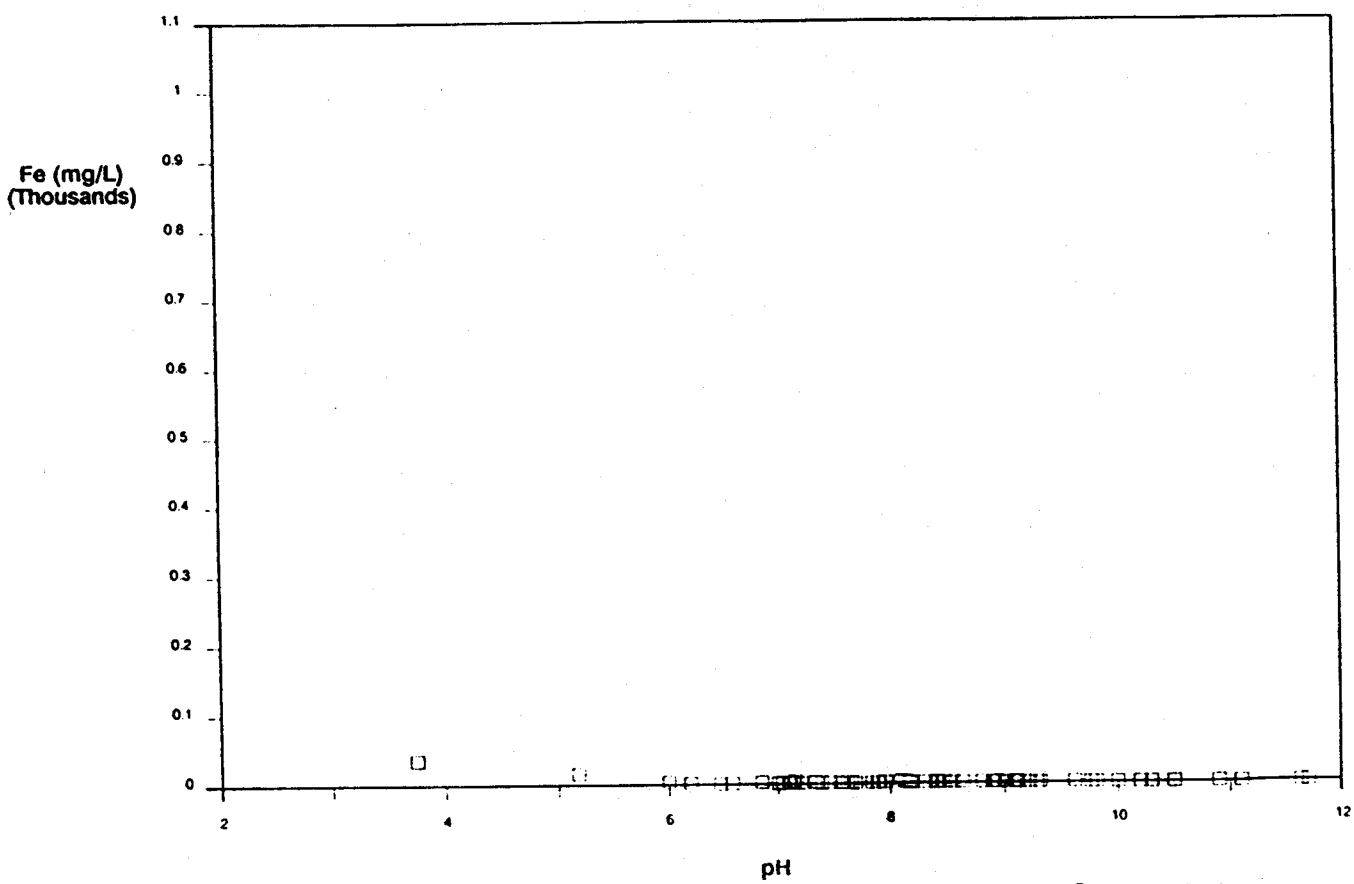


Fig. 15. Correlations of Fe and pH in the North Treatment Plant D203.

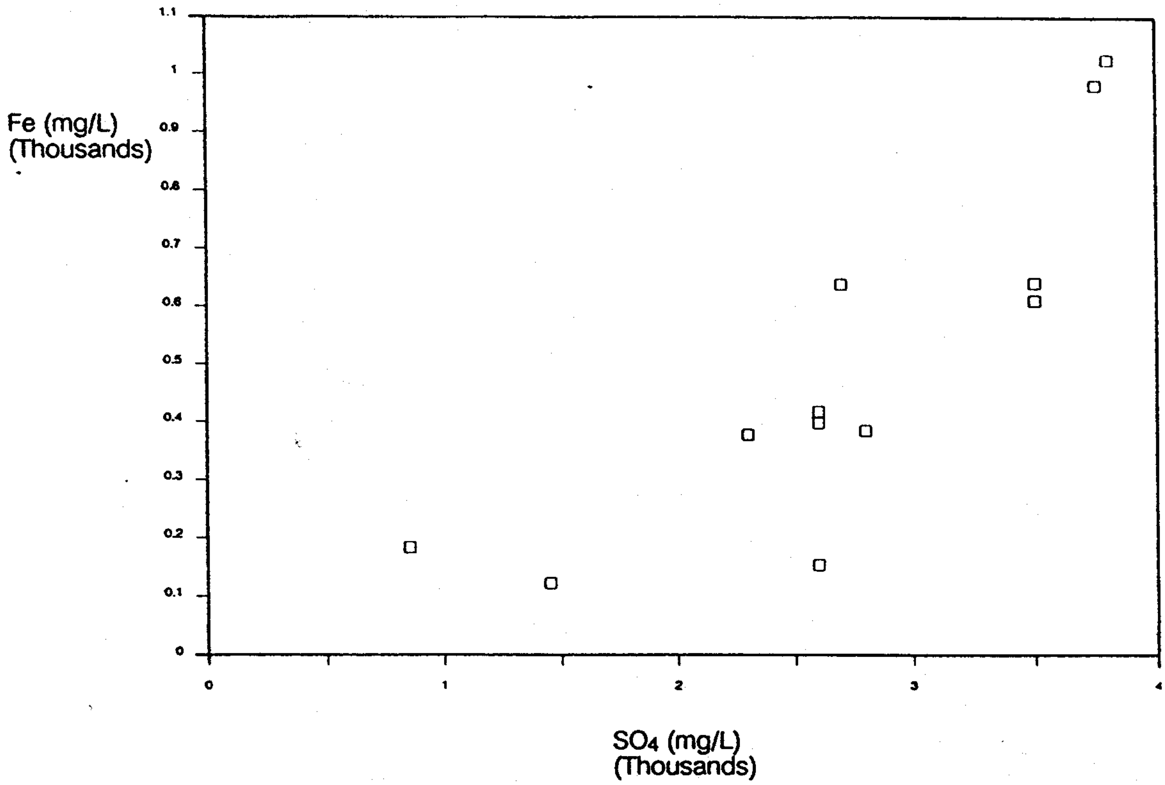


Fig. 16. Correlations of Fe and SO_4 in the North Treatment Plant D201.

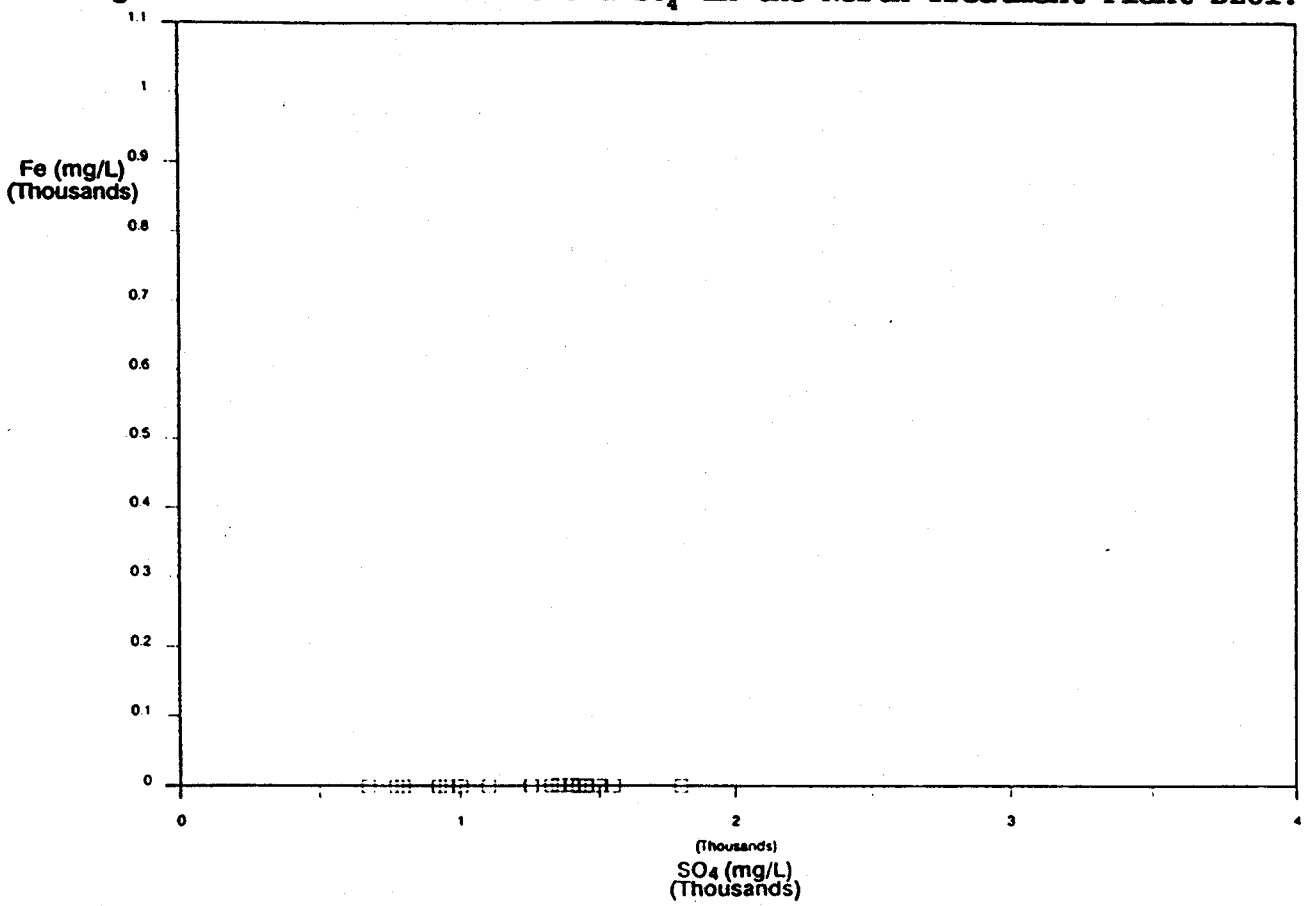


Fig. 17. Correlations of Fe and SO_4 in the North Treatment Plant D203.

This preliminary analysis of the monitoring data indicates the approach which will be taken to understand and control the actual operations of the treatment plant and the resultant water. This will allow an optimization of the water treatment and the achievement of the desired water quality criteria, for both recycle and the final effluent, within the present operating system.

3.4 Sludges/Polishing Ponds and Sludge Disposal

3.4.1 Review of the Literature

Within the framework of the waste management approach for La Mine Doyon, the sludge production by chemical treatment and the disposal of the sludges after settlement and polishing has to be addressed. What is the state of the art in sludge production and what are the associated problems?

Boojum Research Limited made several enquiries with respect to sludges. In discussions with CANMET Mineral Science Laboratory, it came to our attention that a recent study of this problem area has been carried out by this agency. The results of this study were obtained and briefly reviewed. Some important points are highlighted (CANMET, 1987). The treatment of acid mine drainage by chemical neutralization results in about 140,000 dry tons of sludge per year in Canada. The main composition of the sludges is calcium, iron and zinc, accounting for about 23% of the dry mass, the remainder being dependent upon the operation and its waste water characteristics. Sludge densities vary from 1 to 30%, and the sludge stability is extremely variable. Half of all sludges tested for leachability exceeded the Quebec regulatory levels for hazardous waste criteria.

The overall impression gained from this review is that neither sludge production nor sludge disposal have been addressed in a systematic fashion to date.

The next step was to review the available information on treatment and sludge disposal technologies. An excellent review of this area was provided by **Vachon, Siwik and Wheeland, 1987.** These authors concluded that "further work regarding precipitation chemistry, in-situ dewatering of low density sludges and decreased leachability of sludges is recommended". This is in agreement with the previously reviewed paper.

From the treatment options reviewed by the authors, under the heading Sludge Handling, the existing practices are described listing the advantages and disadvantages of low and high density sludges. These are listed in **Table 7**, quoted verbatim from the paper by **Vachon, Siwik and Wheeland**, supra.

ADVANTAGES	DISADVANTAGES
LOW DENSITY SLUDGE	
Low maintenance cost. Low operating cost. Low capital cost. Sludge storage facility.	Wind or thermal disturbance will resuspend settled flocs. Extensive land use. Large reclamation costs. Poor control over discharge. Short circuiting occurs readily. Not acceptable for final storage.
HIGH DENSITY SLUDGE	
Minimal land use. Reduced volume of sludge for disposal. May be suitable for long-term storage.	Higher capital, operating and maintenance costs. Operation requires closer control.

Table 7. Advantages and disadvantages of sludge ponds

It appears that within these two options there is little room for manoeuvering. Either optimize the sludge pond or evaluate sludge dewatering.

Within the spacial and geographical limitations of the North and South treatment plants, spacial problems are the overriding factors which have to be addressed. It follows that one of the options to be evaluated is dewatering and pressure filtering.

Expertise in dewatering or pressure filtering has been developed in municipal and industrial sludges, but not for acid mine drainage sludges. Boojum Research, therefore, requested specialists within this area to review both of the papers previously discussed.

John Seldon of Envirosite, a service company of Tricil, with mobile filtration/dewatering units located in Kitchener, Ontario, and **Ron Hare** from Metropolitan Environmental, with a similar service located in Ohio, were solicited to address the sludge problem. **Boojum** supplied both companies with copies of the articles and requested their technical assessments. **John Seldon** provided **Boojum** with an impressive review of the papers, together with a detailed technical discussion. **Mr. Seldon's** comments are attached hereto in **Appendix C.** His experience (SEE Curriculum Vitae, **Appendix A**), and that of his company, should be utilized to address specifically the sludges produced by the North and South treatment plants. Based on such an assessment, short and long term actions for the waste management strategy could be implemented. In a meeting with CANMET, **Mr. Seldon** discussed the implications of both documents and his company's capabilities. CANMET has expressed an interest in providing financial support to tests carried on after evaluation of this technology for acid mine drainage sludges.

3.4.2 Present Practices of Sludge Disposal

Sludge disposal at the present time at La Mine Doyon is carried out by pumping the sludges onto the waste rock piles. Some background information on the existing sludge ponds has been collected and is presented below.

Treatment plants were started up in the north area in 1985, and in the south area in 1986. All the sludge produced that year was placed by pumping onto the North waste rock pile in July 1986. The pumping rate was 300 gal/min but an estimate of the sludge volume produced over this period is not available.

Initially, the sludge penetrated the waste rock pile, covering some part of the woods below the waste rock dam, before arriving at station D201. Subsequently, the sludge basins were modified during the latter part of 1986 and in the spring of 1987, mainly by the installation of a clay/earthen material liner. Three settlement ponds have been produced.

It appears that the measures to line the containment basins were successful in that they retain the sludge together with a water cover. This raises an important immediate question respecting the precipitation into the ponds. It is anticipated that the sludge production of the North treatment plant from 1987 will be placed into the same ponds on the north pile, which would fill these ponds to capacity.

R. Patterson (1987), reviewing the research carried out by Equity Silver, clearly indicated that metal loads increase after sludge disposal onto waste rock piles. It follows that sludge disposal in this fashion would not be a desirable option for this site, as the waste rock run-off would add additional metal loads to the treatment systems in the long term, particularly if both waste rock piles were used as disposal sites. These samples which have been collected by Lac Minerals from the North waste rock pile represent the first step towards an analysis in light of Equity Silver's research and from the data derived therefrom, future disposal actions, as well as other options, can be considered.

Within the framework of the proposed waste management approach, the technical background available for decision-making is considered an essential component in arriving at sound short and long term solutions

3.4.3 Future Sludge Disposal

If the present sludge ponds are found to be an effective means for storing the sludges, it might be recommended that further sludge ponds be considered for the South waste rock pile. A sludge test pong system with some instrumentation is proposed for the North waste rock pile (Senes, August, 1987). The following comments, provided by R. O. van Everdingen, should be considered from a waste management point of view.

Sludge disposal and acid generation in waste rock piles are two separate problem areas. These two areas should be addressed individually, prior to an attempt to combine the technical information. Several overall considerations are relevant, and these are presented below in point form:

- In principle, the proposed method of depositing sludges onto the waste rock pile can only reduce the acid generation rates if oxygen is not entering through the side slopes of the waste rock pile. The oxygen transport in the waste rock pile is not known at the present time.

- Placing sludge ponds on the pile would tend to reduce infiltration rates of precipitation into the waste rock piles, as the sludge cells have to be lined to prevent penetration of sludges into the pile. This measure however, would in turn lower the water table or water retention in the pile, resulting in exposure of more material to contact with oxygen (air and water), and thus the production of more acid generation.

- Considering the storage volumes for the cell characteristics of 1,640,000 m^3 given in the Senes document (August 1987), and combining these with the total sludge production estimated for the operation in a second Senes report (June 1987) of 160,000 m^3 per year, it appears that there is about 11 to 12 years of storage capacity on the North Waste rock pile. As no freeboard (height of dyke above sludge level of the sludge cells) is given in the August report, it is unclear how the net precipitation of the area is taken into account in the design.

- In view of the sludge estimate provided in the June report on the expected time frame of acid generation or the time frame by which the acid might be depleted (given to be between 140 to 650 years for the North and South waste rock pile), sludge disposal on the waste rock piles does not immediately appear to be a reasonable option in the long term. In fact, given that precipitation in the Doyon area exceeds evaporation, it can be expected that the cells in the ponds accumulate water over the years. It is not difficult therefore to imagine the overflow of sludge ponds in the next 10 years, and such a possibility should be considered.

- Comments on the instrumentation of the test cells are made from a practical viewpoint. For example, steel drill casing for the monitoring holes may not be appropriate, since these are likely to corrode rapidly in acidic conditions, and at the same time, distort the temperature distribution. The use of fiber-reinforced plastic casing is recommended. On a more general note, the proposed air-filled monitoring tubes, surrounded by dry sand, will require long equilibration times for temperature measurements and convection in the tubes is likely to distort the temperature distribution.

As sludge disposal on the waste rock pile is considered in the June report as a potential Control option for acid generation, the evaluation presented above demonstrates that a multi-disciplinary approach to waste management in acid mine drainage is essential.

As a final note on sludge disposal, it became apparent that somebody should investigate the possible beneficial uses of AMD discharge or AMD-treatment sludges not listed by Vachon et al. (Halifax Proceedings, p. 390-391). Two potential ones are: (1) abatement of soil alkalinization (using AMD discharge), and (2) treatment of soil salinization (using gypsum-bearing AMD-treatment sludge). Both alkalinization and salinization are problems of rapidly increasing magnitude in agricultural areas on the Prairies.

A further consideration should be given to the possibility of a fertilizer plant. According to CANMET, this is an option which has been implemented at an operation of Sherritt Gordon Mines, where sulphate is converted to ammonium sulphate.

3.5 Acid Generation From Waste Rock Piles

Acid generation from waste rock is an environmental liability which, at the present state of technology, requires considerable effort in order to understand the process itself and then to find some acceptable means of providing both a short and long term solution. This has been recently expressed by the RATS program (Reactive Acid Tailings Program), a joint industry/government research effort, which is now realizing that the problem of acid generation in waste rock is of similar severity to that in tailings.

3.5.1 Remedial Concepts for Waste Rock

One fundamental aspect emerges on a review of the literature in general and the site specific background for La Mine Doyon provided in the Senes August report. All acid mine drainage control options evaluated, such as, for example, covers of glacial till and synthetic liners, are based on the assumption that a reduction of the reaction rates would be desirable. The same applies for the development of chemical agents which attempt to inhibit or curtail microbial acid generation.

These measures would potentially reduce the annual cost of liming, however, they would not necessarily reduce the associated sludge volume. The sludge volume is dependent on the quantity and the characteristics of the waste water. A cover over the waste rock pile would not necessarily reduce the acidity produced in the pile. Although a reduction of the rate at which water infiltrates would occur, this could in turn lead to a lowering of the water table in the pile and thus a larger section of the pile would be exposed to oxidation.

It follows that measures which reduce infiltration and oxidation rates lead to longer periods of acid generation from the pile, which translates into a longer period of time for which acid mine waste water treatment is required.

The evaluation of the state of the art of acid generation and waste rock carried out during the development of the proposed waste management system, leads to only one conclusion - it is essential to begin at the beginning, i.e. the fundamentals of the problem.

This approach was apparent from a careful review of the assumptions which are presently being used to arrive at acid generation rates and the estimates of same from waste rock piles. The leading work in this area has been carried out by Australian workers, and is presently used as the basis for any of the derivations on acid mine drainage. These were also used in the site specific estimates in the June report by Senes.

Estimating acid generation from waste rock material in itself is based on many assumptions. Further assumptions of the parameters which can be relatively accurately determined for th site, such as infiltration rates and sulfate concentration in the waste rock discharge, should not be made. Such a methodology will lead to a final result which is even more distant to reality and technically unacceptable.

The importance of these considerations for a site specific evaluation is shown by the differences of the two waste rock piles, where their location would indicate differences to exposure to ground water and air flow through the pile. It would follow that the sulphate flux in the North pile and the South pile would be different, as acid generation is affected by the infiltration rate of precipitation, depth of the water table and pyrite content. The pyrite content alone is quoted to be 14% lower in the North waste rock pile than in the South pile. As the implications of acid generation from these waste rock piles have tremendous economic consequences in the long term, the estimates of acid generation from these wastes should be ascertained as carefully as possible.

3.5.2 Comparing Waste Rock Piles

To arrive at some basis for an understanding of the waste rock problem, it is proposed that two avenues be pursued. A written comparison of a waste rock operation equal in size to that of Doyon should be carried out. Some of the basic parameters envisaged for such a comparison are given in **Table 8.**

Mine Sites:	La Mine Doyon (Quebec) Equity Silver Mine (British Columbia)	
	Doyon (1)	Equity (2)
Operating	YES	YES
Waste Rock, Tonnes	$51*10^6$	$60*10^6$ **
Waste Rock Thickness, m	21 to 33	80 **
Waste Rock Area, ha	96	75 **
Pyrite Content, %	3 to 3.5	?
Oxidation Zone, m	8	>10
AMD Production, m3/yr	150,000 *	800,000
AMD Quality:		
pH, units	2.3	2.35
Acidity, mg/L CaCo3	37,900(mean)	10,000
Sulphate, mg/L	50,100 (mean)	8,500
Fe, mg/L	10,530 (mean)	800
Cu, mg/L	?	120
Zn, mg/L	?	80
Watertable Data	Yes(?)	Yes(?)
Temp. Measurements	No(?)	Yes
Thermal imaging	No(?)	Yes
Climatic Data (3):		
Total Precipitation, mm/y	850	490
Snowfall, cm/y	240	250
Lake Evaporation, mm/y	490	500
Evapotranspiration	400	380

NOTES (1) Data and Deductions (*) from Senes Report
(2) Data and Deductions (**) from Patterson Paper (Halifax Workshop Proceedings, p.297-317).
(3) From Hydrological Atlas of Canada.

Obvious differences in: waste-dump geometry, annual precipitation minus annual evapotranspiration, AMD production rate, and AMD quality.

Potential differences in: rock types, particle sizes. reactive-sulfide content, depth of water table etc.

Table 8. Comparison of Equity Silver and La Mine Doyon Waste Rock Piles.

Through such an evaluation and with the co-operation of Equity in providing the data, it will be possible to focus the evaluation of the waste rock piles and derive the required waste management approach.

The waste rock piles of Equity Silver were chosen as those have been studied for some time. Temperature measurements have been carried out for several years in these waste rock piles. As well, thermography has been carried out to identify zones of acid generation in the pile. Equity Silver has some experience with sludge disposal on waste rock. It is, in fact, the only operator **Boojum** could identify with some data base from which information could be obtained. **Boojum Research** has discussed the proposed co-operation with **R. Patterson** of Equity, and the concept was well received. Details of their co-operation and access to the data will have to be discussed further.

A more detailed list of the parameters which will be evaluated in conjunction with the hydrology model is given in **Appendix C.** Relevant background information with respect to facility layout, topography, geology, climate, surface run-off, groundwater, waste rock characteristics, sulfide oxidation and acid generation and is drainage on the site, will be combined and evaluated with **CHINTEX** to arrive at a sound research approach for addressing acid mine drainage from the North and South waste rock piles.

3.5.3 Acid Generation Rates in the short and long term and potential Remedial Measures

After the previously presented evaluation of the background data, it is anticipated that the research team will be in a position to make recommendations. At present we envisage a consideration of the following aspects:

- Determination of the exposed fraction of reactive sulfide

Presumably, only those particles of reactive sulfide will be oxidized that are "exposed" when tailings and igneous or metamorphic waste rock are deposited; in carbonate waste rock additional sulfide particles may become exposed later through carbonate dissolution. Would it be possible to determine the exposed fraction of reactive sulfide and use that in reaction-rate and acidity-production calculations, instead of the overly conservative total reactive-sulfide content used at present?

- Increasing pyrite-oxidation rates

Increasing the pyrite-oxidation and acid-generation rates in tailings and waste rock could increase the acidity and dissolved metal concentrations in AMD discharge, and possibly also the solids content of treatment sludges. This would tend to reduce both the ultimate sludge column and the time during which treatment would have to be provided. Might the recirculation, not of sludge, but of AMD discharge achieve this?

During the perception of this proposal, this avenue was discussed with persons in charge of Environmental Affairs at Inco, Falconbridge and Equity Silver. It became apparent that in fact, Inco has an experiment which has been underway for some years, the data from which would be made available to Boojum Research in connection with its evaluation.

It was generally agreed that our concept, as presented above, respecting the reduction of the oxidation rates which would, of necessity, increase the time required for treatment, should be pursued at least on a conceptual basis.

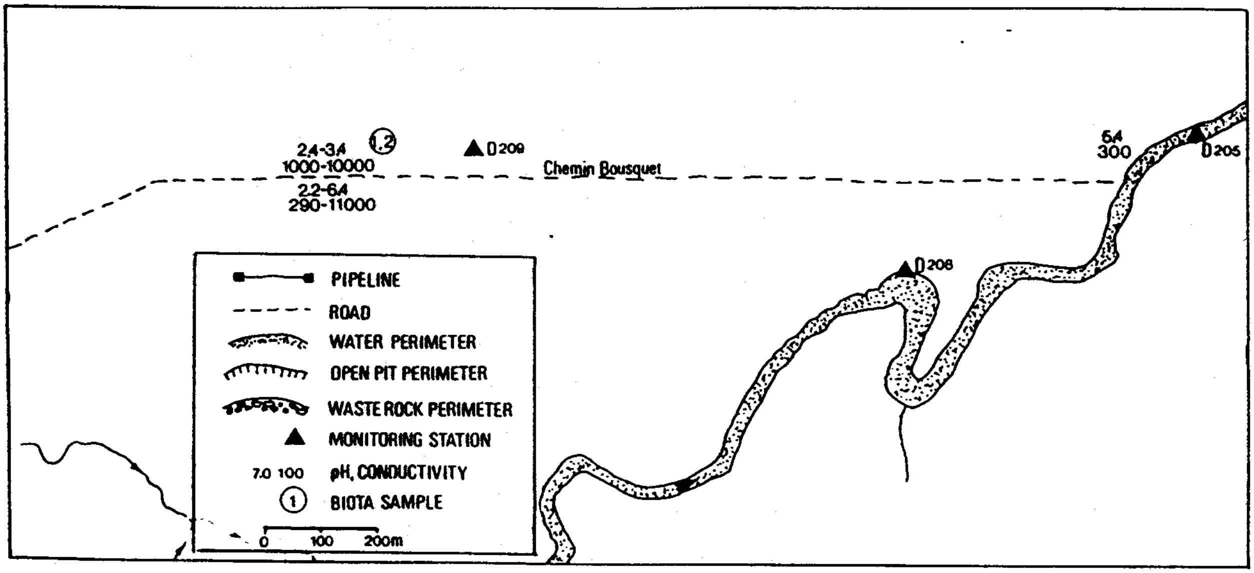
3.6 The Chemin Bousquet/Ancien Reservoir/Open pit

3.6.1 The Chemin Bousquet

The investigation of the area referred to as Chemin Bousquet, given in Map 3, was interesting, as applications of Ecological Engineering methods appear feasible here. The following are the reasons for such application:

- The waste rock road is dormant and not being used, therefore is ready to be closed out through the establishment and promotion of biological self-sustaining measures. Ecological Engineering methods are being developed for just such a close-out application.

- The surface water conditions are within a reasonable quantity for the present state of understanding of the Ecological Engineering methods which are being developed by Boojum Research Limited.



Map 3. Sampling stations along Chemin Bousquet.

- Some section of this road gives the impression of being non-acid generating, possibly due to exposure, waste rock compaction contouring and/or due to the waste rock composition. This provides a unique opportunity for an evaluation of these conditions to derive methods and obtain an understanding of the handling of waste rock, i.e. possibly applicable to the North and South waste rock piles.

In **Table 9**, the pH values and electrical conductivities are given, measured on the left and right sides of one section of the road, which is located in a surface water drainage depression. Clearly, on the right side of the road, a large variety of pH and conductivity values are encountered, indicative of fresh water sources, which are not acidified. On the left side however, there are several pockets of water puddles which show an expressed conductivity and temperature gradient. Unfortunately, the pH meter was defective, resulting in the absence of pH values for these locations.

LOCATION Date: Sept. 1-2, 1987	pH	cond umhos/cm	temp deg. C
LEFT SIDE			
First puddle	2.70	7000	-
Main H2O localization	3.42	1000	14
In white precip.	3.20	-	-
In white pool, top	-	3000	14
In white pool, bottom	-	6000	16
In red pool, top	3.04	3000	14
In red pool, bottom	-	6000	17
In green pool, top	-	3400	13
In green pool, bottom	-	3400	13
Further along road, end of H2O	2.40	10000	11
RIGHT SIDE			
Begin of main H2O body,at road	3.57	420	12
Deep hole along edge of road	6.41	190	11
At begin, away from road	4.11	270	12
Further along road	3.67	-	-
Near live Sphagnum	2.70	1200	12
Base of fallen tree	2.17	11000	12
Milky puddle	3.20	3600	12
RIVIERE BOUSQUET	5.43	300	15
SHORT SIDE ROAD			
Pond, left side	2.90	2300	14
Pond, right side	2.50	4000	15

Table. 9. pH and conductivity of Chemin Bousquet.

Samples for the green algal mats were dominated by *Ulothrix*, an attached algae which occurred in association with diatoms. This combination is repeatedly found in acid mine drainage conditions and serves as a matrix for the precipitation of iron hydroxide. Red and white precipitates were collected by Lac for chemical analysis, however, the data are not available to date. From a microscopic inspection, the material was organic amorphous, which is expected if biological reduction is in progress.

Microbiological reduction processes might take place at one location (Map 3, biota samples 1 and 2) in isolated pockets. **Those are the same processes which are to be induced by Ecological Engineering methods. These could be promoted for this area.**

- Run-off from this waste rock road appears to emerge parallel to the road on the south side in the bush along the drainage basin divide, running either to the north east through the depression described earlier and westward toward the Bousquet River.

Such defined relatively low flows are ideally suited conditions in which ecological methods can be applied.

3.6.2 The Ancien Reservoir

The Ancien Reservoir was only investigated from the edges, due to time constraints and the absence of a boat. This area is acidified from run-off of the South waste rock piles and seepages of retention ponds for the drainage collection, from the open pit and the ditch system.

The Ancien Reservoir, along with the Chemin Bousquet, can benefit from ongoing work at Inco and Denison Mines, where experiments on induction of

microbiological reduction have been ongoing for 1 to 3 years.

The experiments have led to the identification of organic material which provides the food source for reducing bacteria and which, in turn, inhibit and ameliorate the acid mine drainage. However, further work can not be carried out until a microbiological evaluation of the processes has been made.

The experience of **John Cairns** of Dearborn in evaluating anaerobic and aerobic microbial processes and their technology potential will be utilized to assess the existing experiments and to evaluate their applications to the Chemin Bousquet and the Ancien Reservoir.

3.6.3 Open Pit

This area of the site is an open pit in the true sense from a long term waste management point of view. It could result in an endless sink for environmental dollars. On the other hand, it could prove useful for waste management problems encountered in the entire program. The pit was not addressed during the field investigation, but is recognized as an area requiring attention.

Of primary importance will be the hydrological conditions which are anticipated in the pit, once water is no longer pumped from this area. Equally important are the fractures and zones in which acid will be generated, which will contribute to the water in the pit in both the short and long term. These are only some of the questions which have to be addressed, and are presently of a hydrological nature. The most effective way to approach these is by the use of a hydrological model. Its applications are presented in the following section.

However, the hydrology will not identify active zones of acid generation which are important to an evaluation of the long term behaviour. Seepage surveys are a time-consuming but relatively fail safe process in identifying the zones of acid generation. These can be easily used at La Mine Doyon for the waste rock piles. However, such a survey on the walls of the open pit and a quantification of their characteristics will present a problem.

Thermography has been used to identify acid generating zones in waste rock piles and during the proposal, the development of this avenue of potential application was pursued to some extent. It was envisaged that thermography could be tested as a technique in areas previously used, i.e. waste rock piles. The findings through the thermograph can then be confirmed by a seepage survey of the waste rock ditches.

Keith Ferguson (Environmental Protection Service, Vancouver), who was the first to use this technique for the waste rock piles at Equity Silver, was consulted and he recommended that the problem be discussed with **Randy Greenall** from Heat Seekers. A demonstration of the equipment was made by the company at **Boojum Research** and the response was enthusiastic. Some background information on thermography and a quote for a thermograph for the North and South waste rock piles is attached (**Appendix C**).

Through a better understanding of the technique, more specific questions could be asked by Boojum Research to **Keith Ferguson**, Equity Silver, the Centre for Remote Sensing, as well as radiation experts. The method appears to have potential but has to be calibrated to the problem area of acid mine drainage.

It became clear that emissivity of the surface is of paramount importance, and needs to be determined for each surface type. This characteristic is affected by many factors. It was further discovered that a report should exist at CANMET which evaluates the applications of thermography in mining and that thermographic services are available in geotechnical divisions of the National Research Council.

It was concluded, therefore, that a more technical evaluation should be carried out prior to any actual application of thermography to the site. This will be considerably more economical and provide a technical basis from which a decision can be made. Such an evaluation is particularly important, as thermography appears to have become a trendy tool for acid mine drainage detection, and there is little systematic analysis of the effectiveness of the tool carried out.

3.7 Modelling of the Waste Management System

Use of a systematic modelling approach will be essential in optimizing the waste management strategy with a view to minimizing the environmental impact in the long term. A computer model that will adequately describes the basic components of the waste management system at La Mine Doyon can serve to perform the following functions that are integral to the proposed research program:

- to examine and systemize all available data influencing the environmental impact and obtain an understanding of the interaction of the various components of the mine/waste management/environment system.
- to focus the data gathering activities by identifying the data gaps and by identifying the environmentally sensitive parameters.
- to examine the importance and results of the various assumptions that must be made because of data deficiencies that are generally present because of physical limitations in obtaining necessary samples, or economic limitations.
- to assess the long term environmental implications of the present operation and of any process changes or remedial actions taken.
- to assess the environmental implications of actions that may be taken during the operational life to allow the minimization of the environmental impact.

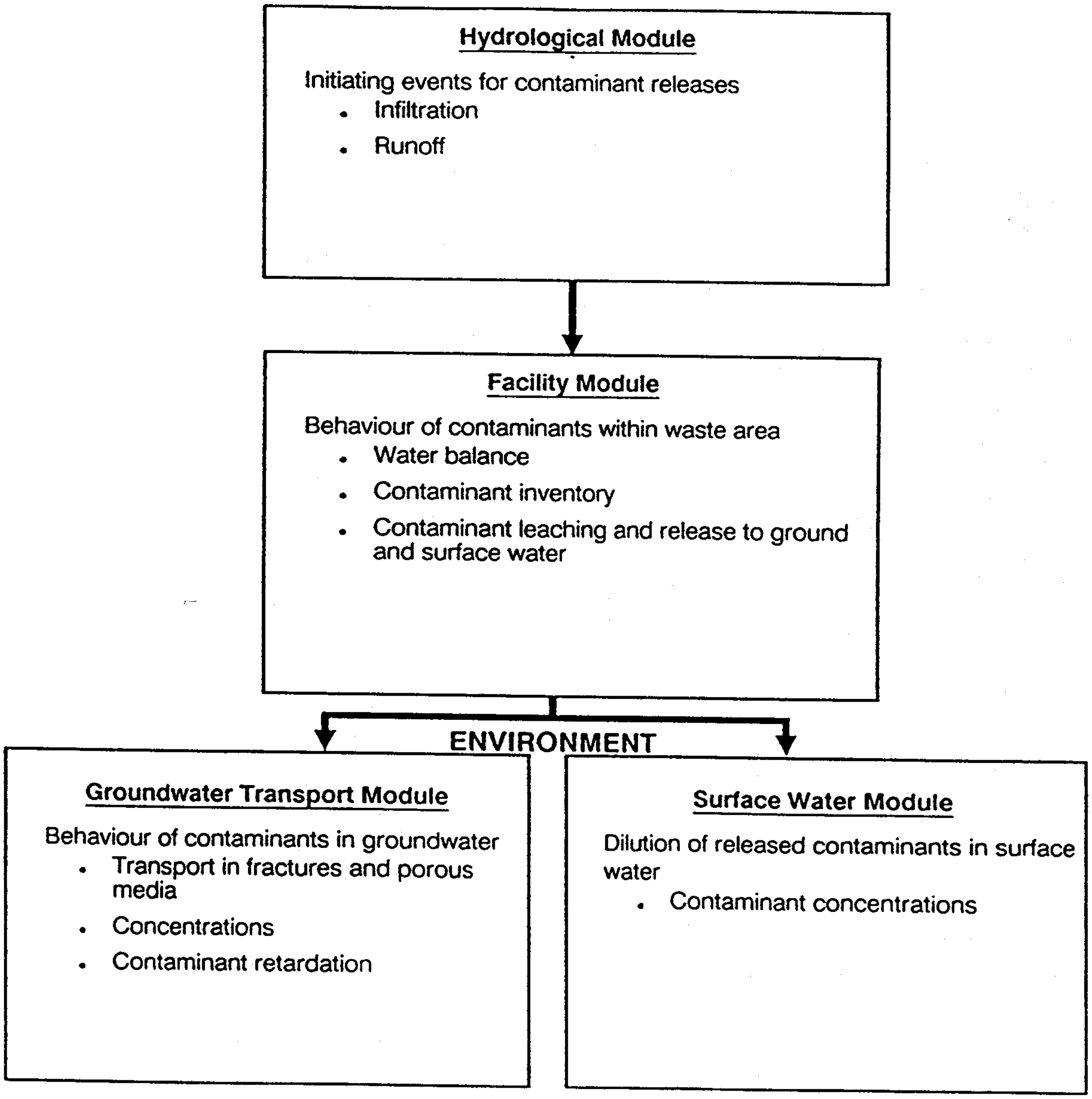
A computer model that is easy to use, that can readily be configured to describe the operations at La Mine Doyon, and that is simple enough that the assumptions made in its use are transparent, is a powerful tool to use in the proposed study. It is the source of great savings in the overall project by focusing the expensive part of data gathering and design activities and also providing a useful framework for assessing the implications of any proposed actions. Finally, it will provide a defensible analysis for implementing proposed measures for the appropriate regulatory bodies.

The CHINTEX model was chosen to provide the necessary analytical capabilities for this study. CHINTEX uses a modular approach and is depicted in **Schematic 1. Appendix B** contains further details on the structure and application of CHINTEX. CHINTEX was designed to allow use of a systematic modelling approach (see **Appendix B**) in a broad range of applications. It has been successfully used in many applications (see **Appendix B**) including mill tailings, refinery wastes and landfills. It has also received extensive review from an inter-agency work group that included members from the Atomic Energy Control Board, Environment Canada, and the Ministry of the Environment of Ontario. It has been used on one application in Quebec for Alcan. The model is jointly owned by SCIMUS Inc. (of which **Dr. Alex Buchnea** is on the current study team) and MacLaren Plansearch Inc. (which is presently marketing the model). **Dr. Alex Buchnea** has worked with **Boojum Research Ltd.** on applying the model to an acid generating mine site that is serving as the first pilot demonstration of a close-out using ecological engineering measures.

The overall structure of CHINTEX is shown in Schematic 1; however, for the present study, only the modules shown in Schematic 2 will be used.

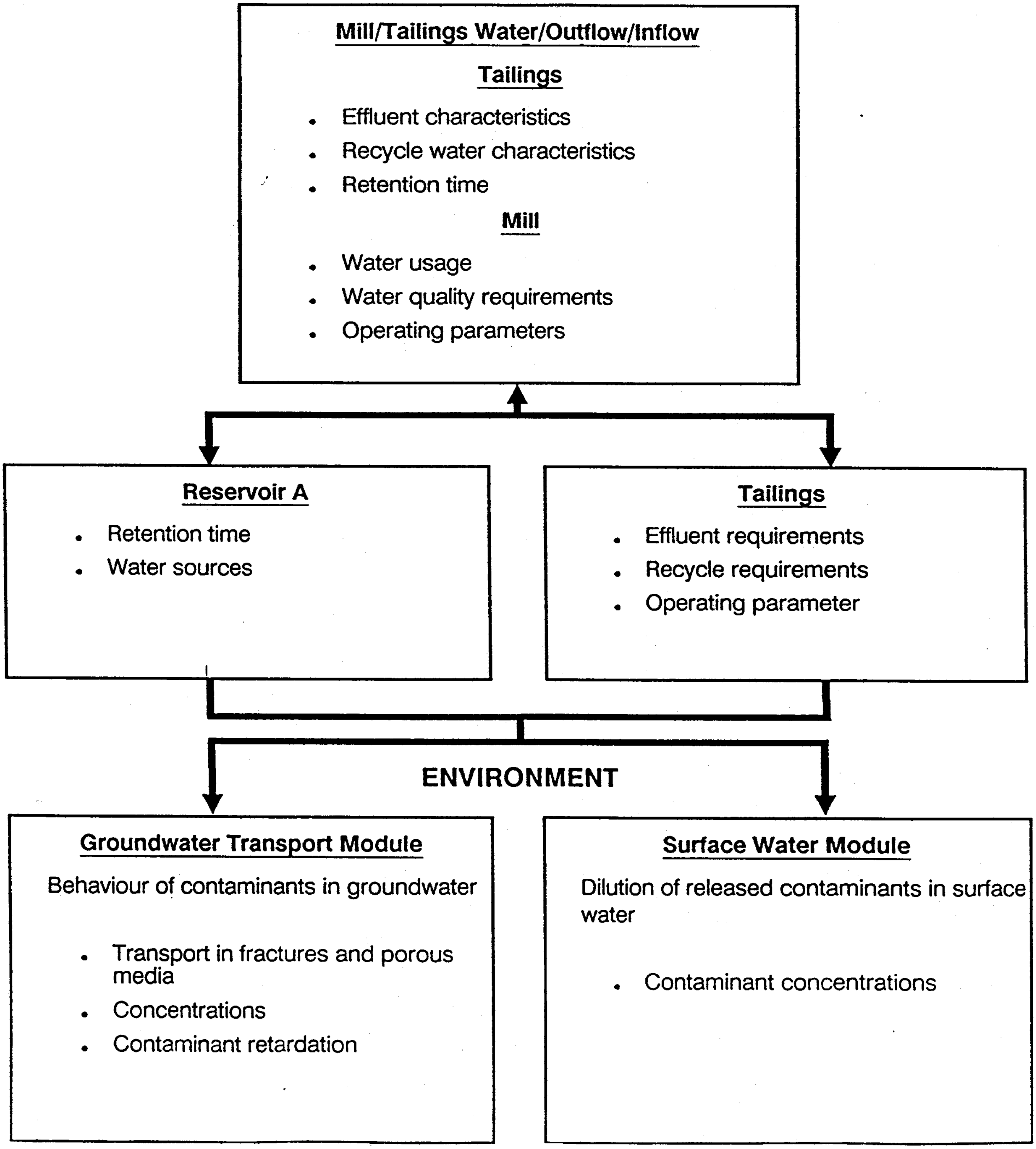
Schematic 1. Hydrological Framework Encompassing the area between Lac Chassignolle and La Rivière Bousquet.

The Environment to be Protected



TASKS:
1. Evalutation without mining impact.
2. Evaluation with waste management.
3. Evaluation of waste management options.

Schematic 2. Water Balance of Tailings Pond [D104 - D113] - Reservoir A - Mill - Effluent [D203]



The hydrological module will be used to determine the natural hydrological water balance in the various drainage areas at the La Mine Doyon site in which the waste management facilities are located. This is generally the area encompassed by Lac Chassignolle and La Riviere Bousquet. Meteorological data for the area as well as the topographical features of the terrain and the characteristics of the surficial soils and vegetation will be used to estimate runoff, percolation, and transpiration in each of the drainage areas.

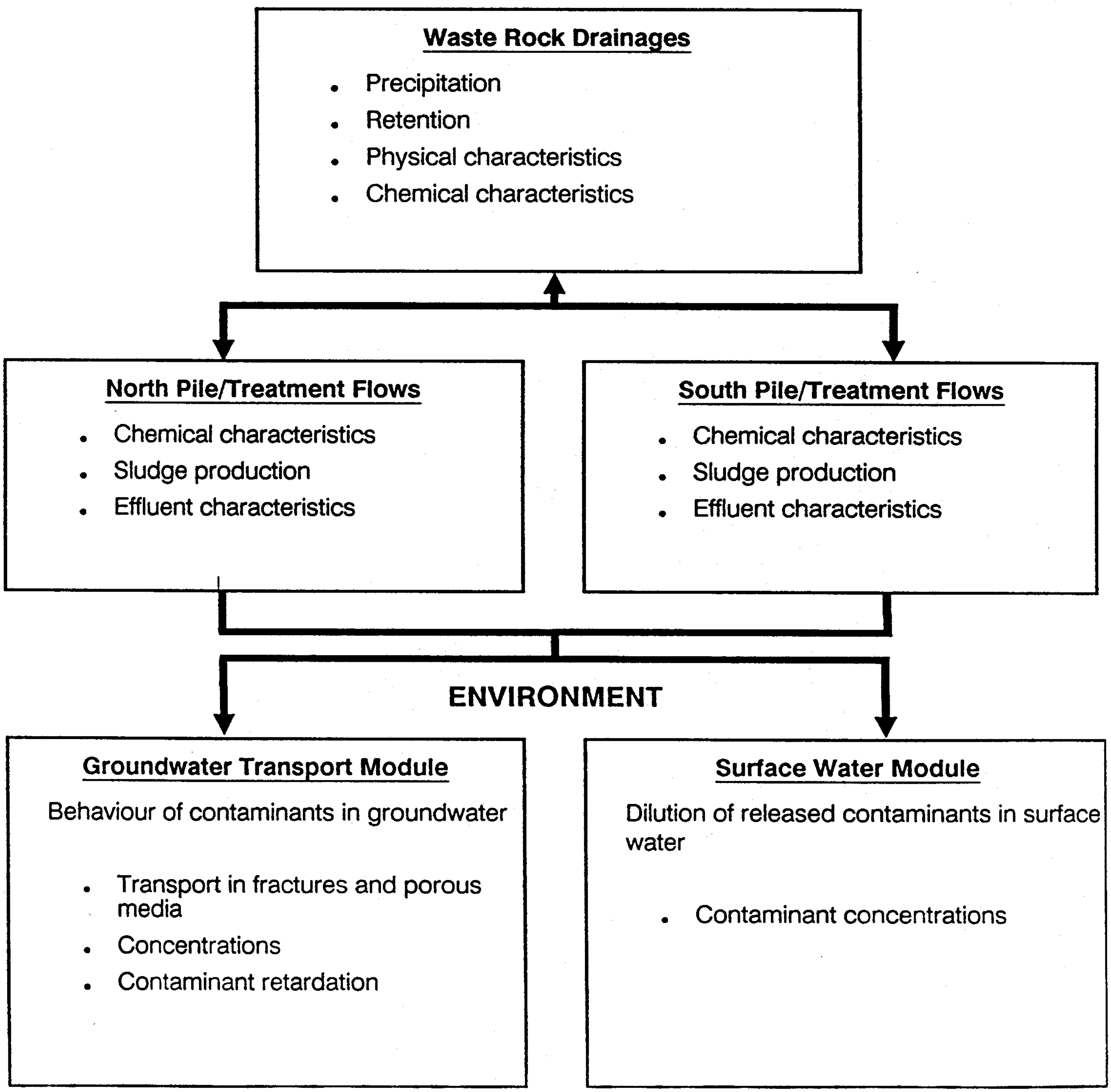
The facility module will be used for each of the drainage areas to investigate the water balance beneath the ground surface and to determine the natural loading of contaminants from the various waste management areas into the surface and subsurface waters.

The surface and groundwater modules will be used to investigate the transport of contaminants through the ground and surface waters into the environment.

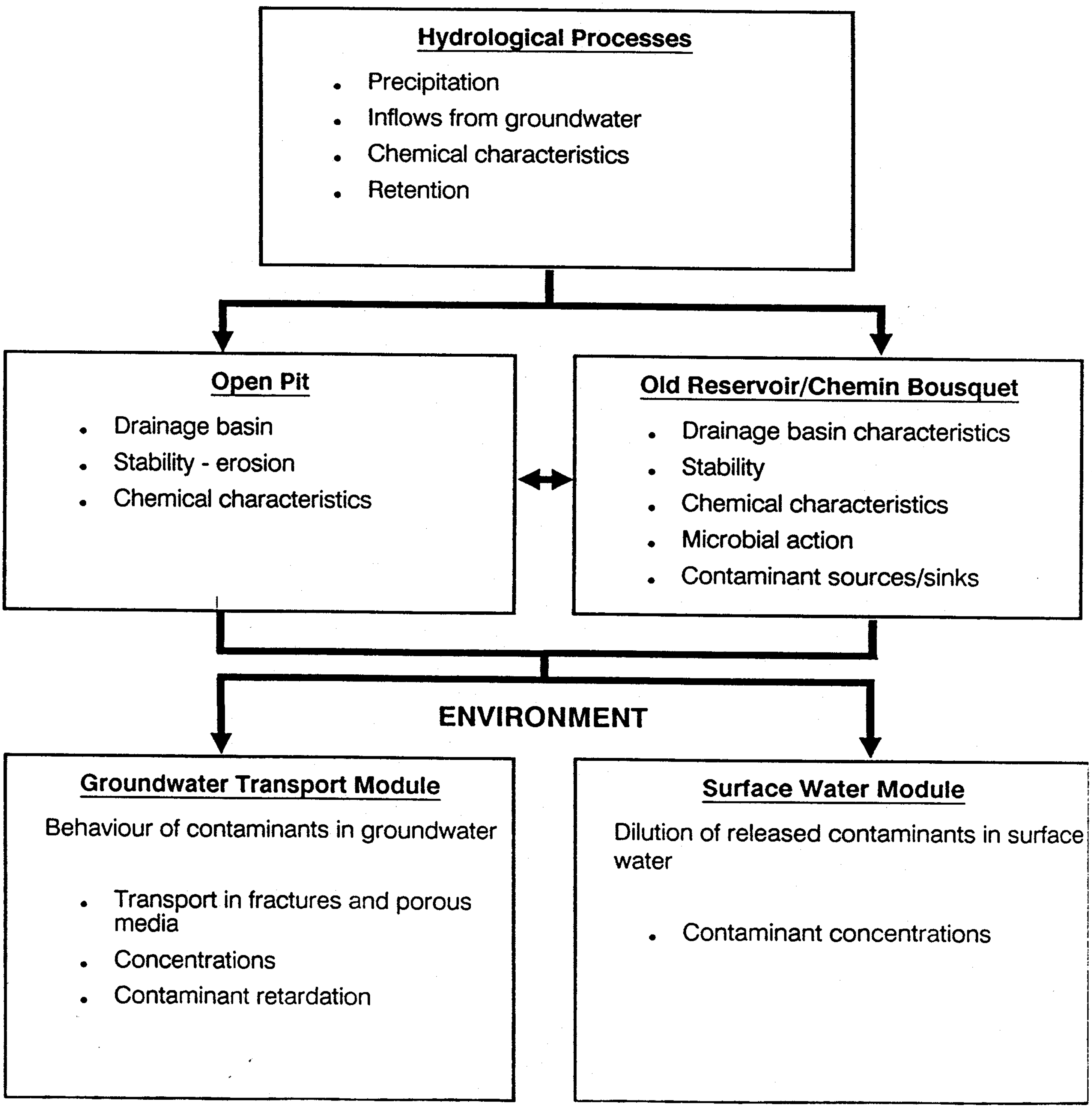
The data that is presently available will be used to set up the model and to allow a cursory analysis of the various waste management systems. The results of this analysis will help to define the data gathering needs and to identify any environmentally sensitive areas or contaminant transport pathways.

Once the various drainage areas have been analysed as indicated above, the data gathering activities will commence and as data is obtained, more detailed analysis of each of the areas indicated in **Schematics 3** and **4** can be performed. This will include the effects of process water addition and recycling, the analysis of the short and long term environmental impacts, the investigation of the various chemical processes occurring within the waste streams and the effectiveness of proposed waste management strategies. The majority of these activities will take place at the end of 1988 and during 1989. Also at this time the importance of the groundwater pathway and the need for an investigation of the groundwater system will be investigated.

Schematic 3. Water Balances of Waste Rock Piles - Treatment Plants [North/South]



Schematic 4. Water Balances of Old Reservoir/Open Pit/Chemin Bousquet



4.0 ORGANIZATION OF THE WORK AND THE RESEARCH TEAM

All the components of the waste management problem presented in the previous section have been reviewed within the technical aspects of acid mine drainage in general, and a focus was provided specifically for La Mine Doyon. The problems were presented based on the information gained during the field investigation, by evaluation of the monitoring data, together with a detailed evaluation of work previously performed.

The approach then to be taken requires a considerable degree of management. It success will depend largely on the expertise of the team, its ability to work well together, and the quality control exerted on the data during collection and processing.

4.1 The Project Team

The study team is presented in **Schematic 5**. The various disciplines which are brought together for the project are outlined on three levels.

Lac Minerals will provide the specifications for the work and the criteria on operations of the mine/mill/waste management to **Boojum Research Limited.** Geotechnical information, design criteria of the operations and historical data will be provided by geotechnical engineering groups which are involved in the operations at the mine site. Those two groups will provide the parameters for the project and **Boojum Research** will act as a distribution centre for the information to the various disciplines in the waste management research program.

The persons representing the disciplines listed on the same level in **Schematic 5**, with the exception of **Dr. Tom Peters**, have worked together for several years. **Dr. Peters'** experience in reclamation, as well as his understanding of mining problems, will be invaluable when reclamation needs are defined within the program. He will critically review the proposal and the ongoing work for **Boojum Research**. Such technical review is an essential part of a research program of this magnitude. **Dr. Peters** has dedicated a large part of his life to reclamation and waste management at Inco in Sudbury. He has the insight and experience necessary to perform this essential function. His involvement is considered to be vital to the overall success of the work. He is a world renown expert in the reclamation of acid generating tailings and probably recognized the environmental problems of acid generation in mining long before thy became apparent to the world at large. He has written numerous articles and received prestigious awards in his field.

An equally prestigious member of the team is **Dr. R.O. van Everdingen**, a scientist to the core. His scientific focus on sulphur geochemistry, through his isotope work, combined with his geochemical knowledge with hydrology, has defined the thermal behaviour of permafrost and unconsolidated material for many problem areas in Canada. He is the author of some 40 articles in refereed journals, chapters in books and many reports.

Tim Edwards, with 11 years' in process design of gold and base metal concentrators, and 8 years' experience in milling operations as a metallurgist, brings to the team an understanding of the processes of waste production and mining and milling activities. His experience with the actual operations of waste management in mining will introduce the desired element of practicality into the recommendations resulting from this work.

Dr. Alex Buchnea brings to the team his experience in systems analysis and modelling, as the author of a comprehensive environmental pathways model, CHINTEX. The experience he gained in the last 10 years in nuclear waste management has been a solid technical basis from which he moved, in recent years, to an analysis of landfill sites, aluminum wastes and phosphogypsum tailings. The CHINTEX model has been adapted to address long term biological, geochemical and ecological processes in the past year in connection with the pilot demonstration of Ecological Engineering for BP-Selco.

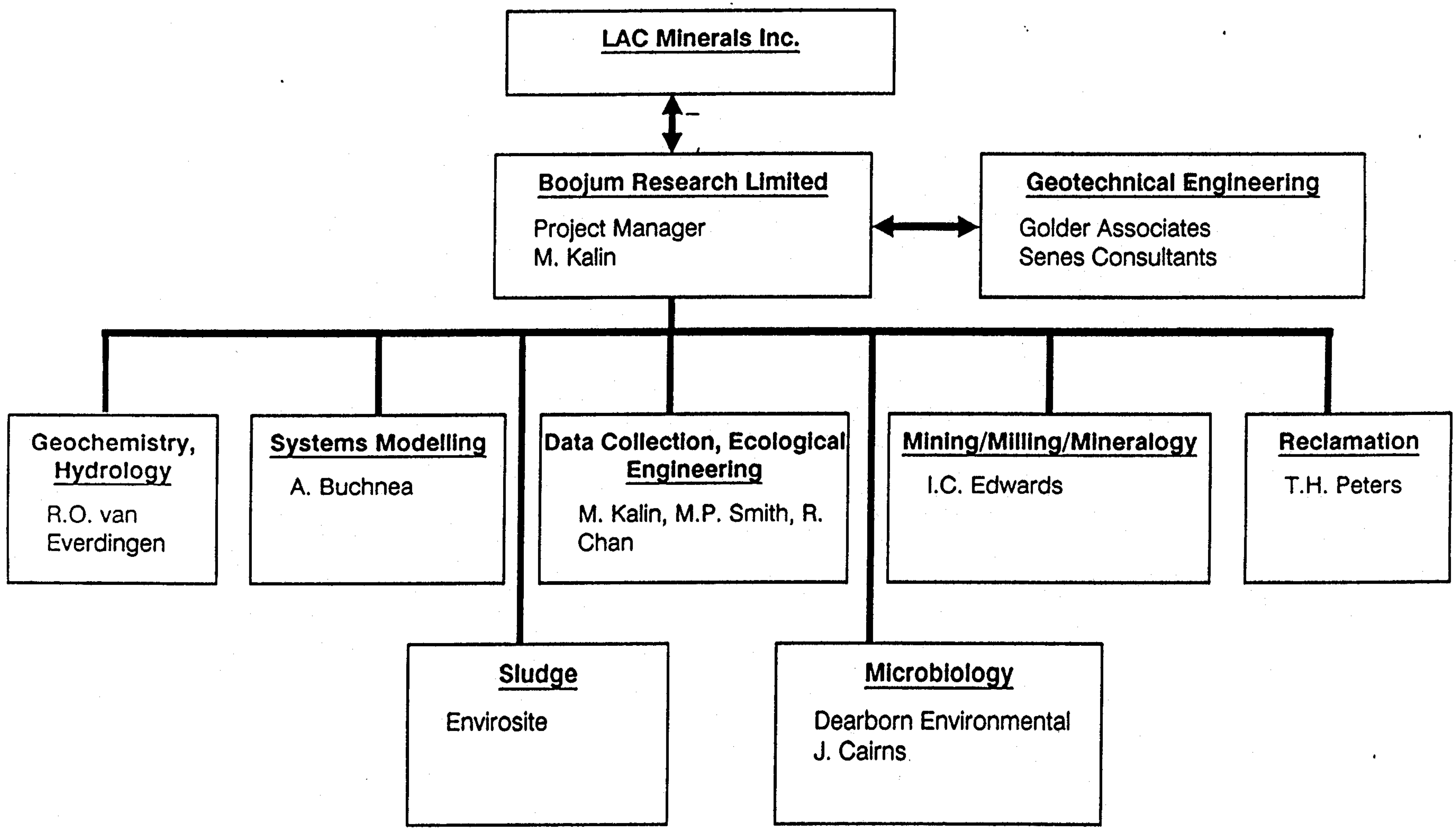
Margarete Kalin, President of **Boojum Research Limited**, is pleased to offer her services as the Research Director of such a highly skilled team. Based on 10 years of research at the University of Toronto as a principal investigator, she gained experience in the management of contracts, and has managed **Boojum Research** since 1982. With the assistance of her staff, **M.P. Smith** and **R. Chan**, **Boojum**'s projects are carried out in a highly efficient, disciplined manner, with an emphasis on quality control.

Particularly important to this project is **Ms. Kalin**'s understanding of the problems of acid generation from both a practical and theoretical point of view. She is able to formulate the questions to be answered in a way that facilitates the interaction of the other disciplines. She is also responsible for the development of the concepts of Ecological Engineering and Biological Polishing, and has implemented these methods for the close-out of mining wastes over the last four years, to the stage of a pilot demonstration.

New members of the team are presented on the third level in **Schematic 5**. Their expertise in microbiology and sludge handling is fundamental to the success of the program. **John Seldon** has 10 years' experience in industrial and municipal waste water treatment, and he has specialized, since 1983, in pressure filtration of sludges from these treatment systems with Envirosite.

J.E. Cairns has over 14 years' experience in industrial microbiology. The multi-disciplinary nature of his work has equipped him with a solid understanding of microbiological processes, particularly the ecology and growth of sulphate reducing bacteria. These are essential to the processes which are being developed by Boojum with CANMET, Inco and Denison Mines. **John Cairns'** background is ideally suited to an assessment and development of the microbiological aspects of the proposed acid mine drainage treatment system.

Schematic 5. Study Team



4.2 Information and Data Management of the Project

Lac Minerals and the consulting firms working with the company are the initial sources of information which specify the requirements for present and future operations.

The information generated from these sources in the different areas, and the data collected by **Boojum's** staff on site during the first year of the study, have to be managed in an organized fashion from one main post. In this way, it will be possible to have, at all times throughout the project, an overview of the program in its entirety, and the work in progress as it relates to the defined objectives.

Boojum Research Limited, Scimus Inc. and R.O. van Everdingen Research Specialties Inc. are all connected by a computer network. This allowed for expedient and compatible data processing through computer exchange of data and text files. CHINTEX and all the computer models related to the geodynamics of acid generation required by **van Everdingen** are compatible with Lotus data base used for data management by **Boojum**. This PC-DOS based computer system served as a cost-effective information exchange providing data processing and statistical analysis media for the project.

In **Schematic 6**, an overview is given of the data flow and management of the program. **Boojum** is central to information input and output and serves as the project data base. **R.O. van Everdingen** will work in close co-operation with the Research Director, thereby sharing the technical responsibility for the data generation in relation to the hydrological and geochemical aspects of the project.

The joint technical creation of the data base will provide inputs to treatment technology and the systems model. The final step of information processing will be the ultimate criteria which was set in the program objectives, i.e. an evaluation of the long term close-out conditions.

4.3 Action Plan and Program Organization

The first year of the program will focus on the objectives and terms of reference for the long term waste management program. In Schematic 7, an action plan is proposed which is self-explanatory. After finalization of the objectives of the program with Lac Minerals, which it is anticipated, will take place at a meeting where the research team will present the proposed work, the next step is the collection and consolidation of existing data. These will be processed as presented in the information flow chart, **Schematic 6.**

The field investigation and data collection can then proceed through the summer months. During this period, it is anticipated that a meeting will be held with Lac Minerals, for presentation of the preliminary findings. Further field investigations will incorporate modifications suggested through client input and the results of the preliminary work carried out.

At the end of the first year, the research team will be in a position to provide recommendations for the program for year 2.

4.4 Overview Of Proposed Time Frame For Waste Management Program

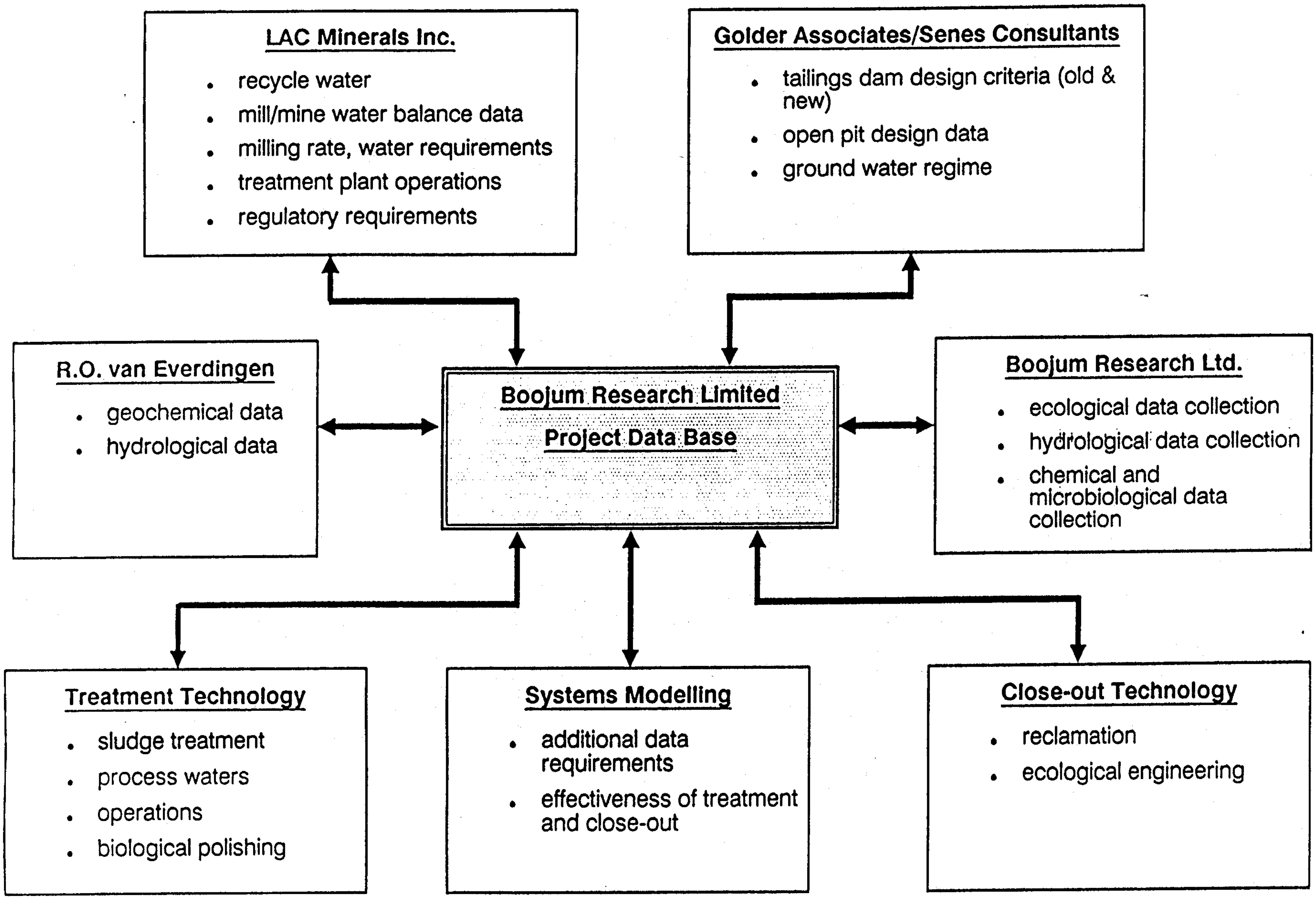
Given the general complexity of the acid mine drainage problem, it would be unrealistic to suggest that the objectives can be achieved in a short time frame. The magnitude of the site and their associated waste management problems require long-term project planning.

The steps which are envisaged for the project are briefly summarized in Table 10. In the first year, the units of the waste management area will be described as carefully as possible, based upon existing information, data gathered throughout the year and the results of the feasibility studies in each unit of the waste management area.

Schedule	Major Tasks
Year 1, 1988	Collection & Evaluation of Existing Data Preliminary Field Data Collection Preliminary Formulation of Remedial Measures
Year 2, 1989	Preliminary Evaluation of Remedial Measures(with Modelling) Additional Data Collection Partial Implementation & Evaluation of Remedial Measures
Year 3, 1990	Implementation of Proposed Measures & Monitoring of Effectiveness
Years 4,5,6: 1991-1994	Monitoring of Measures Review and Evaluation of Measures Implement Required Adjustments
Year of Completion	Confirm all Aspects of System in Longterm and Produce Document for Maintaining Procedures for Plant Personnel Regulatory Approval (?).

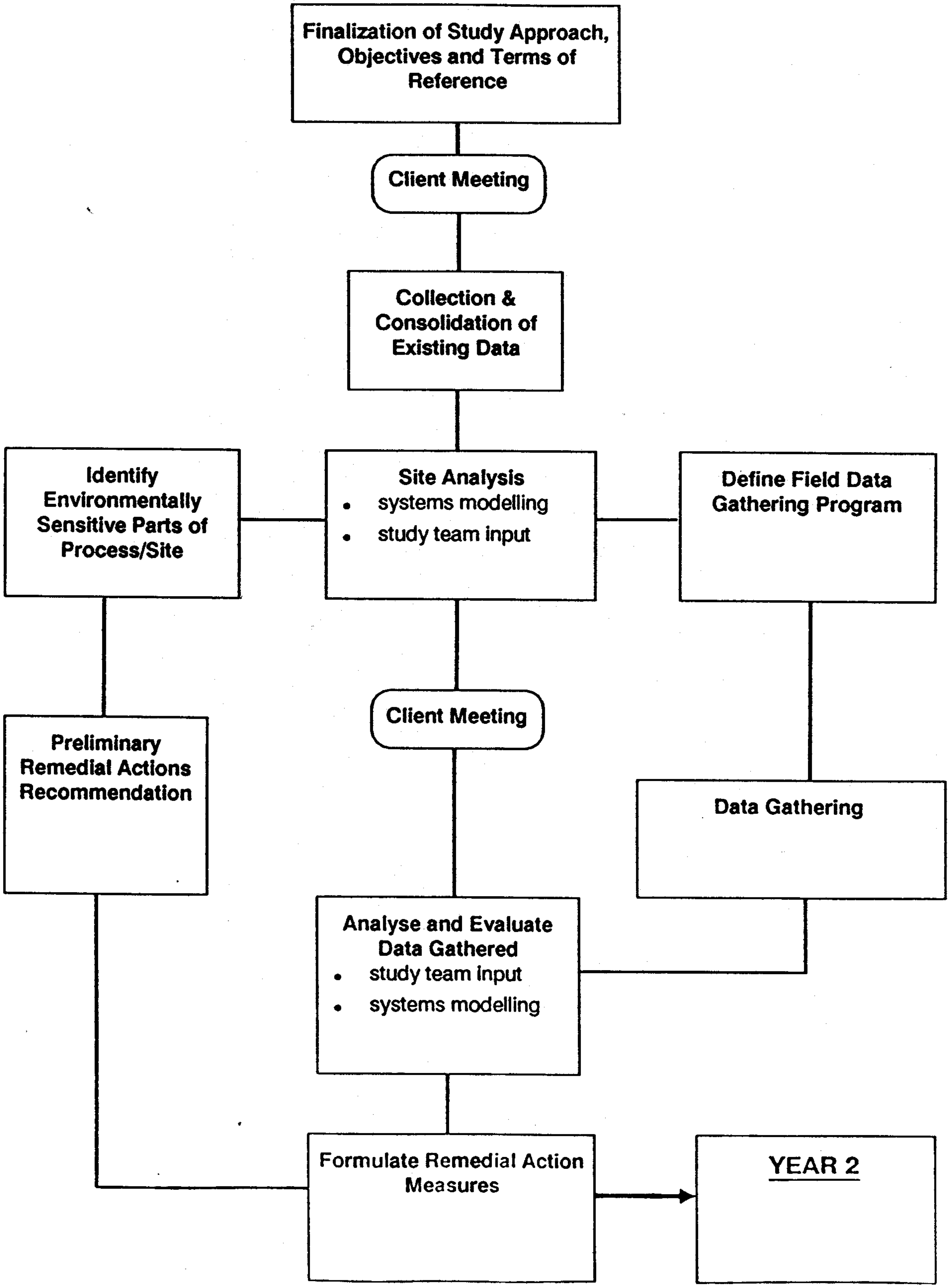
Table 10. Long-term project overview.

Schematic 6. Overview of Information Flow and Data Management of Program



Schematic 7. Project Overview

Year 1 Detailed



Based upon fundamental information collected in year one, emphasis will be placed in year two. These experiments will yield data essential to implement a well defined waste management program in year three.

The following years will be dominated by monitoring activities of the waste management system. This information will be used towards a re-evaluation of the long-term implications and final close-out conditions of the site. It is anticipated that during these years several scientific publications summarizing the experimental results of the work will be written by the research team.

Upon completion of the project, a compendium will be prepared reviewing all aspects of the waste management system performance and its maintenance procedures. With this compendium, Lac Mineral plant personnel can run the program independently, and the system can be submitted for regulatory approval.

PROPOSED DETAILED SCHEDULE OF PROJECT FOR FIRST YEAR

TASKS	1988 F M A M J J A S O N D 1989 J
Start up meeting	XX--------------------------------------
Site visits Sludge disposal and model definition	-X--------------------------------------
Site visit for Microbiological processes	------XX---------------------------------
Background Data collection	--XXXXXXX--------------------------------
Background data analysis first model evaluation	-------XXX------------------------------
Sludge tests	-------------XXX------------------------
Water sampling/ seepage monitoring	-X---XXX-----XXXX---XXX--XXX---XXX--XXX----
Ecological site investigation	------------XXXXXXXXXXXXX----------------
Hydrological site assessment	--------------------XXXX----------------
Preliminary data analysis	-------XXX----------XXXXXX---------------
Site visit for reclamation needs	-------------------------X---------------
Second model evaluation	-----------------------XXXX---------------
Progress report Second meeting	----------------------------XXX-----------
Data analysis and formulation of test program	-----------------------------------XXXXXXXX

4.5 Cost Estimates For The Program

The costs of the first year are simple to estimate and hence, are provided in some detail below. To provide cost estimates for the entire program, given the heavy emphasis on research, would be unrealistic. General trends in expenditures are outlined briefly.

The costs of experimental activities in the second year can only be determined after completion of year one. Costly activities (i.e., installation of piezometers for groundwater and waste rock research; construction activities for Ecological Engineering measures and Biological Polishing experiments; alterations to the treatment system) can be anticipated but might be borne mainly within Lac's own operating funds. However, in the years to come, after the experiments are implemented, the costs of the program will diminish, as the main activities are reduced to data collection and data interpretation.

In summary, the costs of year one (mainly labour of research team) and two (implementation of experiments) are high. For the years to follow, the costs are envisaged to be considerably reduced since by that time all parties involved have defined short-term tasks.

The cost estimate for the first year is a total of $263,105 of which $118,375 is labour from Boojum Research Ltd. and $68,900 are direct costs and administration. The hydrological and geochemical component of the project is estimated at $44,000 and the modelling at $22,500. Together with the input from specialty consultants, the total subcontracts is estimated at $75,830. Details are given below.

COST ESTIMATES FOR YEAR 1

1. LABOUR

M. Kalin @ $ 425/day

Project Management/organization meetings/discussions 6 days/month 72 days/year	$ 30,600
Supervision of all field investigations 27 field days (April - Sept.)	11,475
Data analysis interpretation 3 days/month 36 days/year	15,300
Report writing 30 days	12,750

<u>**Project technicians**</u>

M.P. Smith @ $ 300/day

Field work 60 days (April-Sept) Data collection and supervision of summer students	18,000
Experimental design biological polishing and "*Chara* process" 15 days	4,500
Sample preparation for chemical analysis, Data protocol data summaries 30 days	9,000

R.Chan @ $ 250/day

Data processing/computer systems communications/ report production 35 days	8,750

Summer Students

4 Students for 2 months @ $ 1000/months	8,000
Subtotal Boojum labour	$ 118,375

2. TRAVEL

10 Return Airfares Toronto/Noranda @ $250	2,500
Truck rental for 4 weeks @ $ 800/week including gas and mileage	3,200
Boojum car usage for entire project $400/month for 5 months	2,000

3. ACCOMMODATIONS/SUBSISTENCE

M. Kalin: field investigation and supervision of subcontracts 32 days @ $100/day	3,200
Technician: field investigation, data collection 60 days @ $100/day	6,000
Subcontractors: T. Peters, Dearborn, Envirosite, Scimus each 2 days (8 days total) @ $100/day	800
Summer students: 4 students for 40 days (160 days total) @ $70/day	11,200

4. CHEMICAL ANALYSIS

Assayer (Ontario) Ltd. ICP multi-elemental scan @ $25 per sample - 400 samples	10,000
Nutrients, anions, Microbial determination X-ray defraction, specific ion analysis cyanide, etc. allow	2,000
University of Calgary Isotope analysis, oxygen/sulphur allow	3,500

5. CONSUMABLES

Sampling bottles, bags etc. pH probes, sample shipping, chemicals, photography, telephone	4,500	
Equipment usage Boat, pH-, oxygen-, conductivity meters, hip-waders	3,000	
Subtotal Boojum direct costs		51,900

General and accounting 10 % ($ 51,900 + 118,375)	17,000
Total Boojum Research Limited	$ 187,275

SUBCONTRACTS

1. **HYDROLOGY/GEOCHEMISTRY:**
   R.O. van Everdingen Research Specialties Ltd., Calgary

1. Labour

R.O. van Everdingen @ $400/day 10 days the field investigation	4,000
Evaluation of acid generation quantities, waste rock piles, tailings 25 days	10,000
Analysis of waste rock data 15 days Analysis of chemical data	6,000
Interpretation of hydrology for geochemical dynamics 30 days	12,000
Report writing 20 days	8,000

2. Travel and Subsistence

4 Return Airfares Calgary/Noranda/Toronto @ $800/trip	3,200
Accommodation for 8 days @ $100/day	800
Total Subcontract	$ 44,000

2. MODELLING LONG TERM

Scimus Inc. Willowdale, Ontario

Alex Buchnea @ $500/day Initial analysis of system water balance 9 days	$4,500
Analysis of different waste areas using collected data 18 days	9,000
Discussions, meetings, field trip, report writing 15 days	7,500
Computer usage	1,500
Total Subcontract	$ 22,500

3. CONSULTANTS

MICROBIOLOGY

Dearborn Environmental, Toronto J. Cairns @ $386/day for 5 days	$ 1,930	

SLUDGE EVALUATION

Envirosite, Kitchener J. Seldon @ $300/day for 3 days	900	

RECYCLE WATER/MINING/MILLING

Tim Edwards, Toronto @ $300/day for 3 days	900	

RECLAMATION

Tom Peters, Sudbury @ $400/day for 5 days	2,000	
Subtotal Consultants	5,730	
Total Subcontracts and Consultants		$ 72,230
Boojum Administration Costs 5 %		3,600
Total costs of Subcontracts/Consultants		$ 75,830

Cost Estimate Summary:

Boojum Research Limited	$ 187,275
Subcontracts and Consultants	75,830
Total Cost Estimate for Year 1	$ 263,105

5.0 REFERENCES

Hope, George, (1984). "Operation of La Mine Doyon", 16th CMP Conference, Lac Minerals/La Mine Doyon.

Kalin, M. and M.P. Smith, (1986). "Biological polishing agents for mill waste water. An example: *Chara*, BIOMINET Annual Meeting, Mississauga, Ontario, October 24-25, 1985.

Kalin, M. and R.O. van Everdingen, (1987). "Ecological engineering : Biological and geochemical aspects, Phase I experiments" proceedings: Acid Mine Drainage Seminar\Workshop, Halifax, Nova Scotia, March 23-26, 1987. pp. 565-590.

Patterson, Robert J. (1987). "Environmental & Reclamation Measures at Equity Silver Mines Ltd.", Acid Mine Drainage Seminar\Workshop, Halifax, Nova Scotia, March 23-26, 1987. pp.297-317.

Senes Consusltants Limited, (1987). " La Mine Doyon: Acid Generation Assessment."

Vachon, D., R.S. Siwik, J. Schmidt and K. Wheeland, (1987). "Treatment of acid mine water and the disposal of lime neutralization sludge", Acid Mine Drainage Seminar/Workshop, Halifax, Nova Scotia, March 23-26, 1987. pp.368-395.

van Everdingen, R.O. (1987). "Comments on SENES Consultants Report: La Mine Doyon- Proposed testing program for determining the effectiveness and applicability of a sludge cover on the Doyon waste rock piles."

van Everdingen, R.O. and H.R. Krouse (1987). "Interpretation of isotopic compositions of dissolved sulfate in discharges from sulfide-bearing mine tailings". Abstract submitted to 1988 Mine Drainage and Reclamation Conference, Pittsburgh, PA, April, 1988.

Therrien, D. (1987). "Statistiques d'analyse des effluents du site de la mine". Annual report for La Mine Doyon. August, 1987.

CANMET (1987). "Generation and stability of Canadian mine/smelter effluent treatment sludges". Internal Report.