KAM - KOTIA

PHASE 1 & 2

BY: M. KALIN

Boojum
RESEARCH LIMITED

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KAM-KOTIA TAILINGS

RECLAMATION BY ECOLOGICAL ENGINEERING

PHASE 1

FEASIBILITY EVALUATION

BY

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FOR

MINISTRY OF NATURAL RESOURCES
TIMMINS, ONTARIO

IN FULFILLMENT OF P.O. # 12457

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EXECUTIVE SUMMARY AND RECOMMENDATIONS

Environmental impacts of the acid-generating tailings at the Kar-Kotia site have been investigated and a reclamation scheme proposed by Kilborn (1982) and GTC (1983). The proposed reclamation measures are conventional and include construction of low permeability covers to lirit infiltration of water and air, and cut-off walls to divert groundwater and redirect surface water, and neutralization, seeding and fertilization of large areas.

Both containrent structures and covers consisting of introduced vegetation require long-term maintenance and both are subject to failure. Furthermore, some proposed reclamation measures require the excavation of the tailings, which could result in a severe environmental impact due to the release of acid which is presently contained in the tailings.

Introduced vegetation established on acidic tailings after neutralization, is not tolerant to the acidic conditions which continue to exist underneath the neutralized stratum of the root zone. The loss of vegetation cover has been reported to result from unfavorable conditions in spring when the freeze and thaw cycle can bring acid up into the root zone.

Vegetation covers, therefore? require long-term maintenance before they yield stable conditions. Furthermore, their effectiveness in eliminating acid generation below the root zone is not known at present since the interception of precipitation and the infiltration of air is not necessarily prevented. Conventional methods of establishing vegetation covers including neutralization and fertilization, which are mandatory for the establishment of introduced species, encourage the growth of deep-rooted vegetation.

After maintenance of the cover has ceased, the vegetation is not tolerant to the acidic and low nutrient characteristics of the waste which will remain in the long term. Vegetation covers of introduced species, therefore require long tern maintenance before they yield stable 'conditions. Hence these methods fail to guarantee a total maintenance and acid-generation-free reclaimed site.

The most desirable solution should achieve a reclamation of the site which is completely self-maintaining and should restore the site to its most natural condition within the surrounding environment. To minimize the environmental impact of the site, two principal aspects must be changed:

- the acid generation from the tailings has to be prevented to improve the effluent waters from the site and

- the seepage water from the Impounded tailings area has to be improved by precipitation of dissolved elements.

By building indigenous self-ratntaining ecosystems on the tailings, they will yield biomass which has a cleansing effect on the water. The organic matter which accumulates in the system will produce a layer on the tailings, which will ultimately prevent oxygen penetration. Hence acid generation will be reduced to a point of insignificance. These reclamation measures have been developed, based on the studies of the natural recovery processes. They can yield a final walk-away solution, which will be self-maintaining. The utilization of indigenous plants on the site is the principal component to such a maintenance-free reclaration schere. These plants are tolerant to the acidic conditions and low nutrient concentrations present; in short, once established, they do not require fertilization or neutralization.

Beneficial effects of organic matter, algal populations and macrophytes, on acid mine drainage have been documented by King et al (1974), Dugan (1972), and rany others. The use of these well-documented processes in reclamation measures however, has not been developed·to the point of general application. These reclamation measures are referred to as ecological engineering as opposed to pure civil or geotechnical engineering measures.

Ecological engineering measures are site-specific and require research to identify detailed approaches which will assist the rudimentary indigenous ecosystems present on the site to expand extensively and also to determine the tire required for this assistance. There are generally three phases required:

Phase 1: A brief feasibility study of the site, to identify the rudimentary ecosystea characteristics and the general conditions of surface and water.

Phase 2: Implementation of an experimental approach to ecosystem expansion and development.

Phase 3: Implementation of results of phase 2 for reclamation of entire site and withdrawal of supporting treatment system.

The ecological engineering 'approach presented here is a potential solution in achieving a maintenance-free reclaimed Kar-Kotia tailings site. Although this represents the first 'large scale attempt to apply this approach, much work has been done in the past decade, which strongly suggests that this approach would yield a economic and effective solution to acid generating tailings. Furthermore it has been suggested that if some aspects of ecological engineering are adopted during the life time of a mine, shut down costs would be considerably reduced.

The successful and economic reclamation of the Kam-Kotia tailings site (a severe case of acid generation and associated environmental impacts) by ecological engineering measures would reflect great credit on the cle'an-up sponsor. A demonstration of the effectiveness of these reclamation measures would result in economic benefits for other close-out scenarios of acid generating tailings and future shut down cost of mining operations.

In Phase 1 of the project the feasibility of utilizing the ecological engineering approch to reclaim the Kam-Kotia tailings was assessed.A preliminary survey of the site and collection of indigenous species was undertaken to formulate an overview concept for a reclamation program specific to the Kam-Kotia site.The site was found amenable for reclamation by expansion of existing rudimentary ecosystems , as assemblages of algal biomass and macrophytes, tolerant to the acidic conditions were found at the site.

Encouraging the grouth of existing biota will consist mainly of diversions and chemical treatments of surface water. Treatment of surface water is considered a temporary measure to purge the existing system and initiate the recovery process.

Recovery will not be instantaneous. A minimum of tuo growing seasons is required to assess the rate of recovery of the site. Phase 2 of the reclamation work will therefore consist of setting up experimental treatment areas on site and to model the system under accelerated climatic conditions in the laboratory utilizing lysimeter test facilities. By phasing the reclamation program in this manner, immediate improvements in the effluent quality will be achieved and data collected to provide predictive capability for the long term and ascertain reliable costing parameters for Phase 3.

If this approach to reclamation is taken, within one year, its potential could be evaluated relative to the proposed conventional measures. An initial cost of $15,375 has been calculated for starting the project before the growing season. The expenditures in the fiscal year 1985 are estimated to be $561,825. Proven sucessful the annual costs of the this labour-intensive project are at present estimated for 1986 to be around $302,660 resulting in a completed Phase 2. Full site reclamation is anticipated to occur in 1987 with projected costs of $1,665,500. Between 1988 and 1994, the projected annual costs decrease from $350,000 to $33,000 at which time it is anticipated that a self-maintaining system will be *in* place.

It should be emphasized that these figures are cost projections based on estimates and particular care was taken not to underestimate the costs in view of earlier proposals. The total projected costs of reclaiming the Kam-Kotia tailings with ecological engineering measures will be revised after Phase 2 and may be lower, given the present uncertainties of sore parameters. However at present the total projected estimate for reclamation is $4,120,700 over a period of ten years.

RECOMMENDATIONS

Since observations during a complete growing season are essential, a decision to proceed with the reclamation project should be made by early spring, i.e as soon as possible. Based on the preliminary results of the feasibilty study it is recommended that ecological engineering measures be applied to the Kam-Kotia tailings. To determine if the reclamation measures are effective as proposed it is further recommended that year one of Phase 2 be implemented as soon as practicable.The following schedule is suggested:

1.Project start up: end of February 1985	-detailed design of treatment plant. -laboratory growth experiments . -detailed design of lysimeter facility.
2.On site work: beg. April 1985	-construction road, workpads and water containments -construction of treatment plant -organization of field experiments
3.Evaluation: end of Nov. 1985	-summary of results of year one -project details for year two

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KAM-KOTIA TAILINGS
RECLAMATION BY ECOLOGICAL ENGINEERING

PHASE 1
FEASIBILITY EVALUATION

1. INTRODUCTION

An inquiry by M. Paradis (MNR) was made to M.Kalin (Boojum Research Ltd) in early October 1984 to consider the applicability of ecological engineering measures to reclaim the Kam-Kotia (KK) tailings.

During mid-October a short site visit was arranged and M. Kalin discussed this novel reclamation approach with Ministry of Natural Resources and Ministry of the Environment personel.A proposal for a preliminary study to evaluate the feasibility of reclaiming the KK tailings with ecological engineering measures was prepared and a purchase order issued on the 18th of October 1984.

The objectives of this preliminary study were to;

i) assess the existing information on the site.

ii) identify water and biological characteristics of the site.

iii) assess the feasibility of applying ecological engineering measures to reclaim the site.

iv) formulate site specific conceptual ecological engineering measures.

v) provide estimates of costs and time-frames of the reclamation measures for the entire tailings site.

The fundamental requirement of the proposed approach is the presence and distribution of indigenous pioneering biota on the tailings site and their ecological characteristics in addition to the chemical characteristics of tailings seepage water and fresh water which enters from the vicinity onto the site. If these requirements can be easily assessed, then the feasability assessment can essentially serve as a preliminary Phase 1 of the reclamation measures.

MacLaren Plansearch Inc.(MPI) was subcontracted to provide input to the engineering requirements for the work. Ontario Research Foundation (ORF) was also subcontracted to provide the methodology for the assessment of the long term capability of the proposed measures and analytical services.

This report summarizes the results of the assessments and outlines a general concept for reclaiming the KK tailings with ecological engineering measures.The discussion of the preliminary findings is presented in the report as Phase 1. As the requirements for this approach appeared very promising a detailed outline for a Phase 2 pilot project is provided in Appendix A. The pilot project defines more precisely the long term viabilty of the proposed approach and will result in realistic costing parameters for the overall reclamation scheme of the site.

2. DISCUSSION OF PRELIMINARY FINDINGS: PHASE 1

2.1 Assessment of existing information

Boojum Research Ltd. was provided with a number of reports (listed in Table 1) describing the environmental impact of the tailings and a proposed geotechnical reclamation scheme. These documents served as sources of background information on the site. The reports were reviewed and annotated by M. Kalin for the subcontractors in preparation for discussions on the subject. A project meeting was held on the 31st of October at MacLaren Plansearch Inc., and attended by J.Roberts (MPI), V.I.Lakshmanan (ORF) and M. Kalin to discuss the overall problems at the site.The main conclusions derived from these reports are:

- The acidic water and the solids loading migrating from the Kam-Kotia tailings has severely affected the water quality and the sediments of the Little Kamiskotia and the Kamiskotia rivers. Specifically? both the precipitation of dissolved ions at discharge points or interfaces with fresh water, and the settling of suspended solids, have resulted in sediment destruction,

- "The immediate and most significant environmental impact is a consequence of surface erosion and surface water transport of contaminants. The ground water contamination plume has not migrated a significant distance from the major storage areas. The primary immediate detriment to the receiving environment from the Kam -Kotia tailings is that of surface water erosion of tailings and subsequent overland contaminant transport." (GTC,1984).

Given that the surface water is the major problem, it follows that the ecological approach may be applicable.In general ecological engineering brings about improvements in the surface water and prevents surface erosion of tailings in two ways:

i) Converting areas of exess moisture on the site into wetlands. Wetlands contain algal biomass which precipitate dissolved ions. The precipitate is held in place by the biomass which is of an attached periphytic growth form . In time the biomass will cover the tailings with a layer of organic matter? which will prevent oxygen penetration and hence acid generation.

ii) Enouraging a moss cover with low indigenous shrubs in dry areas prevents wind erosion and with time will limit infiltration of water and air. Moss typically grows in cracks producing annually a thin layer of organic matter, which is completely anoxic.Root formation of indigenous shrubs appears to occur laterally on abandoned unmaintained tailings sites in response to the drought stress in dry areas.

The aim of this preliminary study was to evaluate if these types of ecosystems could be established on the Kar-Kotia tailings. Since the previous work mainly addressed the hydrogeolgical aspects of the site and the receiving environment, little information was available on the following aspects:

- ecological information

- surface water characteristics and fresh water sources
- topographical details for placement of containment structures and access.

This type of information, however, was essential in order to proceed. In the project meeting it is was concluded that a site visit and sample collection were required.

2.2. Ecology and surface water characteristics

On the second of November, J. Roberts (MPI) and tuo biologists (M.P. Srith and M.Kalin) from Boojur Research Ltd. visited the site. Strong winds and below zero temperatures were encountered and extensive wind transport of tailings was observed (Plate 1). Samples of uind blown tailings covering the snow had a pH value of 2.5 (Plate 2).

The weather conditions did not impair the site reconnaissance and in fact the slightly frozen soil facilitated two trips on foot to acquire samples from the North Unirpounded Area and the South Kill area (Figure 1) however sarples from the Little Kariskotia River were collected adjacent to the highway and from an old mine road. A total of 27 sampling locations were chosen. Site descriptions and type of samples are given in Table 2.

2.2.1 Indigenous plants

The essential requirement for building indigenous ecosystems is the presence of colonies of tolerant species which have colonized the tailings site. As the Kar-Kotia tailings have been abandoned for some time, such indigenous colonies could be expected, particularly in association with areas which border on native material (which acts as a seed source) such as dams covered with gravel or along the edges of the tailings boundary. The colonization pattern on the tailings area by indigenous species has to be such that the expansion of islands uould yield a complete cover over the tailings. For example,should colonization have occurred only on the edges of the tailings covering large internal areas could prove to be difficult and depends on the topography of the site.

It uas found that cattails, frequently along with other racrophytes such as rushes and sedges (Plates 3 and 4) had colonized both the tailings area proper and along the edges of the tailings. Most encouraging was the extensive occurance of algal biomass. Thick mats were found in dilute seepages (Plate 5) and also in association with macrophytes on the northern section of the North Unirpounded tailings area (Plate 6). The association of neutral pH water flowing from drill casings (Plate 7) and cattail stands immediate downstream (Plate 8) in the South Kill area suggested that fresh water input in the forr of run-off promotes colonization of indigenous species.

Seepage water , ie. surface water contaminated from extensive contact with tailings by running over them for a long time or fror stagnant conditions, was found to have the most detrimental characteristics. Only unicellular algae are attached to the tailings in these areas of the site and formed a thin film over the tailings. Similar observations were made by M.Kalin on other acidic tailings sites in the Sudbury area.

It was not possible to survey the entire site. However it is suggested that a similar combination of macrophytes and algal biomass can be expected in the southern sections of the North Unimpounded tailings area where run-off water input to the tailings exists.

November is not the appropriate time to collect and assess vegetation because the peak of the growing season has long past.Most life forms are dormant. However algal cultures were obtained fror some locations.In Table 3 those locations are listed and the growth status of the culture is summarized. Since the algal collection covered, even at this unfavourable time, a wide variety of extreme conditions, and a very positive grouth response was noted in the laboratory, it is suggested that during the growing season a wider distribution and a more extensive flora can be expected.

However diversity of the colonizing community and their presence alone is less important then are some of their characteristics. Since the improvement of the water quality of the site is in part dependent upon the precipitation ability of the biomass the presence of mucelage forming algae is essential. (Note brounish preciptitate on Plate 9).

It is believed that a sheet of mucelage around the algal cells is instrumental in the removal of such elements as iron , magnesium and heavy metals.These observations are at present not quantified and work is in progress on this aspect. However it should be stressed that this process has been observed frequently in seepage areas of acidic tailings in Uranium City, Elliot Lake and Sudbury. The ecological characteristics of the indigenous algal populations and their identifications are summarized in Table 4. The taxonomic groups present on the Kam-Kotia tailings are clearly those common in acidic environments and most importantly the mucelage forming filamentous Chlorophyta are present and quite abundant (locations 1,2,3,11,22).

Identification to species were not possible in many cases since the distinguishing morphological and/or reproductive characteristics were absent and have to be obtained from cultures or from samples taken at different times in the growing season. A brief summary of the missing taxonomic Characteristics is given in Table 5. The idenfification to species is secondary to the intended use of this biomass in ecological engineering measures, but more important is the presence of an assemblage of acid-metal tolerant and mucelage forming groups. It will be the aim of the laboratory uork in Phase 2 to determine, not at a species level, but for the community, bloom inducing measures or on the other hand growth controlling factors.

2.2.2. Chemical Characteristics of the Surface Water

Data on the presence of algal biomass and macrophytes is only of significance if the chemical conditions which these plants have to tolerate on the waste site are known. On each sampling location four 250 ml Nalgene sampling bottles were filled. One 250 ml sample was immediately preserved for sulphides which could be present in certain surface waters. This sample was neutralized with 0.1N NaOH and fixed with 10 ml of Zn-acetate (Allen, et.al.1974). Filtration of 250 ml through 0.45 um Sartorius filters was carried out within 10 h of collection. One filtered and one unfiltered sample uere acidified with concentrated Nitric acid and one sample remained natural. The filterpapers uere retained individually in small petri dishes , dried at 105oC and weighted for determination of total suspended solids. At sampling locations where "cleaner" water could be anticipated, 500 ml of water uere collected.

In the same location two biota samples were collected. One sample was immediately fixed uith Lugol's solution and the second one was used for culturing on return to the Boojum laboratory. The samples uere kept in coolers with ice. The chemical analysis was carried out by ORF uithin 5 days from the sampling date. The values reported are total concentrations, determined either on the natural sample or the unfiltered acidified sample as required depending on the parameter determined. This sampling design was chosen to accorodate a stepwise investigation of the cherical characteristics of the water, which would allow the determination of additional characteristics, should this be nessessary.

In Table 6 the pH, conductivity, and the acidity or alkalinity, of the surface water on different locations of the Kam-Kotia tailings site are given. The surface water is extremely acidic and as expected in most cases high acidity values were mesured. Slight differences can be noted in the pH values measured in the field and those measured in unacidified unfiltered samples in the laboratory. This is not suprising since the determinations in the field are prone to contamination working in this very acidic environment, as only a limited amount of rinsing water was carried around on site. The water from the drill casing (20), the seepage from the Impounded tailings (25), and the uncontaminated water from the Esker(24) are neutral to slightly alkaline. The lowest alkalinity was determined in the Little Kariskotia River (21) at a point after it had received the seepage from the South Kill area.

The relationship of conductivity and acidity is more or less linear (Fig.2a), however the relationship between acidity and pH (Fig 2b) suggests the presence of two types of waters. In one type of surface water the hyrdogen ion concentration (pH) increases with acidity, as would be expected. However, a second type of water exists which exhibits relatively low hydrogen ion concentrations with high acidities. This is an indication of complex equilibria which may exist in water at a low pH with high acidities.

The differences in water types which occur on the site is also indicated the their buffering capacity from the titration curves shown in Figure 3. The samples 13 and 15, standing or slow flowing water in the South Kill area, required considerably more NaOH than samples 4,22,17 which were collected from water leaving the North Unimpounded area (4) , the open pit (22) and in the eastern section of the South Kill area (17) (Figure 1). It is important to recognize that all these samples had a similar pH value (~2.5) in the field and in the laboratory (Table 6). The characteristics of the surface water have implications for any potential treatment of the site, as the requirements for neutralizing water with the characteristics of samples 13 and 15, for examples, will be considerably different than for other acidic waters.

This brief investigation into the chemical characteristics indicates clearly that a variety of waters will be encountered on the site. Sould the entire surface water be equally contaminanted, or with equally undesirable characteristics, then it would require a considerably larger treatment effort to initiate the recovery of the tailings area. In fact the values of acidities encountered on the Kam-Kotia tailings, or in the vicinity, are distributed over a large range (Figure 4a) and the same is true for conductivities (Figure 4b). The histograms in Figure 4 rank the values obtained for each site fror the highest to the lowest. Water from locations representing background or the vicinity are, as expected, lower in acidity and contain lass dissolved material, as reflected roughly by the conductivity values.However rany locations on the tailings areas have water characteristics which are not too adverse, and which ressemble those of natural acidic environments, for example, muskegs. These ranges of water characteristics indicate that improvements of the surface in some areas will result in an immediate overall improvement of the effluent quality.

Given the variation in acidity and conductivity value, large variation can also be expected in elemental concentrations arong sites. The concentrations of different elements suggest the possibility of metal toxicities or chemical reactions which yield undesirable water characteristics on the tailings. Hence a subset of samples was selected and analysed in more detail.

In Table 7, the major ions concentrations are given for a subset of samples, consisting of the seepage water leaving the North Unimpounded tailings (4), water running on tailings in the southern section of the North Unimpounded tailings (7), water from the man-made ditch in the South Kill area (15), and the run-off seepage of the eastern section of the South Unimpounded area (18) (Figure 1).

Samples were selected to represent waters on the tailings which need to be improved, and natural waters presently contaminated by the tailings. These included water in the Little Kamiskotia River after mixing with the seepage from the South Kill area (21) , seepage from the Impounded Tailings on the surface discharging into the South Unirpounded tailings area (25). Uncontaminated water from the Esker (24) was also analyzed. The elements chosen for analysis do not represent all of those which are of concern in relation to environmental pollution, as for. example Zn and Cd were not determined. However, a set of elerents was selected which would indicate some of the chewical processes which occur in the surface waters and is relevant to the proposed reclamation measures.

The total amount of cations measured in the analysis of the acidic seepages (4,7,15,18) and the water from the Little Kamiskotia River represented only 50 percent of the total anion (SO4) measured in the sarples. The calculations carried out by GTC on the same basis resulted in a considerably greater cation/anion balance. From the analysis of ferric and ferrous iron and total aluminum it can be suggested that these ions on the surface may forr sulfate complexes, binding a higher number of sulfate molecules.

On the other hand, both in clean water (24) and in seepage from the Irpounded tailings area (25) most of the cations are accounted for (total cation/total anion ratio is higher). This suggests that complexing is probably quite significant on the surface. This condition is further indicated by the comparisons of surface water and water from piezometers collected in similar locations (Table 8).

In Table 8 the elemental concentrations of waters collected during the GTC investigations are listed for those locations which were in the vicinity of sampling locations in this study. The GTC samples were collected from pore water from piezometers, where cation concentrations (Mg, Ca, Na) are expected to be higher than in surface waters. Pore water from piezometers is most similar to seepage water (25), suggesting important differences from the surface water.

The elemental concentrations in the Little Kamiskiota River samples were variable. This could be a result of the quantity of run-off from the South Kill area in addition to oany other factors. However the results of the background water samples agree very well with each other (KK9 and 24). This does suggest that the differences observed are not a result of different analytical techniques or sampling methods.

In the lower part of Table 8, the characteristics of surface water collected on the tailings and in the Little Kamiskotia River by the Ministry of the Environment during the summer of '84 have been presented. A comparision of these elemental concentrations to those determined in this study indicates that in addition to within site variation, seasonal variation in water qualitiy can be extremely large. The total concentrations of Mg, Cu, Al, Na and sulfate in the water on the tailings were higher in July and August 1984 (dates of HOE sampling) than in November 1984 when sampling was done for this study.

2.3 Conclusion and Recommendations

The analysis of the existing inforration on the Kar-Kotia tailings revealed clearly the nature of the environmental problems. The evaluation of the state of colonization of indigenous plants was encouraging. The chemical characteristics of the surface water exhibit a wide range of values, which facilitates the use of different reclamation measures on the site.Seasonal variations in water quality can be expected to be large.The topography of the site is favourable to implementing changes in the surface water flow since the distances between the source of acidic water and the final points of discharge are sufficiently large for ecosystem cleansing to result in effluent improvement. Contaminants will be contained on site and, with inital treatment? ecosystem establishrent and recovery is anticipated.

It is concluded that ecological engineering, based on the data collected, is a viable alternative to the conventional measures proposed in the reclamation of the Kar-Kotia tailings.

It is recommended that before the entire site is reclaimed, a two year investigation program (Phase 2) should be implemented. This is because of the limited arount of seasonal information available which is specific to the surface of the site and the importance of data on water flow and growth characteristics of the indigenous colonizers in the water. At present, there is no information on the colonizing vegetation in dry areas on the site.

It is recommended that during Phase 2 the follwing steps are taken:

- In the first year, treatment of the seepage in the South Unimpounded area should be implemented.This will immediately improve these highly adverse effluents and at the same tire recovery rates can be quantified and effects of such a treatment evaluated.

- The hydrology of the site needs to be investigated along with the surface water chemistry to define areas where wetlands can be built.
- The growth characteristics of indigenous species have to be deliniated seasonally, and measures have to be tested to encourage aerial expansion and growth of existing colonies.
- A predictive capability has to be developed which will provide assurances of final effluent quality and the walk-away system.
- A second year should be allowed to confirm and implement some of the findings of the first year and to test the conditions on the site during run-off.

TABLE 1 : LIST OF DOCUMENTS ON THE KAM-KOTIA TAILINGS

Author	Year	Title	Subject
Gibson, C.R.	1976	Pollution characteristics of Kam-Kotia Mines Ltdm Robb Township: An abandoned base metal mine-mill complex. MOE Ont.	Water pollution
Gibson, C.R.	1978	Report of Provincial officer, pursuant to section 83 of the Environmental Protection act of Property previously known as Kamkotia Mines Ltd.	Water Pollution
MOE.	n.d.	Kam-Kotia mine ı Robb Township, City of Timmins: Environmental considerations and remedial measures.	Water Pollution
MOE.	1982	Technical Memorandum to: N.I.Conroy; Biological survey of the Little Kamiskotia and Kamiskotia River.	Sediment and Water Pollution
MOE.	1984	Draft Report : Kam-Kotia Mine's tailings project, Experience program 1984.	Revegetation trials
MOE.	1984	Water analysis of 4 sites related to Experience program.	Surface Water
Kilborn,	1982	Kam-Kotia Tailings Reclamation Project: Executive Summary, Final Report vol,1,2,3.	Site assessment
GTC.	1984	Kam-Kotia Tailings Reclamation Project: Detailed Hydrogeological Investigations Program, 1983-1984.	Ground water & site ass.

Plate 1: View from South Dyke during strong winds, Nov. 1st, 1984. An example of a severe tailings erosion event.

Plate 2: Tailings on Snow on South Dyke on Nov. 1st. 1984. The acid pulse during spring runoff may have a major impact on the fish populations of the drainage system.

alathuir – from 3,5,6;4;22
(seepage from open pit

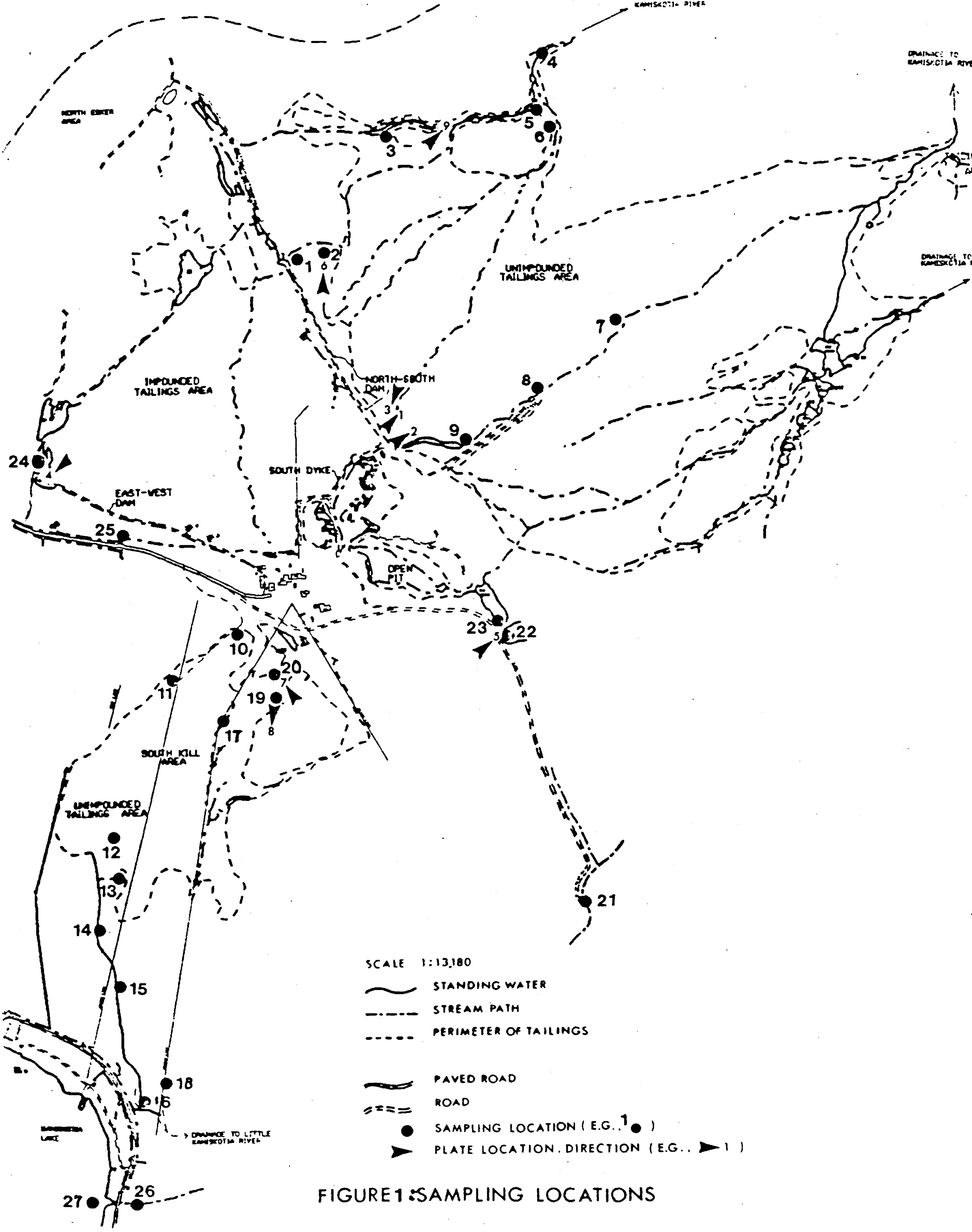


FIGURE 1: SAMPLING LOCATIONS

TABLE 2: SITE DESCRIPTIONS AND FIELD COLLECTIONS, NOV 1-5TH 1984

Site No.	Description	Field pH*	Type of Sample collected Water	 Sediment	 Biota
NORTH UNIMPOUNDED TAILINGS					
1	North of dam in dead Jack pine forest,cattails present shallow puddle	2.2	yes	no	yes
2	large creek	2.2	yes	no	yes
2a	300M NE of open area	2.2	no	no	no
3	large seepage stream	2.2	yes	no	yes
4	below junction of 2 major seepage streams	2.6	yes	no	yes
5	large stream from north end of unimpounded tailings	2.4	yes	no	yes
6	stream above junction flowing north >30 cm tailings	2.4	yes	no	no
7	small stream in middle of tailings	2.6	yes	no	no
8	slow flowing stream	2.4	ye5	no	no
9	slow flowing stream	2.6	yes	no	no
SOUTH UNIMPOUNDED & KILL AREA:					
10	head of seepage at slurry pipe	2.2	yes	no	yes
11	seepage between living forest and cattail stand	4.2	ye5	no	yes
12	small creek on tailings	2.8	yes	no	no
13	in spruce vegetated "island", still water red in colour	<2	yes	no	yes
14	large man-made ditch reddish colour,slow flow	2.3	yes	no	yes

TABLE 2 cont: SITE DESCRIPTIONS AND FIELD COLLECTIONS, NOV 1-5TH 1984

Site No.	Description	Field pH*	Type of Sample collected Water	 Sediment	 Biota
15 -	large stream - dark tea-colour (no biota!)	2.2	yes	(organic ratter)	no
16 -	water in ditch (no biota!)	2.3	yes	no	no
17 -	beside piezometer on hydro-line path (N. of KK17)	2.7	no	yes	yes
17a-	stream under hydro-line (no biota!)	2.7	yes	no	no
18 -	streambed of hydro-line no biota	2.6	yes	no	no
19 -	southern drill casing (depth <9 m)	5.8	yes	no	no
20 -	northern drill casing (depth <85 m)	6.0	yes	no	no
BACKGROUND AND VICINITY:					
21 -	Little Kariskotia River slow flow	4.8	yes	no	no
22 -	seepage from open pit water pool	2.6	yes	no	yes
23 -	beach of open pit	2.8	yes	no	no
24 -	freshwater pond (above the impounded tailings area)	5.8	yes	no	no
25 -	seepage from Impounded by road	6.0	yes	no	no
26 -	Little Kariskotia River (at lake shore)	6.0	yes	no	no
27 -	Kariskotia Lake (at bridge)	6.0	yes	no	no

Field pH meter calibrated against lab pH meter:
Meter reading ~0.2 pH units lower than lab meter on both buffers pH 7 (field meter gave 6.8) and pH 4 (field meter gave 3.9) and on field samples.

PLATE 3: Cattail stand at the foot of South Dyke.

PLATE 4: Vegetation cover at the north-west end of the Impounded tailings.

PLATE 5: Filamentous green algal mat in seep from the open pit (sampling site 22). Note brownish precipitate around algae.

PLATE 6: Mougeota-Zygogonium spp. mat at sampling site 2 in the northern section of the North Unimpounded Tailings area.

PLATE 7: Drill casing with fresh water flow (sampling site 20).

PLATE 8: Island of cattails (arrow) downstream from sampling site 19 in northern section of South Unimpounded tailings area north of the South Kill area.

TABLE 3: SUMMARY OF ALGAL CULTURES AND THEIR STATUS AS OF DEC.1984

Site	Description	pH* current	Preserved Sample	Culture Medium liquid	Culture Medium plate	Growth Results
1	shallow puddle north of dam	2.8	yes	yes	yes	+
2	large creek	3.0	yes	yes	yes	+
3	large seepage stream	2.6	yes	yes	yes	+
4	below *junction* of 2 **seepage** streams	2.5	yes	yes	yes	+
5	stream at north end of N unirpounded	2.7	yes	yes	yes	+
10	head of **seepage** at slurry pipe	2.3	yes	yes	yes	+
11	seepage between forest & cattail std	5.3	yes	yes	yes	+
13	spruce-vegetated **island**	2.1	yes	yes	yes	+
14	man-made ditch	**2.3**	yes	yes	yes	+
17a	near KK-17 beside hydro-line path	solid	yes	yes	yes	+
KK22	seepage from open pit	2.5	yes	yes	yes	+

* pH measured November 7, 1984; + indicates cultures growing

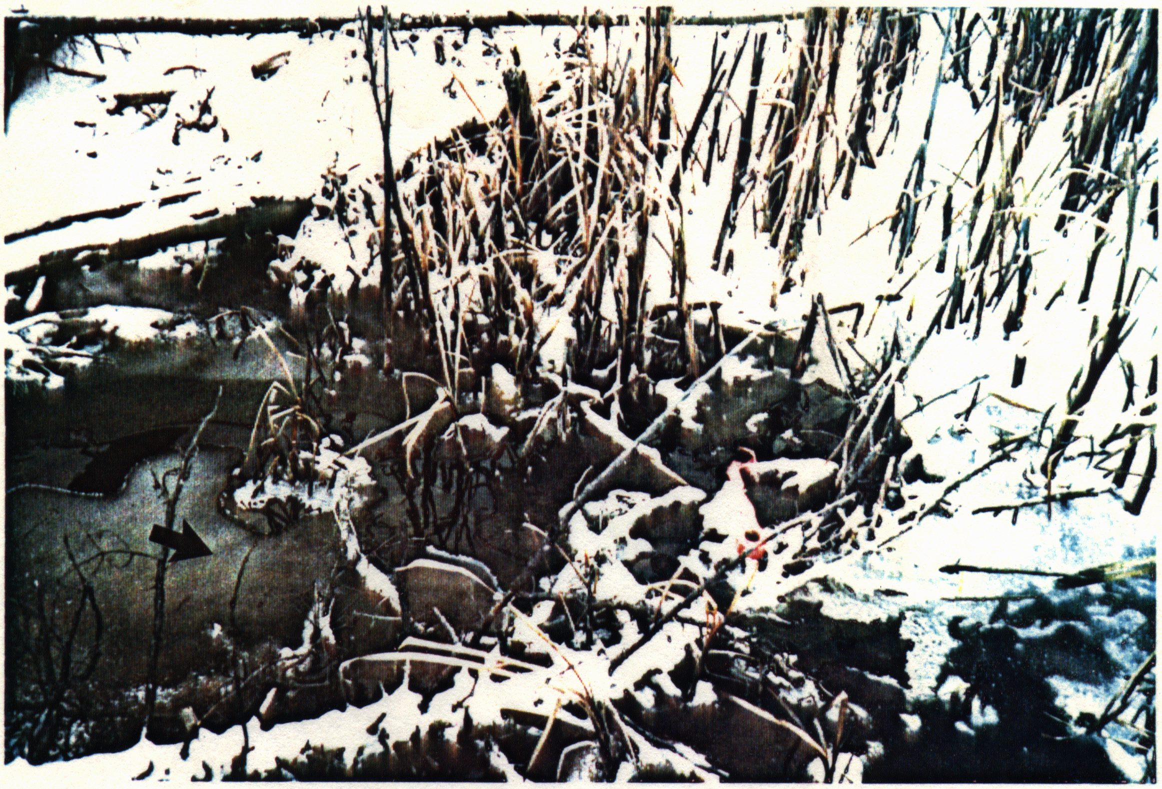


PLATE 9: Algal biomass with precipitate in North Unimpounded tailings area.

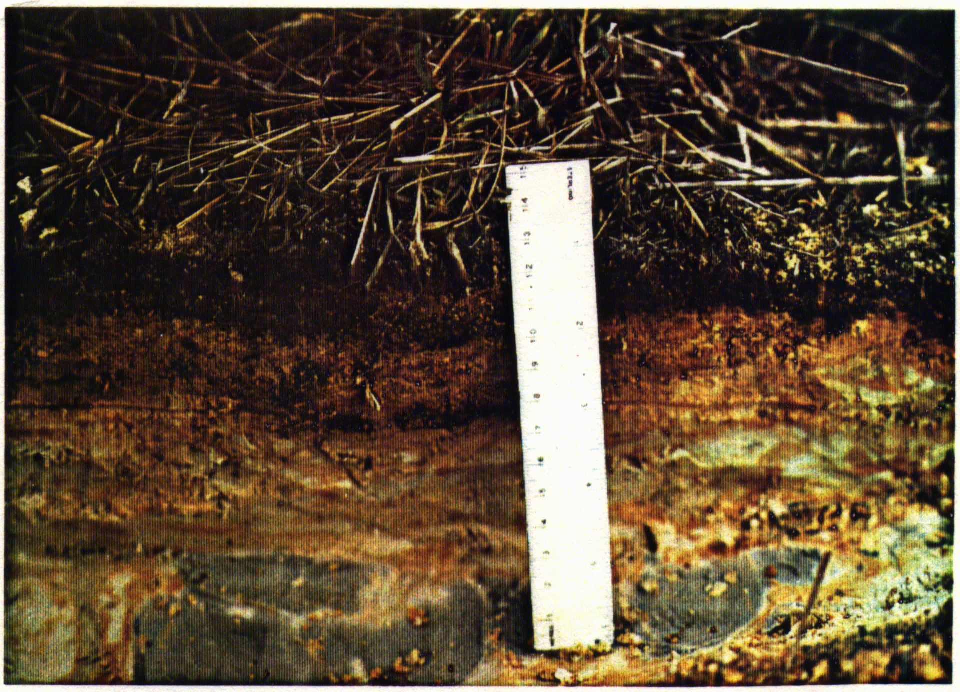


PLATE 10: A tailings profile on the Stanleigh-Milliken tailings (Elliot Lake, Ontario).

TABLE 4: IDENTIFICATION AND ECOLOGICAL CHARACTERISTICS OF ALGAE

ALGAE FOUND IN ACID SEEPAGE MIXED WITH FRESH WATER RUNOOFF

FILAMENTOUS ATTACHED BIOMASS

Sample number	Taxonomic Group	Ecological Characteristics
1,2,3, 11,22	CHLOROPHYTA Conjugales Zygnemataceae	Green algae found in acid habitats Many species bloom forming clurps and floating rats; often tend to produce mucilage
	Mougeotia spp.	Common genus in flowing waters; prefers oligotrophic waters; sore species dominate acid waters
	Zygogonium spp.	Common genus in acidic habitats (eg. peat bogs, acid soils, acid thermal springs) with pH < 3
22	Ulotrichales Ulotrichaceae	Species frequently form attached mats in quiet or running waters
	Hormidium spp.	Frequently reported species from peat bogs and acid mine drainage
	Ulothrix spp.	Occurs in a wide range of habitats with preference for low pH

ALGAE ON TAILINGS SEEPAGES, UNICELLULAR ONLY
UNICELLULAR BIOMASS

	CHLOROPHYTA	Common in acid habitats
1,2,3, 4,5,10 13,14.	Chlorophyta Uolvocales Volvocaceae	Green flagellates are frequently reported from bogs and other acid habitats
	Carteria spp. *Chlamydomonas spp.*	Common species in bogs, and acidic habitats
1,2,3, 5,13,	Chlorococcales Chlorococcaceae *Chlorella spp.* *Chlorococcum spp.* *Nannochloris spp.* *Oocystis spp.* *Protococcus spp.*	Cormon algal group found in both aquatic and terrestrial habitats

TABLE 4:IDENTIFICATION AND ECOLOGICAL CHARACTERISTICS OF ALGAE (continued)

ALGAE ON TAILINGS SEEPAGES, UNICELLULAR ONLY
UNICELLULAR BIOMASS

Sample number	Taxonomic Group	Ecological Characteristics
	EUGLENOPHYTA	Euglenoid algae frequently reported from acidic freshwater habitats
1,3,4	Euglenales	
10122	Euglenophyceae	
	Euglena mutabilis	One of most frequently reported organisms from acid mine drainage; often one of early colonizers in such areas

TABLE 5:DISTINGUISHING TAXONOMIC CHARACTERISTICS OF ALGAL GROUPS COLLECTED FROM THE KAM-KOTIA TAILINGS

DIVISION	ORDER	DISTINGUISHING TAXONOMIC CHARACTERISTICS
Chlorophyta	Conjugales	Reliable identification to genus is possible based on large distinguishing chloroplast. Accurate identification to species within these genera is only possible after examination of mature sexual reproductive structures (zygospores).
	Ulotrichales	Accurate identification to genus requires examination of holdfast structures and often ultrastructural features.
	Volvocales	Positive identification requires culturing to avoid confusion uith reproductive stages of other species.
	Chlorococcales	Positive identification requires culturing to avoid confusion with reproductive stages of other species.
Euglenophyta	Euglenales	Reasonably easy to identify; *Euglena mutabilis* is quite distinctive.

TABLE 6: CONDUCTIVITY, pH AND ACIDITY IN SURFACE WATER

Site No.	pH		Conductivity (umhos/cm)	Total Acidity to pH 8.3 (mg/l as CaCO3)
	Field	Lab		
1	2.2	2.58	1700	715
2	2.2	2.46	3200	1245
3	2.2	1.47	2350	1070
4	2.6	2.72	1500	590
5	2.4	1.45	2000	830
6	2.4	2.54	3400	2980
7	2.6	2.71	6800	5610
8	2.4	2.75	6700	5220
9	2.6	2.80	5900	4540
10	2.2	2.50	3800	2615
11	2.4	3.76	1250	25
12	2.8	2.68	2050	465
13	<2	2.23	6800	7450
14	2.3	2.42	3600	2250
15	2.2	2.25	5000	4655
16	2.3	2.36	3700	2480
17	2.7	2.55	2500	1150
18	2.6	2.60	2200	975
19	5.8	6.58	2000	20
20	6.0	6.57	2550	20
				(365)
21	4.8	6.02	160	<5
				(15)
22	2.6	2.61	2000	695
23	2.8	2.60	2500	1350
24	5.8	7.30	150	<5
				(85)
25	6.0	6.05	3500	20
				(155)
26	6.0	7.30	115	<5
				(45)
27	6.0	6.04	150	<5
				(10)

Note: numbers in ( ) are alkalinities.

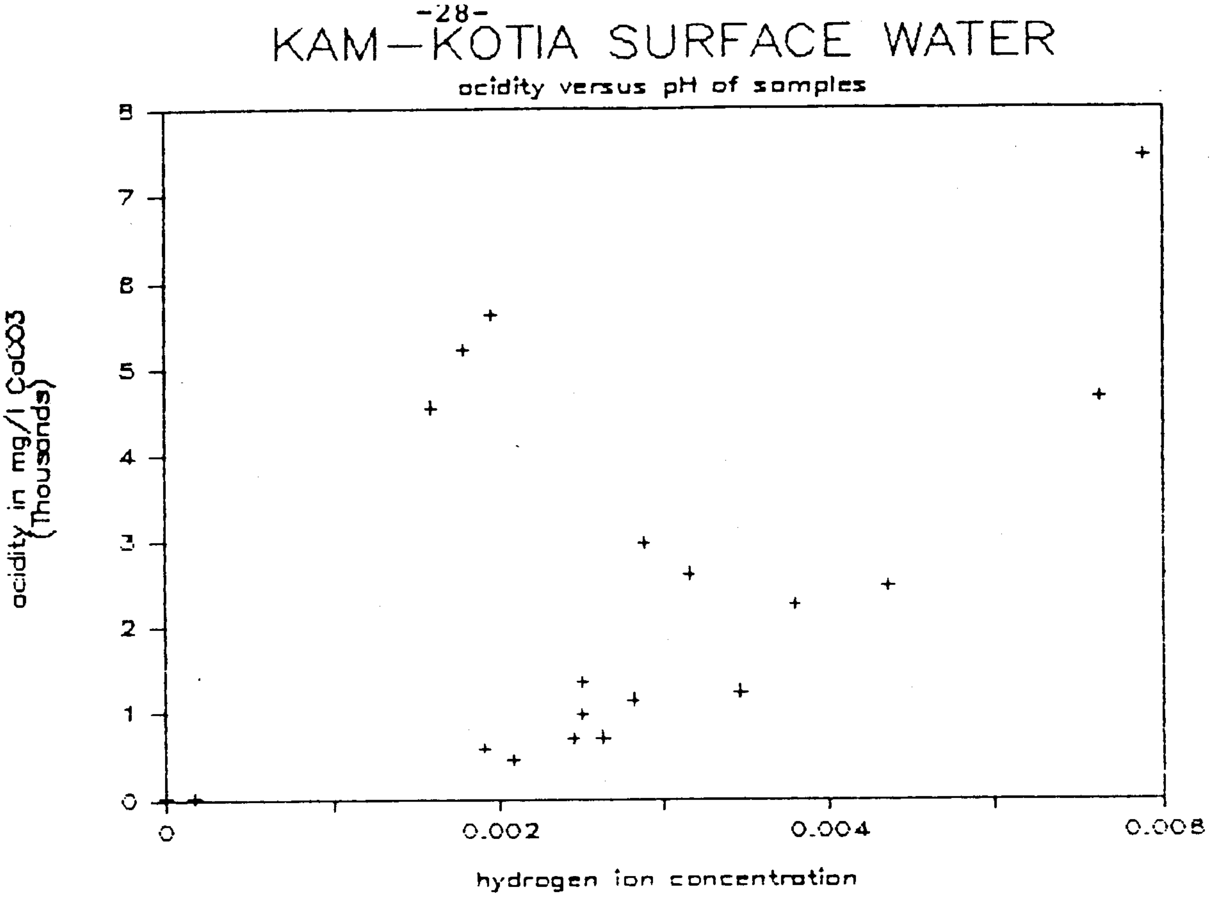


FIGURE 2a: The relationship of conductivity and acidity in surface water on the Kam-Kotia tailings.

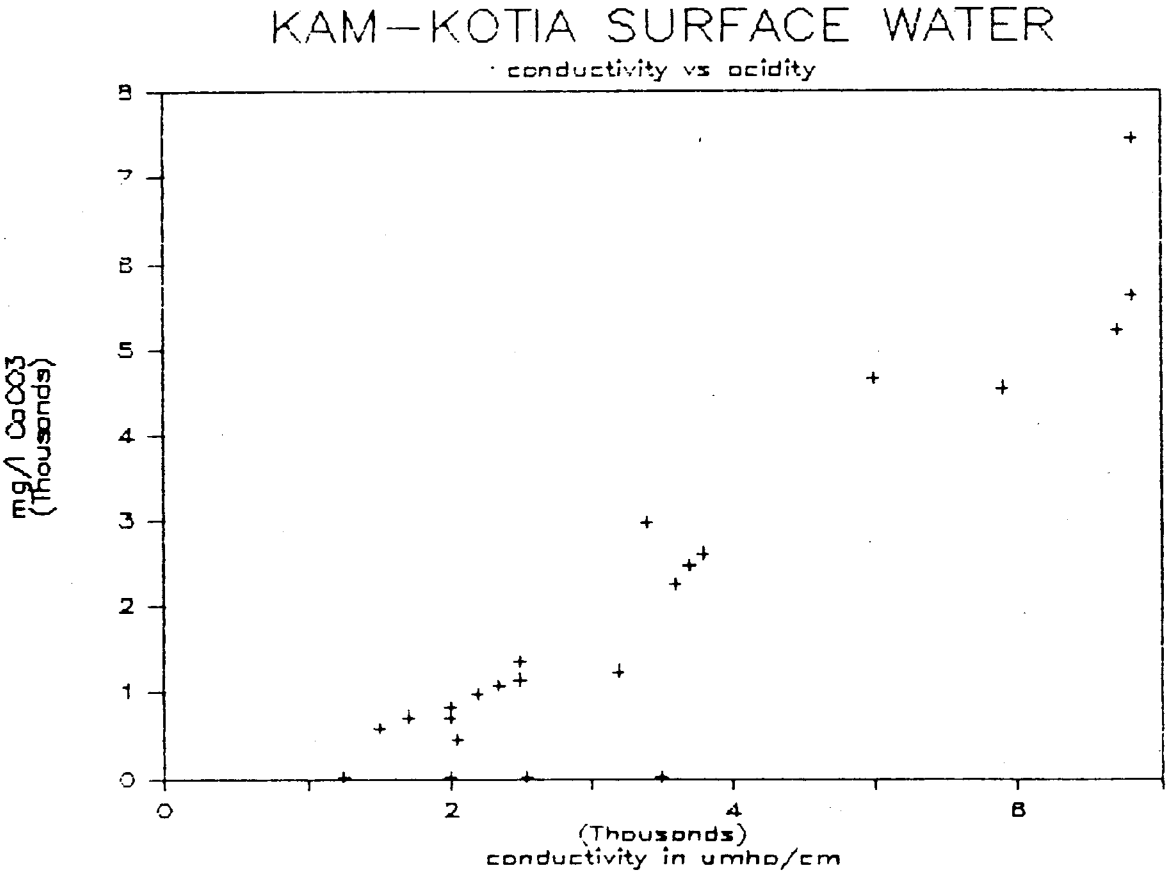


FIGURE 2b: The relationship of hydrogen ion concentration and acidity in surface water of the Kam-Kotia tailings.

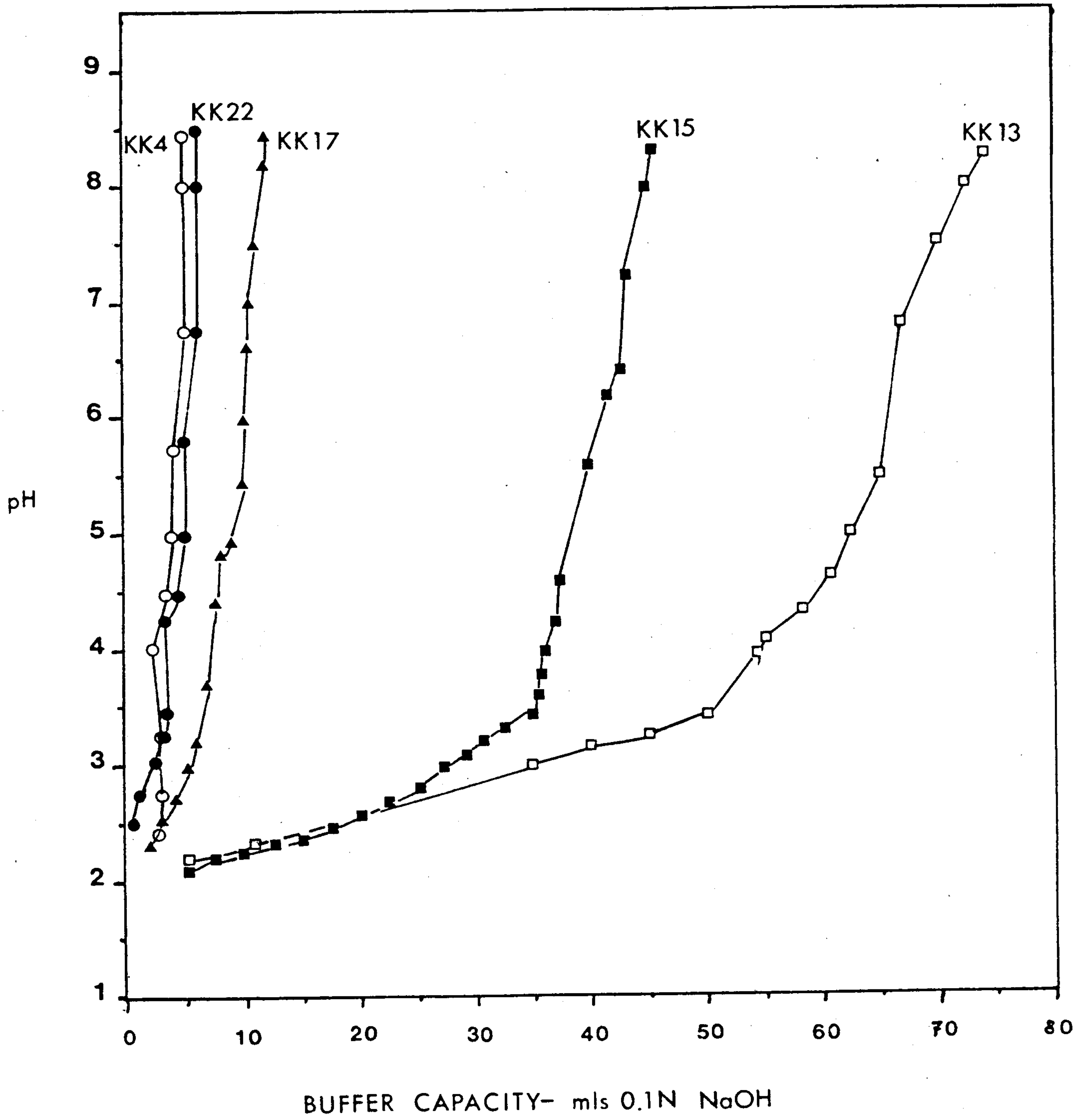


FIGURE 3 :COMBINED BUFFER CURVES FOR FIVE SITES

FIGURE 4a: KAM-KOTIA SURFACE WATER

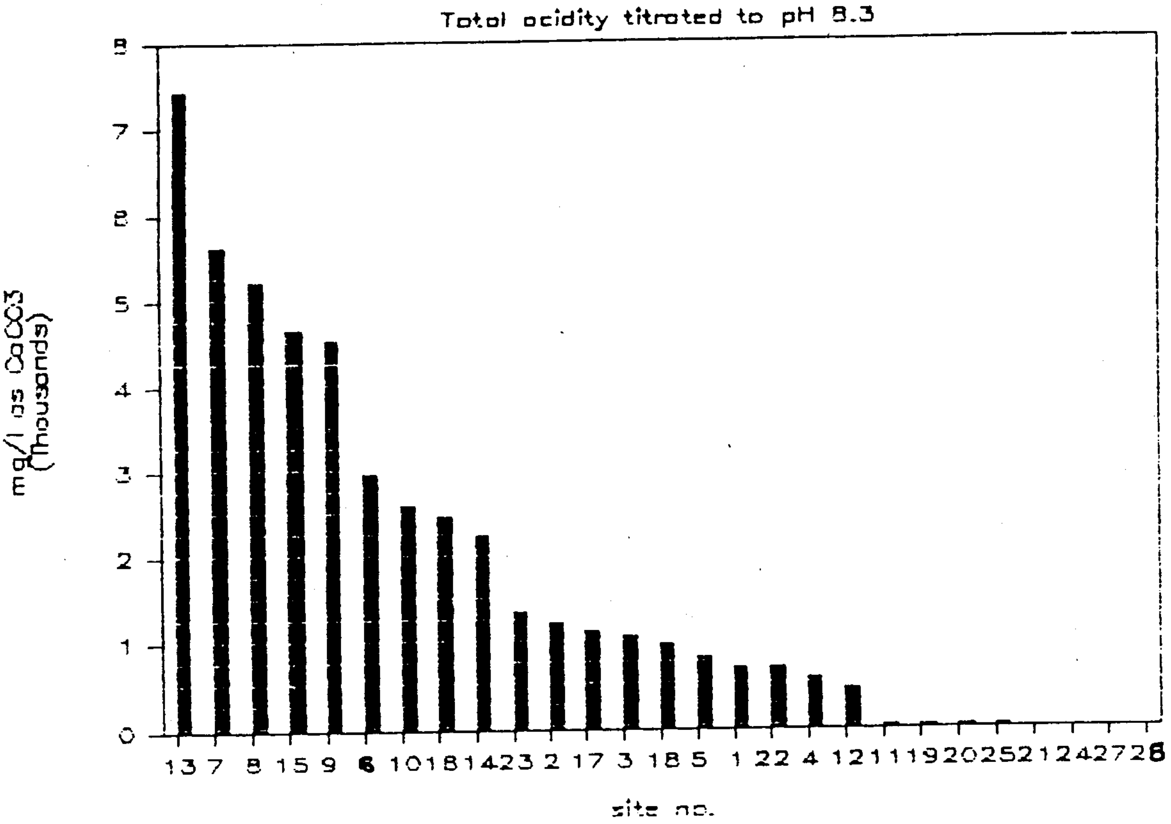


FIGURE 4b: KAM-KOTIA SURFACE WATER

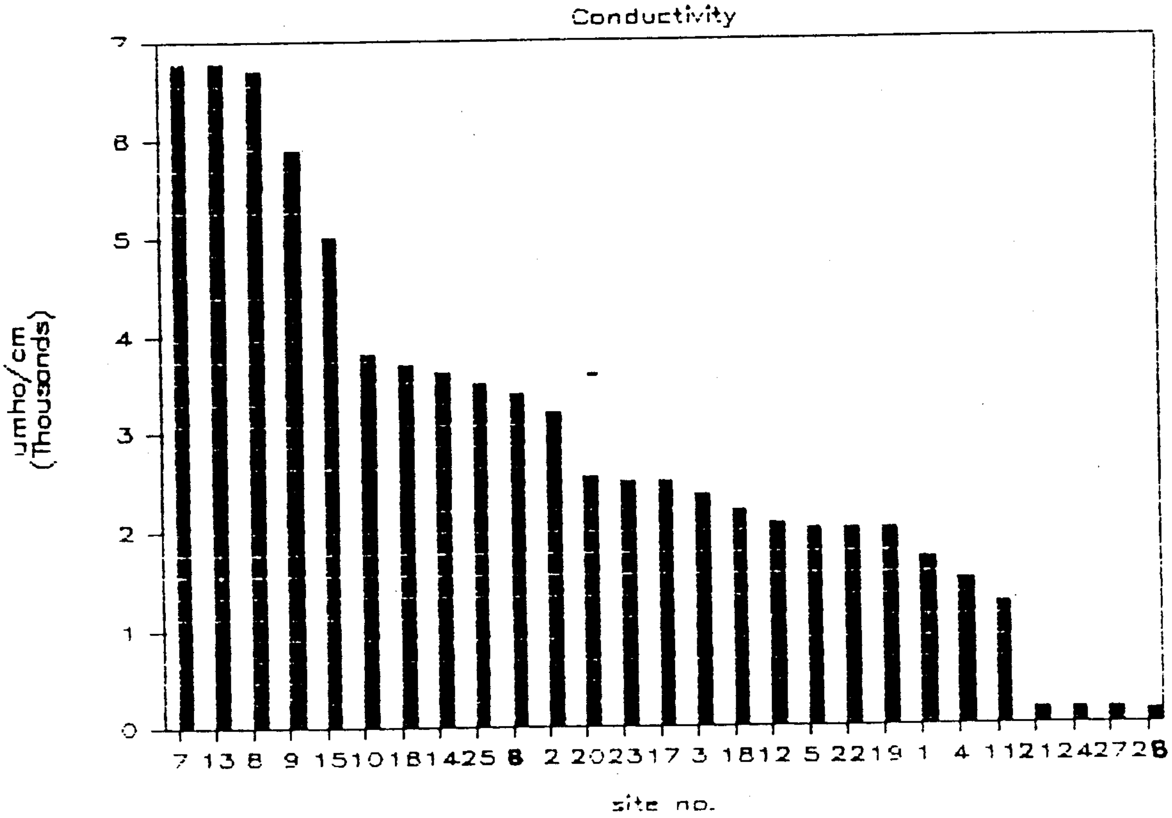


TABLE 7: CHEMICAL CHARACTERISTICS OF SURFACE WATER COLLECTED NOV 1 TO 5 1984

Site No.	Units	Fe++	Fe+++	Tot. Fe	Ca	Mg	Cu	Al	Pb	Na	K
4 Seepage & run off	mg/l mM	1.2 0.021	123.0 2.20	124.0 2.22	72.0 1.80	33.0 1.36	1.0 0.016	23.0 0.85	0.04 0.00019	4.1 0.18	0.82 0.021
7 Seepage on tailings	mg/l mM	1460.0 26.14	460.0 8.24	1920.0 34.38	385.0 9.60	542.0 22.29	30.0 0.47	132.0 4.89	0.57 0.0028	25.0 1.087	3.7 0.095
15 Seepage slow flow	mg/l mM	70.0 1.25	1415.0 25.34	1485.0 26.59	235.0 5.86	203.0 8.35	21.0 0.33	57.0 2.11	0.33 0.0016	14.0 0.61	2.1 0.054
18 Seepage stagnant	mg/l mM	36.0 0.64	174.0 3.12	210.0 3.76	161.0 4.02	73.0 3.00	9.1 0.14	35.0 1.30	0.06 0.0028	8.1 0.35	1.7 0.043
21 Little KK River	mg/l mM	1.0 0.018	2.7 0.048	3.7 0.066	16.0 0.40	5.1 0.21	0.2 0.0031	0.64 0.024	<0.04 <0.00019	2.5 0.11	0.47 0.012
24 Clean background	mg/l mM	<0.05 <0.0008	0.9 0.016	0.86 0.015	28.0 0.70	3.3 0.14	0.08 0.0012	0.10 0.0037	<0.04 <0.00019	1.6 0.070	0.33 0.0084
25 Seepage impounded	mg/l mM	0.9 0.016	112.0 2.00	113.0 2.02	861.0 21.48	240.0 9.87	0.06 0.00094	0.98 0.036	0.26 0.0012	38.0 1.65	12.0 0.31

TABLE 8: COMPARISONS OF WATER CHARACTERISTICS

Site No.		Tot. Fe	Ca	Mg	Cu	Al	Pb	Na	K	SO4
21 KK 14	mg/l mg/l	3.7 0.77	16.0 83.0	5.1 29.5	0.2 0.43	0.64 n.g.	<0.04 0.049	2.5 23.0	0.47 3.0	130.0 37.5
24 KK 9	mg/l mg/l	0.86 0.29	28.0 51.0	3.3 6.9	0.08 0.08	0.10 n.g.	<0.04 <0.03	1.6 17.5	0.33 0.6	<5.0 22.0
25 KK 8	mg/l mg/l	113.0 300.0	861.0 790.0	240.0 525.0	0.06 0.05	0.98 n.g.	0.26 0.39	38.0 21.5	12.0 5.0	4600 4250
MOE 1, J MOE 1, A	mg/l mg/l	9116 6580	39 350	1163 1600	1.5 0.8	46 58	0.32 <0.3	23.4 18.7	1.2 0.5	20400 21200
MOE 2, J MOE 2, A	mg/l mg/l	4500 5560	48 270	962 1100	4.9 1.8	65 55	0.19 <0.03	17.8 17.9	4.5 2.0	14300 16800
MOE 3, J MOE 3, A	mg/l mg/l	2600 1200	39 192	470 440	113 98	230 174	0.38 <0.3	16.1 15.5	1.6 2.1	9800 8200
MOE 4, J MOE 4, A	mg/l mg/l	830 620	76 212	106 105	3.7 8.4	19 30	0.05 <0.3	43.3 13.5	1.6 2.8	2800 2950

Legend: KK samples are pore water collected from piezometers by GTC in 1983.
MOE samples are surface water collected in July (J) and August (A) 1984.
21,24,25, are samples of surface water collected during this study in November 1984.

CTERISTICS OF SURFACE WATER COLLECTED NOV 1 TO 5 1984

e++	Fe+++	Tot. Fe	Ca	Mg	Cu	Al	Pb	Na	K	SO4	cations	% cations
1.2 0.021	123.0 2.20	124.0 2.22	72.0 1.80	33.0 1.36	1.0 0.016	23.0 0.85	0.04 0.00019	4.1 0.18	0.82 0.021	1880.0 19.57	6.28	32%
60.0 26.14	460.0 8.24	1920.0 34.38	385.0 9.60	542.0 22.29	30.0 0.47	132.0 4.89	0.57 0.0028	25.0 1.087	3.7 0.095	14000.0 145.74	72.8	50%
70.0 1.25	1415.0 25.34	1485.0 26.59	235.0 5.86	203.0 8.35	21.0 0.33	57.0 2.11	0.33 0.0016	14.0 0.61	2.1 0.054	10000.0 104.10	43.9	42%
36.0 0.64	174.0 3.12	210.0 3.76	161.0 4.02	73.0 3.00	9.1 0.14	35.0 1.30	0.06 0.0028	8.1 0.35	1.7 0.043	3100.0 32.27	12.6	39%
1.0 0.018	2.7 0.048	3.7 0.066	16.0 0.40	5.1 0.21	0.2 0.0031	0.64 0.024	<0.04 <0.00019	2.5 0.11	0.47 0.012	130.0 1.35	0.8	61%
<0.05 0.0008	0.9 0.016	0.86 0.015	28.0 0.70	3.3 0.14	0.08 0.0012	0.10 0.0037	<0.04 <0.00019	1.6 0.070	0.33 0.0084	<5. <0.05	1.0	--
0.9 0.016	112.0 2.00	113.0 2.02	861.0 21.48	240.0 9.87	0.06 0.00094	0.98 0.036	0.26 0.0012	38.0 1.65	12.0 0.31	4600.0 47.88	35.3	73%

WATER CHARACTERISTICS

Fe	Ca	Mg	Cu	Al	Pb	Na	K	SO4
3.7 0.77	16.0 83.0	5.1 29.5	0.2 0.43	0.64 n.g.	<0.04 0.049	2.5 23.0	0.47 3.0	130.0 37.5
0.86 0.29	28.0 51.0	3.3 6.9	0.08 0.08	0.10 n.g.	<0.04 <0.03	1.6 17.5	0.33 0.6	<5.0 22.0
3.0 00.0	861.0 790.0	240.0 525.0	0.06 0.05	0.98 n.g.	0.26 0.39	38.0 21.5	12.0 5.0	4600 4250
16 80	39 350	1163 1600	1.5 0.8	46 58	0.32 <0.3	23.4 18.7	1.2 0.5	20400 21200
00 60	48 270	962 1100	4.9 1.8	65 55	0.19 <0.03	17.8 17.9	4.5 2.0	14300 16800
00 00	39 192	470 440	113 98	230 174	0.38 <0.3	16.1 15.5	1.6 2.1	9800 8200
0 0	76 212	106 105	3.7 8.4	19 30	0.05 <0.3	43.3 13.5	1.6 2.8	2800 2950

water collected from piezometers by GTC in 1983.
face water collected in July (J) and August (A) 1984.
es of surface water collected during this study in November 1984.

3.3 ECOLOGICAL ENGINEERING MEASURES

3.1. General Concept

To improve the conditions of the site tuo aspects have to be altered. The acid generation from exposed tailings has to be curtailed, and the effluent characteristics of the site have to be improved by precipitation of dissolved cations and metals before they reach the receiving waters. These aspects have to be altered to result in self maintaining conditions for both wet and dry areas of the tailings site.

Building wetlands on the tailings will have a cleansing effect on the water. In turn the annual accurulation of biomass in these wetlands will ultimately result in a layer of decaying organic matter. This will prevent oxygen penetration and limit infiltration to the tailings,thus curtailling acid generation in the long term. This process is depicted schematically in Figure 5 and applies to wet areas on tailings sites.

In dry areas of the tailings site, studies on inactive and abandoned acidic uranium mill tailings indicate that an indigenous vegetation cover consisting of moss and low shrubs appears to be effective in curtailing oxidation of deeper layers of tailings. The moss carpet produces annual layers of a thin organic mat which appears to prevent further oxidation of the tailings below it (Plate 10). A moss layer is shown which has developped on an unattended acidic site in Elliot Lake within the last 10 years. Lenses of virgin tailings are apparent only 6 cm below the surface and deeper layers have remained unoxidized.

The dense shallow rooted shrub cover which has developed in the same timeframe which was not fertilized and received only minimum lime application indicates that oxidition has only occured on a thin fraction of the tailings surface (Plate 10).Lateral root penetration of these indigenous trees and shurbs form a dense organic rat on the tailings surface. The developrent of these types of covers are prevented with the application of seeding mixutres and fertilisation.

If the root region of the shrub cover on the same site is excavated a shallow rat of roots can be lifted off the tailings (Plate 11). This dense oxidized layer in the of root region is not connected to the tailings below. It appears that this lateral root mat has developed to absorb most of the precipitation on the site.Drought is indicated from many studies as one of the most severe stresses for vegetation on tailings sites, hence this root formation. These roots and the moss are growing directly in acidic tailings and pH values as lou as 2 have been measured.Any acid produced during the freeze-thaw cycle, which could destroy vegetation not tolerant to acidic conditions would not harm this type of cover. In conjunction with the moss layer, it is believed that this type of indigenous vegetation cover will prevent infiltration of a large fraction of precipitation into the tailings.

Moss and shrub establishrent have been observed frequently in volonteer vegetation (Plate 12 and 13). The moss protonera in Plate 12 have volonteered on fine tailings in the Sudbury area with a pH value of 2.5. The White birch populations depicted in Plate 13 has established after the surface of a acidic tailings site in the Elliot Lake area had been stabilized with limestone to prevent wind erosion. These tree populations have been extensively studied and it has been found that the roots grow laterally below the lime layer in a manner similar to root formation observed after several years on an unamended tailings site (Plate 11). By encouraging conditions on the tailings uhich will facilite the establishrent of these types of vegetation covers it is believed that an effective selfmaintaining ecosystem can be developped on dry areas.

3.2. SITE SPECIFIC MEASURES

Based on the preliminary survey of the site, it appears that 5 surface types can be identified which exhibit distinctly different chemical and biological characteristics, and hence require different types of reclamation effort. Four of these surface types are addressed with ecolocjical engineering measures.

Areas which receive fresh water or seepage and contain macrophytic islands and algal biomass, are differentiated from areas of saturated tailings and seepage which have little or no macrophytes and algal biomass.

In those areas where tailings are less saturated with water, reclamation measures have to be considered which would induce the establishrent of terrestrial (dry) ecosystems. There are also those areas which appear amenable to recovery by improvement of the surface seepage water characteristics alone. Finally there is a small area of the waste rock pile and the open pit where reclamation measures as propsed by Kilborn appear at present the appropriate measures. The effects of placement of the waste rock into the open pit need to be evaluated in addition to the acid generation potential of this waste material.

In Figure 6 the locations of these surfaces are schematically outlined to the extent uhich can be anticipated with the existing data. The recommended ecological engineering actions for each surface type are briefly described below.

Wet areas with vegetation: The water will be contained in such a way that existing cattail growth is promoted along with the growth of attached algal biomass. At present cattail stand expansion is prevented by the abscence of water,

Wet areas without vegetation: The water quality will be improved by treatment of surface water to facilitate establishment of macrophytes and algal biomass. At present the conditions of these areas facilitate extensive acid generation and resultant high metal concentrations prevent establishment of vegetation of any form.

? **Wet areas with natural recovery potential:** Seepage water will be treated and natural recovery which does not require establishment of macrophytes and algal biomass is anticipated. At present these areas can not recover due to the continued input of metal contaminated acidic seepage, preserving the organic material and preventing recovery. However many signs of recovery can be noted in these areas such as the South Kill.

Dry areas: Natural material (chipped dead wood from the site) and possibly woodwastes will be used in combination with limestone to encourage moss establishment and provide microhabitats for establishment of a low shrub cover.Such a low shrub moss cover is believed to produce the most effective self maintaining oxygen barrier.

This broad overall reclamation concept can not be implemented at once, but should proceed in several stages.The implementation of one stage will be based on the resulsts of the previous stage , indcluding the results of the lysimetry and ecological laboratory studies.

The second phase of this program will therefore consist of setting up experimental treatment areas in which data can be collected to stage effectively the proposed reclamation methods. The operation of the experimental plots will also aid in generating realistic costing parameters, which can then be applied to the entire site.

All experiments in the different areas will use the existing conditions (fresh water from the site) and encourage the growth of indigenous species, or tolerant species from other acid tailing areas.

Encouraging growth of existing biota will consist principally of making changes in water flow and treatment of water in those areas were extremely adverse conditions have prevented the establishment of indigenous vegetation. The treatment of these surface water is considered as a temporary measure to clean out the system and initiate the recovery process. But how long has this been going on to date??

Recovery will not be instantaneous. Two years of data collection are required to assess the rate of recovery of the site and to produce information which will reliably facilitate the detailed costing of the overall site relamation. Phase 2 of the project will therefore consist of three parts:

1. Engineering
2. Ecology
3. Prediction and analysis
4. Detailed planning and design of overall site reclamation program.

It is anticipated that Phase 3 will be implemented in 1987 and will consist of construction of containments for wetlands in the North Unimpounded tailings area, relocation of the treatment facility from the middle of the South Unimpounded tailings area to the northern location (Figure 7).The surface covers for the dry areas will be applied and the reclamation of the open pit area will be carried out. Phase 3 will requires intensive work followed by 3 to 4 years of full operation of the treatment plant and monitoring of the expansion of the ecosystems and their effect on the water quality.

Finally ,when the point is reached at which the systems are well enough established;(which can be predicted from the lysimetry work carried out Phase 2) treatment will be reduced gradually over several years.The site will be restored and can be abandoned. A monitoring program throughout this period will provide continuing feedback to assure a complete recovery of the site before treatment is withdrawn. Phase 3 is anticipated to take place over a period of approximately 7 to 8 years.

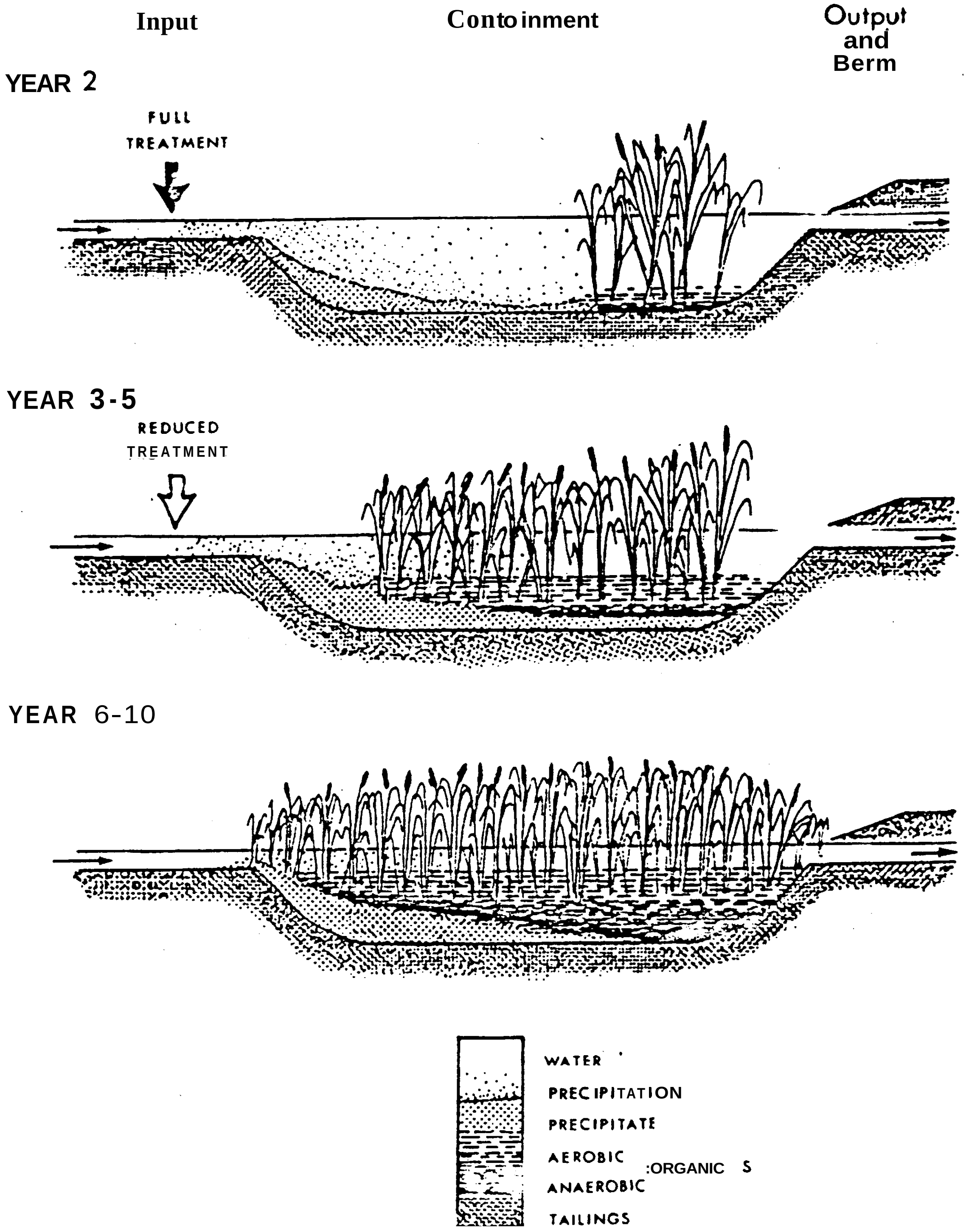


FIGURE 5 GENERAL CONCEPT OF ECOLOGICAL ENGINEERING

PLATE 11: Root and moss mat on 10 year old una mended tailings in Elliot Lake Ontario.

PLATE 12: Moss protonemata on 'pyrrhotite fine' in the Sudbury area.The pH of the surface is 2.5.

PLATE 13: A tree colony on the Stanrock tailings in Elliot Lake, established after limestone application for erosion control.

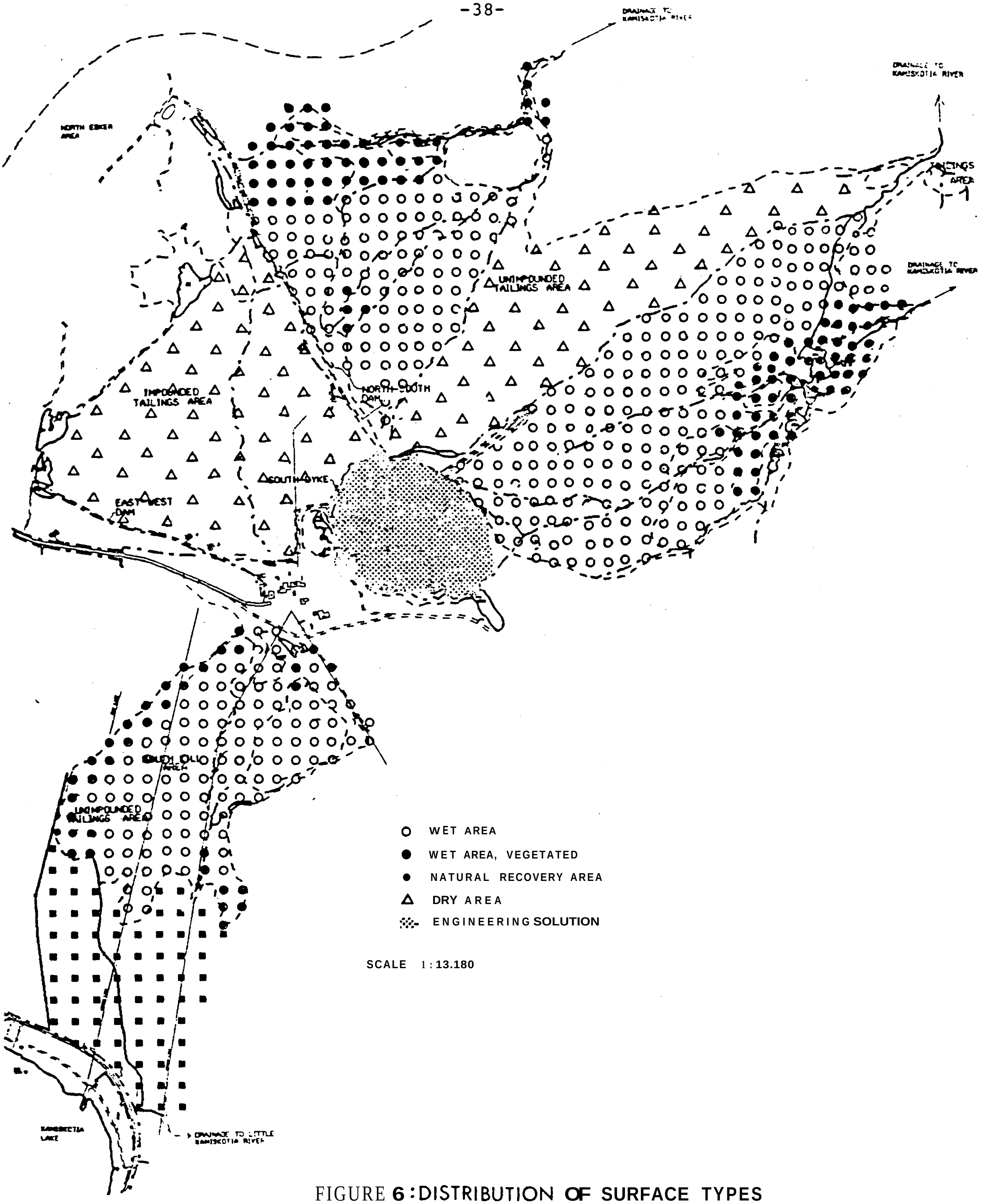


FIGURE 6: DISTRIBUTION OF SURFACE TYPES FOR RECLAMATION

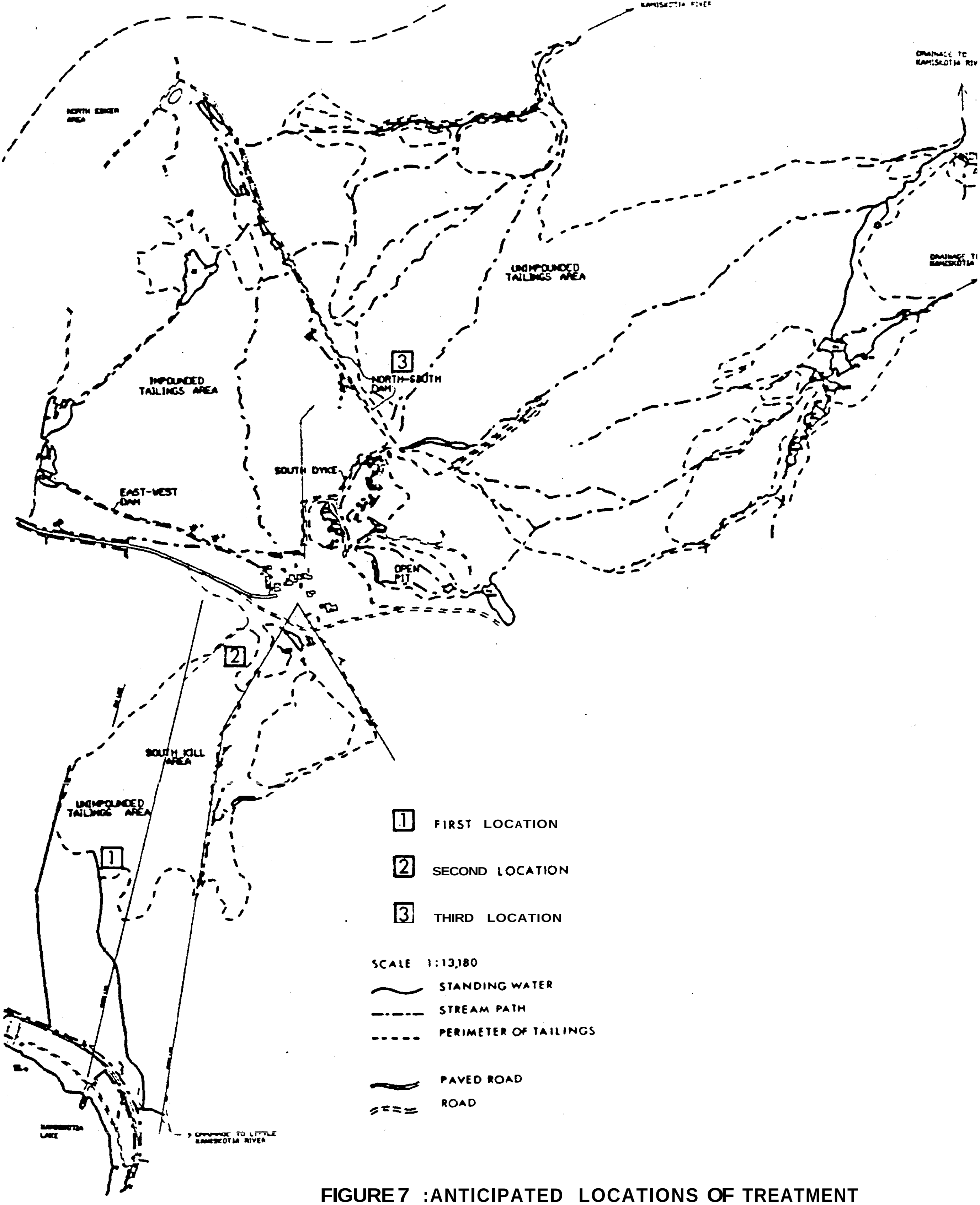


FIGURE 7 : ANTICIPATED LOCATIONS OF TREATMENT FACILITIES THROUGHOUT PROGRAM

3.3 OVERALL COST PROJECTION

Total site reclamation

Phase 2 of the ecological engineering reclamation measures is planned to start up in 1985 with an anticipated duration of two years. The major components of the reclamation program will be implemented after phase 2 in 1987.A maintenance free site should be achieved between the years 1991 and 1994 however a better prediction can be made after the first year of Phase 2.At this stage, without any further information on rates of recovery and establishment of indigenous vegetation, the project projection is based on time frames. observed on other abandoned tailings sites. Phase 3 is considered as the implementation for the whole site over the entire lifetime of the project 1987 to 1994.

An rain activities of the program are outlined below.

```
                      1985  1986
PILOT TESTS          ==Phase 2==
                                   TOTAL SITE RECLAMATION PROGRAM

                                1987  1988  1989  1990  1991  1992  1993  1994
                                ================Phase 3====================
TREATMENT

Plant construction               ===
Full operation                   ================
Reduced operation                               ===============
Shut down                                                      ==

CONSTRUCTION

Water Containments               ===
Surface covers                   =====

MONITORING:

Intense                         ================================
Reduced                                                          =============
```

There are two points during the program when the expenditures will peak. These are in the first year, when the experimental areas have to be constructed and then two years later when the reclamation scheme is implemented over the entire site.In year one and two of phase 2 the program is labour intensive as data acquisition and analysis are required.

Costing of the ecological engineering appraoch for the entire site is difficult at this stage. The best possible estimates are made based on the costs determined for Phase 2.An overview of the of the total cost of each component of phase 2 is given below. The details of the costs for Phase 2 are presented in the appendix. Only the overall costs are considered in this section. Phase two was planned within the fiscal year restraints, which required some start up funds, to begin the work in the growing season in 1985. Total cost for the pilot scale project,including start up costs are $880,000. The costs for year 2 of Phase 2 will be reviewed after year 1.

COMPONENT	START UP Feb - March	YEAR 1 ----1985----	YEAR 2 ---1986---	TOTAL
Engineering 10 days sup. Engineer	6,000	190,005	65,500	
Ecology 15 days sup.P.I.	5,250	272,000	201,100	
Lysimetry 10 days Prof.	4,125	99,820	36,060	
	$15,375	$561,825	$302,660	$879,860

From each of the components in Phase 2 fixed costs, ie. one time expenses have been taken and multipliers are derived in several ways, for example from hectares to be covered or the fraction of the run-off to be treated.These multipiers were then applied to the inital cost estimates to derive the costs for Phase 3. Continous costs have been developed based on manpower requirements. Costing unit components taken from Phase 2 are presented in Table 9 in brackets and the multipling factor is stated, from which the figures for Phase 3 are determined.

Major factors are unknown such the amount of lime required to achieve the desired effects or the length of time required for treatment. Furthermore the size of the areas which will require surface works and the costs of reclaiming the sections which are not amenable to ecological engineering measures are uncertain.

Several assumptions had to be made to derive the multipliers

1. Total length of time treatment is required is taken at 3 years full scale witha a further 3 years for reduced operation.

2. Usage of only one (1) treatment plant. The plant will be moved to its final application from the initial position on the South Kill area to the last section to be treated on the North Uninpounded area of the tailings.

3. Wood wastes to cover the terrestrial dry areas would be available at no cost.

4. All costs are estimated in 1984 $ and no adjustment is made for inflation.

5. No allowance has been made for removal of the treatment plant.

6. No allowance has been made for a power supply on site.

TABLE 9: FIXED AND CONTINOUS COST PROJECTIONS FOR PHASE 3

FIXED ONE TIME EXPENSES FOR IMPLEMENTATION IN 1987

	PHASE 2 Estimate	PHASE 3 **Total** Projection
Treatment Plant:		
Construction	($53,000.00)	
5 x Scaling		$ *2651000.00*
Construction of:		
Water containments		
To Cover 1 ha	(2,625.00)	
To Cover 150 ha		*3931750.00*
Waste Rock Road		
1.7 kr	(27,730.00)	
3.4 **km**		*55,460.00*
Equipment for:		
Waste Wood and Limestone Distribution		
100 ha		15,000.00
Agricultural Limestone		
100 ha		**16,250.00**
Site Supervision:		
30 days @ 10 hrs/day, $53/day	(16,750.00)	
90 days		*50,250.00*
Open Pit		500,000.00
TOTAL		$1,295,710.00
Contingency 10%		129,571.00
TOTAL FIXED EXPENSES		$1,425,281.00

TABLE 9 (Cont'd) CONTINUOUS EXPENSES FROM 1987 TO 1994

	PHASE 2 Estimate	PHASE 3 Total Projection
Materials:		
time	($40,000.00)	
3 x Scale, 3 years		$ 360,000.00
Reduced Treatment, 3 years		180,000.00
Labour:		
1 Biologist		
1 Technologist		
@ $65,000/man year		
6 years		780,000.00
Sueervision, Ecology and Engineering:		
70 days/year, 5 years @ $450/day		157,500.00
40 days/year, 3 years @ $500/day		60,000.00
Travel and Accommodation:		
@ $7,000/year, 5 years		35,000.00
@ $5,000/year, 3 years		15,000.00
Report Preparation:		
1 Report/year @ $3,000, 8 years		24,000.00
Analytical Services:		
200 water samples/year @ $2,400/year, 7 years		16,800.00
100 tailings samples/year @ $5,000/year, 3 years		15,000.00
200 plant samples/year @ $2,400/year, 3 years		7,200.00
TOTAL		$1,650,500.00
Contingency @ 10%		165,050.00
TOTAL CONTINUING EXPENSES		$1,815,550.00
TOTAL FOR PHASE 3		$3,240,831.00

Since these cost projections run over several years costs are summarized by category and by year in Figure 8 to provide a perspective.It is evident that the engineering costs and those of the treatment of the surface water take up a large fraction of the budget. This does suggest that emphasis should be placed in Phase 2 on producing the most economic surface water treatment system along with surface water containrent structures. At present the implementation of the reclamation program in 1987 requires essentially 50 percent of the entire phase 3 budget. Since one of the objectives of Phase 2 is to derive realistic costing parameters, this expenditure ray be reduced. The annual costs of Phase 3 are tabulated in Table 10 presenting in detail the fractions presented in the pie chart in figure 8.

TABLE 10: TOTAL BUDGET FOR PHASE 3

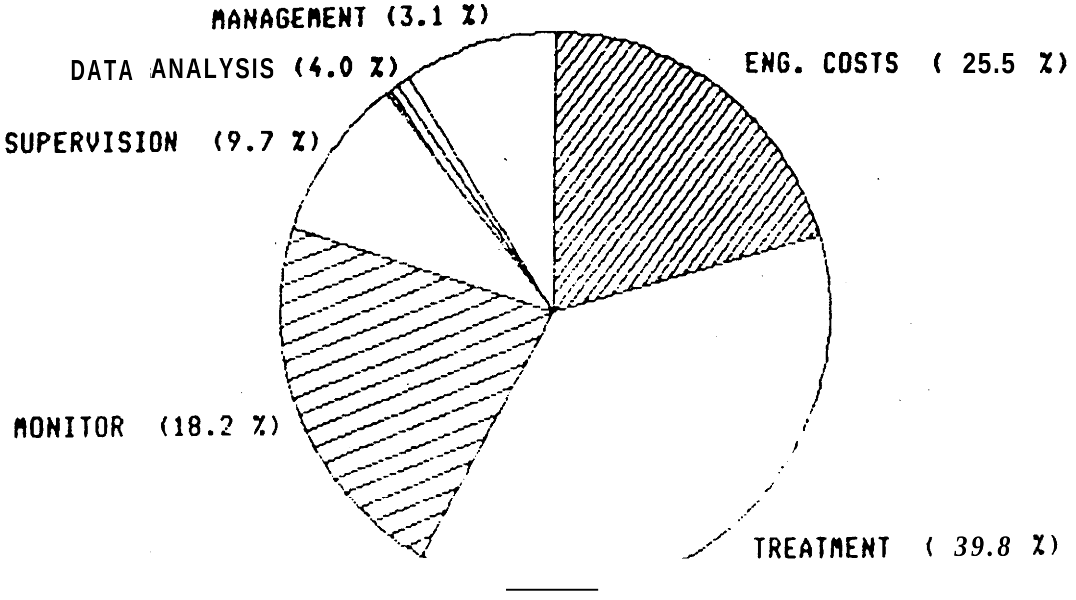
	1987	1988	1989	1990
Eng Construction	$586,710.00	$ 0.00	$ 0.00	$ 0.00
Treatrent Plant	658,750.00	120,000.00	120,000.00	120,000.00
Control 8 Monitoring	156,000.00	156,000.00	156,000.00	156,000.00
Supervision	91,750.00	41,500.00	41,500.00	41,500.00
Data Analysis	3,360.00	3,360.00	3,360.00	3,360.00
Ranagerent	168,962.00	32,086.00	32,086.00	32,086.00
	$1,665,532.00	$352,946.00	$352,946.00	$352,946.00

	1991	1992	1993	1994
Eng Construction	$ 0.00	$ 0.00	$ 0.00	$ 0.00
Treatrent Plant	90,000.00	90,000.00	0.00	0.00
Control 8 Monitoring	156,000.00	0.00	0.00	0.00
Supervision	41,500.00	19,200.00	19,200.00	19,200.00
Data Analysis	3,360.00	10,350.00	10,350.00	10,350.00
Ranagerent	29,086.00	11,955.00	2,955.00	2,955.00
	$319,946.00	$131,505.00	$ 32,505.00	$ 32,505.00

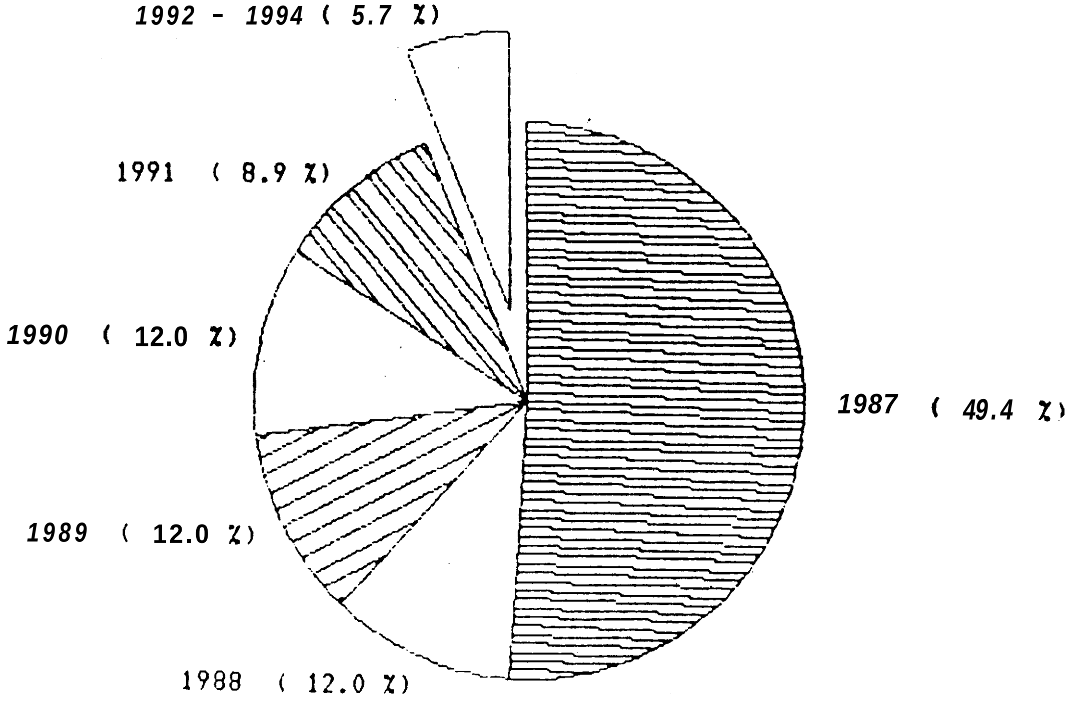
TOTAL PHASE 3	$3,240,831.00
TOTAL PHASE 2	$ 879,860.00
GRAND TOTAL	4,120,691.00

In summary the estimated cost of the entire reclamation of the Kam-Kotia tailings area by ecological engineering including Phase 2 (start up) and Phase 3 is $4,120,700.00.

Figure 8: PHASE 3 COST PROJECTION BY CATEGORY



PHASE 3 COST PROJECTION BY YEAR



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