DECOMMISSIONING OF SOUTH BAY

PHOSPHATE ROCK/BRUSH APPLICATION IN BOOMERANG LAKE

EM34 BACKGROUND MUD LAKE SURVEY

SEEPAGE CANYON DEFINITION

1995 FINAL REPORT

Submitted to:

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March, 1997

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1.0 OVERVIEW AND INTRODUCTION

In 1994, the decommissioning activities for the South Bay mine site focused on two main areas. For the overall site the measures taken in 1993 were evaluated (trial phosphate rock application to tailings and Boomerang Lake sediment and ARUM beach installation on Decant Pond). The biological polishing process used in Boomerang Lake was summarized, focussing on contaminant fate. The mine/mill site was surveyed using EM to determine changes brought about by the diversion of the seepage from the Backfill Raise area to Boomerang Lake. A report was issued in December 1994 which concluded that the measures for Decant Pond had been successfully curtailing the deterioration of the water quality. The seepage from the mine/mill site have been diverted away from Confederation Lake. However, the contaminant load to Boomerang lake has increased. It was recommended that application of phosphate rock to the lake sediments is required to curtail acidification due to iron oxidation. Due to logistics problems encountered in 1993, the phosphate rock application to Boomerang lake was carried out in 1994. Eighty tonnes of phosphate rock were made into a slurry and applied via barge to the lake sediment in 1994.

The tailings have given rise to a deterioration of the water quality in Mud Lake, which was predicted based on the reevaluation of the hydrological conditions in the tailings basin in 1993. Insufficient quantities of water were reporting to the ground water diversion ditch at the southern end of the tailings deposits. In early 1994, the deterioration of Mud lake was documented. Subsequently, activities in 1995 centred around the hydrology of the tailings and drainage basin.

The hydrology of the tailings basin was originally defined in 1987, excluding the area around Mud Lake. During 1994, the sampling efforts in and around Mud Lake were intensive in order to define the origin and the pathways of the contaminants moving towards Mud Lake. A report was issued summarizing the historic and current status of the area. Based on a preliminary hydrological investigation focusing on the area between the tailings and Mud Lake, a deep bedrock valley was described, which appeared to define the seepage path underneath Mud

Lake, leading to the discharge of the seepage at the north end of Mud Lake. Many hydrological questions were raised by the investigations of 1994, the first year when Mud Lake was contaminated. Thus, to answer key questions, extensive EM surveys were carried out in 1995 to define the contaminant pathway and bedrock conditions.

This information was considered essential to any remedial action plan. After completion of the 1994 investigation, it was possible to estimate, utilizing elemental concentrations of surface water in the drainage basin along with flows and precipitation data, a contaminated ground water discharge volume of 0.6 to 1.0 L/s. This volume of contaminated seepage was considered significant, leading to potential contamination of lakes further north. The 1995 work therefore concentrated on defining possible pathways of contaminants to lakes further north of Mud Lake. The hydrological balance (precipitation/ infiltration/ evaporation) produced an expected surface water flow volume for the drainage basin containing the tailings and Mud lake. These estimates agreed very well with the measured flow volumes leaving Mud Lake, the ground water seepage discharge and flows leaving Decant Pond. These results suggested that it might be possible to contain the contaminants in Mud Lake, if the drainage basin provides a solid containment structure.

Extensive coverage of the site by EM measurements in the areas surrounding Mud Lake was implemented in early 1995, followed by a hydrogeological investigation where piezometers were installed to define the seepage characteristics. The bedrock topography of the tailings needed to be refined, as containment of the contaminants within the drainage basin could also be assisted through identification of the location where the ground water seepage was leaving the tailings deposit. If such a location could be defined, many alternatives would arise in selecting options to contain contaminants.

Therefore, the activities in 1995 focused heavily on collecting hydrological information addressing the spatial distribution of the seepage path and locating the origin of the seepage from within the tailings basin. A summary of the key findings of the hydrology and bedrock definitions is given in Section 2.

Although water balance calculations for the Mud Lake/tailings drainage basin agreed with the relatively sporadic flow measurements and the mass balance using conservative elements of in the surface water, the aerial extent of a plume which would be moving below ground out of the drainage basin was not known. In Section 3, electromagnetic survey data are presented which are used to define the extent of the plume in the Mud Lake drainage basin. The EM survey can also be used as a monitoring tool to determine movement of the plume through repeat surveys in subsequent years.

From the hydrological understanding, based on the data collected in 1987, it was expected that surface and ground water would leave the tailings basin via Decant Pond outflow and passing through the muskeg between the tailings and Mud Lake. Zinc removal was effective to date with extensive algal growth. Surface water leaving Decant Pond could only improve further upon passage through the muskeg. Contaminants leaving the tailings basin via the ground water was evaluated in 1987 and 1988. Piezometer water quality was used, together with modelling of natural contaminant attenuation, to determine potential problem areas of Confederation lake. The assessment indicated that sufficient attenuation will take place and contaminants would not reach Confederation Lake. At the time this assessment of a reasonable evaluation had to be reconsidered, given the findings in 1994.

The 1994 hydrological investigation found the depth of the seepage path at 16 m, discharging directly into the north end of Mud Lake with a water quality which suggested no natural attenuation of contaminants. A reassessment of the status of the ground water chemistry, collected sporadically since 1987, was carried out along with an evaluation of seasonal changes in the surface waters, monitored on a more regular basis. The objective of these evaluations, presented in Section 4, was to determine if the ground water and surface water conditions of the entire drainage basin had undergone significant changes which warranted attention.

Passive treatment of acid mine drainage utilizes sediment microbial activity. These approaches have been developed over the past decade and have proven effective on an experimental and field trial basis. A review of microbial-driven treatment processes by Kalin et al. 1995a test work on Mud Lake sediments carried out in 1995, suggested that this process would be applicable to the remediation of Mud Lake (Appendix 3). The scale up of this process, at this stage only developed on an experimental basis, requires a stepwise approach. The development of floating cattail rafts, representing one task, and quantities of carbon additions, to activate the sediment, had to be determined. The physical and chemical conditions of Mud Lake were described in 1994. A location was selected for an enclosure which could contain potato waste and the floating cattail rafts, the corner stones of the process. These activities are described in Section 5. Based on results of the organic matter requirements determined from the test work with the sediments, an enclosure around the ground water seepage discharge was designed and constructed. The first application of organic matter to the sediments was carried out. The first set of floating vegetation cover was installed, which is needed to promote the development of reducing conditions in the enclosure.

Boomerang Lake receives seepage from the mine site via Backfill Raise and the Mill site as well as diffuse seepage through the tailings dams. Since 1992, deterioration of the lake water quality was evident. Experimentation with different phosphate rock types in the laboratory and the field has been carried out in 1992 and 1993 to curtail the deterioration.

With the reduction in iron cycling, the co-precipitation of zinc by iron will be reduced. The Biological Polishing capacity, i.e., zinc removal due to algal adsorption, was quantified previously for Boomerang Lake. Cut brush was added to the lake to provide surfaces for algal growth. Further brush was added to the lake in 1995. In Section 6, the work on Boomerang Lake is summarized, providing the background to the application of 80 tonnes of phosphate rock to the lake.

Phosphate additions to the sediment are counteracting. The acidification has been taking place due to the iron cycling and the oxidation of iron in seepage entering the lake. The oxidation of ferrous iron, released from the sediments by microbial activity, generates hydrogen ions when iron (II) hydrolyses.

A literature review was carried out in 1994 under joint contract with CANMET, examining iron cycling in sediments. Although iron (III) hydroxides have large specific surface areas and therefore assist in metal removal from the water column, iron cycling also contributes to increased hydrogen ion concentrations and decreases in pH. Phosphate additions to the sediment are expected to form iron (III) phosphates and reduce the mass of available iron or the oxidation-reduction cycle between sediment and water.

In 1995, the logistics involved in applying the appropriate fine rock formulation were addressed and 80 tonnes of rock were applied. Test work leading to the application procedure was carried out examining means by which the rock could be applied in such a manner that a fine layer is deposited over the sediment after slowly settling through the water column. Monitoring data were collected after the application, along with quantification of primary productivity in the form of phytoplankton.

The surface and ground water diversions to reduce seepage from the underground workings on the mill and mine site to Confederation Lake were re-evaluated in 1995. Seepage appeared in 1993 from the old mine portal and the Backfill Raise area, as well as the warehouse area. An electromagnetic survey identified the depth of the seepage in 1992 at about 4 to 6 metres, entering Confederation Lake through the sediment.

A diversion ditch was constructed, directing the flow of Backfill Raise drainage area away from Confederation Lake and towards Boomerang Lake. The ground water table in the mine/mill site was lowered appreciably and small seepage flows remained. Further curtailment of seepage flow was achieved by additional ditching below the Portal Raise in order to divert fresh water draining from Antenna Hill away from waste rock on the mine site beach. The electromagnetic survey was repeated to compare the conditions to those prior to the diversion of the seepage. These findings are presented in Section 7 of this report.

In Section 8, the last section of the report, conclusions are drawn based on the findings and options for evaluation of remedial actions are identified.

2.0 HYDROGEOLOGICAL CONDITIONS OF THE TAILINGS SEEPAGE PATH BETWEEN THE TAILINGS AND MUD LAKE AND THE BEDROCK TOPOGRAPHY OF THE TAILINGS BASIN.

In 1991 Albert Vonhof Consulting Ltd of Calgary, Alberta was retained to address precipitation processes taking place in the South Bay tailings deposit. These studies and his involvement in other Ecological Engineering projects at Boojum Research familiarized him with the South Bay site. He was retained to carry out the preliminary investigations in late 1994 and, subsequently, the test drilling program and piezometer installations for the seepage in 1995. A brief summary of the key findings is presented below.

Paddock Drilling Ltd. from Brandon, Manitoba was engaged to conduct the test drilling and piezometer installation program at South Bay, Ontario. A Mobil S61 track-mounted drilling rig was used to ensure maximum mobility. Similarly, the accompanying water truck was also track-mounted. This equipment is highly versatile because auguring, (solid and hollow stem) mud rotary drilling and diamond coring can be performed with the same rig. Despite the utilization of mobile and versatile equipment, the weather conditions did not allow access to the northern part of Mud Lake. Hence no data could be obtained from the northern part of Mud Lake and the investigation focused on accessible areas.

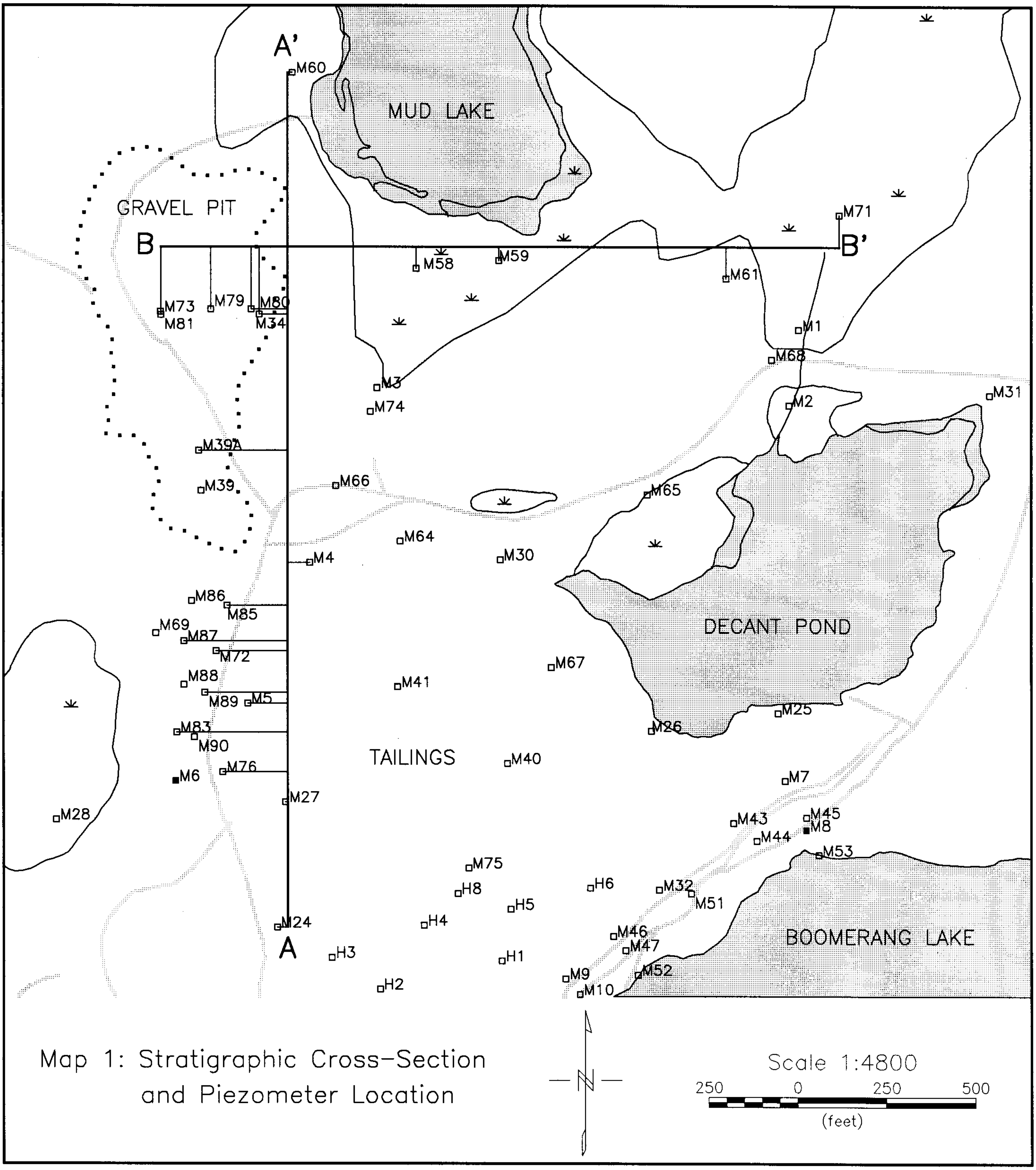
Bedrock topography: Bedrock conditions covering the tailings basin and the seepage path to Mud Lake were determined. The bedrock topography is, as expected, quite irregular which is typical for the Canadian Shield. The surface was modified by glacial erosion and very rapid lateral changes in the elevation can and do occur. This is illustrated by the outcrops in the area of the deep valley carrying the seepage from the tailings between elevation 395 m and 400 m, compared to the surface elevation of 415 m. The present situation represents the best approximation based on the available information.

The bedrock topography is characterized by a southward trend bedrock valley. This bedrock valley skirts the western side of Mud Lake and runs under the gravel pit towards the northwestern corner of the tailings basin. In this area, it appears to split into two arms. One arm follows the western tailings basin towards the south, exits the tailings basin in its southwest corner and appears to run under the eastern part of the old town site towards Confederation Lake. The other arm of the valley appears to run toward Confederation Lake under the western part of the town site. The north-south trending buried valley, in all likelihood, follows a major fault zone. it was also determined that the arm of the bedrock valley under the tailing basin is joined by another tributary originating in the northeastern part of the tailings basin underneath Decant Pond.

The portion of the buried valley which is clearly defined is located under the gravel pit. It is bounded on the west side by a bedrock outcrop and on the east side by a bedrock high. Three locations (M79, M80, M81), more or less equally spaced, were drilled across this valley (Map 1). It appears that the valley has relatively steep walls and a flat bottom (the “Kalin Canyon”). Hole M81 appears to be close to the western edge of the valley as is suggested by the presence of a considerable boulder lag just above the bedrock surface. Both the northern extent of the buried valley under Mud Lake and the southern extent of the two arms under the town site are not well defined.

South of the northern edge of the tailings basin the buried valleys split into two arms and becomes diffuse south of the southern edge of the tailings basin.

The bedrock topography indicates that the tailings impoundment is situated on a topographic bedrock low which, in the shallow subsurface, is connected to the surrounding area by a number of buried valleys. These buried valleys, south and west of the tailings basin, in all likelihood, are directly connected to Confederation Lake. The main seepage path, however, appears to be through the "Kalin Canyon" as all the water in the drainage basin is reporting to Mud Lake and leaves through its outflow.



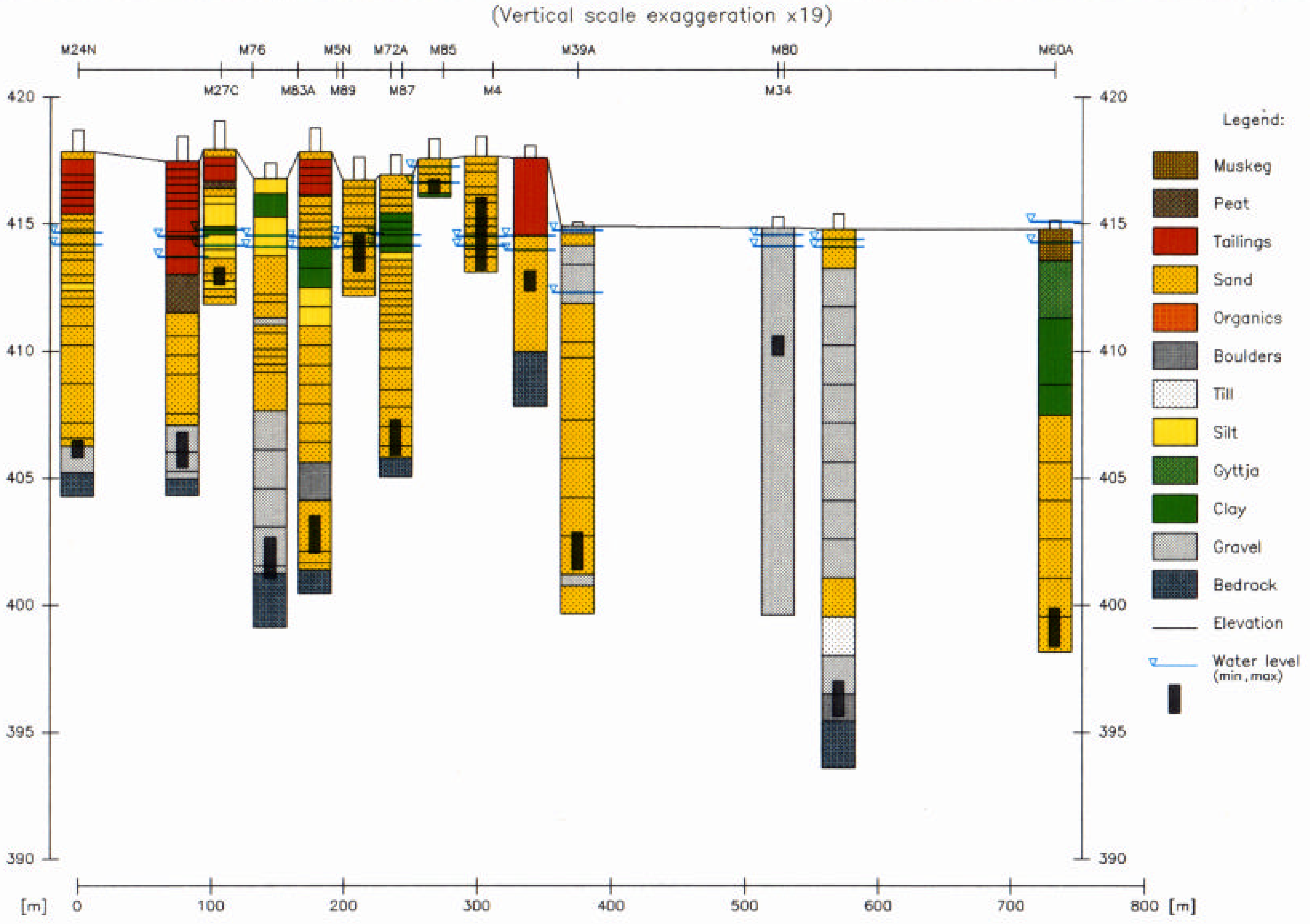
Map 1: Stratigraphic Cross-Section
and Piezometer Location

The stratigraphy of the boreholes is used to derive the south-north cross section (Schematic 1) and west-east cross section (Schematic 2). General observations on the stratigraphy are as follows, almost all boreholes show that the coarsest sediments (boulders, gravel, granules) overlie the bedrock surface which then grade into subsequent finer sediments in ascending order. In many boreholes the finest sediment is clay or silt. Furthermore, the overall grain size of the sedimentary section decreases from north to south, and becomes more interbedded and variable towards the south.

Stratigraphic information with respect to the underlying material at the interface of the tailings was examined. The majority of the stratigraphic section indicates that most tailings are underlain by a sandy material.

The hydraulic head distribution in the drainage basin, derived from the water level measurements, leads to the conclusion that the tailings seepage (in Kalin Canyon) originates from the areas around the northwestern corner of the tailings impoundment where sand is in direct contact with the tailings. Thus, essentially the tailings seepage spills from the tailings pond over into Kalin Canyon at the northwestern portion of the tailings impoundment. At this point no information is available on the bedrock below Decant Pond.

Stratigraphy and water level information from the 1987 hydrogeological work was to be interpreted with the new piezometer locations to obtain a complete new hydrogeological evaluation. A survey was carried out after completion of the drilling program in June 1995 with Total Survey Equipment. A detailed map for the site was derived in 1987 through aerial photographs, where the piezometers drilled in 1987 were marked on the ground. Contours of this site were based on this aerial map and elevations of the piezometers were determined manually with a theodolite. Unfortunately, the total survey results produced in 1995 and those produced in 1987 did not agree, both in locations and in elevations at some locations. Rather large differences were reported for some locations. This severely hinders the development of hydraulic head calculations, which determine the direction of water flow.



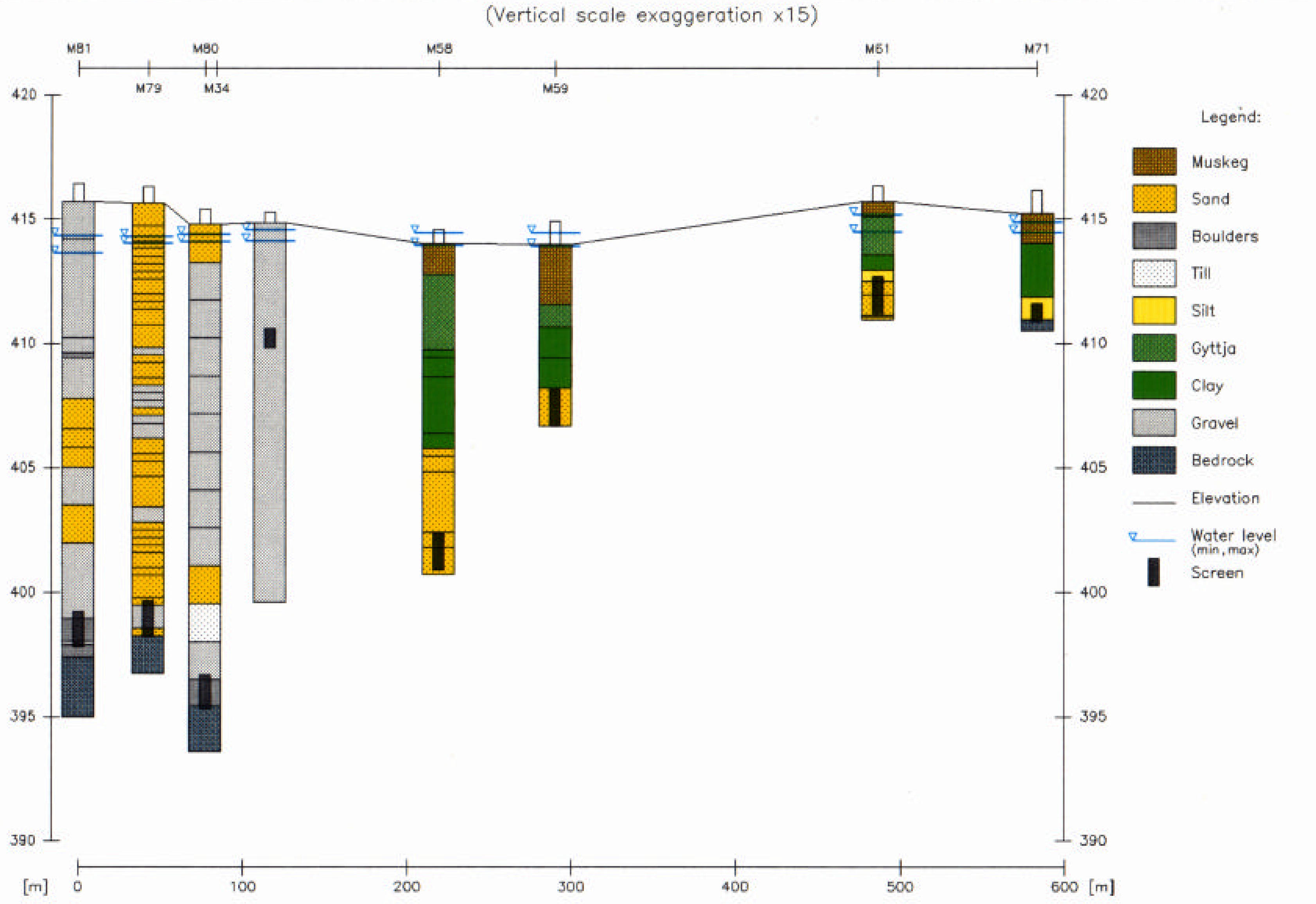
SOUTH BAY PIEZOMETER STRATIGRAPHIC AND HYDROLOGICAL SECTION

A-A' CROSS-SECTION (SOUTH-NORTH)

Schematic 1

December, 1995

Boojum Research Ltd.



SOUTH BAY PIEZOMETER STRATIGRAPHIC AND HYDROLOGICAL SECTION
B-B' CROSS-SECTION (WEST-EAST)
Schematic 2

December, 1995

Boojum Research Ltd.

In order to address the differences and resolve all potential errors, a GPS Total Station survey system was used in 1995. It was found that distortions were introduced through the interpretation of the airborne information, in addition to errors which were made in the Total Survey of the year 1995. With the results of the GPS Total Station survey system, obtained in October 1995, two errors were noted, one due to distortion in the original Airquest Map and the second due to errors made in the 1995 survey. This information will be assessed in 1996 to determine the consequences of the errors for the hydrology. Unfortunately due to a severe winter storm it was not possible to complete the GPS survey for the site.

The new piezometers installed in 1995 are located in their approximate position, using the 1987 topographic map as a basis and site knowledge of where the holes were drilled, until the mapping problem is resolved.

The elevations obtained from the 1995 survey were used to calculate the elevation of various geological contacts. It is realized that a potential error may be introduced by using the 1995 survey data but it is felt that such an error is not significant considering the degree of variability of this geological environment.

Accurate elevation measurements are much more critical when water levels between piezometers are compared, especially in this area where the sediments have very high permeability. The data discussed in this report utilizes the information without resolution of the errors associated with the differences in elevation, as an interpretation was needed for the progress of the project.

Ground water flow: Precipitation falling on the tailings basin, once infiltrated, will flow vertically downward through the tailings. Upon reaching the underlying aquifer it moves laterally and predominantly towards Mud Lake. The actual path taken by the ground water in the tailings will depend on the permeability distribution within the tailings. Both the presence of compacted muskeg and clay layers under the tailings will affect the ground water flow path.

The hydraulic head distribution is based on water levels measured in piezometers completed immediately above the bedrock surface on July 29, 1995. It is assumed that the contrast in hydraulic conductivity between the bedrock and the overlying permeable sand and gravel deposits is sufficiently large that, for all practical purposes, the bedrock surface can be considered impermeable. Ground water will, therefore, flow laterally along this surface. The tailings basin is partially surrounded by ground water recharge areas. These areas correspond to topographic highs which are predominantly bedrock hills. Pine trees grow characteristically in those areas. Fresh ground water flows from this recharge area towards the tailings basin and is, in places, conveyed for a considerable distance under the tailings basin.

Piezometer M26B, located more or less in the middle of the tailings basin, was completed near the bedrock surface contact in a NE-SW trending tributary of the main buried valley. The chemical analysis shows that the water from this piezometer is uncontaminated. Clean ground water is also present in the arm of the main buried valley west of the tailings basin near M28. This uncontaminated water flows northerly in the direction of M83 (Map 1).

All piezometers near the edge of the northeastern part of the tailings basin (M1, M61, M68) show uncontaminated water, although a steep hydraulic gradient from the tailings basin towards M61 appears to be present. The north-south trending buried valley on the western edge of the tailings is the main ground water discharge path for the tailings basin. Contaminated ground water in the tailings basin flows along the buried valley towards Mud Lake and discharges into Mud Lake. The water levels in all piezometers completed in the immediate vicinity of Mud Lake (M58, M59, M60A & B, M62 and M63) are above the water level of Mud Lake.

It is known that active discharge (springs) of contaminated ground water occur in the northern part of Mud Lake near M62 and M63. No piezometers have, as yet, been installed in the deeper part of the aquifer in this area. The configuration of the buried valley and its extent in this area are unknown at the present time. However, the evidence of ground water discharge in this area indicates that there is a major change in stratigraphy along the path of the buried valley, due to the ground water that is upwelling in Mud Lake.

This change could be due to a facies change in the sediment of the buried valley resulting in a sharp reduction of the permeability of the aquifer and/or a significant change in the physical continuity of the buried valley. In other words, the northern part of Mud Lake may be the start of the main buried valley aquifer. Additional subsurface data will be required to resolve this.

The dams constructed in the southeastern part of the tailings basin to prevent major discharge of contaminated ground water into Boomerang Lake have achieved, in principle, their objective of creating a low to very low permeability wall (boundary) as is manifested by the steep hydraulic gradients between the tailings basin and Boomerang Lake. However, in at least three places, seepage is occurring.

Another area which warrants discussion is the southwest corner of the tailings basin (i.e. old town site, situated south of the tailings basin). The bedrock topography, southwest of M78, and the water chemistry of the piezometer, indicate that the ground water *immediately* above the bedrock in location M78, is contaminated. This indicates that contaminated ground water is flowing towards the south from the tailings basin, possibly at a depth deeper than the ground water diversion ditch.

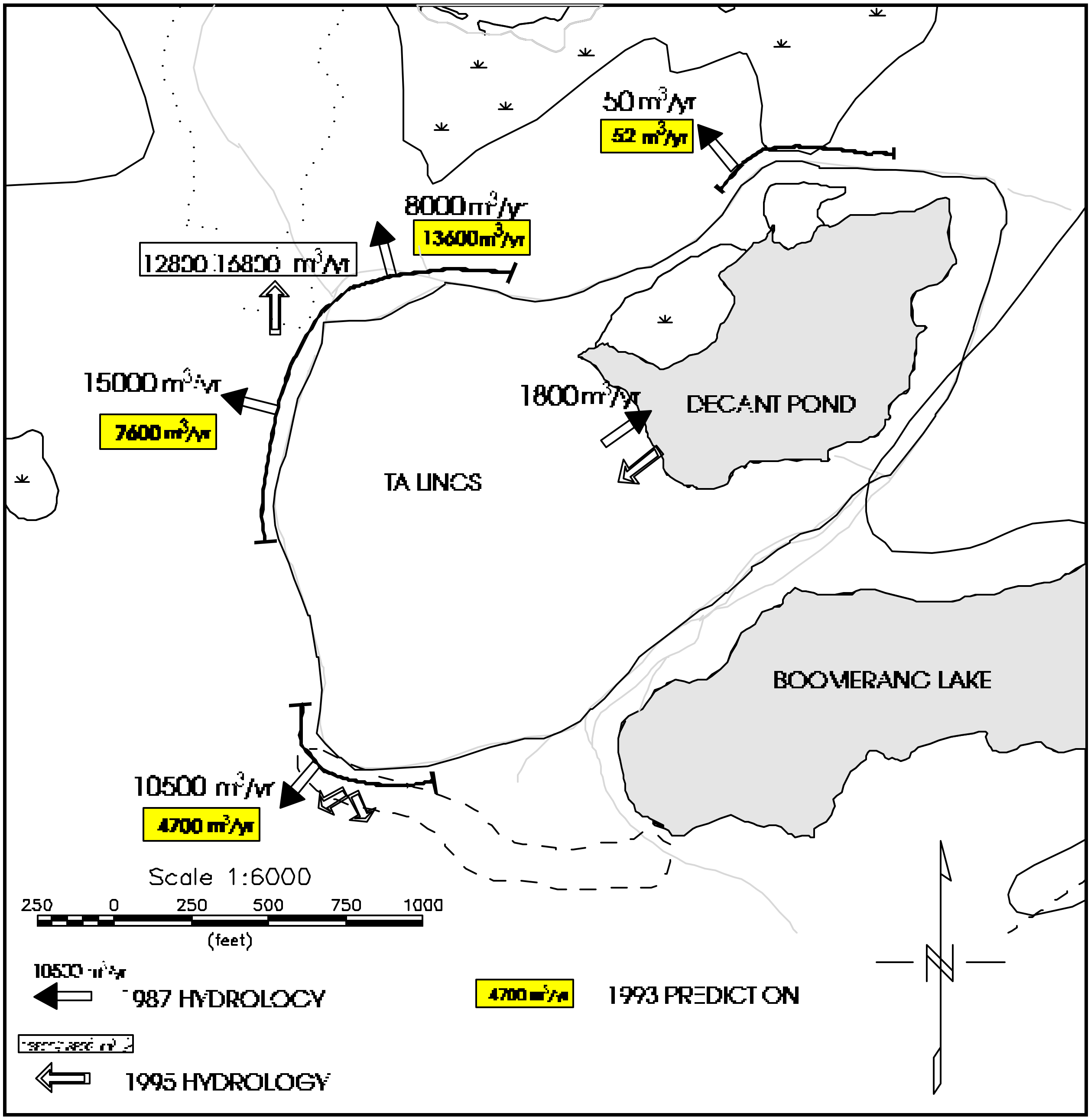
The EM survey for this area shows the presence of a well defined but relatively small anomaly. However, it is known from the stratigraphic information in boreholes M78 and M82 that significant clay deposits are present in the shallow subsurface which will mask the effect of the contaminated ground water in the EM surveys. The water chemistry indicates that contaminated water has travelled southward to the location of M82. The hydraulic head in M78A confirms that movement is taking place from the tailings basin towards the south.

On the other hand, water level measurements in piezometers M50 and M77A show that the hydraulic head in these piezometers is at least 150 cm lower than in M78. This difference cannot be accounted for by survey errors only. This strongly suggests that ground water flow from the tailings basin towards the south is likely to occur. This significant difference in hydraulic head implies a relatively steep gradient towards the south. Steep gradients between two measuring points generally signal a drastic reduction in the permeability of the sediments.

The existence of much greater variability in the stratigraphy in this area was confirmed by boreholes M78 and M82. In summary, although the elevation differences may shed a different light on the situation, it is possible that the ground water diversion ditch intercepts only a part of the seepage as it might not have been constructed sufficiently deep to catch the entire plume.

Seepage flow to Mud Lake: The main pathway for contaminant transport towards Mud Lake is a buried valley which narrows to a canyon in part of the area between the tailings basin. Utilizing the water level data collected between June and September 1995 and considering hydraulic conductivities in the ranges of 0.157 cm/sec and 0.26 cm/sec, a volume of water can be estimated to pass from the tailings to Mud Lake ranging from 10,100 m^3/yr to 16,800 m^3/yr (June) and 7,700 m^3/yr to 12,800 m^3/yr (September). These estimates will be revised after the elevation data have been corrected with the GPS data. Every cm of error in the elevation of the water levels between M39A and M80 introduces a change of 7.5 - 10 % in the above listed values.

The contribution of ground water flow to the contaminant loading of Mud Lake is somewhat lower than the estimate arrived at in 1994 with 0.6 l/sec, based on water balance of the drainage basin, compared to the range determined based on hydraulic gradients 0.2 L/sec to 0.5 L/sec. In summary, the changes in the flow volume estimates, evaluated over the last 10 years, are depicted schematically in Map 2.



Map 2: Hydrological Balances of Tailings Basin, 1987-1995

3.0 EM INTERPRETATION OF MUD LAKE AREA and WEST OF TAILINGS

Electromagnetic surveys carried out in the South Bay Mine area have been used since 1992 to detect and monitor effectively AMD occurrences and their migration. This can be achieved together with detailed site knowledge. To guide the hydrogeological investigations around Mud Lake and the seepage path, the same methods have been employed for the following areas of the South Bay site in 1995:

(1) Mud Lake to determine the extent of the AMD contamination;
(2) West of the Tailings to delineate other potential pathways of contamination leaving the tailings impoundment;
(3) South of the Tailings/Town site to delineate the extent potential AMD sources in the ground water not intercepted by the diversion ditch;
(4) Mine Site to evaluate the effects of the Backfill raise diversion ditch on the seepage from the underground workings.

This section presents the key findings based on the EM survey and presents a discussion of the Mud Lake area with the results of the water quality data obtained from the piezometers that were installed to test geophysical anomalies. All of the EM surveys in this area are "exploratory" in nature and where carried out in progression, focussing on the objectives, to support the hydrological investigations and to delineate possible other contamination pathways in the drainage basin.

The Mud Lake area grid covers an area roughly 1 kilometre square immediately north of the Tailings, including all of Mud Lake, the area north of Decant Pond Outflow, and a portion of the Mud Lake Outflow. The response of the coil separations of 10 m , 20 and 40 m were examined, representing progressively deeper penetrations (Maps 3a, 3b, 3c). The overburden response can also be subtracted from the deeper portions in order to focus on these layers' responses without those of overburden, reflecting a more realistic picture of the conditions to a depth of about 15 m (Maps 3d and 3e).

NOTE

Map 1 to Map 5 as well as Map 8a and 8b are Geomar Maps 1995, which are paper copied only. They are gone to Laurantian Sudbury Library.

MAP S1

MAP S2

MAP S3

MAP S4

MAP S5

In the Mud Lake area there are two main anomalous features, namely the MUD LAKE ANOMALY and the EAST OF MUD LAKE GROUP OF ANOMALIES). The Mud Lake anomaly has three sources contributing to the conductivity; that of the sediment, that of clay and that of the contaminated water. The seepage ground water discharge zone is located along the north shore of Mud Lake. Readings taken at 10 m and 20 m coil separations indicate that the Mud Lake Anomaly currently extends for about 100 m beyond the north shore at depths of probably less than 12-15 m.

One interpretation of the geophysical results suggest that an upward migration of contaminated ground water from a deeper to a shallower aquifer occurs somewhere between L600mN and L700mN, and lateral flow continues at shallower depths for another 100 m to the north. If contaminated ground water is indeed at least in part the source of the anomalous readings, it would suggest that not all of the seepage is discharging into Mud Lake and that the plume continues to travel. However, taking the hydrological data into account, essentially only a small fraction can be expected to leave the drainage basin, since all the water can be accounted for in the drainage basin at large. However the cause of the upwelling is to date not clarified. The temperature of this area with the floating muskeg did not allow the installation of piezometers in this area. The only information about the north end of Mud Lake is therefore that which is derived from the EM-Survey.

Two well defined anomalies which originate in the NW corner of the Tailings merge into the Mud Lake Anomaly in between lines 100N and 100S. This anomaly is referred to as the CHARA PONDS ANOMALY, algae named after a small pond in which Chara grows. This alga is indicative of alkaline water. The anomaly trends north from the tailings dam and links up with the Mud Lake Anomaly at the south end of Mud Lake.

The CHARA POND ANOMALY extends from about 50mE on L50mN originating from the NW corner of the tailings impoundment and merges into the Mud Lake Anomaly at approximately 150mE on L230mN. It has been tested by piezometers M66A and M74. Electrical conductivities in water from M66A and M74 were recorded as high as 1465 :S/cm and 1604

:S/cm respectively in the ground water. Zinc concentrations were 60 mg/L in M66A which is located very close to the tailings impoundment, but outside the dam. In M74 the zinc concentration had dropped to 1.27 mg/L in M74, located further north in the anomaly.

The second anomaly is referred to as the GRAVEL PIT ANOMALY and originates along the western margin of the NW corner of the tailings impoundment. It also connects with the Mud Lake Anomaly at approximately 50mE on L400mN along the western margin of Mud Lake. This anomaly was previously identified in 1994 in piezometers M39A and M60A as a major plume of contaminated ground water originating from the tailings impoundment. This area is very important possibly representing the major portal for tailings seepage to leave the tailings 16 additional piezometers along 5 sections were installed along the EM anomaly in 1995.

Piezometers installed along both these anomalies indicate the conductivity response is the source of contaminated ground water as no clay is present in this area. It could therefore be confirmed that the anomaly represents the beginning of that section of the tailings where seepage is leaving the pond and entering into the deep valley seepage areas, referred to as Kalin Canyon.

The EM survey results, together with the hydrology, suggest an ridge of outcropping bedrock trends parallel to the shore of Confederation Lake. The Kalin Canyon is likely the major barrier for ground water flow into Confederation Lake. The presence of a bedrock outcrop hill situated immediately southwest of the tailings would further supports this conclusion.

The EAST OF MUD LAKE GROUP OF ANOMALIES produce a much lower response than those of the Mud Lake areas. They extend northward from the Decant Pond Outflow and appear to tend towards the northern part of the drainage basin which contains Lena Lake between 600E and 900E.

The anomalies were tested with 6 piezometers in 1995 (M68, M70A, M70B, M70C and M71). In all cases, the source of the anomalous responses was clay. This indicates that no seepage are leaving in this direction the tailings impoundment. Electrical conductivities of the ground water from these holes were in the range of 152 to 329 :S/cm and the highest zinc concentration was 0.29 mg/L in M68, which is close to background in this area.

4.0 TEMPORAL VARIATIONS IN WATER QUALITY IN SOUTH BAY

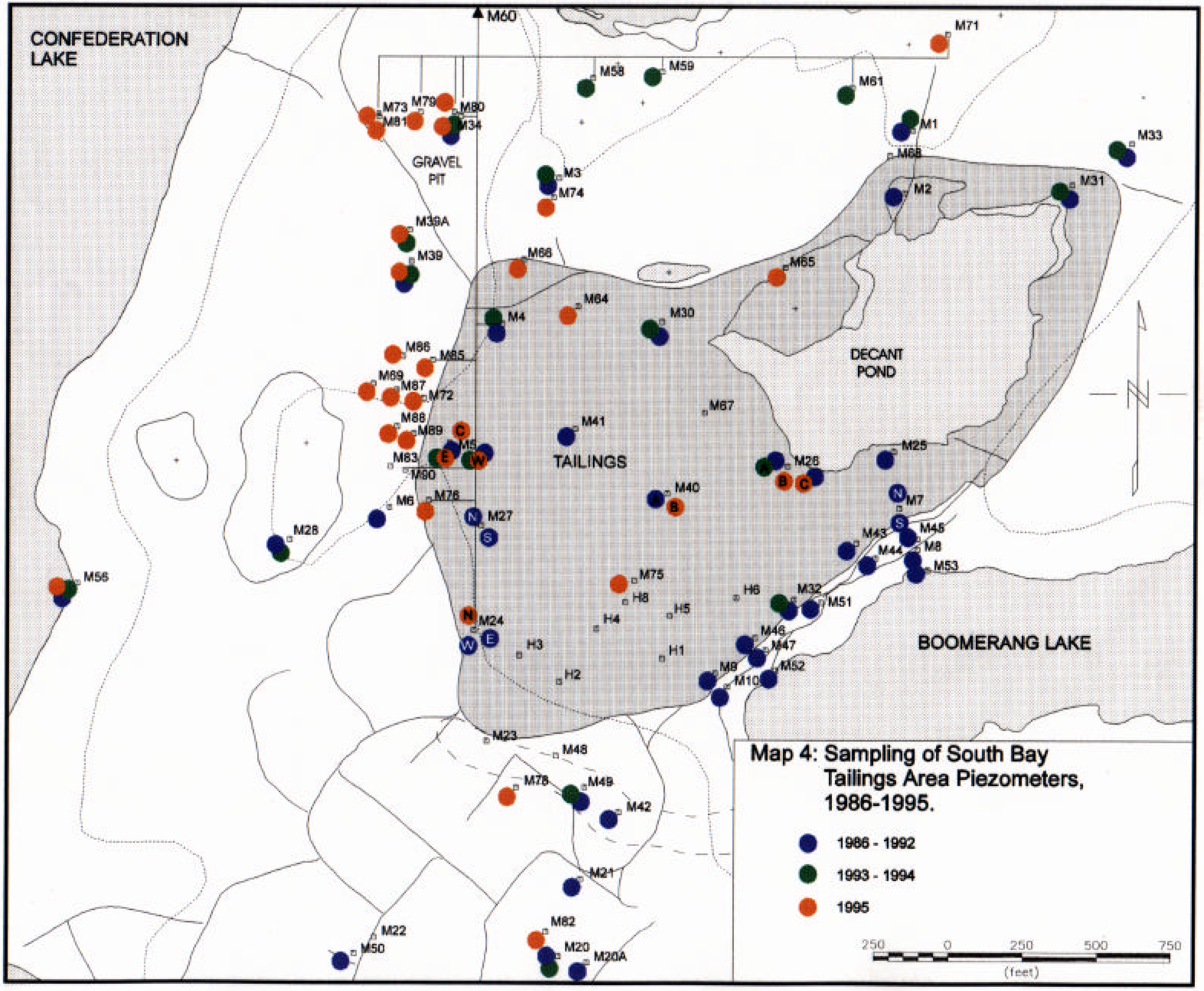
4.1 Summary of Piezometer Water Quality

With the deterioration of Mud Lake water quality and the ongoing deterioration of Boomerang Lake water quality, it is essential to assess if the geochemical/ hydrological conditions of the site have changed. When there is a significant change in the results from year to year, previous evaluations and decisions carried out during the project must be reassessed.

Predictions of seepage pathways had been made and contaminant loadings from these sources to Confederation Lake were evaluated, based on one piezometer sampling campaign. Subsequent sampling of piezometers was sporadic, addressing mainly the areas of concern which were determined by unusually high concentrations of metals in the piezometer water.

In Map 4, the spacial distribution is plotted for the sampling events of the most important area, the tailings, for the years 1986 to 1995. Sampling frequencies for the piezometers are plotted in Figures 1a to 1c. It can be noted, that sampling, which was accompanied by chemical water analysis for the piezometers, was generally focused on the areas where potential problems appeared (M38 and M18 on the mine site Figure 1a). On the other hand, the standpipes M55 and M56 , which are regulatory points, have been sampled to assure that all is in order. Discharges in these areas would represent a major problem. However to assess changes, either with time or in a certain location, the data set has to first be evaluated in more detail.

It was also noticed, that some data, preceding the first complete round of sampling of water in 1987 was not included in the database, established in 1992. It was found necessary to update and complete the database both with samples collected at the very beginning of the project and more recently, with the new piezometers



Map 4: Sampling of South Bay Tailings Area Piezometers, 1986-1995.

Fig1a: Mine, BFR, MPRO, Confederation
Piezometer Sampling Frequency,1986-95

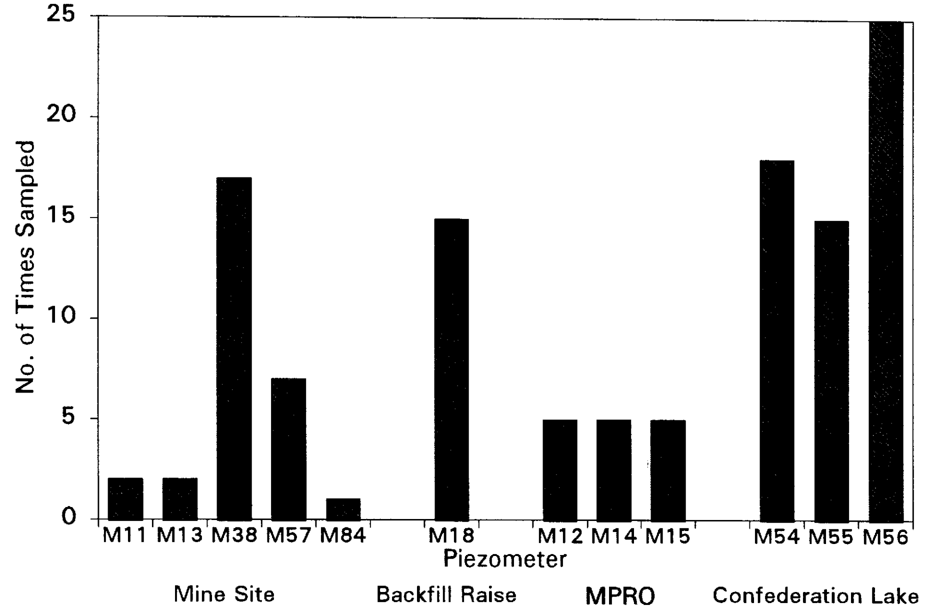


Fig1b: Decant P, Gravel P, Town, Mud L
Piezometer Sampling Frequency,1986-95

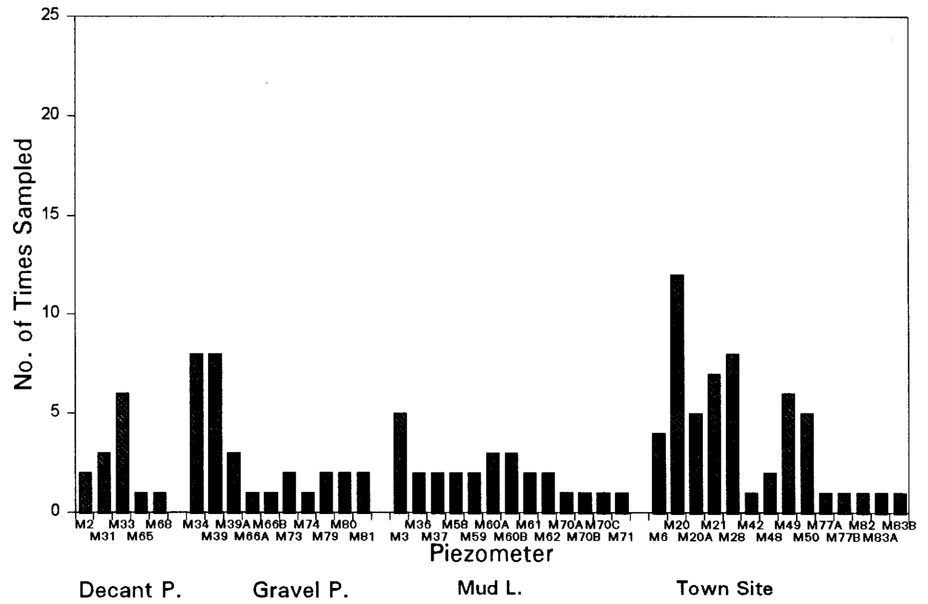
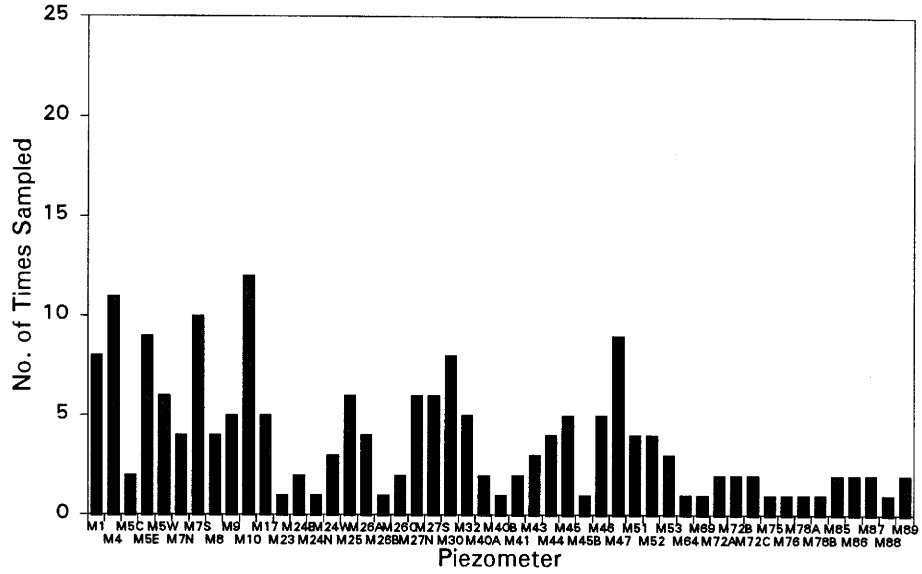


Fig1c: Tailings Incl. Boomerang L Dams
Piezometer Sampling Frequency,1986-95



added in 1994 and 1995. Assessment of potential changes with time, ie. a deterioration of the geochemical conditions in the tailings pile, which would contribute to changes in contaminant loading to the subdrainage basins, was considered vital for any decisions on remedial measures.

A preliminary examination of the chemical analysis for two piezometers, the most continuous data set, was easily accessible and considered quite reliable. The magnitude of changes in elemental concentrations which can take place is given in Table 1 for piezometers M10 and M47, where samples had been collected in 1988, 1989 and 1990 or 1992.

Table 1: Temporal variations in chemical composition of the water in piezometers M10 and M47

Assayer #	DATE	Location	Al [mg/L]	Cu [mg/L]	Mn [mg/L]	Zn [mg/L]	F*pH [mg/L]	F*Cond [mg/L]	L*pH [mg/L]	L*Cond [mg/L]
Piezometer M10										
345	08-Apr-88	surface,before bail.	505	64	25	274	2.29		2.14	7000
346	08-Apr-88	surface,after bail.	340	54	18	35	2.26		2.11	6000
1467	14-Oct-89	surface,before bail.	520	45	23	168				
1468	14-Oct-89	surface,after bail.	502	51	22	164				
2255	13-Oct-90	surface,before bail.	196	27	6.3	75	2.14	7000	1.99	6500
2256	13-Oct-90	surface,after bail.	208	30	7.1	76	2.08	5000	1.89	7000
2257	13-Oct-90	bottom,before bail.	212	34	7.7	88	2.20	7000	2.10	7000
Piezometer M47										
341	08-Apr-88	surface	0.6	0.05	45	219	6.05		5.57	3150
2263	12-Oct-90	bottom	<0.01	<0.01	29	73	5.23	3300	5.30	3500
2262	13-Oct-90	top	<0.01	<0.01	24	61	3.83	4000	5.12	3750
3673	25-Mar-92	surface	<1	<1	82	174			5.34	3900

In addition to the long time lapses between sampling intervals, the effects of water taken from the piezometer before or after bailing is evident. For M10, the Zn concentrations in April 1988, before bailing and after bailing, varied from 274 mg/L to 35 mg/L, respectively. Comparing October 1989 and October 1990 data, when the sampling campaigns were performed, repeated in subsequent years and in the same month, a large difference in Zn concentrations was noted. Similar Zn concentrations were determined in samples collected before and after bailing in both the October 1989 and October 1990 samples.

When surface and bottom water of piezometer M47 was sampled in October 1990 before bailing and after bailing, Zn concentrations were low, compared to samples collected in April 1988 (219 mg/L). In March 1992, the M47 sample again contained a high zinc concentration. These examples from this small set of data suggest that seasonal variations exist in the porewater chemistry.

Water chemistry data for the new piezometers installed in 1995, which were received at the time of data analysis (therefore not included in report 1995), suggested very large seasonal variations. Although the results are not reported here, an example can be given using the water quality data for piezometer M72C located in Kalin Canyon. In May, a concentration of 1,430 mg/L of zinc was reported along with 7,690 mg/L of iron. However, in October, these concentrations had decreased to 523 mg/L and 192 mg/L respectively. The calculation of contaminant loads, given these seasonal trends, would generate very different assessments regarding the magnitude of the problem. On the other hand, these large differences indicate the possibility of retardation, which could be due to the precipitation processes taking place over the seepage path. When concentrations are very high, the solution could potentially be brought to saturation, which in turn would facilitate precipitation of the contaminants underground.

If this is possible, it would represent an avenue for in-situ treatment. A detailed evaluation of the long-term geochemical changes in the tailings should be carried out. However, this brief evaluation indicates, that the estimates of loads of contaminants from the tailings to the receiving environment can potentially vary by orders of magnitude, when seasonal variations in piezometer water quality are included in estimates of the potential range. Seasonal variation in the piezometers' water quality of such a magnitude was not previously reported in the literature. All data have to be evaluated from this perspective in order to address potential contaminant loads. Given the volume of data available from this site, a further update of the Paradox database, completed up to 1993, is absolutely necessary since the efficiency with which this assessment can be done can greatly be increased.

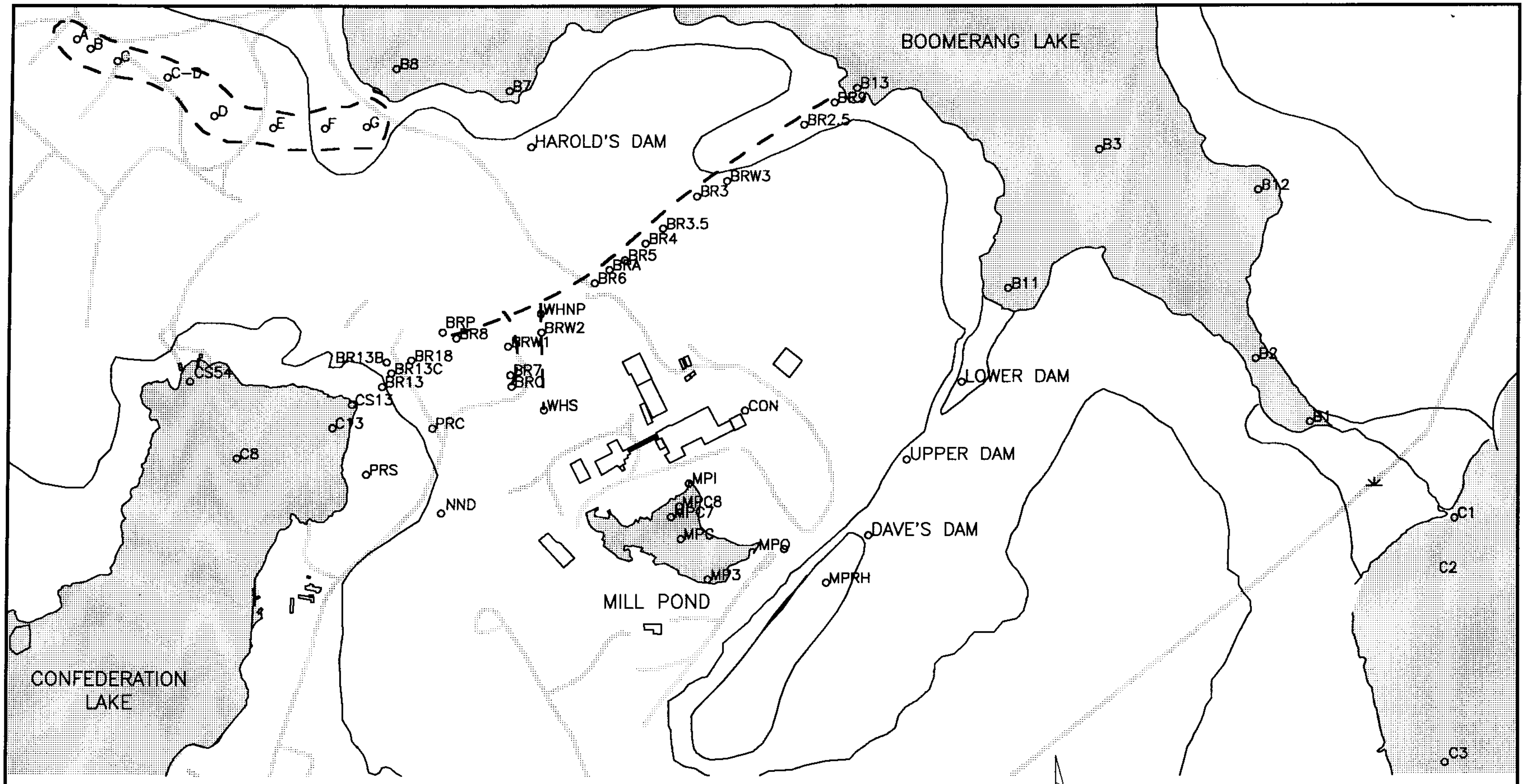
4.2 Temporal Variations in Metal Concentrations in Surface Waters

Given that the large differences in chemical composition was evident in the piezometers, it was considered useful to assess the seasonal variation in the surface waters associated with the South Bay site. Available analyses for samples collected from a number of selected points at the South Bay site, between October 1986 and September 1994, have been plotted to determine where heavy-metal concentrations are increasing or decreasing with time.

It should be kept in mind that the detection limits for the heavy metals has changed over the years, as analytical laboratories have become more advanced. Thus for some of the pre-1994 analysis, where the detection limit was apparently set at 1.0 or 0.1 mg/L, rather than 0.01 mg/L or lower, it may appear erroneous that very low metal concentrations existed, which in fact is not the case in the early 1990 samples.

A brief evaluation of the data set available is given for each area of the site below, starting with the mine site. This site was sampled quite frequently due to the diversions required to prevent seepage into Confederation Lake. The sampling stations are given in Map 5.

Warehouse Seep (WHS) (Figure 2) was sampled since 1992 and shows increases in the values for [Al], [Cu], and [Fe], but no clear trend for [Mn] and [Zn]. Some seasonal variations may be apparent. For Backfill Raise Cap (BRC) the data in Figure 3 shows an increase in the values for [Al] and [Fe], and a decrease in the values for [Cu], [Mn], and [Zn]. Seasonal variations appear stronger for metal concentrations determined in BRC water samples than in WHS. Both WHS and BRC are draining into the larger ditch, leading to Boomerang Lake, where sampling locations have been established since 1992 (Figure 4). The 1994 analyses for location BR2.5 show increases in the values for all metals compared to samples collected from location BR4 in 1992. Apparent seasonal variation is strongest in [Fe].



Map 5: Mill Site Surface Water Sampling Locations

Mill Pond Outflow (MPO), the sampling location where water is leaving Decant Pond, also drains toward Boomerang Lake. Seasonal variations are evident both in 1992 and 1994, but the concentrations are overall lower in 1994 (Figure 5).

Boomerang Lake Outflow (B1) (Figure 6) displays an increase in the concentrations of all five metals, more than an order of magnitude, from 1990 to 1992 and somewhat smaller increases from 1992 to 1994. All metal concentrations, with the exception of copper, were well above 1 mg/L in 1994. The seasonal variations are not evident.

The water leaving Boomerang Lake is sampled at a station about 5 to 10 m outside the mouth of the outflow area in Lost Bay in Confederation Lake (C1, Figure 7). Seasonal variations are stronger than in Boomerang lake. The 1994 values (are above 1 mg/L for Zn and Mn) are somewhat lower than those for the same months in 1992. There is some uncertainty regarding [Al] and [Cu], due to the higher detection limits used for the 1992 samples.

The seepages which drain toward Confederation Lake , also indicated on Map 5, are seeps (BR13, 13B and 13C) and their seasonal metal concentrations are summarized in Figure 8. As would be expected strong seasonal variations occurred in all five metal concentrations, primarily due to varying degrees of dilution with time. Overall the 1994 values for all metals are lower than the 1992 values. This may well reflect the effect of the drainage ditches.

The metal concentrations of Portal Raise Cap (PRC) (Figure 9) show some seasonal variations. Overall, the 1994 values for all metals are higher than the 1992 values and at this point can not be explained. The Portal Raise Seep (PRS) (Figure 10) displays strong seasonal variations in 1992 and smaller variations in 1994. The 1994 values for [Fe], [Mn], and [Zn] are higher than those for 1992; the 1994 values for [Al] and [Cu] are within the ranges for these metals for 1992. In 1994 the metal concentrations were higher in the PRS samples than in the PRC samples. This is highly likely due to the fact that more fresh water from Antenna hill was diverted and thus generally less water enters the PRC.

In Confederation Lake a shore sample is collected to determine the degree of dilution which takes place on the shores of (CS13) (Figure 11). Metal concentrations show some seasonal variation for 1994, with a possible increasing trend for Mn and Zn. The 1994 values, all below 1.0 mg/L, are apparently lower than those for 1992.

The surface waters leaving the tailings basin to Mud Lake are referred to as stations. Decant Pond Outflow (DPO) metal concentrations are plotted with respect to time in Figure 12. Some seasonal variations are noted and in 1994 all [Mn] and [Zn] values were lower than those in 1992. Trends for [Al], [Cu] and [Fe] are uncertain, due to strong seasonal variations. For the 1992 data for this station may be missing due to higher detection limits (1.0 or 0.1 mg/L) for these years.

For the station Mud Lake Outflow (ML18) (Figure 13) some seasonal variations can also be observed (higher than average concentrations in March, followed by lower than average concentrations in April) except for [Zn] and [Cu]. The data for [Zn] suggest a long-term increase. After April 1994, all Fe, Mn, and Zn concentrations exceeded 5 mg/L. This increase is clearly connected to the slow breakthrough of the ground water seepage through the sediment.

In summary, the metal concentrations of the surface water also shows seasonal variations as was suspected from the piezometer data. Unfortunately the same situation arises, that a more complete data set should be evaluated for seasonal and long term trends. Of the 19 sampling stations, seasonal variations occur at 14 locations and were noted. This in part limits a non-statistical approach to the data set. A trend analysis would be required to assess such differences. At 4 stations, increases in Zn concentrations are noted, including the seepages from the underground workings which report to Boomerang Lake. Subsequently, the zinc concentrations have also increased in Boomerang Lake. At two stations, marginal increases in Zn concentrations were observed, but concentrations remain below 1 mg/L.

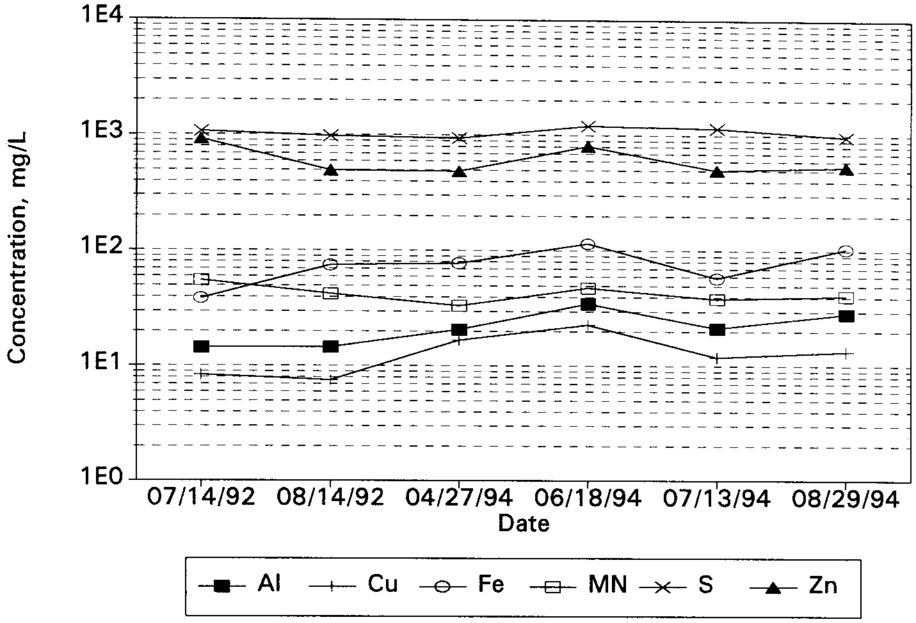


Figure 2: Warehouse Seep (WHS)
Metal concentration versus time

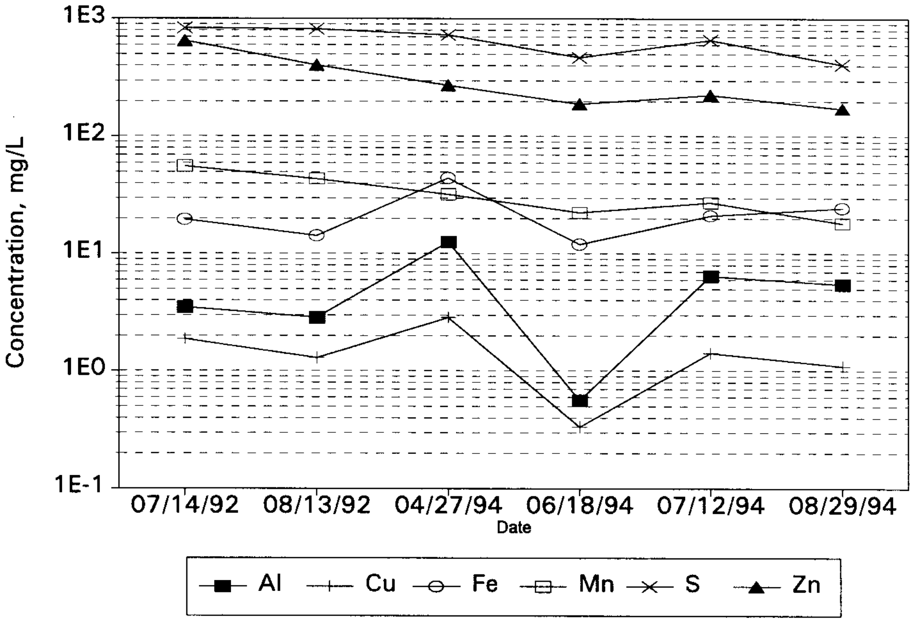


Figure 3: Backfill Raise Cap (BRC)
Metal concentrations versus time

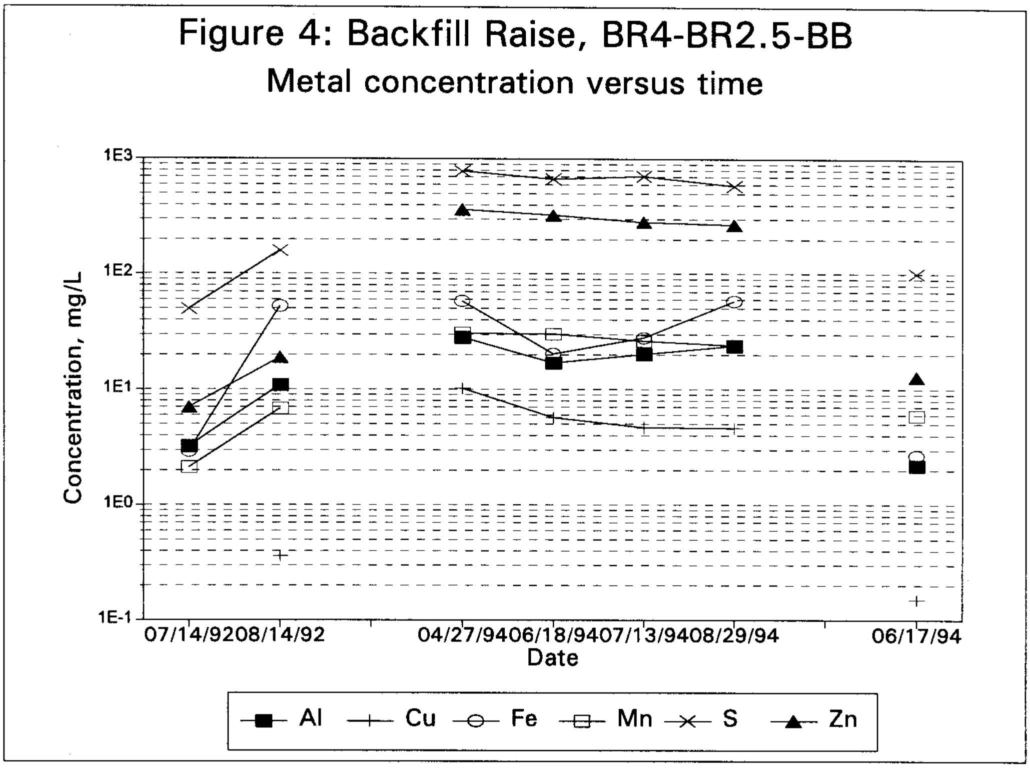


Figure 4: Backfill Raise, BR4-BR2.5-BB
Metal concentration versus time
1E3
1E2
1E1
1E0
1E-1
Concentration, mg/L
07/14/92
08/14/92
04/27/94
06/18/94
07/13/94
08/29/94
06/17/94
Date
Al
Cu
Fe
Mn
S
Zn

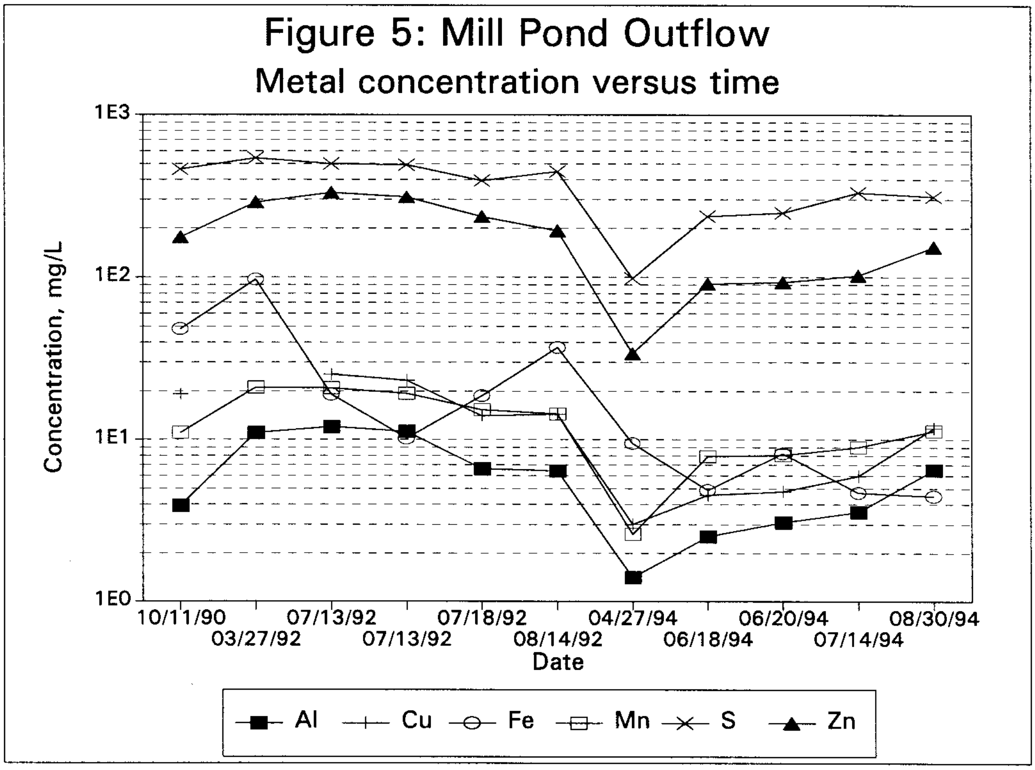


Figure 5: Mill Pond Outflow
Metal concentration versus time
1E3
1E2
1E1
1E0
Concentration, mg/L
10/11/90
03/27/92
07/13/92
07/13/92
07/18/92
08/14/92
04/27/94
06/18/94
06/20/94
07/14/94
08/30/94
Date
Al
Cu
Fe
Mn
S
Zn

Figure 6: Boomerang Lake B1

Metal concentration versus time

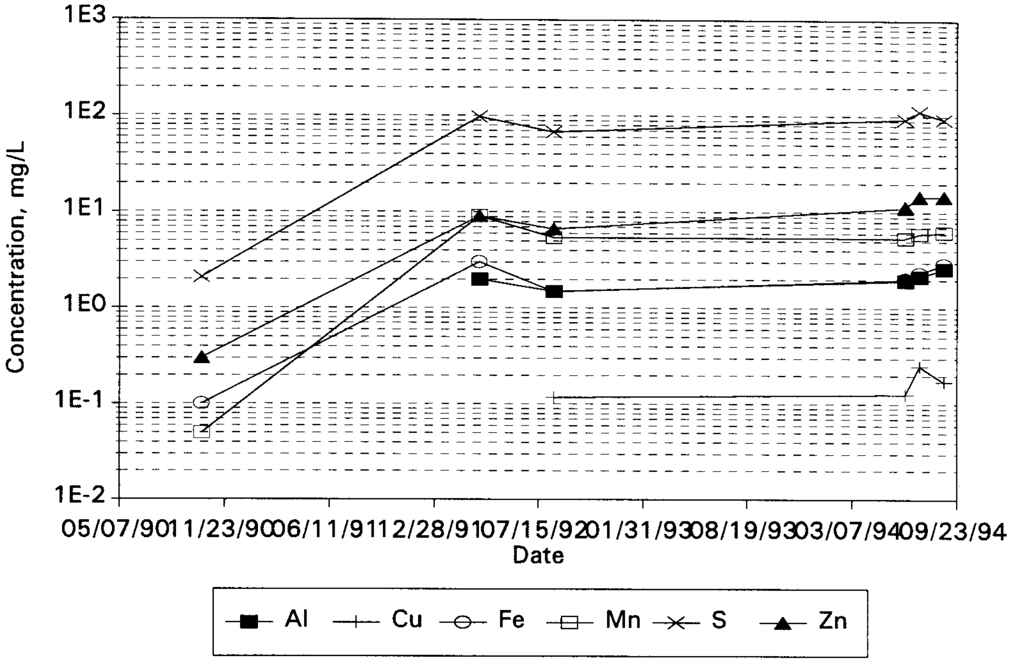
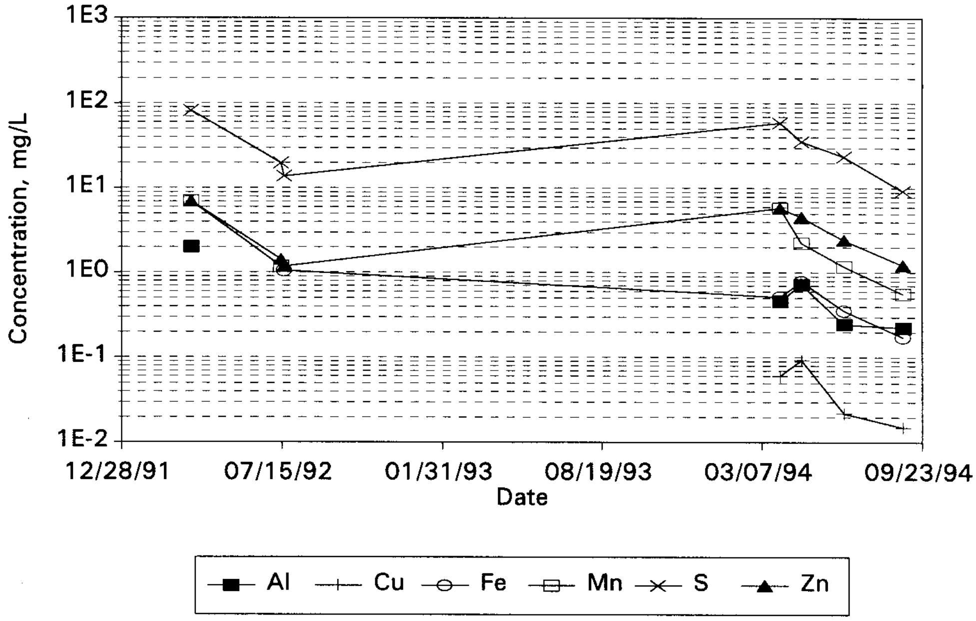


Figure 7: Confederation Lake, C1

Metal concentration versus time



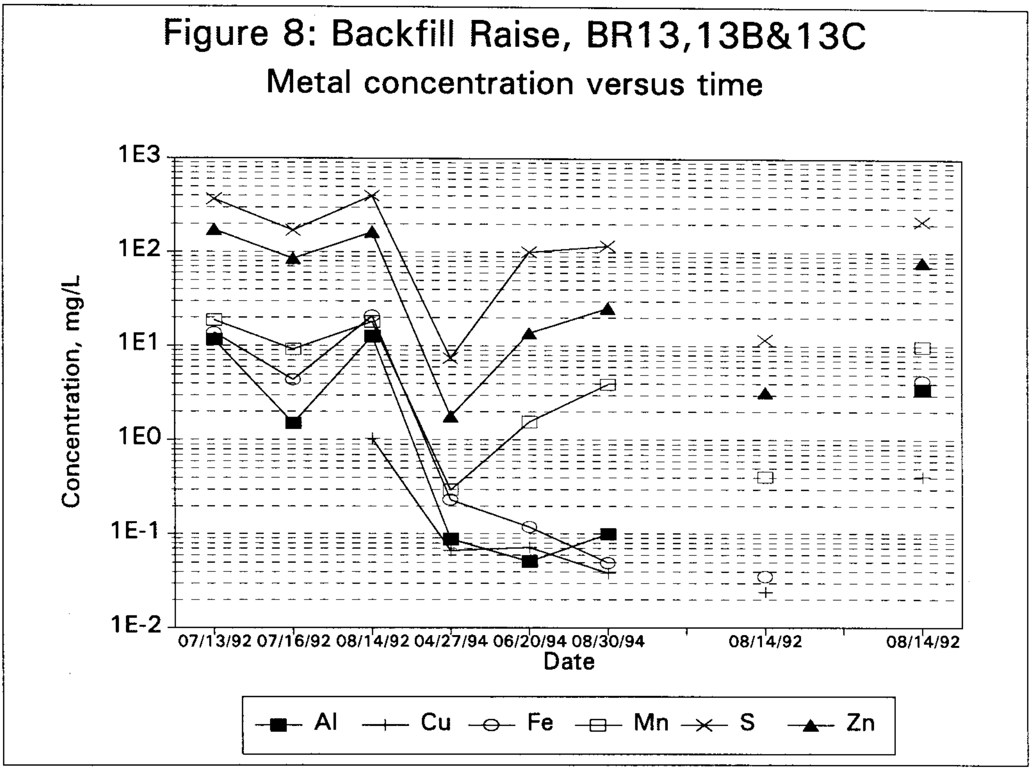


Figure 8: Backfill Raise, BR13,13B&13C
Metal concentration versus time
1E3
1E2
1E1
1E0
1E-1
1E-2
Concentration, mg/L
07/13/92
07/16/92
08/14/92
04/27/94
06/20/94
08/30/94
08/14/92
08/14/92
Date
Al
Cu
Fe
Mn
S
Zn

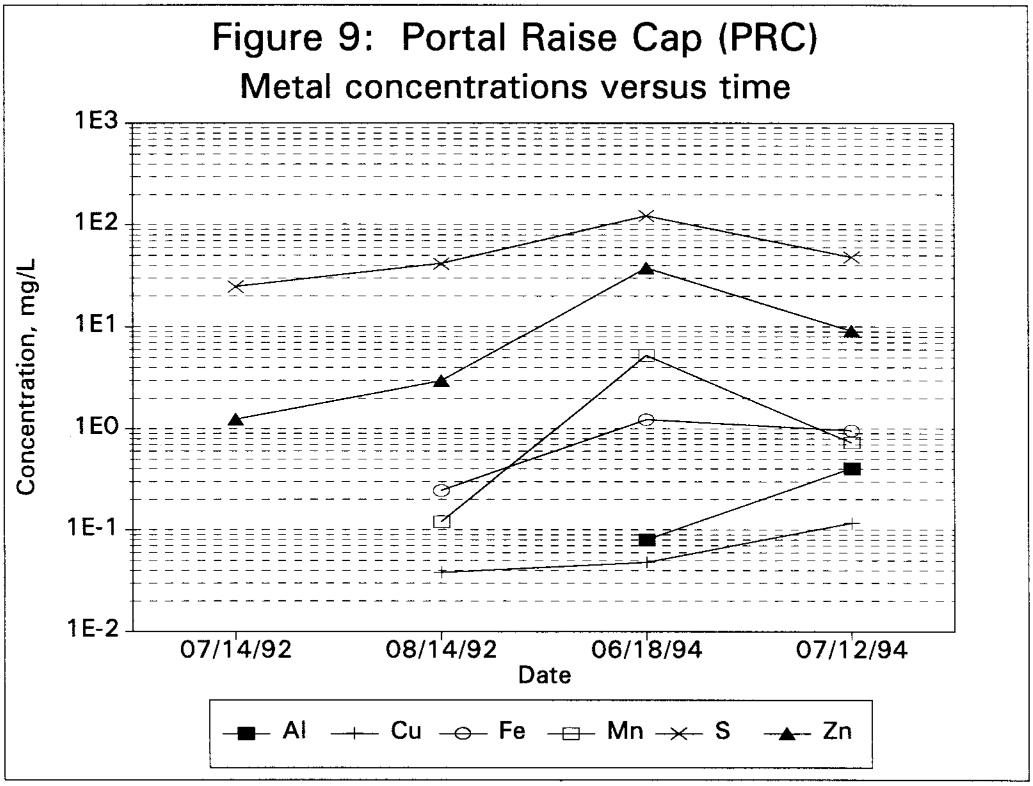


Figure 9: Portal Raise Cap (PRC)
Metal concentrations versus time
1E3
1E2
1E1
1E0
1E-1
1E-2
Concentration, mg/L
07/14/92
08/14/92
06/18/94
07/12/94
Date
Al
Cu
Fe
Mn
S
Zn

Figure 10: Portal Raise Seep (PRS)

Metal concentration versus time

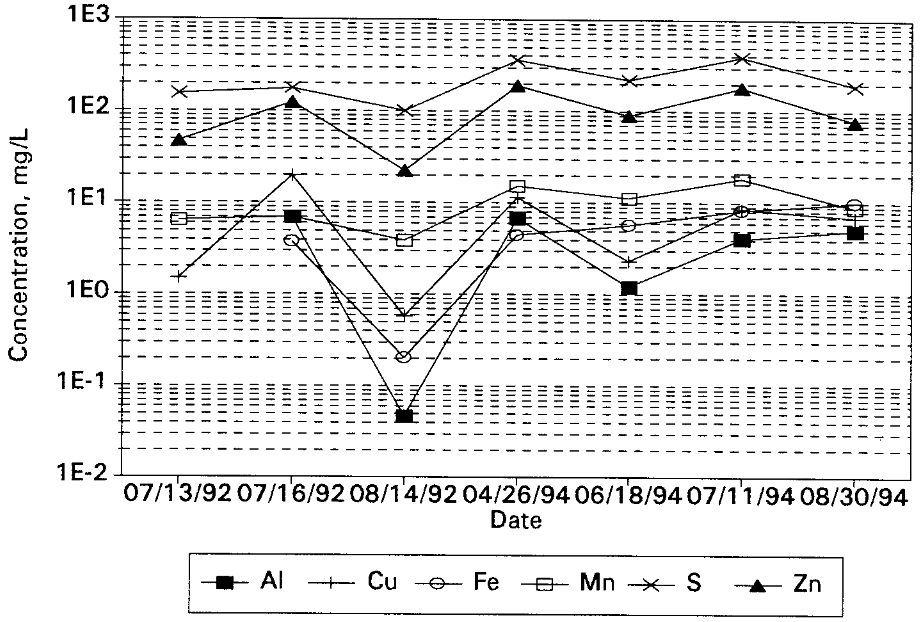


Figure 11:Confederation L. Shore,CS13

Metal concentration versus time

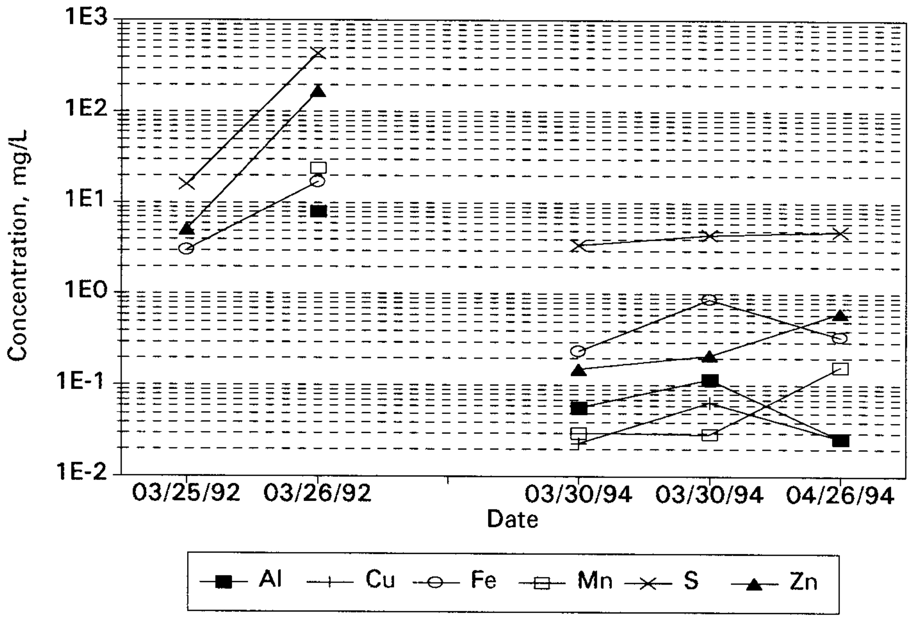


Figure 12: Decant Pond Outflow (DPO)

Metal concentration versus time

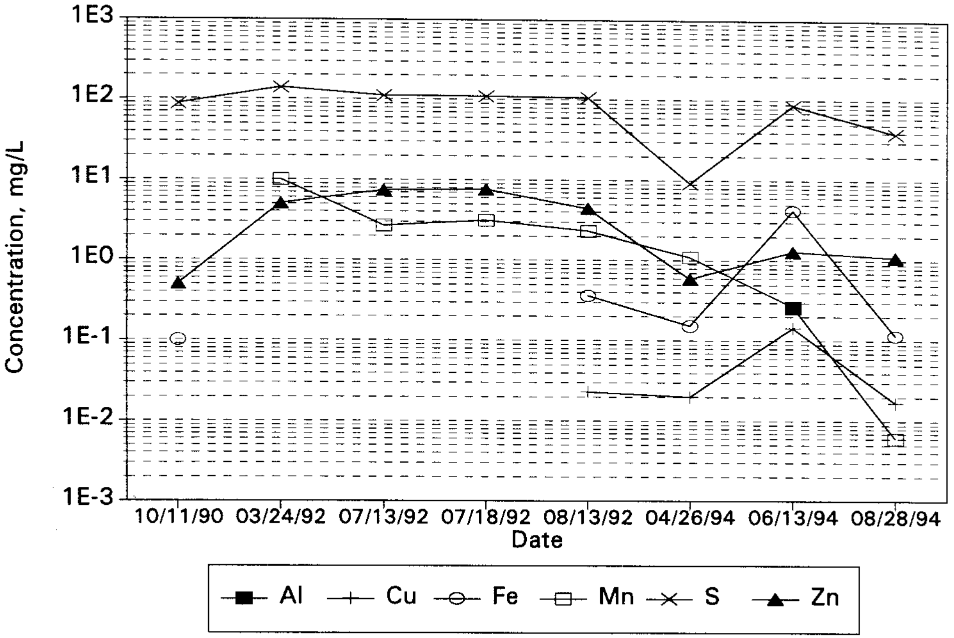
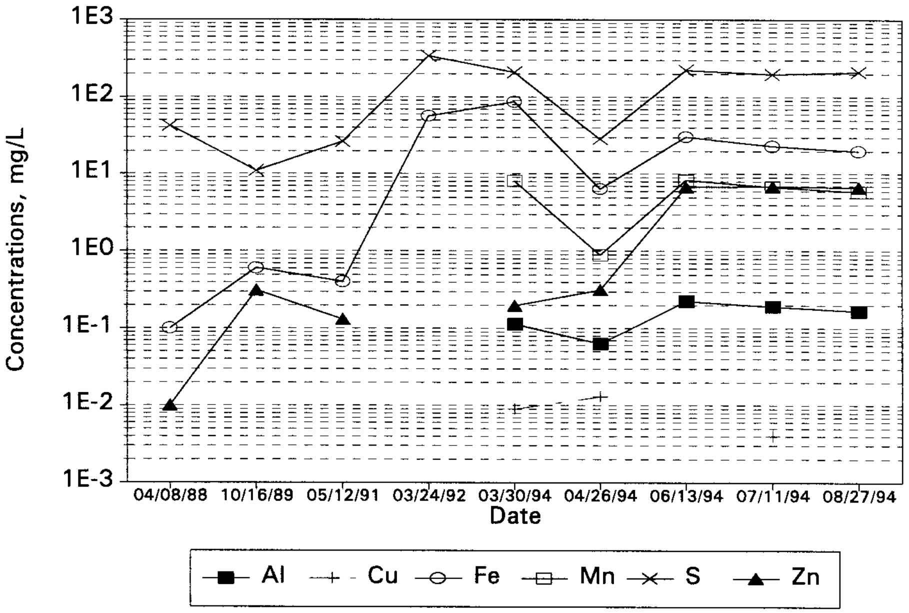


Figure 13: Mud Lake Outflow, ML18

Metal concentration versus time



5.0 MUD LAKE: EXISTING CONDITIONS AND THE APPLICATION OF ARUM

5.1 Mud Lake Water Quality

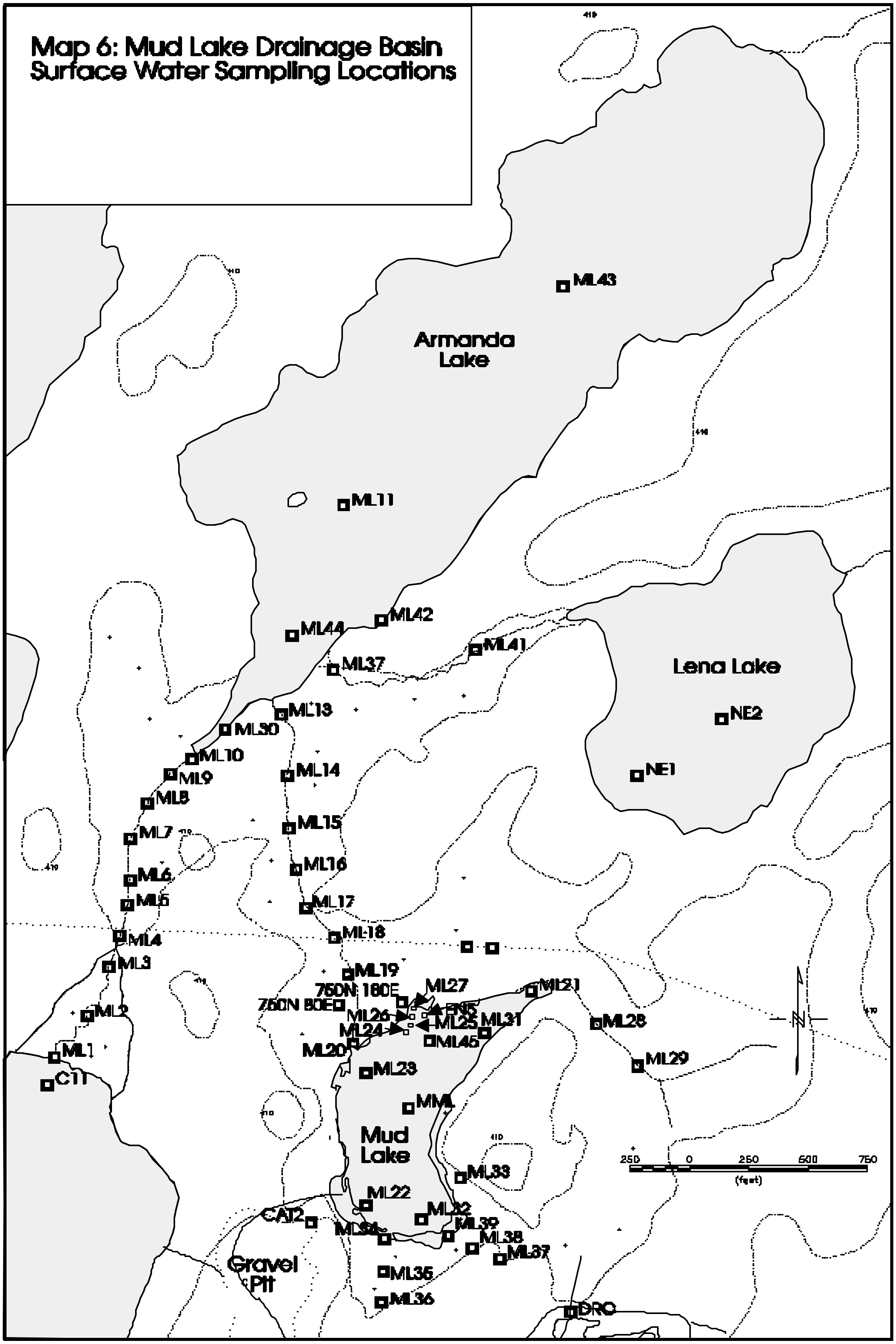
Mud Lake water quality has been measured intermittently between 1986 and 1993, and intensively since March, 1994, when it was determined that entry of acid mine drainage into Mud Lake had commenced.

Surface water sampling locations in the vicinity of Mud Lake are shown in Map 6. Water quality has been determined for major surface water inflows to Mud Lake (DRO, ML28, ML29), ground water inflow (ML27), Mud Lake proper (MML, ML21, ML22, ML23, ML24, ML25, ML31, ML32, ML45), locations with an newly constructed enclosure (ML26, ML27, EN5) and the Mud Lake outflow path (ML20 - ML13). Muskeg pore water quality in the Mud Lake vicinity has been sampled at CAT2, ML33, ML34, Ml35, ML36, ML37, ML38, ML39, 750N 180E and 750N 80E.

Water quality has also been determined for Lena Lake (NE1, NE2) whose outflow (ML41, ML37) reports to Armanda Lake (ML11, ML43, ML44), which also receives Mud Lake discharge. The combined flows of these three lakes is likely mixed at ML30 prior to discharging to Confederation Lake via a stream (ML1 - ML10). Water quality of the mixing zone of the three lakes' discharge with Confederation Lake is sampled at C11, located approximately 15 m from the ML1 discharge (Map 6).

All available water quality data for Mud Lake south end (ML22), middle (MML), and outflow (ML18) are presented in Table 2. Water quality in the mixing zone of fresh surface water run-off and Mud Lake presented for ML21.

There is some evidence of Mud Lake contamination at the outflow (ML18) by acid mine drainage from the South Bay tailings as early as March 24, 1992 (Table 2). The sulphate concentration was 336 mg/L, while in the previous three samples, sulphate



Map 6: Mud Lake Drainage Basin Surface Water Sampling Locations

Table 2: Mud Lake-Water Chemistry, 1986-1995.

Location	Sample Date	Zn mg/L	pH	Acidity mg/L	SO_4 mg/L	Fe mg/L	Cond. uS/cm	Em mV
ML18	08-Apr-88	0.01	5.7	nd	42	0.08	350	
	16-Oct-89	0.31	7.2	11	11	0.6	41	
	12-May-91	0.13	6.2	40	26	0.4	197	
	24-Mar-92	<1	6.6	180	336	56	432	
	30-Mar-94	0.20	5.5	353	621	86	1050	65
	26-Apr-94	0.31	4.8	48	85	6.4	246	169
	13-Jun-94	6.8	2.8	218	666	30	1436	693
	11-Jul-94	6.8	2.9	188	585	23	1085	455
	27-Aug-94	6.7	2.8	148	627	20	780	457
	04-Dec-94	8.6	2.9	230	462	58	108	371
	05-May-95	8.3	3.2	342	462	152	967	511
	27-Jul-95	6.5	3.1	185	696	27	1071	440
	14-Aug-95		3.7					
ML21	05-Apr-86	0.06	6.1	nd	42	0.5	130	
	17-Jun-86	0.05	6.3	nd	36	0.2	150	
	25-Jul-86	<0.005	6.6	nd	180	0.3	480	
	08-Apr-88	0.01	nd	nd	144	0.2	nd	
	10-Jul-94	0.16	5.8	28	15	1.2	64	152
	27-Aug-94		6.1	14			175	109
	05-May-95	0.07	5.3	3.4	26	0.29	135	282
MML	17-Jun-86	0.02	7.6	nd	160	0.1	430	
	25-Jul-86	0.03	6.2	nd	183	0.4	475	
bottom	30-Mar-94	11.8	5.3	600	1143	218	2200	333
	30-Mar-94	9.8	3.2	304	834	79	1423	393
bottom	27-Apr-94	8.0	5.1	379	954	168	1430	121
	27-Apr-94	1.7	4.2	79	188	19	406	272
	15-Jun-94	8.1	2.8	290	681	55	1450	660
bottom	15-Jun-94	8.1	2.8	280	690	55	1455	662
	28-Aug-94	7.9	2.7	171	494	27	700	384
bottom	28-Aug-94		5.6	281			1790	377
	26-Feb-95	7.7	5.6	269	519	83	1043	42
	05-May-95	4.9	4.7	185	366	77	769	330
	27-Jul-95	7.8	3.0	207		53	925	431
ML22	05-Apr-86	0.22	6.1	nd	28	0.6	130	
	17-Jun-86	0.04	7.3	nd	154	0.1	435	
	25-Jul-86	0.12	6.2	nd	132	0.6	480	
	19-Jul-87	<0.005	6.2	nd	51	6.9	200	
	14-Aug-87	<0.005	6.2	nd	27	1.0	240	
	16-Apr-91	0.67	6.3	nd	109	0.1	418	
bottom	27-Apr-94	7.0	3.8	500	1164	269	1670	264
	15-Jun-94	7.5	2.8	263	660	48	1440	668
	28-Aug-94		2.6	164			700	408
bottom	28-Aug-94		4.0	161			640	408
(A-6 loc)	26-Feb-95	0.34	5.7	127	51.9	35	375	168
(B-6 loc)	26-Feb-95	1.3	5.7	240	363	72	722	118
	28-Sep-95	11	2.7	216	513	31	1530	540

concentrations did not exceed 42 mg/L.

Relatively high zinc concentrations in Mud Lake outflow (ML18) were first measured on June 13, 1995, when 6.8 mg/L Zn was detected in the outflow. Since this date, the pH of outflow water has remained less than 3.7, and is typically around pH 3.0. Because of the relatively low pH, dissolved iron remains is solution, ranging from 20 to 152 mg/L, and because of dissolved iron and zinc concentrations, the acidity has ranged from 148 to 342 mg/L.

Although Mud Lake is relatively shallow (< 2 m), water quality differences between surface and bottom water have been regularly detected, particularly during winter sampling (Table 2). Bottom water pH, conductivity and particularly iron concentrations are usually much higher at the sediment-water interface than surface water. Since Mud Lake sediments are comprised of highly organic materials, microbially-mediated ferric iron reduction in near-surface sediments appears to be an very active process year-round. Recycling of iron as dissolved ferrous iron-ferric iron - ferric hydroxide, then iron reduction again, is likely rapidly occurring throughout Mud Lake.

Zinc concentrations in bottom water are only slightly elevated, compared to surface water zinc concentrations. This may indicates that recycling of iron, but not zinc, between sediment and the water column is occurring. In fact, ferrous iron oxidation and ferric hydroxide precipitation is likely already contributing to zinc removal from Mud Lake surface water prior to its discharge.

Surface water quality at ML22, located at the south end of Mud Lake, is similar to MML water quality. This is expected, since surface water freely mixes throughout most of Mud Lake in the ice-free season. One notable exception is the north-east section of Mud Lake (ML21), where fresh water run-off mixes with Mud Lake water. Water quality is this small bay is typically good, with high pH, low acidity and relatively low zinc and iron concentrations.

The long term pH and zinc concentration data for station MML are shown in Figure 14a. It is evident that regular sampling should have been performed between 1986 and 1994.

Fortunately, the outflow of Mud Lake (ML18) was more regularly sampled (Figure 14b), and the rapid deterioration of Mud Lake water quality in the spring of 1994 is clearly evident. From estimates of hydraulic conductivity in the region of "Kalin Canyon" it can be projected, that the time the seepage would take to travel the distance between the northwestern edge of the tailings pond and the northern end of Mud lake is about 5 to 6 years. Thus the sudden appearance of contamination in Mud lake, supports a very well defined ground water seepage path. It will be interesting to determine a contaminate mass balance for the drainage basin integrating, both ground water and surface water loadings when a complete data set is generated in 1996.

Figure 14a: Mud Lake Middle
MML Long-Term [Zn]. pH

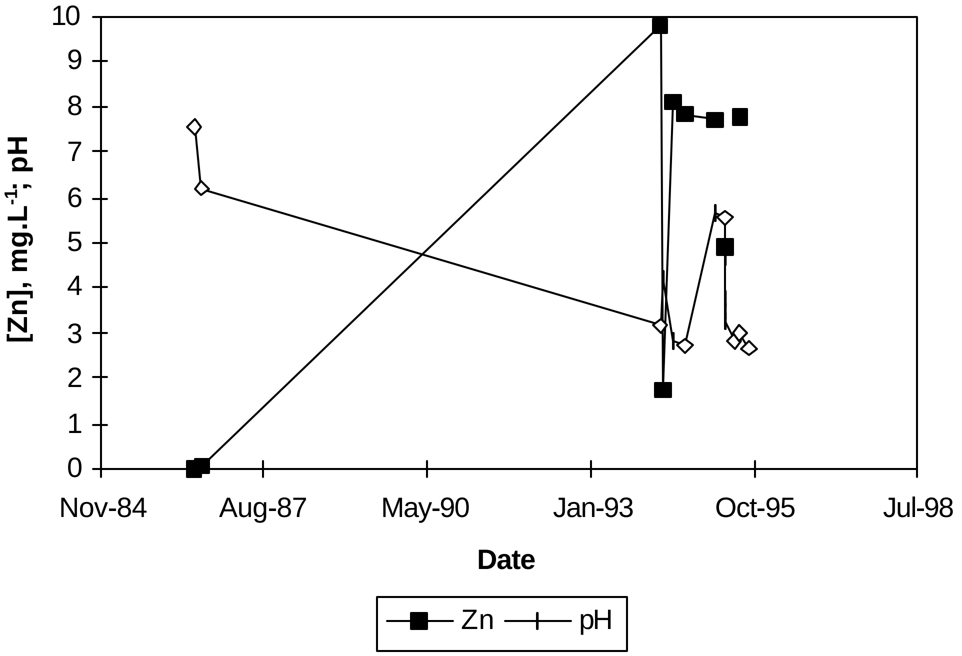
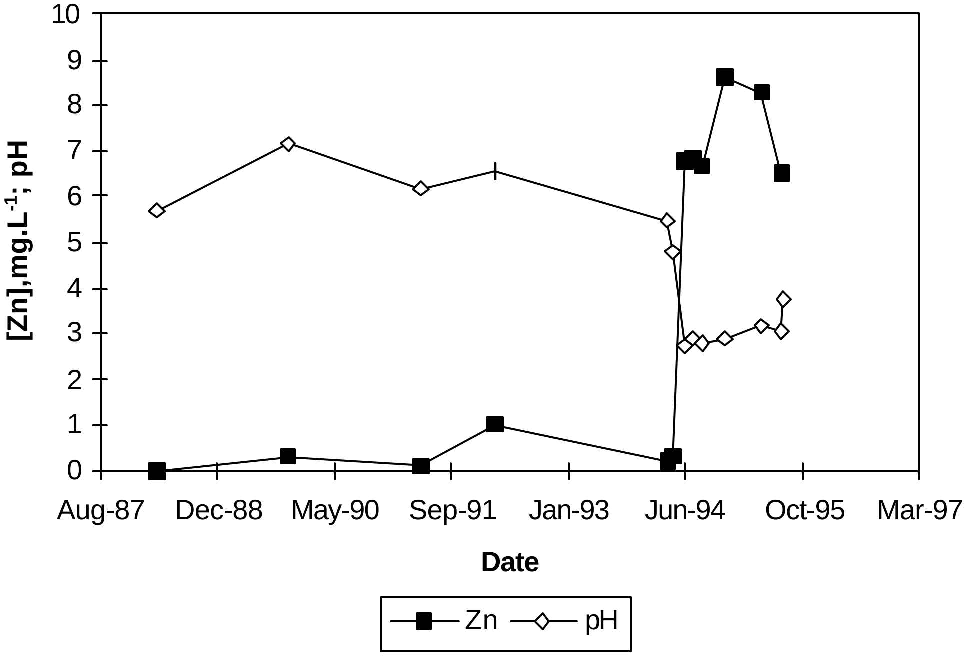


Figure 14b: Mud Lake Outflow
ML18 Long-Term [Zn], pH



5.2 Receiving Water (C11) Water Quality

The combined flows of Mud Lake, Lena Lake and Armanda Lake report to Confederation lake and are sampled in the mixing zone, about 5 to 10 metres away from a diffuse stream bed defined by a beaver dam at station C11 (Table 3). Zinc concentrations were typically less than 0.1 mg/L between 1996 and September 1991. Essentially since 1994 higher zinc concentrations are reported, particularly during run-off season in April 1994 and May 1995 and then reported in October 1995, where concentrations of zinc were as high as 2 mg/L. In October 1995 the pH measured was also low with a value 3.6 and the acidity elevated 206 mg/L in comparison to no detectable acidity . Values of 1 to 10 reported in Table 3 compare to alkalinity very well. Alkalinity and acidity values are generally very low in the October, 1995 sample. However, a sample collected 15 m further out in Confederation Lake (@ sedges) contained only 0.054 mg/L and the pH was 5.6, indicating that the discharge dissipates very fast.

Table 3: Confederation Lake at C11-Water Chemistry, 1986-1995

Sample Date	Zn mg/L	pH	Acidity mg/L	Alkalinity mg/L	SO4 mg/L	Fe mg/L	Cond. :S/cm	Em mV
18-Jun-86	0.04	7.0	N.D.		N.D.	0.07	70	N.D.
26-Jul-86	0.03	7.2	N.D.		N.D.	0.09	51	N.D.
17-Aug-86	0.02	7.7	N.D.		N.D.	0.02	60	N.D.
15-Oct-86	0.33	6.6	N.D.		N.D.	0.89	50	N.D.
16-Jul-87	1.00	6.9	N.D.		174	99	100	N.D.
13-Aug-87	<0.005	7.2	N.D.		<0.01	<0.01	70	N.D.
05-Oct-87	0.04	6.6	N.D.		24	<0.01	38	N.D.
24-May-88	0.04	7.2	N.D.		39	<0.01	120	N.D.
19-Jun-88	<0.01	6.9	N.D.		24	<0.1	N.D.	N.D.
23-Aug-88	0.01	6.0	N.D.		36	0.1	N.D.	N.D.
14-May-89	0.03	6.3	N.D.		36	0.1	142	N.D.
25-Aug-89	0.30	6.6	N.D.		33	0.7	60	N.D.
23-Jun-90	<0.01	6.3	N.D.		42	0.1	N.D.	N.D.
11-Oct-90	0.05	5.8	N.D.		3.3	0.1	150	3
28-Sep-91	0.04	6.6	10		15	<1	N.D.	N.D.
24-Mar-92	<1	5.8	10		39	<1	92	321
14-Jul-92	0.70	8.0	5.5		78	<1	140	360
17-Oct-92	0.31	6.2	4.7		N.D.	0.33	218	218
10-Apr-93	0.17	6.3	7.9	17	N.D.	0.53	190	156
11-Sep-93	0.43	6.9	1.2	21	16	0.046	78	29
10-Oct-93	0.27	6.4	6	12	80	0.35	244	100
30-Mar-94	0.11	6.1	17	30	24	0.10	119	169
26-Apr-94	0.15	6.9	6.6	8	38	0.42	128	53
18-Jun-94	0.10	7.2	2.2	11	86	0.16	216	394
14-Jul-94	1.1	5.7	14		35	0.26	222	103
30-Aug-94	0.06	6.0	4.1	22	8.04	0.033	55	134
20-Mar-95	0.48	6.1	5.1	8	86	0.67	226	139
11-May-95	0.72	6.7	5.7	4	95	0.69	170	584
11-May-95	0.64	6.7	0	8	76	0.84	140	536
21-Oct-95	2.02	3.6	206		48	1.8	401	206
21-Oct-95 *	0.054	5.6	78		3.8	0.019	69	78

5.3 Mud Lake mass balances

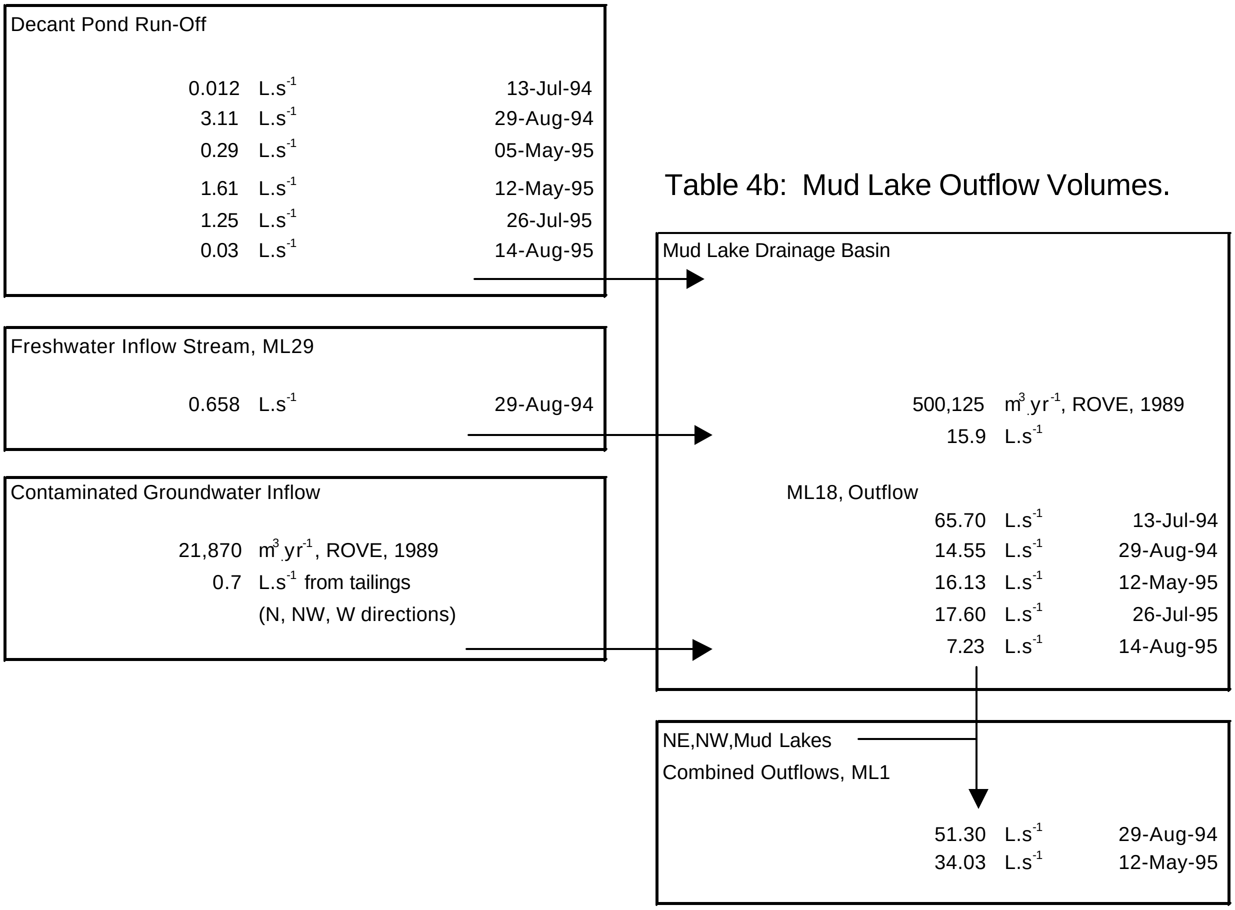
Measurements of flows at key locations in the Mud Lake drainage basin and downstream had been carried out in 1994 August and chloride analysis where performed to arrive at a mass balance of elements in the drainage basin. The frequency of the measurements is not very high, however, they are useful for comparison to estimates of drainage basin base flow made based on drainage basin area and net precipitation data for the region.

The Mud Lake drainage basin area is estimated to generate a base flow of 15.9 L/s (Table 4a and 4b). Measured flow volumes at Mud Lake outflow (ML18) are in good agreement for the month July and May 1995 and the May measurement in August 1994, but the measurements in July 1994 with 66 L/s, and the measurement in August 1995 with 7.23 L/s are either half or four times the estimated base flow. In order to resolve these differences it is necessary to obtain the area for the total drainage basin of which Mud Lake is only a subbasin, and includes Armanda Lake and Lena Lake.

Extensive sampling of water and measurements of flows were performed on August 29, 1994 in the immediate area of Mud Lake. This data were reported in the Mud Lake report in November 1994 and are used to compare the data which have been collected in 1995 at the same locations with the May 12, 1995. The results are presented for sources of water to Mud Lake, including Decant Pond Outflow (DRO), fresh water inflow (ML29), and two examples of contaminated ground water emergence into Mud Lake at its north end (ML26 bottom, ML27 bottom). The final water quality of Mud Lake, following mixing of fresh and contaminated water, is presented for ML18 Mud Lake Outflow, the location where good flow measurements can be carried out as the channel is well defined (Table 5). Generally the concentrations of Ca, K, S are higher in the fresh water in August 1994 than in May 1995. Unfortunately the Na concentrations are higher in May and the pH is lower than in 1994 fall.

Table 4a: Water Balance for Mud Lake Drainage Basin, 1994 - 1995.

Table 4b: Mud Lake Outflow Volumes.



Decant Pond Run-Off

0.012 L.s^{-1}	13-Jul-94
3.11 L.s^{-1}	29-Aug-94
0.29 L.s^{-1}	05-May-95
1.61 L.s^{-1}	12-May-95
1.25 L.s^{-1}	26-Jul-95
0.03 L.s^{-1}	14-Aug-95

Freshwater Inflow Stream, ML29

0.658 L.s^{-1}	29-Aug-94

Contaminated Groundwater Inflow

21,870 m^3.yr^{-1}, ROVE, 1989
0.7 L.s^{-1} from tailings
(N, NW, W directions)

Mud Lake Drainage Basin

500,125 m^3.yr^{-1}, ROVE, 1989
15.9 L.s^{-1}

ML18, Outflow

65.70 L.s^{-1}	13-Jul-94
14.55 L.s^{-1}	29-Aug-94
16.13 L.s^{-1}	12-May-95
17.60 L.s^{-1}	26-Jul-95
7.23 L.s^{-1}	14-Aug-95

NE,NW,Mud Lakes
Combined Outflows, ML1

51.30 L.s^{-1}	29-Aug-94
34.03 L.s^{-1}	12-May-95

Table 5: Mud Lake Area Water Chemistry and Flows.

	Decant Pond Outflow DRO	Decant Pond Outflow DRO	Fresh Inflow Stream ML29	Fresh Inflow Area ML21	Ground Water Inflow ML26 Bot	Ground Water Inflow ML26 Bot	Ground Water Inflow ML27Bot	Mud Lake Outflow ML18	Mud Lake Outflow ML18
	29-Aug-94	12-May-95	29-Aug-94	12-May-95	29-Aug-94	12-May-95	29-Aug-94	29-Aug-94	12-May-95
Flow, L/s	3.11	1.61	0.66	N.A.	N.A.	N.A.	N.A.	15	16
pH	5.7	5.8	6.1	5.3	5.3	5.4	5.7	2.8	3.2
Cond, uS/cm	450	517	175	135	3520	1464	4120	780	967
TDS,mg/L	252	N.A.	156	N.A.	10200	N.A.	12900	774	N.A.
Na,mg/L	1.2	2.8	0.40	2.2	15	14	15	2.5	4.7
Cl,mg/L	0.25	N.A.	1.6	N.A.	20	N.A.	23	2.2	N.A.
S,mg/L	39	62	29	8.6	2553	1500	3400	209	232
Zn,mg/L	1.1	2.0	0.05	0.07	184	113	184	6.7	8.30
Al,mg/L	0.03	0.01	0.03	0.01	0.19	0.01	0.03	0.17	0.01
Fe,mg/L	0.12	0.01	0.21	0.29	1610	1730	1790	20	152
K,mg/L	5.6	1.80	4.4	1.40	20	17	23	2.3	3.6
Ca,mg/L	87	65	38	13	502	364	508	91	107

N.A. Not assayed/measured.

As the water quality and flow data collected in August 1994 were used to derive an estimate of the seepage flow of the ground water seepage discharge, the variation in these concentrations would of course be reflected in changes in the estimates of the ground water discharge. Based on the 1994 water chemistry, the ground water contribution was estimated to be 0.6 L/s but using the May 1995 data, based on the concentrations of Na, the contribution of contaminated ground water could be as high as 3.4 L/s (Table 6).

Table 6: Mud Lake Area Contaminant Loadings, May 12, 1995, adjusted to balanced sodium mass.

Percent fresh water set at 76.4% of Mud Lake outflow minus DRO flow, = 14.52 l/s
Therefore, groundwater inflow is 23.6% of Mud Lake outflow minus DRO flow

	DRO Loadings mg/s	Freshwater Loading ML29 mg/s @ 11.09 l/s	Groundwater Loading ML27 Bottom mg/s @ 3.43 l/s	DRO+FW +GW Loading,mg/s	M.L. Outflow,ML18 Loading mg/s	% Diff. (`-'=loss)
Na	4	25	47	76	76	0%
S	100	95	5144	5340	3742	-30%
Zn	3	0.8	388	392	134	-66%
Al	0.02	0.11	0.03	0.16	0.16	0%
Fe	0.02	3.2	5933	5936	2452	-59%
K	2.9	16	57	75	58	-23%
Ca	105	149	1248	1502	1726	15%

For the May, 1995 data, a higher ground water flow (23.6 %) and a lower fresh surface water flow (76.4 %) required to balance the Mud Lake mass balance using the sodium concentration instead of the chloride, which is considered more conservative, as it would not likely precipitate from the water, the shortcomings of this approach based on limited sampling is evident. Considering the effects of this change in flow distribution on the other elements, it would have to be concluded, that iron, zinc and potassium are removal, and calcium is gained. Furthermore in sharp contrast to the chloride in August 1994 the May distribution would indicate that sulphur is removed in the Mud Lake system, and aluminum is not mobilized from the sediment in Mud lake.

Similar to the conclusions reached based on the evaluation of the new flow data obtained during 1995 the mass balances have to be evaluated in the context of the seasonal variations and the entire drainage basin.

5.4 Sedimentation in Mud Lake and Sediment Composition

From the mass balances and the visual observations it is undebatable that iron is precipitating in Mud lake. The ARUM process, Acid Reduction Using Microbiology, is a natural process, which can support iron precipitation, but for the implementation it is necessary to determine the rates at which iron is precipitating, in order to design the section of the treatment system in which this precipitation is to take place. After precipitation of iron, the microbial acid reduction will increase the pH and metals are relegated to the sediment. From sedimentation traps the quantity of iron particles, which are settling out of the water column can be quantified.

5.4.1 Sedimentation Rates

Removal of iron from Mud Lake is suggested both from visual observations of massive iron hydroxide precipitation in Mud Lake and confirmed by the mass balance evaluations.

Elevated pH (~ pH 5) in Mud Lake surface water beneath the ice in April 1994 and March, 1995 suggests that iron reduction with subsequent pH increases occurs in the water column during winter. Following the melt of the ice cover in early May, 1995, the pH of Mud Lake surface water rapidly decreased, suggesting that ferrous iron accumulated in the water column over winter oxidized to ferric iron, which in turn hydrolysed and generated hydrogen ions.

Seasonal variation in iron hydroxide sedimentation rates are anticipated, based on the seasonally variable chemistry of Mud Lake. Sedimentation traps were installed in Mud Lake in June, 1994, and periodically sampled since. Sedimentation rates have ranged from 14 to 75 g/m^{2}/d in the period between June, 1994 and October, 1995. The average sedimentation rate over the entire surface area of Mud Lake is equivalent to 634 t of new sediment per year (Table 7).

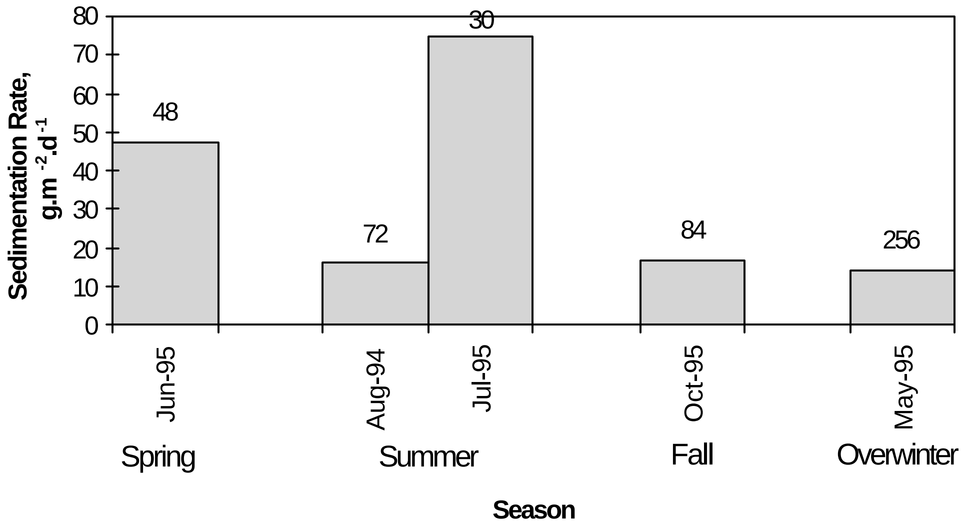
Table 7: Mud Lake Sediment Trap Data for 1994 and 1995.

Period		Days in period	Cum. Days in Period	Avg. t Sed. in Lake During Period	Cum. t Sed. in Lake During Period		Avg. g.m^{-2}.d^{-1} Sed. in Lake During Period	
From	To							
17-Jun-94	28-Aug-94	72	72	93	93		16.1	
28-Aug-94	11-May-95	256	328	286	379		14.0	
11-May-95	28-Jun-95	48	376	183	561		47.6	
28-Jun-95	28-Jul-95	30	406	179	741		74.6	
28-Jul-95	20-Oct-95	84	490	110	851		16.4	
			Average Sedimentation		634	t.lake^{-1}.yr^{-1}	33.7	g.m^{-2}.d^{-1}

The iron load removed in the Mud Lake system was estimated at 801 mg/s, from the chloride-based mass balance estimates. This is equivalent to only 25 t of iron each year. The sedimentation data indicate, compared to estimates of the iron load that iron is recycled in Mud Lake, possibly as many as 12 times each year, assuming that about 50 % of the sedimenting particles are iron. It is this process which should be utilized to remove zinc, either through the microbially-driven iron cycling, which could be supplemented by organic carbon stored in surface sediments or through a better understanding the zinc iron particulate interaction as part of the zinc removal process.

The seasonal sedimentation rates are shown in Figure 15. As expected, sedimentation rates are highest in spring in summer, while in fall and winter, sedimentation rates are low. High spring sedimentation rates may be due to oxidation of accumulated ferrous iron concentrations, while high rates in summer may be due to both higher microbially-mediated iron reduction rates and possibly remobilization of settled sediments by wind-driven circulation in the lake.

Figure 15: Mud Lake Seasonal Sedimentation Rates
Value above bars denotes no. of days in situ.



5.4.2 Settling Particles and Sediment Composition

The solids recovered from the Mud Lake sedimentation trap on five occasions were assayed for metals and cations (Table 8). The iron content in these solids range from 41 % to 60 %. Zinc concentrations in these samples are relatively low, ranging from 0.01 % to only 0.1 %. However, the 634 t of particles settling each year contain 63 to 630 kg of zinc. The zinc removal estimate, according to the chloride-based load calculations, is very similar, suggesting that 599 kg of zinc remain in Mud Lake.

Table 8: Mud Lake 1994, 1995 Sed Trap Solids; 1995 Sediments Elemental Composition.

	Sedimentation Traps					Sediment	
Date	10-Jul-94	28-Aug-94	07-May-95	28-Jul-95	20-Oct-95	20-Oct-95	20-Oct-95
Assay No.	5708	5709	5710	5711	5712	5713	5714
Location	South Bay Mud Lake Sed Trap	South Bay Mud Lake Sed Trap	South Bay Mud Lake Sed Trap	South Bay Mud Lake Sed Trap	South Bay Mud Lake Sed Trap	South Bay Mud Lake Inside Enclosure	South Bay Mud Lake Outside Enclosure
Al	39	22	47	< 1.0	15.6	4030	4570
Co	21	16	< 1.5	42	37	10.8	28
Cr	< 0.30	< 0.30	< 1.5	< 0.30	< 0.30	26	81
Cu	11	2.7	134	0.20	0.70	16.2	20
Fe	410000	422000	457000	59900	55300	133000	109000
Mn	337	< 0.30	155	< 0.30	27	475	615
Pb	< 1.0	2.2	< 5.0	< 1.0	< 1.0	14.5	16.8
S	43400	37800	226	49900	44600	26000	26300
SO_4	130200	113400	678	149700	133800	78000	78900
Zn	535	120	963	195	752	3350	12100

The May 7, 1995 sedimentation trap solids sample was collected after the traps overwintered in Mud Lake. These solids' composition varies from the remainder of trap solids which collected in the traps over the ice-free season (Table 8). The May, 1995 sample contains only 0.07 % sulphate, compared to 11 to 15 % in the other four samples. However, this sample contained higher concentrations of zinc, copper, manganese and aluminum than most or all of the other samples. Freeze-out of these elements from the ice cover and precipitation due to this increased concentration may be an other possible mechanism which should be investigated, since the amount of zinc which had accumulated in the particles is higher. The lower sulphate concentration in the May, 1995 sample is possibly a reflection of the changes in ground water composition, where a reduction of sulphur in the discharge from the ground water can be noted (Table 5) between August 1994 and May 1995.

The composition of lake sediment is notable different that the composition of new sediment particles forming in the water column, according to the composition of materials collected in the sedimentation traps (Table 8). Lake sediment collected from inside and outside of the Mud Lake ARUM enclosure contains much higher aluminum and zinc concentrations, and somewhat higher manganese, lead and chromium concentrations than sedimentation trap solids. However, lake sediments contain less iron and sulphate, compared to sedimentation trap solids (in most cases).

The higher pH and lower redox of lake sediment, compared to the water column, likely favours the formation of metal hydroxides and the adsorption of metals onto sediment organics. Therefore, the sediment pore water concentrations may have low concentrations of dissolved forms or these metals, and serve as a metal sink, such that there is a net flux of dissolved metals from the water column to the sediment.

It is suggested that a undetermined fraction of the iron which settles to the lake sediment each year is reduced and remobilized as dissolved ferrous iron. This dissolved iron may not only diffuse back into the water column, but could also diffuse downwards to greater depths in the sediment. Elevated concentrations in bulk surface sediment samples would therefore not necessarily reflect increases in sediment iron concentrations.

Long-term changes in Mud Lake sediment composition might provide some indication of the long term accumulation of elements in these sediments. Sediments collected in 1986, 1994 and 1995 were analyzed and comparisons is possible (Table 9). Aluminum, and organic content (according to % loss on ignition) have diminished over the ten years. Leaching of aluminum from clay particles in sediments by the recent decrease in pH is likely.

Table 9: Comparison of 1986, 1994 and 1995 Mud Lake Sediment Composition.

Date Sampled				20-Oct-95		20-Oct-95
Assayer No.	1986	1994		5713		5714
Station	Avg, n=6	Avg, n=5		ML26, n=1		ML24, n=1
Al	1.6	0.54		0.40		0.46
Ba	0.027	0.008		0.0068		0.0086
Cd	<0.001	<0.00005		0.00026		0.00032
Co	<0.001	0.0015		0.0011		0.0028
Cr	0.0037	0.011		0.0026		0.0081
Cu	0.0027	0.0017		0.0016		0.0020
Fe	1.2	7.1		13		11
Mn	0.048	0.068		0.048		0.062
Mo	<0.001	<0.00005		0.00043		0.00061
Ni	<0.001	0.0012		0.00060		0.00088
Pb	0.005	0.00085		0.0015		0.0017
S	1.4	3.2		2.6		2.6
Sn	<0.001	0.00026	<	0.00025	<	<0.00025
V	<0.002	0.0017		0.00086		0.0009
Zn	0.027	0.37		0.34		1.2
L.O.I.	0.0058	0.0047		N.A.		0.0044

N.A. Not Analysed

As expected, iron concentrations in sediments have increased, from about 1.2 % in 1986 to 7 % in 1994, to 11 to 13 % in 1995. Sulphur concentrations have also increased, from about 1.4 % in 1986, to 2.6 to 3.2 % in the last two years.

Sediment zinc concentrations have increased by an order of magnitude, from about 0.02 % in 1986 to 0.3 to 1.2 % in 1996.

5.5 Application of ARUM in Mud Lake

The long-term nature of the zinc load leaving Mud Lake is of primary concern to the overall health of the downstream aquatic ecosystems. A process which could serve as a long-term, passive biological treatment system, ARUM (Acid Reduction Using Microbiology), is being applied to the Mud Lake system for precipitation and storage of this zinc in Mud Lake. With successful application, acidity and other elements' concentrations will also be reduced, and effluents with a higher pH will discharge from Mud Lake.

ARUM is a sediment-based process in which chemical conditions are maintained that favour the formation, and maintain stable conditions for the storage of, metal precipitates as hydroxides, carbonates and sulphides. These chemical conditions are created by several microbially-mediated reductive processes, including nitrate, iron and sulphate reduction, as well as ammonification of nitrogen compounds. The microbial communities responsible for accelerating these processes are dependent on a degradable organic carbon supply.

To date, Boojum initiates the ARUM process by the addition of waste materials containing easily degradable organic carbon. This is followed by installation of floating vegetation covers, which serve to eliminate wind driven circulation and oxygen of the water column, and supply organic carbon for long term operation of the process.

In Table 10 the dimensions, operating parameters and overall performance of ARUM field systems designed by Boojum are presented. Mud Lake water quality is in the range treated at locations 1 and 2, characterized by higher acidities, metals and sulphate concentrations.

Table 10: ARUM Field Systems Dimensions, Operating Parameters and Overall Performance.

AMD Type	Location	System Type	Surface Area m^2	Volume m^3	Flow $L.min^{-1}$	Retention Days	Acidity		Iron		Sulphate		Metals	
							$mg.L^{-1}$ Initial	$mg.L^{-1}$ Final	$mg.L^{-1}$ Initial	$mg.L^{-1}$ Final	$mg.L^{-1}$ Initial	$mg.L^{-1}$ Final	$mg.L^{-1}$ Initial	$mg.L^{-1}$ Final
Ni/Cu	Central Ontario #1	Cells Flow Through	224	188	0.9	145	139	27.5	13	7.6	2400	450	Ni 15.3	Ni 0.8
Coal	Nova Scotia #2	Cells Diffuse	100	40	0.3 (a)	93	504	242	30	4.3	1213	920	Al 23.5	Al 12.7
Zn/Cu	Central Newfoundland #3	Cells Stagnant	12.5	34	-	151 (b)	57.5	<1	(c)	(c)	202	27	Zn 23	Zn 0.7
Zn/Cu	Central Newfoundland #4	Bog Diffuse	44	22	14.7	1	431	217	2.3	2	0.92	0.5	Zn 127	Zn 56
As/Ni	Northern Saskatchewan #5	Cell Stagnant	5.8	2.9	-	74 (b)	(d)	(d)	2.2	0.06	264	40	Ni 26 As 9.3	Ni 2.6 As 0.9
Zn	Mud Lake ARUM Enclosure	Flow Through	4800	4800	36.6	91	364	?	87	?	660	?	Zn 13.8	Zn ?

(a) Estimated flow

(b) Time to onset of treatment used to calculate removal

(c) Metals not present in significant concentra

(d) < 10 $mg.L^{-1}$ in seepage

5.5.1 Summary of Laboratory ARUM Treatability Experiment

A laboratory experiment was carried out to determine whether ARUM can remove Zn and other contaminants from Mud Lake water.

A preliminary experiment was carried out to determine what would happen to the ground water in oxidising conditions. Such conditions will be present in the mixed surface waters of Mud Lake. This experiment sought to determine whether, to what extent and at what rate Fe oxidation and subsequent precipitation of $Fe(OH)_3$ can occur.

This oxidation experiment determined that aeration of ground water entering Mud Lake (GD trap water) at room temperature (similar to summer conditions in the field) results in oxidation, hydrolysis and precipitation of Fe commencing at 88 h. From around 213 h, an equilibrium between Fe^{2+} and Fe^{3+} is attained with no further net oxidation or removal of Fe from solution. The oxidation rate was estimated as around 103 $mg/m^3/min$ and was little influenced by the presence of a sediment. However, in the presence of sediment approximately 50 % of the Fe and acidity in the water was removed in 27 days.

In cold room conditions, where the temperature (1-5°C) is similar to what would be encountered within and just above sediments in the field in winter, oxidation did not occur during the first 27 day period of observations with all Fe remaining in the Fe^{2+} state. However, within 72 days, oxidation had commenced in jars with sediment and pH had declined to <3. As at room temperature, 50 % of the acidity and Fe was removed by the sediment. The data are presented in Table 11 together with all the other ARUM laboratory results obtained since work on this process started.

Table 11: Acidity, Sulphate and Metal Removal in Reactors.

AMD Type	Location	Acidity Removal $g/m^3/d$	Iron Removal $g/m^3/d$	Sulfate Removal $g/m^3/d$	Metals Removal $g/m^3/d$
Cu/Ni	Central Ontario	2.5	0.8	8.6	Ni 0.2
U	Central Ontario	5.3	2.5	7.1	(a)
Cu/Zn	Northern Quebec	8	3.1	12	Zn 1.2
Cu/Zn/Pb	South Bay (22°C)	49	39	51	Zn 3.8
Cu/Zn/Pb	South Bay (5°C)	11	5.5	18	Zn 0.8
U	Northern Saskatchewan	4.1	0.005	16	Ni 0.17 As 1.8

(a) Only low concentrations of metals in solution.

ARUM worked very well on ground water entering Mud Lake (GD trap water). Within 23 days at room temperature, dissolved Zn concentration was reduced from >80 mg/L to <1 mg/L in reducing condition induced through addition of decomposable organic matter (alfalfa or potato waste). With added alfalfa, some of the Zn remained in the suspended solid fraction. This is potentially mobile. With potato waste, the Zn was almost totally removed to the sediment. Therefore, potato waste is the amendment of choice. In cold room conditions, and in the presence of an amendment and Mud Lake sediment, reducing conditions were established in Mud Lake ground water within 54 days and Zn concentration reduced to 0.334 mg/L in the presence of potato waste.

5.5.2 Installation of ARUM Enclosure

In May, 1995, a crescent-shaped, 100 m long curtain was attached to a series of posts, driven into the sediment, extending from two locations along the shore, enclosing a 0.48 ha area of Mud Lake where contaminated ground water was observed emerging from the bottom of the lake.

Some problems with the enclosure curtain were experienced, including lifting of the curtain by high winds, and waves overtopping the curtain, when strong winds prevailed from the south-west. In Plate 1 the curtain can be seen after installation, having developed a problem. Due to the strong winds over Mud lake area, the posts driven into the sediment loosened and had to be reinforced. The curtain was secured by September 1995.

An application of 800 kg of potato waste was distributed inside this enclosure for stimulation of sediment microbial activity. The potato waste was distributed with the boat in the original bags contained each about 20 pounds in July 1995. All potato waste purchased in 1994 was transported to the site and stored on the concrete pad on the town site, for future application.

A total of 25 cattail rafts, each 6' by 12' in area, were installed as three strips over sections of the enclosure, covering an area of 167 m^2. However, this has left most of the surface area of the ARUM enclosure exposed to wind-driven circulation of the water column. In Plate 2 the initial construction of the rafts with the organic substrate is depicted and Plate 3 displays the planted rafts installed in the enclosure.

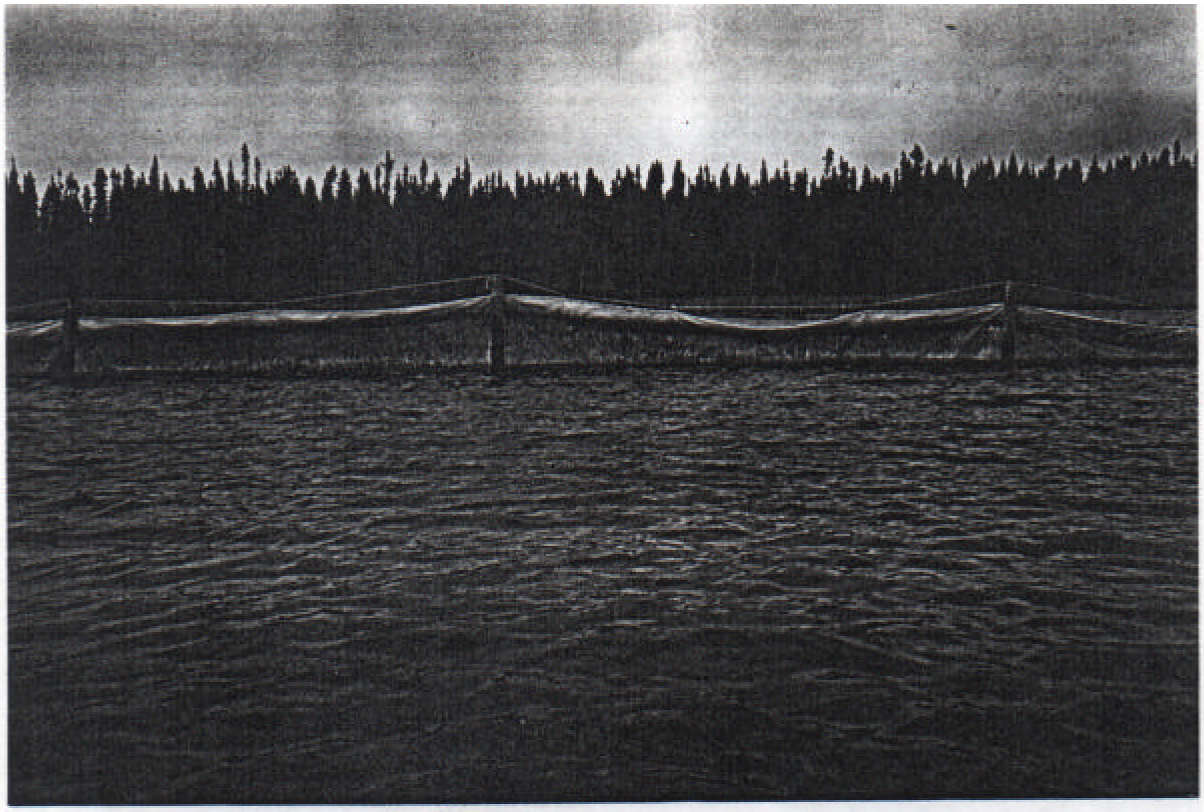


Plate 1: Curtain of Enclosure in Mud Lake being lifted by high winds.

Plate 2: Initial construction of cattail rafts for Mud Lake Enclosure.

Plate 3: Planted rafts installed in the Mud Lake Enclosure.

5.5.3 Water Quality in the ARUM Enclosure

In Table 12, the water quality for the enclosure area before and after curtain installation (ML27) and Mud Lake middle (MML) are provided.

The enclosure appears to be retaining contaminated ground water emerging from the lake bottom within its perimeter, and preventing mixing of this ground water with the rest of Mud Lake, as designed. A higher zinc concentration was determined inside the enclosure (10.3 mg/L) than at MML (7.8 mg/L) on July 27, 1995. On October 1995, the highest surface water zinc concentration (13.8 mg/L) ever measured in the Mud Lake system was present in enclosure water.

Table 12: Mud Lake Outflow(ML18), Centre(MML) and Enclosure(ML27 after May, 1995) Chemistry,1986-1995.

			Sample	Zn	pH	Temp	Acidity	SO4	Fe	Cond.	Em
		Location	date	mg/L		Celcius	mg/L	mg/L	mg/L	uS/cm	mV
	Mud Lake Enclosure										
Open	ML27	SURFACE	11-Jul-94		2.8	22.7					
Open	ML27	SURFACE	28-Aug-94		2.7	14.6					
Open	ML27	SURFACE	01-May-95		5.5	13.7					
Open	ML27	SURFACE	05-May-95	5.8	4.4	13.9	202	393	85	600	356
Open	ML27	SURFACE	07-May-95		3.6	11.8					
Open	ML27	SURFACE	08-May-95		3.3	14.8					
Open	ML27	SURFACE	10-May-95		3.1	15					
Enclosed	ML27	SURFACE	28-Jun-95		2.8	26					
Enclosed	ML27	SURFACE	26-Jul-95		3.0	20.2					
Enclosed	ML27	SURFACE	27-Jul-95	10.3	3.0	19.9	240		54	935	383
Enclosed	ML27	SURFACE	14-Aug-95		3.4	18.1					
Enclosed	ML27	SURFACE	20-Oct-95	13.8	2.8	0.9	285	660	87	1480	285
Open	ML27	BOTTOM	11-Jul-94		4.9	21.3					
Open	ML27	BOTTOM	28-Aug-94		5.7	9.1					
Enclosed	ML27	BOTTOM	28-Jun-95		6.5	18					
Enclosed	ML27	BOTTOM	26-Jul-95		6.0	18.8					
Enclosed	ML27	BOTTOM	20-Oct-95		5.8	6					
	Mud Lake Middle		date	Zn	pH						
	MML	SURFACE	17-Jun-86	0.02	7.6		nd	160	0.13	430	
	MML	SURFACE	25-Jul-86	0.03	6.2		nd	183	0.36	475	
	MML	SURFACE	30-Mar-94	9.8	3.2		304	834	79	1423	393
	MML	SURFACE	27-Apr-94	1.7	4.2	17.1	79	188	19	406	272
	MML	SURFACE	15-Jun-94	8.1	2.8	21.3	290	681	55	1450	660
	MML	SURFACE	28-Aug-94	7.9	2.7	15.5	171	1482	27	700	384
	MML	SURFACE	26-Feb-95	7.7	5.6	6.4	269	519	83	1043	42
	MML	SURFACE	01-May-95		5.6	12.8					
	MML	SURFACE	05-May-95	4.9	4.7	13.5	185	366	77	769	330
	MML	SURFACE	07-May-95		3.7	12.5					
	MML	SURFACE	08-May-95		3.5	14.2					
	MML	SURFACE	10-May-95		3.3	14.5					
	MML	SURFACE	28-Jun-95		2.8	24					
	MML	SURFACE	26-Jul-95		3.0	20.9					
	MML	SURFACE	27-Jul-95	7.8	3.0	20.9	207		53	925	431
	MML	SURFACE	28-Sep-95		2.7		216			1530	540
	MML	BOTTOM	30-Mar-94	12	5.3		600	1143	218	2200	333
	MML	BOTTOM	27-Apr-94	8.0	5.1	17	379	954	168	1430	121
	MML	BOTTOM	15-Jun-94	8.1	2.8		280	690	55	1455	662
	MML	BOTTOM	15-Jun-94		2.8	21.2					
	MML	BOTTOM	28-Aug-94		5.6		281			1790	377
	MML	BOTTOM	26-Jul-95		3.0	20.9					

There is evidence that zinc concentrations were increasing in the enclosure. If, in fact, concentrations remained the same or even decreased, then this would be evidence of effective ARUM activity inside the enclosure. In Figure 16 zinc concentrations Mud Lake middle surface and bottom (MML) and inside the enclosure (ML27) are plotted. Zinc concentrations at MML were relatively constant in 1995, while there is some indication that enclosure zinc concentrations were increasing.

In Figure 17, the expected zinc concentration in the enclosure is modelled, assuming a ground water inflow of 0.61 L/s, containing 184 mg/L, and assumes no loss of zinc by dilution of the enclosure water, except that water flowing out of the enclosure, or precipitation as zinc. This graph shows that enclosure zinc concentrations should reach approximately 180 mg/L in 1996. For 1995, measured zinc concentrations in the enclosure were increasing at a much lower rate that expected from the modelled concentrations. This suggests, that the other factors are affecting the zinc concentration which should be addressed and that likely the assumptions are not justified. Most likely however this simple model approach is at best an approximation `of what could be expected. In summary, to date the enclosure does not appear to work which is not unexpected, given the conditions of the curtain and the cattail cover being incomplete.

Figure 16: Mud Lake
Middle (MML), Outflow (ML18) and Enclosure (ML27)

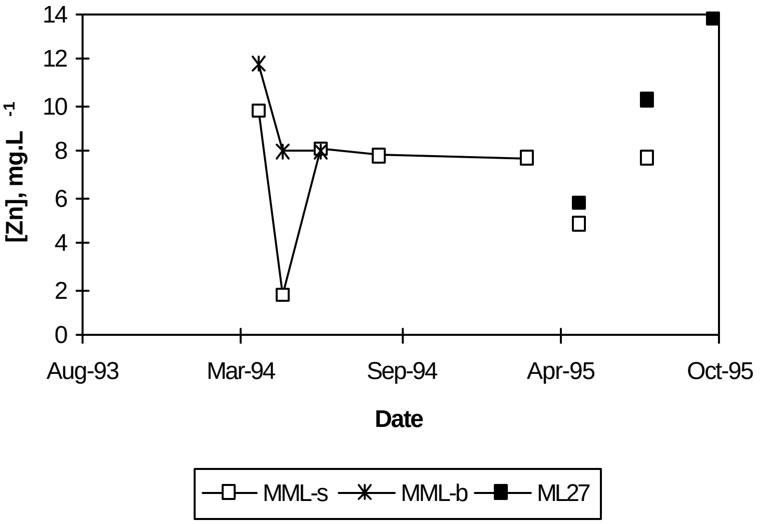
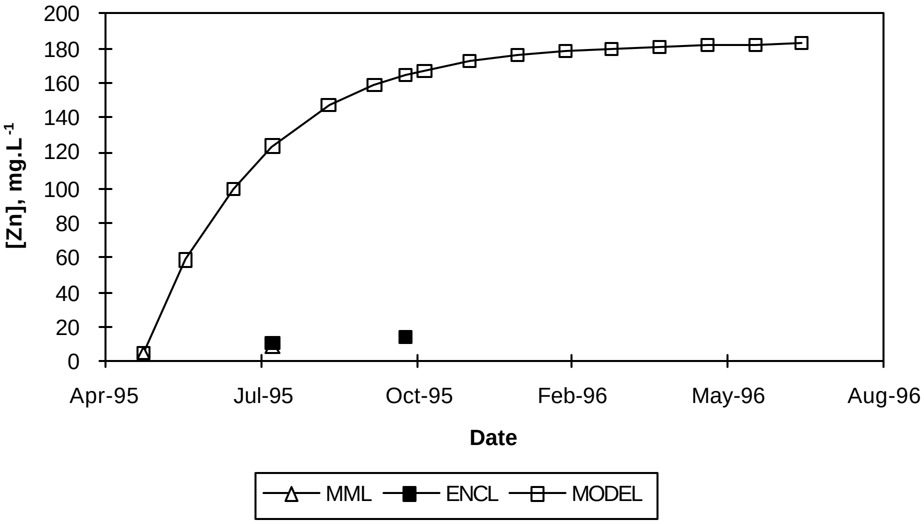


Figure 17: Mud Lake ARUM Enclosure
Measured [Zn] vs Expected [Zn]



5.5.4 Pore Water Quality

As the sediment in the enclosure will accumulate significant amounts of iron and zinc, pore water peepers, 0.5 m long plastic chambers containing distilled water and covered with a semi-permeable membrane, were installed in enclosure sediments in July and recovered in October, 1995. Their construction is displayed in Schematic 3. In Table 13 the general chemistry and dissolved concentrations of zinc, sulphur and iron in the solutions recovered from the porewater peepers are presented and compared to enclosure surface water chemistry in October, 1995.

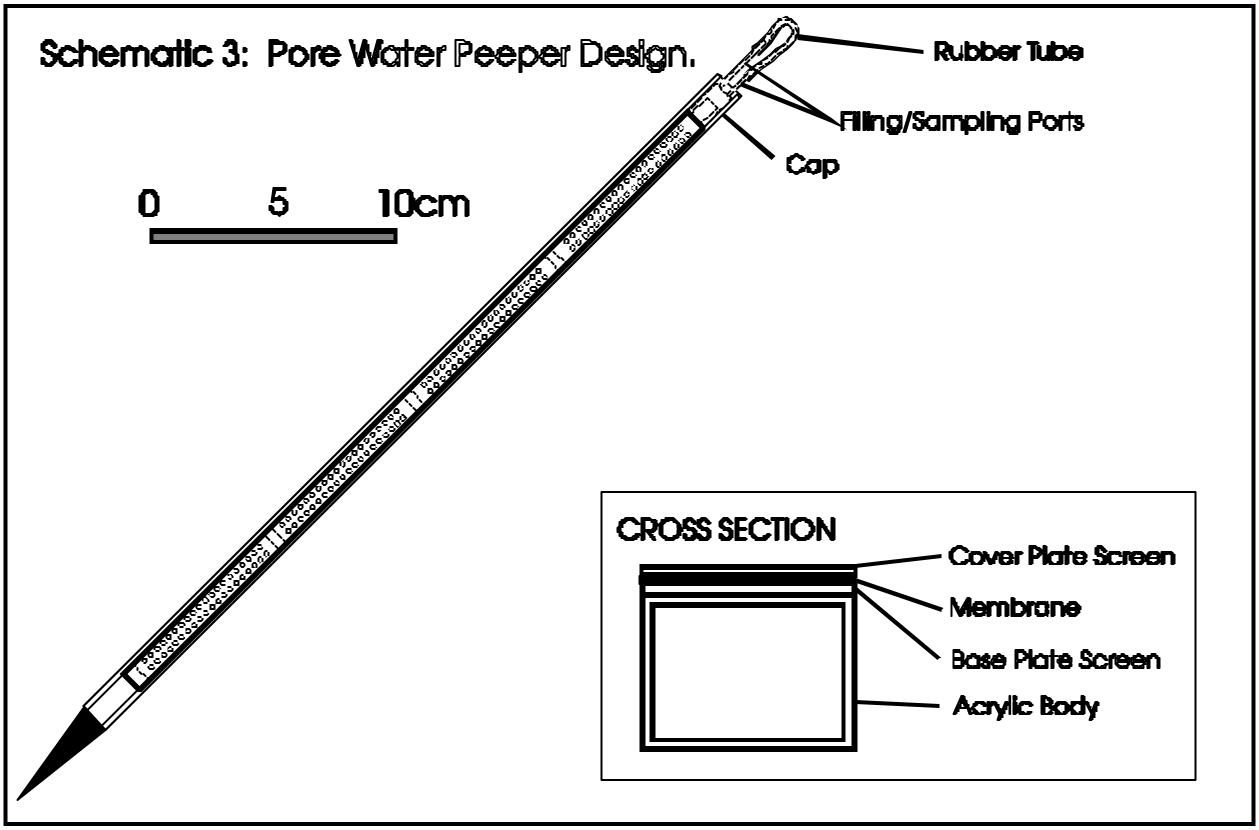

Schematic 3: Pore Water Peeper Design.

Table 13: Enclosure pore water chemical composition, compared to enclosure surface water, October 21, 1995.

		Date Sampled	pH	[H+]	Cond uS/cm	Eh mV	Zn mg/L	S mg/L	Fe mg/L	Acidity mg/L
Enclosure Surface	ML27	21-Oct-95	3.18	6.61E-04	1,480	285	13.8	220	86.9	364
Pore Water Peepers	PWP-1	21-Oct-95	6.13	7.41E-07	2,360	125	0.56	423	269	399
in Enclosure	PWP-2	21-Oct-95	6.45	3.55E-07	1,650	98	0.19	254	104	151
July-Oct, 1995	PWP-3	21-Oct-95	6.32	4.79E-07	2,450	101	0.24	455	248	177
	PWP-4	21-Oct-95	6.61	2.45E-07	1,660	86	0.24	257	103	477
		Avg	6.34	4.55E-07	2,030	103	0.31	347	181	301

The pH of enclosure sediment pore water averaged 6.3, compared to pH 3.18 in surface water. Ferric iron reduction is likely responsible for elevated pH in sediment pore water. However, some additional alkalinity generating processes are likely occurring in these sediments following addition of the potato waste.

Overall, zinc concentrations in enclosure sediment pore water averaged 0.31 mg/L, compared to 13.8 mg/L in surface water. Therefore, the enclosure sediments represent a sink for zinc, and diffusion of zinc from the water column into the sediments is occurring. Iron and sulphur concentrations in sediment pore water are high that overlying water, and the sediments represent a source of these elements to overlying water.

Experience results from the treatability study and all other ARUM experiments (Table 10 and 11) indicated that, if sufficient ferric iron is available at the sediment surface, the activity of iron-reducing bacteria remains high at the expense of other microbial processes. Clearly with the present configuration there are problems which have to be overcome.

5.5.5 Possible Modifications to ARUM Enclosure

Improvement of the enclosure curtain will be required in order to retain contaminated ground water in the enclosure are for as long as possible for treatment.

Installation of a cover over the ARUM enclosure is required in order to prevent oxidation of ferrous iron entering the enclosure area from contaminated ground water sources.

The floating cover should, ideally, be comprised of a floating vegetation mats, in order that a long-term source of organic carbon is available to sediment microbial communities.

All sediments in Mud Lake contain some organic carbon which should assist in the removal of zinc. Presently, a relatively large volume of fresh water run-off enters Mud Lake, reducing its overall retention time. Options for diverting fresh water run-off around Mud Lake should be examined.

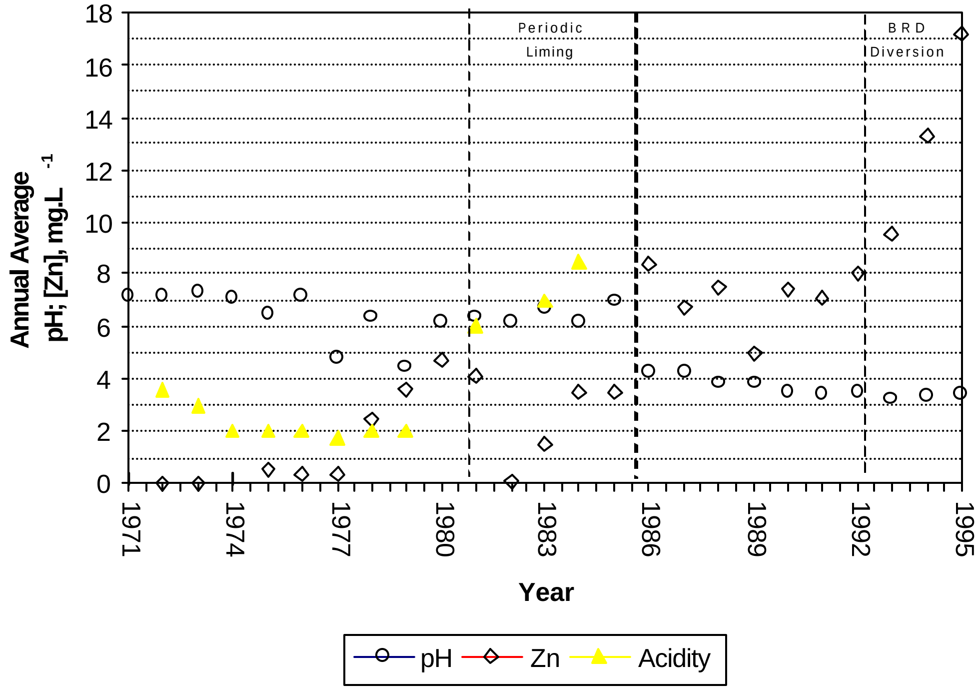
6.0 BOOMERANG LAKE: EXISTING CONDITIONS AND THE APPLICATION OF PHOSPHATE ROCK

6.1 A Brief History of the Boomerang Lake Drainage Basin

The Boomerang Lake drainage basin has historically received run-off from the mine site, including Mill Pond and Backfill Raise Ditch, seepage from the east and west tailings dams, and some run-off from the Tailings Diversion Ditch. The Boomerang Lake drainage basin also collects clean run-off from areas to the north and east.

Boomerang Lake is the recipient of all surface and seepage water from these various sources. Historically, annual average pH decreases were first noted in 1977 (Figure 18), and zinc concentrations began to climb in 1978. Acidity remained less than 10 mg/L ($CaCO_3$ equivalent) up to 1984. Thereafter, acidity measurements were consistently climbing.

Figure 18: Boomerang Lake
Historical Annual Average pH, [Zn], [Acidity]



Lime was periodically added to Boomerang Lake to precipitate zinc and maintain neutral pH. Following cessation of liming, the pH of Boomerang Lake steadily declined to level out at pH 3 to 4, the acidity has increased to as high as 90 mg/L, and annual average zinc concentration reached 17 mg/L in 1995 (Figure 18). The steep increase in annual average zinc concentrations between 1992 and 1995 is due to diversion of Backfill Raise Ditch water, containing Backfill Raise Cap and Warehouse Seep waters, to Boomerang Lake following excavation of a deep ditch.

Remedial measures have been taken since 1990 to reduce zinc concentrations in Boomerang Lake. Substrate has been placed in Boomerang Lake to support Biological Polishing for zinc removal. Phosphate rock applications have been mad to precipitate iron as ferric phosphate, in order to reduce iron cycling and acidity regeneration in the lake.

6.2 Water Balance for Boomerang Lake Drainage Basin

In order to assess the contributions of the various sources of contaminants to Boomerang Lake, the annual water volumes of, and contaminants concentrations in, these sources to Boomerang Lake have been estimated. Periodic field measures of flow have been performed in order to verify some of the hydrological estimates and assumptions.

In Table 14, hydrological estimates of flows from the various sources of water and contaminants are provided for comparison with flow measurements. Generally, estimated base flows, in L/s (R.O. van Everdingen), fall within the range of measured flow data collected to date, for those sources where measurements were possible.

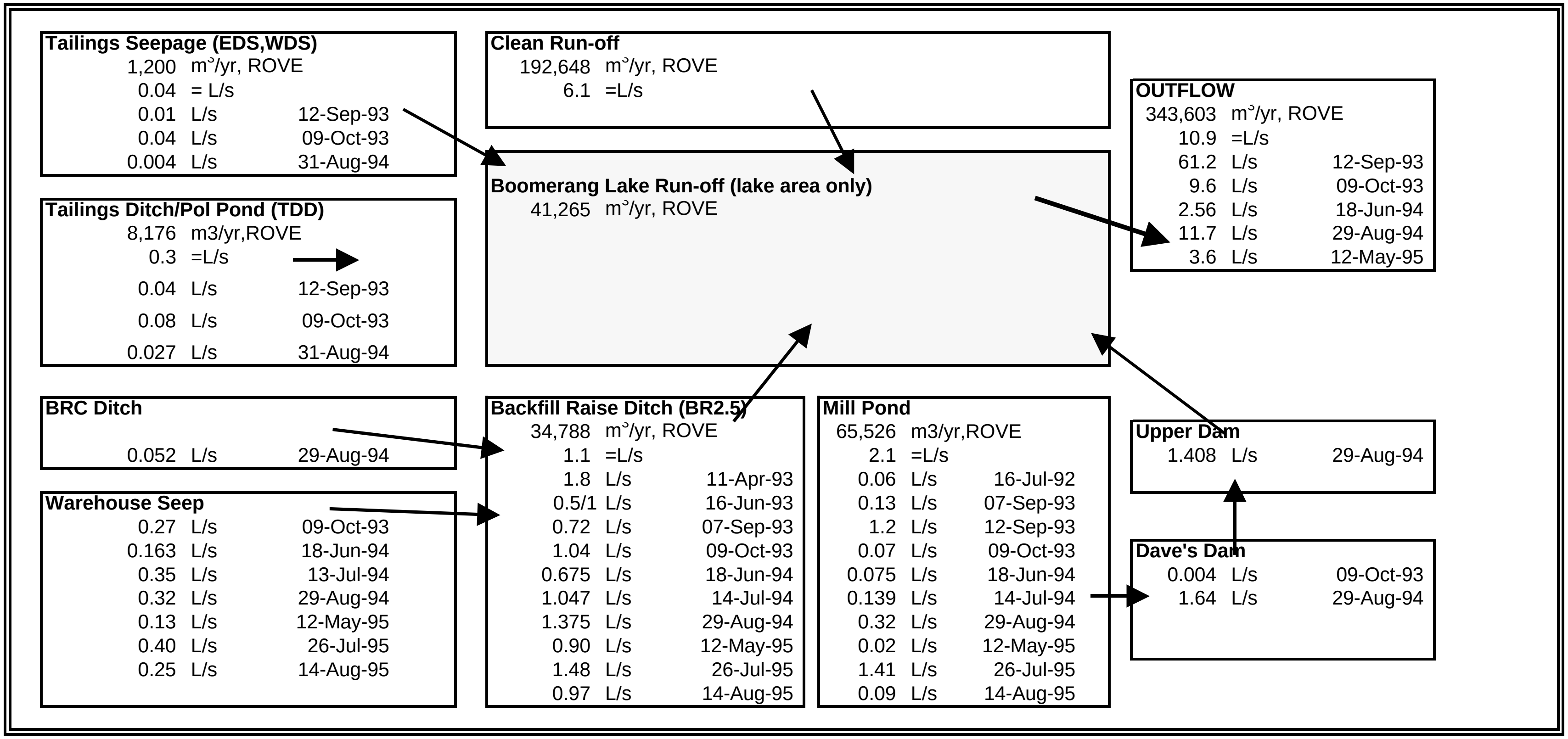
Since the volume of Boomerang Lake is approximately 1,000,000 m^3, and the volume of water discharged from Boomerang Lake is approximately 344,000 m^3, the retention time of water in Boomerang Lake in approximately 3 years.

Run-off and seepage water reports to Boomerang Lake from five major areas (Table 14):

- Clean run-off from surrounding forested areas (6.1 L/s).
- East and West Tailings Dam seepage (0.04 L/s)
- Tailings Diversion Ditch (0.3 L/s)
- Backfill Raise Ditch, including BRC and WHS (1.1 L/s)
- Mill Pond area (2.1 L/s)

In addition, direct precipitation onto the surface of Boomerang Lake contributes 41,265 m^3/yr^-, equivalent to 1.3 L/s. Collectively, run-off from these five areas, plus direct precipitation onto Boomerang Lake, amounts to 10.9 L/s. Between 1993 and 1995, flow measures at Boomerang Lake outflow have ranged from 2.6 to 61 L/s (Table 14).

Table 14: Water Balance for Boomerang Lake Drainage Basin, 1992 - 1995.



Tailings Seepage (EDS,WDS)

1,200	m^3/yr, ROVE	
0.04	= L/s	
0.01	L/s	12-Sep-93
0.04	L/s	09-Oct-93
0.004	L/s	31-Aug-94

Clean Run-off

192,648	m^3/yr, ROVE
6.1	=L/s

OUTFLOW

343,603	m^3/yr, ROVE	
10.9	=L/s	
61.2	L/s	12-Sep-93
9.6	L/s	09-Oct-93
2.56	L/s	18-Jun-94
11.7	L/s	29-Aug-94
3.6	L/s	12-May-95

Tailings Ditch/Pol Pond (TDD)

8,176	m3/yr,ROVE	
0.3	=L/s	
0.04	L/s	12-Sep-93
0.08	L/s	09-Oct-93
0.027	L/s	31-Aug-94

Boomerang Lake Run-off (lake area only)

41,265 m^3/yr, ROVE

BRC Ditch

0.052	L/s	29-Aug-94

Warehouse Seep

0.27	L/s	09-Oct-93
0.163	L/s	18-Jun-94
0.35	L/s	13-Jul-94
0.32	L/s	29-Aug-94
0.13	L/s	12-May-95
0.40	L/s	26-Jul-95
0.25	L/s	14-Aug-95

Backfill Raise Ditch (BR2.5)

34,788	m^3/yr, ROVE	
1.1	=L/s	
1.8	L/s	11-Apr-93
0.5/1	L/s	16-Jun-93
0.72	L/s	07-Sep-93
1.04	L/s	09-Oct-93
0.675	L/s	18-Jun-94
1.047	L/s	14-Jul-94
1.375	L/s	29-Aug-94
0.90	L/s	12-May-95
1.48	L/s	26-Jul-95
0.97	L/s	14-Aug-95

Mill Pond

65,526	m3/yr,ROVE	
2.1	=L/s	
0.06	L/s	16-Jul-92
0.13	L/s	07-Sep-93
1.2	L/s	12-Sep-93
0.07	L/s	09-Oct-93
0.075	L/s	18-Jun-94
0.139	L/s	14-Jul-94
0.32	L/s	29-Aug-94
0.02	L/s	12-May-95
1.41	L/s	26-Jul-95
0.09	L/s	14-Aug-95

Upper Dam

1.408	L/s	29-Aug-94

Dave's Dam

0.004	L/s	09-Oct-93
1.64	L/s	29-Aug-94

6.3 Contaminant Sources in the Boomerang Lake Drainage Basin

Direct measurement of flow volumes and water quality for some sources of water in the Boomerang Lake drainage basin is possible, while for other sources, both these parameters must be based on indirect evidence, such as piezometer and seepage water quality. Direct measurements have been made for the Backfill Raise Ditch and Mill Pond outflow path, and contaminants carried in these flows paths are known to enter Boomerang Lake. However, Tailings Dam seepage, Tailings Diversion Ditch water and clean run-off have not been directly measured in most cases.

There is visual evidence of seepage from the East and West Tailings Dams emerging below water in Boomerang Lake. A minor seepage can periodically be sampled at the base of the East Dam.

In Table 15, annual average East Dam pH, and zinc, iron, sulphate and acidity concentrations have been summarized for all years when data is available (1987, 1988, 1992 - 1994). The pH of seepages and piezometer was is typically high since these solutions are likely still reduced, as indicated by high iron concentrations. The average annual zinc concentration has reached 192 mg/L, while acidity may average as high as 1,476 mg/L.

For assessing West Dam seepage, only single samples of piezometer M47 water were collected for the years 1987, 1988, 1990 and 1992 (Table 16). The solutions have consistently contained high zinc (73 to 219 mg/L) and iron (290 to 2300 mg/L) concentrations.

Table 15: East Dam Seepage, M8 and M47 Long Term Water Chemistry, 1985 - 1995.

	pH			Zn, mg/L			Fe, mg/L			Sulphate, mg/L			Acidity, mg/L $CaCO_3$ equiv.		
Year	avg	max	min	avg	max	min	avg	max	min	avg	max	min	avg	max	min
1985															
1986															
1987	6.4			3.8			3.0			663					
n=1															
1988	5.7	6.6	5.4	192	382	2.0	156	311	0.01	2549	4566	531			
n=2															
1989															
1990															
1991															
1992	6.7			1.0			1.0			264			50		
n=1															
1993	5.3	5.5	5.1	118	139	98	885	1030	739	2204	2541	1866	1476	1904	1048
n=2															
1994	4.9	4.9	4.9	151	180	121	1315	1420	1210	3066	3600	2532	1275	2335	215
n=2															
1995															

Table 16: West Dam M47 Long Term Water Chemistry, 1987 - 1995.

Year	pH	Zn, mg/L	Fe, mg/L	Sulphate, mg/L	Acidity, mg/L $CaCO_3$ equiv.
1987	5.2	143	290	3855	
n=1					
1988	6.1	219	311	5841	
n=1					
1989					
1990	5.2	73	615	2742	
n=1					
1991					
1992	5.3	174	2300	6180	3975
n=1					
1993					
1994					
1995					

Seepages emerging from the walls of the Tailings Diversion Ditch can, at times, collectively generate a small stream. The quality of this stream was periodically measured between 1987 and 1994 (Table 17). Annual average zinc concentrations have been as high as 65 mg/L (1990), but are typically less than 15 mg/L. There is some indication that iron, sulphate and acidity concentrations have been increasing with time, generally reaching maxima in 1994.

Table 17: Tailings Diversion Ditch (TDD) Long Term Water Chemistry, 1987 - 1995.

	pH			Zn, mg/L			Fe, mg/L			Sulphate, mg/L			Acidity, mg/L $CaCO_3$ equiv.		
Year	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
1987	6.0	6.8	5.6	2.8	10	0.01	13	79	0.01	397	723	33			
n=7	(n=6)														
1988	4.7	7.2	3.7	4.2	35	0.01	0.16	0.80	0.01	347	672	69			
n=9															
1989	5.4	8.8	5.1	5.1	10	0.20	11	14	7.8	260	312	207			
n=2															
1990	4.5	5.9	4.2	65	128	2.7	15	29	0.50	686	1140	231			
n=2															
1991	6.3	6.7	6.1	2.3	2.5	2.0	0.85	1.0	0.70	119	144	95	28	30	25
n=2															
1992	3.4	6.4	3.0	13	31	0.61	804	2410	0.10	2785	5400	171	2564	5105	23
n=3										(n=2)			(n=2)		
1993	3.1	5.6	2.8	8.4	13	0.27	526	791	5.3	1472	2169	95	1272	2547	6.9
n=3															
1994	3.0			14			834			2292			1902		
n=1															
1995															

Between 1987 and 1992, Backfill Raise Ditch was basically a shallow depression directing some surface run-off from the mine and mill area to Boomerang Lake. Surface water overlying Backfill Raise Cap and the Warehouse seep area drained to Confederation Lake. In 1993, the Backfill Raise Ditch was deepened in order to direct all Backfill Raise Cap and Warehouse seep water, as well as BR13 water, towards Boomerang Lake and away from Confederation Lake.

Since the deepening of the ditch and excavation of the Backfill Raise Cap and Warehouse Seep area in 1993, year-round flow is present in the ditch.

In Table 18, annual average pH and zinc, iron, sulphate and acidity concentrations for Backfill Raise are presented. Since deepening of the ditch in 1993, the pH is consistently low (3.1), and zinc, sulphate and acidity generally higher than in the previous years.

The current zinc concentration in the ditch is approximately 240 mg/L, while the iron, sulphate and acidity concentrations are approximately 60, 2000, and 860 mg/L, respectively.

Since mining commenced, Mill Pond has always received run-off from the mine and mill site, including the old concentrate storage pads. Subsequently, Mill pond water and sediments contain high concentrations of copper and zinc.

Annual average zinc concentrations have historically been as high as 1,012 mg/L (Table 19). There is some indication that zinc concentrations in Mill Pond Outflow water are diminishing with time, and the 1995 annual average zinc concentration was 139 mg/L.

The pH of Mill Pond outflow water has remained around pH 3.5 over the past five years. Since the pH is above pH 3.0, dissolved iron concentrations have remained below 28 mg/L, and in 1995 averaged only 7.8 mg/L.

Deepening of the Backfill Raise ditch was performed in order to reduce the amount of shallow ground water moving from the mine and mill area towards Confederation Lake through waste rock in the vicinity. Flow and water quality at the Portal Raise Seep (PRS), periodically monitored (Table 20) since 1992, indicate that seepage flows are generally diminished, and zinc, iron, copper, sulphate and acidity concentrations have also diminished.

Table 18: Backfill Raise Ditch (BR2.5) Long Term Water Chemistry, 1987 - 1995.

		pH			Zn, mg/L			Fe, mg/L			Sulphate, mg/L		Acidity, mg/L $CaCO_3$ equiv.		
Year	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
1987	6.3			0.13	0.40	0.01	0.91	3.5	0.01	80	129	24			
n=4	(n=1)														
1988				2.2	3.6	0.70	0.40	0.70	0.10	75	108	42			
n=2															
1989	3.0			20			72			507					
n=1															
1990	4.2			128			29								
n=1															
1991	3.1	3.7	3.0	170	295	39	33	47	21	1209	2067	435	574	600	556
n=5													(n=3)		
1992	3.4	3.9	3.1	13	19	6.9	28	52	2.9	311	474	148	206	340	73
n=2															
1993	3.7	4.3	3.4	256	288	213	15	22	1.9	1598	1863	1281	795	1128	578
n=3															
1994	3.1	3.4	2.8	309	362	268	41	58	20	2054	2343	1749	898	1014	840
n=4															
1995	3.1			237			60						861		
n=1															

Table 19: Mill Pond Outflow (MPO) Long Term Water Chemistry, 1987 - 1995.

	pH			Zn, mg/L			Fe, mg/L			Sulphate, mg/L			Acidity, mg/L $CaCO_3$ equiv.		
Year	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
1977	7.0	7.1	6.9	21	40	0.30	0.60	1.8	0.09						
n=5															
1978	4.4	6.8	3.8	259	794	63	14	50	1.3						
n=4															
1979	6.0			42			1.5								
n=1															
1980	3.6			1012			5.0								
n=1															
1981															
1982	4.8	6.1	4.2	197	710	14	39	150	0.04	2665			1398		
n=4										n=1			n=1		
1983	3.8			280			65			2100			842		
n=1															
1984	3.5	3.7	3.3	510	620	330	47	49	45	2428	2456	2400	1102	1388	815
n=2				(n=3)			(n=3)								
1985	6.8			517			51								
n=1															
1986	4.3	6.0	3.8	223	406	118	9	78	0.01	1230	1866	657			
n=12	(n=6)														
1987	4.6	6.5	3.9	176	503	74	17	87	0.01	1107	2892	381			
n=8	(n=7)														
1988	3.0	7.2	2.7	271	876	0.30	41	164	0.01	1901	4098	39			
n=4	(n=2)														
1989	3.3	4.9	2.9	267	463	112	34	72	3.9	1832	3504	705	1304		
n=3													n=1		
1990	2.7	3.7	2.4	264	320	175	22	48	4.4	1489	1566	1386	800		
n=3													(n=1)		
1991	3.3	4.1	3.1	234	320	107	28	51	10	1353	1815	714	444	817	133
n=6															
1992	3.5	4.7	3.2	281	383	191	23	84	2.8	1394	1911	1107	583	765	430
n=9										(n=7)			(n=6)		
1993	3.3	3.7	3.1	158	188	128	11	20	3.1	1067	1299	816	543	629	439
n=3															
1994	3.6	4.9	3.1	89	152	34	5.2	9.5	2.5	673	987	294	222	392	87
n=7															
1995	3.4	3.6	3.2	139	146	132	7.8	11	4.6	1079	1134	1023	435	474	395
n=2															

Table 20: Chemistry of Sampling Location PRS, Mine Site

Year	Date	Assay. No.	Concentrations									
			Cu mg/L	Zn mg/L	Fe mg/L	Pb mg/L	pH	Ni mg/L	Acidity mg/L	Alkalinity mg/L	Sulfate mg/L	Flow L/s
1992	Average		5.5	53	1.5	0.52	4.1	0.51	103	20	428	0.41
1993	Average		2.7	111	4.7	0.025	5.7	0.08	209	2.6	992	0.03
1994	Average		7.3	133	7.1	0.07	5.7	0.06	279		863	0.01
1995			1.4	32	0.27	0.038	5.1	0.01	105		269	NR
1992	13-Jul	3868	1.5	46	< 1.0	< 1	5.6	< 1.00	53	15	459	0.04
	16-Jul	3877	20	122	3.7	< 1	3.5	< 1.00	264		525	1.5
	14-Aug	4038	0.6	22	0.2	< 0.025	5.6	0.01	49		299	0.06
	16-Oct	4218	0.32	23	0.95	0.037	6.0	0.01	44	25		0.08
1993	11-Apr			19	0.31		5.8		82			0.05
	16-Jun						5.8		44			0.05
	07-Sep	4565	1.7	137	7.2	0.025	5.6	0.08	293	2.6	936	0.01
	09-Oct	4592	3.6	176	6.7	<< 0.025	5.7	0.08	419		1047	0.02
1994	28-Mar											No flow
	28-Apr		11	186	4.5	0.025	5.1	0.07	400	1.0	1071	NR
	18-Jun		2.3	89	5.7	0.025	5.4	0.05	58	5.6	648	0.007
	11-Jul		8.5	180	8.2	0.05	4.4	0.08	410		1167	0.023
	30-Aug		6.9	76	10.0	0.17	4.3	0.04	246		567	0.020
1995	20-Mar	5397	1.4	32	0.27	0.038	5.1	0.01	105		269	NR

The long term water quality of Boomerang Lake is presented in Table 21, which includes annual average pH and zinc, iron, aluminum, sulphate and acidity concentrations between 1971 and 1995.

Over the last six years (1990 - 1995), the pH has remained relatively constant at about pH 3.3 - 3.5. However, zinc concentrations have more than doubled, from 7.4 mg/L in 1990 to 17.2 mg/L in 1995. Sulphate concentrations have also gradually increased, from 200 mg/L in 1990 to current levels of 300 mg/L. A minor trend of increasing aluminum concentrations is also noted for these years, while iron concentrations are variable. Despite increasing concentrations of zinc, sulphate and aluminum, a trend of increasing acidity is not apparent from the annual averages between 1990 and 1996 (Table 21).

Table 21: Boomerang Lake Long Term Water Chemistry, 1971 - 1995.

	pH			Zn, mg/L			Fe, mg/L			Al, mg/L			Sulphate, mg/L			Acidity, mg/L $CaCO_3$ equiv.		
Year	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
1971	7.2	7.5	6.9	0.15	0.45	0.02	0.63	2.1	0.09				5.8	8.0	5.0			
n=9	(n=7)												(n=5)					
1972	7.1	7.6	6.6	0.03	0.07	0.02	0.19	0.50	0.03				15	22	6.0	3.6	6.0	1.0
n=10				(n=9)			(n=8)						(n=8)			(n=8)		
1973	7.4	7.6	7.1	0.04	0.07	0.02	0.15	0.36	0.03				18	22	10.0	3.0	4.0	2.0
n=6	(n=5)						(n=5)						(n=4)			(n=4)		
1974	7.0	7.9	6.6	0.17	0.64	0.00	0.94	5.7	0.10				30	36	25	2.0	2.0	2.0
n=13	(n=10)						(n=10)						(n=4)			(n=4)		
1975	6.4	7.8	6.0	0.55	1.44	0.06	0.74	3.0	0.09				38	43	30	2.0	2.0	2.0
n=8				(n=7)			(n=7)						(n=3)			(n=2)		
1976	7.2	8.3	7.0	0.38	1.14	0.05	0.20	0.46	0.05				40	50	20	2.0	2.0	2.0
n=11	(n=10)						(n=10)						(n=4)			(n=3)		
1977	4.8	8.1	3.4	0.31	1.49	0.04	0.35	3.1	0.01				63	64	62	1.8	2.0	1.0
n=41													(n=3)			(n=4)		
1978	6.4	7.9	5.2	2.4	5.1	0.08	0.45	2.9	0.01				108	267	68	2.0	2.0	2.0
n=63	(n=62)												(n=7)			(n=2)		
1979	4.5	7.2	3.2	3.6	5.5	0.58	0.56	2.6	0.01				90	135	31	2.0	2.0	2.0
n=58							(n=59)						(n=4)			(n=2)		
1980	6.2	6.9	5.9	4.7	6.0	2.5	1.4	8.7	0.01									
n=24																		
1981	6.3	7.5	5.5	4.1	7.3	0.10	1.2	2.2	0.01				148	153	143	6.0	6.0	6.0
n=24													(n=2)			(n=2)		
1982	6.2	6.9	5.7	0.1	0.3	0.01	0.16	0.56	0.01									
n=5																		
1983	6.7	7.1	6.6	1.5	3.4	0.03	0.91	1.9	0.05				166			7.0		
n=10													(n=1)			(n=1)		
1984	6.2	7.7	5.4	3.5	4.5	0.68	1.8	2.8	0.19				168	171	164	8.5	9.0	8.0
n=9													(n=2)			(n=2)		
1985	7.0	7.2	6.8	3.5	6.1	0.33	0.93	1.5	0.07									
n=6	(n=2)																	
1986	4.3	5.4	4.1	8.4	9.4	6.9	1.2	2.0	0.50				169	183	150			
n=56	(n=48)												(n=28)					
1987	4.3	5.4	3.8	6.7	9.3	0.01	3.2	62	0.01	1.4	2.9	0.60	226	744	57			
n=40	(n=35)									(n=3)			(n=28)					
1988	3.9	4.9	3.5	7.5	10.0	5.8	0.76	6.6	0.01	0.53	0.70	0.30	218	303	183			
n=22	(n=21)												(n=20)					
1989	3.8	4.7	3.6	5.0	7.7	0.07	1.9	8.9	0.50	1.0	1.1	0.90	188	255	72	43		
n=7	(n=8)									(n=3)			(n=7)			(n=1)		
1990	3.5	3.6	3.5	7.4	8.7	5.2	0.53	0.80	0.40	1.3	1.3	1.2	202	228	168	150		
n=3	(n=2)									(n=2)						(n=1)		
1991	3.4	3.8	3.2	7.1	10.8	0.8	1.73	4.5	0.50	1.6	3.0	0.11	232	285	31	67	120	22
n=16	(n=14)									(n=3)						(n=15)		
1992	3.5	3.8	3.0	8.0	9.3	6.7	1.66	3.0	1.00	2.1	2.6	1.5	228	294	203	54	75	43
n=15										(n=4)			(n=12)			(n=11)		
1993	3.3	3.6	3.1	9.5	10.2	8.7	2.7	8.3	1.4	1.8	2.0	1.7	251	265	236	77	130	39
n=14										(n=7)								
1994	3.3	3.6	3.1	13.3	17.7	11.1	3.3	13.9	2.0	2.2	2.9	1.9	304	339	280	89	104	77
n=16																		
1995	3.4	4.9	2.9	17.2	19.2	13.9	1.4	3.6	0.30	3.0	3.5	2.5	304	327	290	80	100	57
n=10																(n=9)		

TThe absence of a trend of increasing acidity may be related to the additions of phosphate rock performed in 1993, 1994 and 1995. This is further discussed in section below.

6.4 Contaminant Loads To Boomerang Lake

The annual average concentrations of iron, zinc and sulphate in major drainage paths to Boomerang Lake, presented in Tables 15 through 21, and the estimated flows from these drainage paths, presented in Table 14, can be used to estimate contaminant loads from these various sources.

In Table 22a, the estimated annual iron loads from the Mill Pond area, Backfill Raise Ditch, Tailings Diversion Ditch, the East and West Dams and fresh water run-off are presented for the years 1987 to 1995. Estimated loads for the first six months are presented separately from the second 6 months of 1995, since phosphate rock was added in June of 1995. These iron loads from various sources are summed in the column "Sum of Fe Input to B.L., t/yr". The same type of estimates are presented for zinc (Table 22b) and sulphate (Table 22c).

Annual average iron, zinc and sulphate concentrations measured in Boomerang Lake are presented in these tables for comparison to estimated concentrations, based on a simple model incorporating the estimated iron input from various sources to Boomerang Lake, the mass of iron in Boomerang Lake, and the annual loss of iron in effluent from Boomerang Lake. Based on the measured and estimated annual average concentrations, percent removal of iron, zinc and sulphate are presented in the last column of each table.

Table 22a: Iron loadings to, and removal by Boomerang Lake, 1987 - 1995.

YEAR		MPO [Fe] g/m^3	BRD [Fe] g/m^3	TDD [Fe] g/m^3		EDS [Fe] g/m^3		WDS [Fe] g/m^3		Fresh [Fe] g/m^3	Fe Input B. L. t/yr		Boom. L. Meas. [Fe], mg/L	Boom. L. Est [Fe], mg/L	Boom. L. Est Fe Rem,%
1987		17	0.9	13		3.0	PZ	290	PZ	0.1	1.5		3.2		
1988		41	0.4	0.2		156	PZ	311	PZ	0.1	3.1		0.8	1.5	51%
1989		34	72	11		53	Avg	879	Avg	0.1	5.6		1.9	3.1	38%
1990		22	29	15		53	Avg	615	PZ	0.1	3.2		0.5	5.6	91%
1991		28	33	0.9		53	Avg	879	Avg	0.1	3.8		1.7	3.2	46%
1992		23	28	804		1.0	PZ	2300	PZ	0.1	11		1.7	3.8	56%
1993		11	15	526		885	Seep	879	avg	0.1	6.6		2.7	11.1	76%
1994		5.2	41	834		1315	PZ	879	avg	0.1	9.8		3.3	6.6	50%
1995		7.8	60	275	Avg	369	Avg	879	avg	0.1	5.8		1.4	9.8	85%
1995	1st 6 mo	7.8	60	275		369		879	avg	0.1	2.9	t/6 mo	2.1	9.8	78%
	2cd 6 mo	7.8	60	275		369		879	avg	0.1	2.9	t/6 mo	0.7	9.8	92%
											5.6	t/yr		Avg Removal/yr	62%

Table 22b: Zinc loadings to, and removal by Boomerang Lake, 1987 - 1995.

YEAR		MPO [Zn] g/m^3	BRD [Zn] g/m^3	TDD [Zn] g/m^3		EDS [Zn] g/m^3	Data*	WDS [Zn] g/m^3	Data**	Fresh [Zn] g/m^3	Zinc Input Boom. L. t/yr		Boom. L. Meas. [Zn], mg/L	Boom. L. Est. [Zn], mg/L	Boom. L. Est Zn Rem,%
1987		176	0	2.8		3.8	PZ	143	PZ	0.01	12		6.7		
1988		271	2	4.2		192	PZ	219	PZ	0.01	18		7.5	12	36%
1989		267	20	5.1		73	Avg	152	Avg	0.01	18		5.0	18	73%
1990		264	128	65		73	Avg	73	PZ	0.01	22		7.4	18	60%
1991		234	170	2.3		73	Avg	152	Avg	0.01	21		7.1	22	69%
1992		281	13	13		1.0	PZ	174	PZ	0.01	19		8.0	21	62%
1993		158	256	8.4		118	Seep	152	avg	0.01	19		10	19	50%
1994		89	309	14		151	Seep	152	avg	0.01	17		13	19	32%
1995		139	237	14	Avg	87	Avg	152	avg	0.01	18		17	17	-2%
1995	1st 6 mo	139	237	14		87		152		0.01	8.8		18	17	-8%
	2cd 6 mo	139	237	14		87		152		0.01	8.8		16	17	5%
											18	t/yr		Avg Removal/yr	47%

* PZ, M8, M44 piezometer data; Avg, average of piezometer data; Seep at B.L. s ** PZ, M47 piezometer data; Avg, average of piezometer dat

Table 22c: Sulphate loadings to, and removal by Boomerang Lake, 1987 - 1995.

YEAR		MPO [SO4] g/m^3	BRD [SO4] g/m^3	TDD [SO4] g/m^3		EDS [SO4] g/m^3		WDS [SO4] g/m^3		Fresh [SO4] g/m^3	SO4 Input Boom. L. t/yr		Boom. L. Meas. [SO4], mg/L	Boom. L. Est [SO4], mg/L	Boom. L. Est. SO_4 Rem,%
1987		1107	80	397		663	PZ	3855	PZ	0.1	82		226		
1988		1901	75	347		2549	PZ	5841	PZ	0.1	136		218	83	-162%
1989		1832	507	260		1159	Avg	4655	Avg	0.1	144		188	137	-37%
1990		1489	858	686		1159	Avg	2742	PZ	0.1	136		202	145	-39%
1991		1353	1209	119		1159	Avg	4655	Avg	0.1	136		232	136	-70%
1992		1084	311	2785		264	PZ	6180	PZ	0.1	110		228	137	-66%
1993		1067	1598	1472		2204	Seep	4655	avg	0.1	142		251	112	-124%
1994		673	2054	2292		3066	Seep	4655	avg	0.1	139		304	144	-112%
1995		1079	837	1045	avg	1749	Avg	4655	avg	0.1	113		304	141	-116%
1995	1st 6 mo	1079	837	1045		1749	Avg	4655	avg	0.1	57		312	141	-121%
	2cd 6 mo	1079	837	1045		1749	Avg	4655	avg	0.1	57		296	141	-110%
											127	t/yr		Avg Removal/yr	-91%

		m^3/yr
MPO	Mill Pond Outflow	65526
BRD	Backfill Raise Ditch	34788
TDD	Tailings Diversion Ditch	8176
EDS	East Dam Seepage	300
WDS	West Dam Seepage	900
Fresh	Fresh Water Run-off	192648

It is estimated that, on average (1987 - 1995), 5.6 t of iron enter Boomerang Lake each year from the various sources. Higher annual iron loads from 1992 to 1995 (5.8 to 11 t/yr^{-}) are due to larger contributions by the Tailings Diversion Ditch and Backfill Raise Ditch.

Higher iron concentrations in Boomerang Lake would be expected if iron entering Boomerang Lake were to remain in solution. It appears that, annually, 47 to 92% (1987 - 1995) of the iron entering Boomerang Lake is precipitated as iron hydroxides and remains in Boomerang Lake.

According to zinc load estimates from the various sources, about 18 t of zinc enter Boomerang Lake each year (1987 to 1995), ranging from 12 to 22 t/yr^{-} over this period. However, between 1987 and 1992, measured annual average zinc concentrations were only 5 to 8 mg/L, but have since steadily increased to 17 mg/L. The relatively constant load, but recent increase in measured Boomerang Lake zinc concentrations, indicates that the zinc source and/or attenuation of the zinc load prior to reaching Boomerang Lake has changed since 1993.

Deepening of the Backfill Raise Ditch, and exposure and drainage from the Backfill Raise Cap and Warehouse seepages, have created a large zinc load which reports directly to Boomerang Lake. This change in hydrology and subsequent zinc load more than off sets the diminishing zinc load from the Mill Pond area. Furthermore, zinc moving in run-off from Mill Pond resides in a series of ponds prior to discharge to Boomerang Lake, in contrast to Backfill raise Ditch drainage, which drains to Boomerang Lake in a matter of hours. Biological Polishing processes in the series of pond receiving Mill Pond outflow may be a more significant process than previously anticipated.

The annual zinc removal estimates for the years between 1987 and 1994 (48 to 78% removal) indicate that there was a net loss of zinc in the Boomerang Lake drainage basin. However, in 1995, it appears that a smaller percentage of the higher zinc load to Boomerang Lake is being removed (33 %). Backfill Raise Ditch directs 8 t (1995) of dissolved zinc each year to Boomerang Lake, since no opportunity for zinc removal, such as by adsorption onto organics, exists along this water course.

Further measures to augment zinc removal in the Boomerang Lake are required to reduce zinc concentrations in Boomerang Lake outflow. The two focus areas are clearly Mill Pond Outflow and Backfill Raise Ditch, given that these two areas represent the major sources of zinc.

According to estimated sulphate loads to Boomerang Lake and measured sulphate concentrations in Boomerang Lake, approximately 14 % of the sulphate load may be removed in the Boomerang Lake drainage basin.

6.5 Sedimentation in Boomerang Lake

Iron removal in Boomerang Lake is likely due to oxidation of dissolved ferrous iron in run-off and seepages and the formation of ferric hydroxide particles which settle to the lake bottom. A monitoring program examining sedimentation rates using sedimentation traps has been ongoing since 1991.

Measured sedimentation rates in Boomerang Lake between 1991 and 1995 range from 0.22 to 7.5 g/m^2/d. On a whole lake basis, these sedimentation rates are equivalent to 121 to 196 t of sediment per year (Table 23).

Based on chemical analyses of sediments collected in the traps, this rate of sedimentation is equivalent to approximately 18 (1994) to 27 (1992) tonnes of iron settling in Boomerang Lake each year, 15% and 18% of iron respectively (Table 23). Since the total annual input of iron to Boomerang Lake is only estimated at 1.5 to 11 t/yr (Table 22a), cycling of iron between the water and sediment phases is strongly suggested.

Table 23: Boomerang Lake Sediment Trap Data for 1991 to 1995.

Period From	To	Days in period	Cum. days in period	Avg. t Sed. in lake during period	Cum. t Sed. in lake during period		Avg. g/m^2/d sed. in lake during period	
15-May-91	23-Jun-91	39	39	22	22		2.3	
23-Jun-91	23-Jul-91	30	69	19	40		2.6	
23-Jul-91	25-Sep-91	64	133	20	60		1.3	
25-Sep-91	13-Jul-92	292	425	73	133		1.1	
13-Jul-92	17-Oct-92	96	521	87	220		3.8	
		Avg. Sedimentation, 1991-1992			154	t/lake/yr		
17-Oct-92	17-Jun-93	243	243	116	116		2.0	
17-Jun-93	12-Sep-93	87	330	57	174		2.8	
12-Sep-93	11-Oct-93	29	359	4.8	179		0.69	
11-Oct-93	17-Jun-94	249	608	13	192		0.22	
17-Jun-94	28-Aug-94	72	680	33	225		1.91	
		Avg. Sedimentation, 1993-1994			121	t/lake/yr		
28-Aug-94	11-May-95	256	256	50	50		0.81	
11-May-95	28-Jun-95	48	304	86	135		7.5	
		Avg. Sedimentation, 1995 pre-PR			162	t/lake/y	4.1	g/m^2/d
28-Jun-95	28-Jul-95	30	30	42.28	42.3		5.9	
28-Jul-95	20-Oct-95	84	114	18.86	61.1		0.94	
		Average Sedimentation, 1995 post-PR			196	t/lake/yr	3.4	g/m^2/d
Precip. Comp.	% Fe	% Zn	% SO4	% Al	t Fe/yr	t Zn/yr	t SO$_4$/yr	t Al/yr
1992 *	18	0.59	8.3	0.42	27	0.91	13	0.6
1994 **	15	0.31	2.5	0.24	18	0.37	3.0	0.3
1995 pre PR #	21	0.38	8.1	0.25	35	0.61	13	0.4
1995 after PR @	26	0.34	3.0	0.40	51	0.66	6.0	0.8

* Average concentrations from assay #'s 4293-4295 (1992)

** Average concentrations from assay #'s 5716,5717 (1994)

Average concentrations from assay #'s 5718,5719. 5720 (1995)

@ Average concentrations from assay #'s 5721,5722, 5723 (1995)

Based on the measured sedimentation rates and the zinc content of collected sediments, approximately 0.37 (1994) to 0.91 (1992) tonnes of zinc are settling to the Boomerang Lake sediments annually. In contrast to iron, apparent zinc removal in Boomerang Lake is much higher than indicated by sedimentation trap data, according to the mass balance calculations presented in Table 23. For these years, 8 (1994) and 13 (1992) tonnes of zinc entering Boomerang Lake were removed prior to the outflow.

According to sedimentation trap data, 13 t and 3 t of sulphate (1992 and 1994, respectively) are removed in sediments settling to the lake bottom. For these same years, the mass balance estimates suggest that 23 t and 1.4 t of the sulphate load are moved prior to Boomerang Lake discharge.

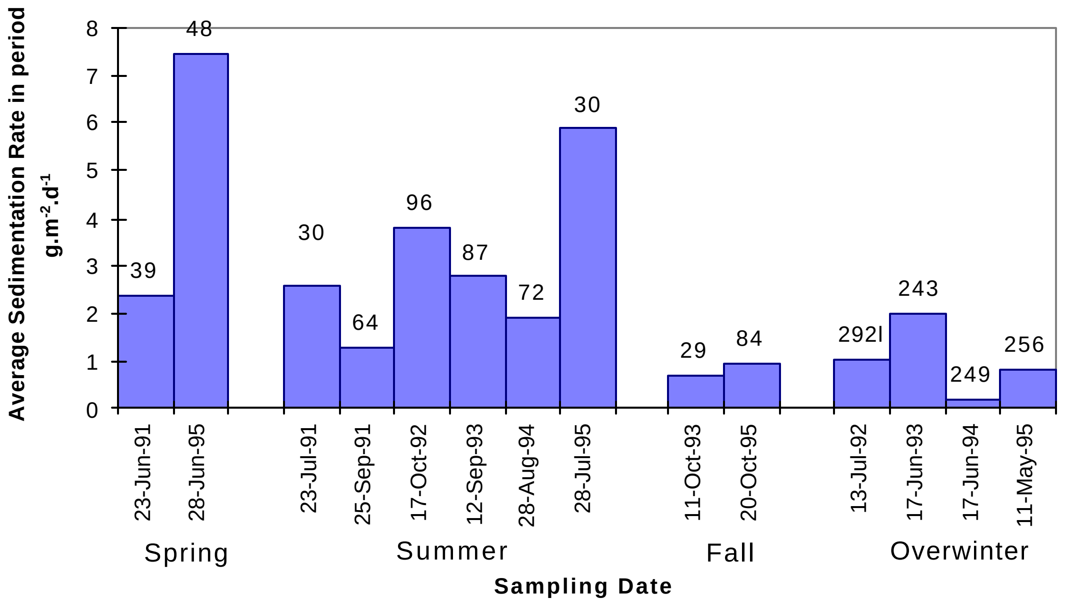
Overall, it appears that the mass balance estimates and removal rates according to sedimentation trap data are somewhat similar for sulphate, and the observed sulphate removal in Boomerang Lake could be attributed to particle formation and settling. For iron, the sedimentation trap data suggests recycling of iron between water and sediments, since measured iron-bearing particle settling greatly exceeds the estimated iron removal according to load calculations.

Since sedimentation trap data indicate much lower zinc removal that the calculated zinc removal according to load estimates, direct uptake of zinc from the water column by sediments is suggested. Boomerang Lake sediment pore water quality, measured using pore water peepers in 1993 (CANMET Report, pg 58), indicated that zinc concentrations in Boomerang Lake sediment pore water are one order of magnitude lower than lake water concentrations. Therefore, a diffusive flux of zinc from the water column into the sediments is occurring, and the sediments may still be serving as a sink for zinc.

This same Boomerang Lake sediment pore water quality data set indicates that dissolved iron concentrations in sediment pore water area about an order of magnitude higher than in the water column, and diffusive flux out of the sediments into the water column is occurring. Calculations based on Fick's equation indicated than 13 to 100 t of iron may flux from Boomerang Lake sediments into the water column, an estimate in the same order of magnitude as those made based on sedimentation rates and composition (18 to 27 t Fe/yr).

In Figure 19, seasonal sedimentation rates are presented for Boomerang Lake, based on sedimentation trap data. Spring and Summer sedimentation rates are typically higher than fall and winter rates. Higher temperatures promoting more active sediment microbial activity (including ferric iron reduction) in spring and summer are probably responsible for higher iron flux from sediment and subsequent ferrous iron oxidation and ferric hydroxide precipitation. Periphytic and phytoplanktonic growth in the ice-free season also contribute to sediment formation and settling.

Figure 19: Boomerang Lake Sedimentation Rates According to Sedimentation Trap Data: Values above bars denote days in situ.



6.6 Boomerang Lake Particle and Sediment Composition

Sedimentation traps solids and Boomerang Lake sediment composition are presented in Table 24 for comparison. Sediment samples are collected using an Ekman dredge, which collects the top 10 to 15 cm of sediment.

The iron concentrations in sedimentation trap solids (14 to 33 %) are consistently higher than the iron concentration in sediment (4.5 %). The processes, dissolution of ferric hydroxide, reduction of ferric iron to ferrous iron and flux of ferric iron from sediment to water, are likely minimizing the accumulation of iron in the sediments.

The zinc concentration in the Boomerang Lake sediment sample is higher than those found in all sedimentation trap solids to date. Zinc present in settled solids is being concentrated in the sediment. It is noteworthy that the zinc concentration in Boomerang Lake sediment trap material shows large variations from 0.1% to 0.5% zinc.

Table 24: Boomerang Lake Sedimentation Trap Solids Elemental Composition, 1994, 1995.

Date	28-Aug-94	28-Aug-94		11-May-95	11-May-95	11-May-95		28-Jul-95	28-Jul-95	20-Oct-95		20-Oct-95
Assay No.	5716	5717		5718	5719	5720		5721	5722	5723		5715
Location	South Bay Boomerang Lake B5 middle	South Bay Boomerang Lake B5 top	Average	South Bay Boomerang Lake B5-1	South Bay Boomerang Lake B5-2	South Bay Boomerang Lake B5-3	Average	South Bay Boomerang Lake B4 middle	South Bay Boomerang Lake B4 bottom	South Bay Boomerang Lake B4 surface	Average	South Bay Boomerang Lake Sediment
Al	2,600	2,260	2,430	1,850	2,500	3,070	2,473	3,540	4,540	3,800	3,960	14,100
Co	16	11	14	15	14	28	19	3	20	8	10	48
Cr	11	11	11	8	16	11	12	62	65	43	57	43
Cu	199	194	197	187	196	238	207	150	298	575	341	299
Fe	142,000	161,000	151,500	331,000	154,000	158,000	214,333	160,000	334,000	279,000	257,667	45,300
Mn	1,170	919	1,045	336	1,080	2,280	1,232	402	509	293	401	734
Pb	60	47	54	28	58	47	44	198	131	87	139	44
S	7,150	9,500	8,325	26,300	8,150	46,100	26,850	9,050	10,900	10,500	10,150	15,200
SO_4	21,450	28,500	24,975	78,900	24,450	138,300	80,550	27,150	32,700	31,500	30,450	45,600
Zn	3,440	2,710	3,075	1,490	3,280	6,570	3,780	1,530	5,440	3,130	3,367	8,620

The concentration of aluminum in the sediment is significantly higher than in sedimentation trap solids. Unlike iron, aluminum can not be reduced to a more soluble form and subsequently is less likely to flux as a dissolved compound from the sediments.

6.7 Biological Polishing Capacity of Boomerang Lake

In June, 1995, 100 truckloads of cut brush were distributed in Boomerang Lake in order to provide substrate for periphytic algal growth. This quality of brush is estimated to equal 127 t of brush (Table 25). In Plate 4, a flat bed with brush is depicted, which is considered representative of a load of brush.

Samples of brush were sampled in August and October, 1995, 49 and 115 days after placement. On average, 0.1 g of algal biomass covered each g of brush, equivalent to 12,600 kg of algal biomass on the 127 t of brush. In Plate 5, the algal growth in 1995 is depicted.

Table 25: Boomerang Lake 1995 periphyton population biomass,elemental composition and contaminant removal capacity.

Assay #	Location	Substrate	Date From	Date To	Days	Branch wt. (g dry wt)	Biomass (g dry wt)	g dw algae/ g dw branch	g/kg/d	Biomass % L.O.I.
5795	B2	Spruce	27-Jun-95	15-Aug-95	49	66	7.0	0.11	2.1	45.8%
5796	B11	Spruce	27-Jun-95	15-Aug-95	49	25	4.4	0.17	3.6	52.7%
5797	B8	Aspen	27-Jun-95	20-Oct-95	115	66	7.4	0.11	0.97	48.0%
5798	Control Bay	Aspen	27-Jun-95	20-Oct-95	115	73	2.6	0.04	0.32	81.9%
	MPO	Aspen	27-Jun-95	20-Oct-95	115	45	3.1	0.07	0.60	
Average								0.10	1.5	

Assay #	Location	Substrate	Date	Zn, %	Fe, %	S, %	Al, %
5795	B2	Spruce	15-Aug-95	0.10%	16%	0.41%	0.25%
5796	B11	Spruce	15-Aug-95	0.12%	14%	0.34%	0.22%
5797	B8	Aspen	20-Oct-95	0.09%	22%	1.6%	0.16%
5798	Control Bay	Aspen	20-Oct-95	0.07%	3.1%	0.62%	0.06%
				0.09%	14%	0.73%	0.17%

1995 Brush Addition to Boomerang Lake				
	100	Truckloads (7x1x3m)	12,600	kg algal standing biomass
	140	brush units/load	11.67	kg zinc
	9.1	kg/brush unit	1,721	kg iron
	127,273	kg of brush	92.3	kg sulphur
Therefore,	12,600	kg of algae, standing biomass	21.5	kg aluminum

Plate 4: An example of the size of a load of brush distributed in Boomerang Lake.

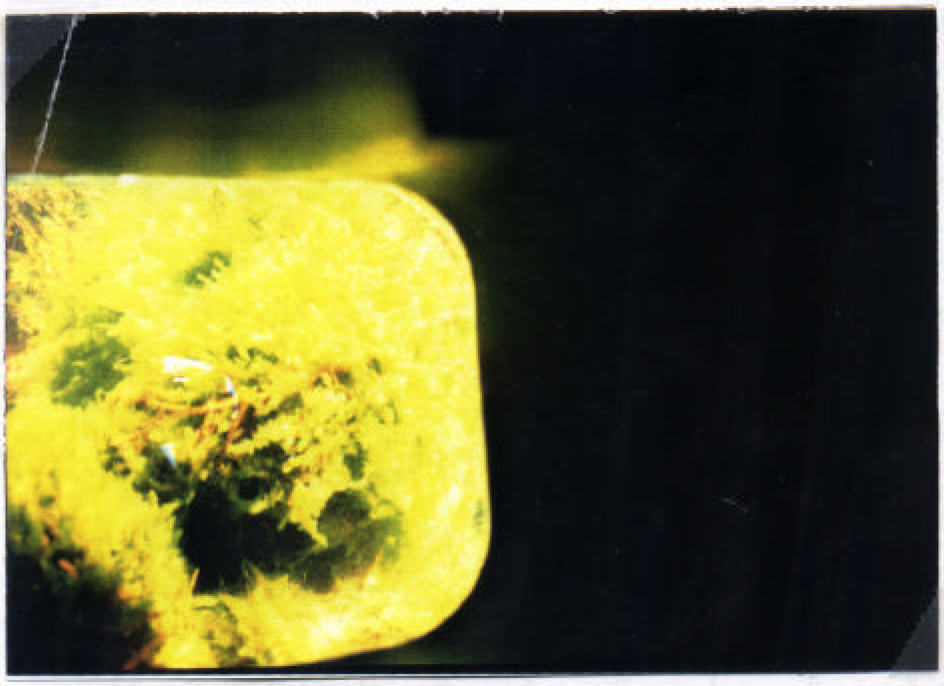


Plate 5: Algal growth in 1995 in Boomerang Lake.

This algal biomass contained on average 14 % iron, 0.09 % zinc, 0.73 % sulphur and 0.17 % aluminum. Therefore, the Boomerang Lake periphyton population's standing biomass contained 1.7 t of iron, but only 12 kg of zinc, 92 kg of sulphur and 22 kg of aluminum.

The measured growth rate of periphyton on the brush was 1.5 g/kg/d. Assuming a growing season of 180 days, 270 g of periphyton could be produced per kg of substrate per year, or 34,364 kg of biomass in the whole lake. Therefore, only 32 kg of zinc can be expected to be directly removed per year by incorporation into algal biomass.

Despite the observed clarity of Boomerang Lake's water column, several species of phytoplankton maintain populations (Table 26). Approximately 2 million phytoplankton cells/L were present in Boomerang Lake surface water in May, 1995, while 482,000 cells/L were present in August 1995. Although lower phytoplankton number were present in August, compared to May 1995, the total phytoplankton biomass was higher in August, due to increases in the number of larger celled species. The biomass measured is possibly relevant to the biological polishing surface area for adsorption. Estimates of productivity of phytoplankton for the lake would result in 4-10 kg of biomass assuming 5 day doubling time for 180 days for growing season.

Table 26: Boomerang Lake Phytoplankton Phyla Cell Density and Biomass, 1995.

Phylum	11-May-95 Total Cells per L	15-Aug-95 Total Cells per L	11-May-95 Total biomass ug/m^3	15-Aug-95 Total biomass ug/m^3
Cyanobacteria	0	0	0	0
Chlorophyta	8,434	44,589	6.2	6.9
Euglenophyta	2,294	25,659	23	107
Chrysophyta	2,118,982	370,526	34	30
Cryptophyta	0	13,170	0	5.0
Pyrrophyta	0	5,820	0	11
Diatoms	691	23,231	0.36	37
Rhodophyta	0	0	0	0
	2,130,401	482,995	64	197

6.8 Phosphate Rock Additions to Boomerang Lake

Natural phosphate rock (Texasgulf) was added to Boomerang Lake in 1992, 1993, 1994 and 1995 (Map 7). Phosphate rock is being added to, first, react with iron in order to form stable ferric phosphate particles which reduce or eliminate iron cycling, and subsequent acid generation in Boomerang Lake. Second, excess phosphate released by the phosphate rock should provide along term supply of phosphate to algal populations in Boomerang Lake.

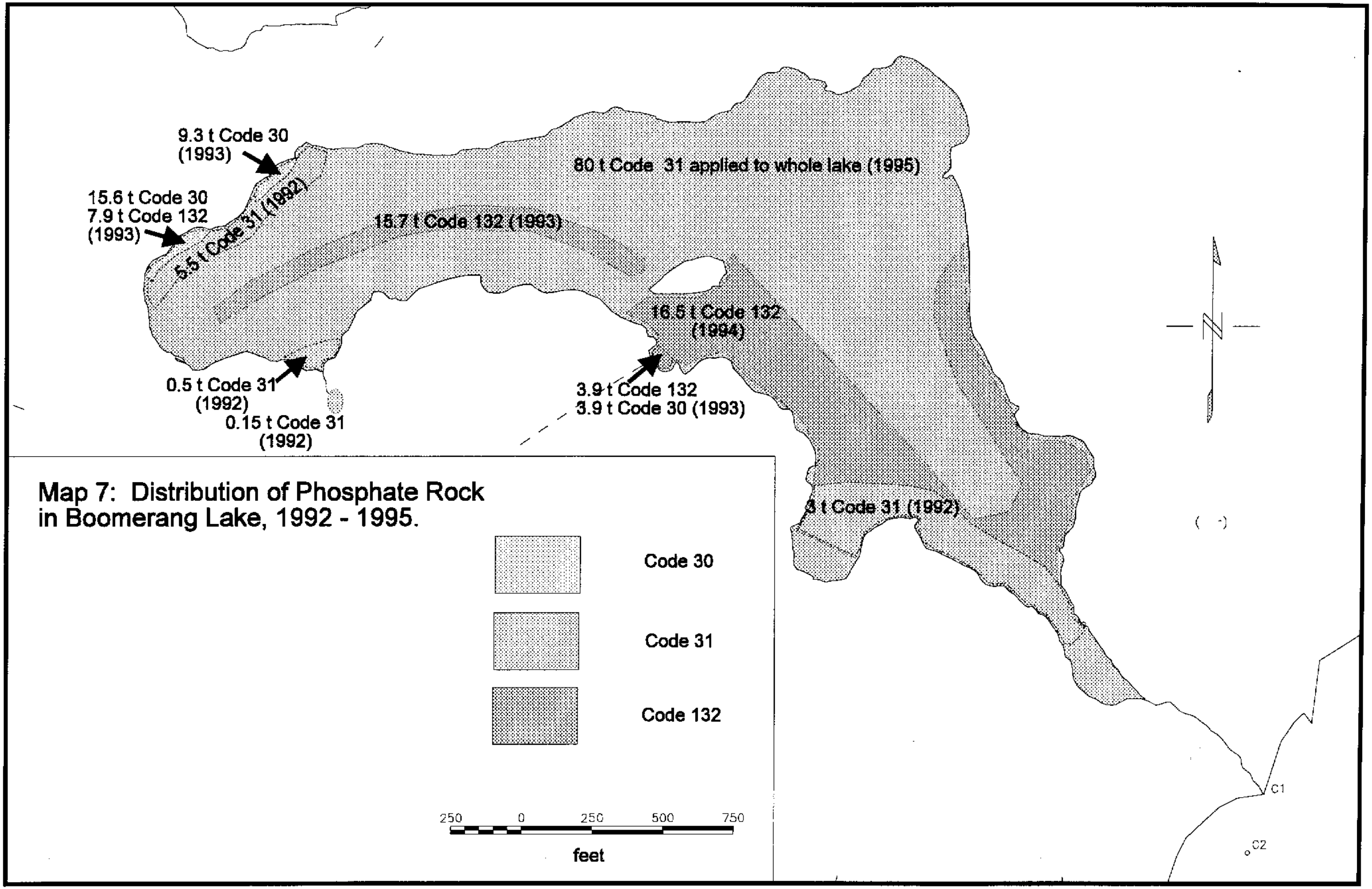
Three types of phosphate rock, Code 30, Code 31 and Code 132, have been added to Boomerang Lake. Code 30 phosphate rock is simply ground phosphate ore, with a fine sand composition. Code 31 is a calcined phosphate rock ground into a fine powder. Code 132 has a similar particle size distribution as Code 30, but has been calcined.

In 1992, 5.5 t of Code 31 was distributed by hand from a boat along the shore between B9 and B10. The bay in the vicinity of B7 received 0.5 t of Code 31. A widespread distribution of 3 t of Code 31 from B11 bay to B2 was also applied.

In 1993, 9.3 t of Code 30 phosphate rock was distributed from a barge in the B10 area close to the East Dam, and another 15.6 t in the vicinity of B9 close to the West Dam. In addition, 7.9 t of Code 132 was distributed in the B9 area. Code 132 (15.7 t) was also distributed along the centre of Boomerang Lake Between B8 and the island. In Backfill Bay, 3.9 t of Code 30 and 3.9 t of Code 132 were applied.

In 1994, 16.5 t of Code 132 were distributed from a barge over the lower third of Boomerang Lake's shores from the island to B2 and then towards Control Bay.

In late June - early July, 1995, 80 t of Code 31 was distributed over the entire surface of Boomerang Lake, using an tank and pump apparatus mounted on barge which slurried the phosphate rock with lake water prior to discharge. In Plates 6 and 7, the barge constructed for this purpose is depicted. The loading of the barge and the distribution system can be seen.



Map 7: Distribution of Phosphate Rock in Boomerang Lake, 1992 - 1995.

Plate 6: Barge used for phosphate rock distribution in Boomerang Lake.

Plate 7: Barge used for phosphate rock distribution in Boomerang Lake.

Based on a limited set of samples, it appears that the Boomerang Lake iron concentration was lower (2.1 mg/L) in the second half of 1995 following phosphate rock addition (Table 22a), compared to the first half of 1995 (2.1 mg/L). The Boomerang Lake zinc concentrations in the second half of 1995 was slightly lower (16 mg/L) than in the first half (18 mg/L Table 22b).

There is some indication that sedimentation rates in Boomerang Lake were relatively high before (May - June, 1995; 7.5 g/m^2/d) and during (June - July, 1995; 5.9 g/m^2/d) application of phosphate rock in 1995, and much lower in the summer and fall of 1995 (July- October, 1995; 0.94 g/m^2/d). The iron, zinc, sulphate and aluminum content of trapped sediments collected in the first half of 1995 were similar to those collected over the summer and fall following application (Figure 19). If sedimentation rates were lower in the second half of 1995, then less dissolved ferrous iron was diffusing from sediments and re-precipitating as ferric hydroxide. At this point it is not clear how effectively the phosphate rock application was, but the sedimentation traps clearly looked free of iron in comparison to the encrustment which was viewed previous to phosphate rock addition. Unfortunately we do not have a photographic record of this.

The pH of Boomerang Lake was higher following the 1995 phosphate rock application, while Iron, zinc, aluminum, sulphate and acidity concentrations were lower (Table 27). it is estimated at 2.3 t of zinc were removed by the phosphate rock application, and 1.4 t of iron, 16 t of sulphate, 0.8 t of aluminum and approximately 27 t of acidity were also removed. It is anticipated that iron cycling in Boomerang Lake will be diminished following application of sufficient phosphate rock for precipitation of iron as phosphates. Sedimentation rate monitoring data in 1996 should indicate whether iron cycling has in fact diminished.

Table 27: Contaminant concentrations in Boomerang Lake in 1994 and in the first and second halves of 1995.

	pH			Zn, mg/L			Fe, mg/L			Acidity, mg/L			Sulphate, mg/L			Al, mg/L		
	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
a: 1994 (n=16)	3.3	3.1	3.6	13	18	11	3.3	14	2.0	89	104	77	304	339	280	2.2	2.9	1.9
b: 1995, 1st 6 mo (n=5)	3.2	2.9	3.7	18	19	18	2.1	3.6	0.80	95	100	92	312	327	290	3.4	3.5	3.3
										(n=4)								
c: 1995, 2cd 6 mo (n=5)	3.8	3.4	4.9	16	19	14	0.74	1.3	0.30	68	88	57	296	296	296	2.6	2.9	2.5
Tonnes element removed																		
d: from [] difference, b-c				2.3	t		1.4	t		27	t		16	t		0.8	t	
e: Sed Trap data(196 t/y)				0.71	t		46	t					11	t		0.6	t	
f: Periphyton (from Table 25)				0.01	t		1.7	t					0.09	t		0.02	t	
g: Sed uptake, by diff.(d-e,f)				1.6	t		-47	t (sed is source)					4.7	t		0.2	t	

7.0 INTERPRETATION OF EM SURVEY DATA FOR MINE SITE AND SOUTH OF TAILINGS / TOWN SITE

7.1 Mine Site

The February 1995 survey was carried out over essentially the same grid that was established in March 1992. This year, two lines were added at both the east and west ends, and the complete grid surveyed with receiver - transmitter coil separations of 10 m, 20 m and 40 m. In the March 1992 survey, only 10 and 20 m coil separations were used. The 1992 results have been presented in Kalin and Pawlowski (1993). Differences between two sets of results are reported on Map 8a (MS-9) and Map 8b (MS-10).

Although the 1995 survey recovered the same 10 anomalies initially identified in 1992, differences in both horizontal and vertical positioning, as well as changes in the levels of conductivity, imply that significant changes have occurred in the ground water regime in the area of the Mine Site. Some of these changes appear to be directly related to the presence of the Backfill Raise Diversion Ditch which was constructed shortly after the 1992 survey.

Review of Anomalies: In total, 10 anomalies have been designated for ease of discussion from "A" to "J", and their sources, if known, are listed below. Except for Anomalies G, H and I, which likely represent portions of one anomalous trend, most other anomalies are one line, or point source, Bull's Eye type anomalies, which rarely extend more than the 50 m distance to the adjacent grid line.

ANOMALY	SOURCE/COMMENTS
A	- directly at the shaft - may reflect contaminated ground water or a cultural source
B	- directly at the concentrator - likely a cultural source

MAP 8a

MAP 8b

C	- concentrate loading area - likely reflects an accumulation of concentrate spilled during the loading of the concentrate trucks during the 12 year life of the mine
D	- Mill Pond anomaly - metal precipitation at entry point of contaminated ground water originating from the mine and mill areas
E	- Warehouse Seep / Backfill Raise Cap anomaly (WHS & BRC) - contaminated ground water discharging at surface at two locations. - survey too coarse to separate the two sources, or surface seeps are joined in the subsurface
F	- probably the site where the mine core was buried - likely acid mine drainage originating from the sulphide rich cores
G	- Tailings Line Spill - acid mine drainage originating from tailings spilled when the tailings pipeline broke during operations
H & I	- probably portions of the same anomaly related to the Backfill Raise spill during operations - Backfill Raise Diversion Ditch may have merged these waters from H & I with anomaly G
J	- Portal Raise Cap anomaly (PRC) - acid mine drainage flowing out of the Portal Raise

A detailed discussion of the anomalies at the mine site can be provided on request, as the data of the survey are compiled in a map catalogue for the site, serving as the baseline data for the monitoring program. The main conclusion can be derived from the different maps presented, since positive conductivity values indicate an increase (since 1992) and a negative value indicates a decrease in ground conductivity.

The following summary describes the changes most effectively.

- Anomalies A, E and J have significantly diminished in intensity and in some cases areal extent.
- Anomaly B appears to have changed very little.
- Anomaly C may have spread laterally to the north at depths of below 20 m, and to the south west, to Mill Pond at shallower depths.
- Anomaly D may have diminished slightly in intensity.
- Anomaly F has increased dramatically in both intensity and size, and appears to be migrating northward to the Backfill Raise Drainage Ditch.
- Anomaly G has increased in both extent and intensity, but at least in part appears to be captured by the Backfill Raise Ditch. Movement northward away from the ditch, but still towards Boomerang Lake, is suggested by the responses on the 10 m survey.
- Anomaly H appears to be contaminated water captured in the western portion of the Backfill Raise Drainage Ditch and is being drained towards Boomerang Lake.
- Anomaly I has almost been eliminated. Some contaminated water may still be draining westward into Mine Bay, while most appears to be draining to Boomerang Lake via the Backfill Raise Drainage Ditch.

Recommendations: Anomaly F is a known source of AMD that appears to be spreading northward. The present coverage is inadequate to the north and requires an additional 100 m of surveying to the north. Total geophysical coverage would be on the order of 300 m to 400 m. Resurveying of the complete grid for monitoring purposes should be performed within the next 3-4 years to monitor the remedial work.

7.2 South of the Tailings/ Town Site

A small grid was established through the former South Bay Mine town site. It extended from the southwest corner of the Tailings southward to the shores of Mine Bay. The survey plan indicates 6 apparently separate "bull's eye" type anomalies (Map 3a to 3d)

The strong anomaly adjacent to the Tailings is referred to as the SOUTH TAILINGS ANOMALY. It was tested at two levels with 2 piezometers. M78A tested the basal aquifer and returned a conductivity of 3084 :S/cm in the ground water. The accompanying piezometer M78B tested a shallower aquifer, and returned a lower conductivity of 1150 :S/cm. The zinc concentrations were 198 mg/L and 1.14 mg/L respectively.

Both these piezometers are located south of the previously constructed Tailings Diversion Trench, and extend to an elevation below the bottom of the trench excavation. Although the South Tailings Anomaly does not appear immediately south on the adjacent line located 100 m to the south, the fact that both holes were drilled 35 m south of L450mS indicates that the plume extends at least 45 m and as much as 90 m south of L450mS. Alternatively, the plume may be trending SSW, connecting with other bull's eye type anomalies on L550mS and L650mS. A better definition of this anomaly/plume could be achieved through fill in lines at 50 m or 25 m spacing. The L650mS ANOMALY is centred at station 100mE on this line. The anomaly is of moderate strength and was tested with M-82 which returned a moderate conductivity of 1086 :S/cm from ground water immediately above the bedrock. The zinc value in this water was 4.08 mg/L.

The origins of this contaminated water is uncertain as geophysically there does not appear to be a link to the South Tailings Anomaly. It is possible, however, that this linkage does exist at a depth that is below the depth penetration capabilities of the EM34 survey. Alternatively, a locally buried pile of AMD generating waste rock may be the source of this anomaly. The 750mS ANOMALY is geophysically weak, allocated immediately north of an area of iron precipitate observed on the shores of Confederation Lake in the vicinity of the old dock. Two piezometers, M77A and M77B tested this anomaly and returned conductivities of only 241 and

480 :S/cm in the ground water. However, the zinc concentrations are noticeably elevated at 3.77 mg/L and 23.4 mg/L respectively. The anomaly source may reflect AMD seepage from a nearby waste rock that was used as fill to stabilize the back yards in this area. In addition, iron cables were encountered in the drilling. The L550mS ANOMALY is located at the eastern end of the line and adjacent to the former tailings pipe line to the pond and road. This anomaly is thought to be the result of seepages generated during a break and spill of tailings at this location. The strong anomaly at the eastern end of L700ms may be cultural cables and other mine debris present at this site, besides road construction. The two weak anomalies on L500mS and L650mS are as yet unexplained but may be either cultural or as previously suggested, linked with the South Tailings Anomaly.

Recommendations: Additional EM34 surveying on 50 m and 25 m line spacing for a better definition/linkage of the 6 "bull's eye" anomalies in this area. If the survey would be conducted during the summer time, possible cultural sources may be identified. Total lines surveying that would be required is estimated at 3-4 km.

In summary, the mine site investigations confirmed that most of the work on the ditching was successful and the usefulness of the diagnostic tool of EM surveys are indicated by both the information gained on the changes in anomalies and the connections which can be made to the piezometer installations. The significance of the town site anomalies has to be evaluated in context of all other areas of the site, as the amount of water leaving in this direction from the tailings, in comparison to that volume leaving towards Mud Lake, is relatively small.

8.0 CONCLUSIONS AND RECOMMENDATIONS

In 1995 many activities took place in South Bay summarized in Table 28. Most of the activities were reported on in detail in the individual sections of the report, with the exception of the GPS Survey, where no details were reported. Unfortunately the GPS could not be completed since a severe snowstorm was approaching the site. The data were processed and the errors which occurred in the two previous surveys where resolved. The initial work with the GPS focussed on the resolution of the errors, and then surveying in the new piezometer locations, hence the snowstorm interrupted the completion of the work.

Table 28: South Bay 1995 Activities List

Date	Activities
January	Mud Lake ARUM Experiment
February	Electromagnetic survey, Mud Lake
March	Electromagnetic survey, completed
April	Boomerang Lake - Phosphate Rock requirement experiment
April	Geochemical Evaluation of Surface and Ground Waters, 1992-1994
April-May	Drilling, piezometer installation, enclosure construction, cattail planting
April 25 - May 9	Installation of ARUM Enclosure and cattail raft construction
May 24-June 1	Arrival of Phosphate Rock
June 27 - 29	Inspection of Phosphate Rock application+Boomerang Lake Outflow Assessment
June 27 - July 25	Starting of brush cutting and placement
June 27 - July 12	Placement of Phosphate Rock 80 tons
July 2 - 5	Completion of Mine Site Ditches
July 4 - 5	Application of potato waste
July 26 - 28	Inspection of Arum Enclosure and cattail growth
August 13-16	Salmo Consulting , MOE and MNR
September 24 - 26	Repair of ARUM Enclosure
October 19 - 22	GPS survey, water sampling

The updated database was submitted under separate cover. It contains now all chemical analysis which have been carried out for all solid and liquid samples. A total of 2268 samples were analysed on the project up to 1996. Such a data set is now suitable for statistical analysis of long term trends, once sampling and seasonal variations in concentrations are delineated. A summary of the 1212 titrations is also ready for processing, determining acidity and alkalinity up to 1995. This is an important background monitoring parameter, to a certain changes in the water quality cost effectively .

In 1994, an environmental impact assessment was commissioned by Talisman to SALMO Consulting, which addressed the accumulations of zinc in the sediments in the receiving waters and their potential effects on benthos. Boojum Research assisted with the field work and provided assistance in the data assembly from historic records.

In summary , the 1995 work , lead to the conclusion, that a broader view has to be taken to identify remedial options. In the past years, a relatively limited view of the site was necessary, in that areas where addressed, which required immediate attention to comply with the regulatory requirements. Although this approach is was effective, it is recommended that in 1996 a broader view of the project is taken. The conclusions are presented in point form and options for evaluation of future remedial actions are outlined to develop at long term strategy for the site. These remedial actions should be viewed in the context of 1993/1994 work, where cost estimates for conventional liming options were obtained. Those options were considered as non-sustainable, due to the sludge disposal problem, which is associated with the conventional approach to treatment.

8.1 Conclusions

! From the hydrological investigations it can be concluded, that a good understanding of the drainage basin and the path of the seepage to Mud Lake has been obtained. The problem of bedrock closure remains to be addressed with ground trouthing of the area at the North end of Mud Lake. It was not possible to model the EM responses based on the reference points of the piezometers in the Gravel pit.

- The hydrogeological investigation resulted in strong recommendations, that in the North end of Mud Lake the installation of piezometers is risky, since a hydrological pressure exists surrounding Mud Lake of undefined magnitude. With the use of non-intrusive measures to determine bedrock depth, at least the existing retaining strata which must exist at the north end of Mud lake, will not be disturbed. Historical information on water quality in the northern part of the total drainage basin, containing NW lake should be evaluated to determine possible contamination of these lakes in the future.

- The differences in elemental concentrations in both surface water and ground water are found to be too large to decern either seasonal or long term trends in water quality. A summary and review of the entire data base is recommended, to arrive at contaminant loadings from the tailings in the various directions within the Mud lake drainage basin. Contaminant pathway / direction and the associated metal loading are fundamental requirements to evaluate the treatment options.

- The results of the porewater peepers placed in the Mud Lake enclosure are indicating that the porewater has no or low zinc concentration in the porewater . This would generally facilitate at least for some time a zinc flux from the water to the sediment. This is similar to the finings for Boomerang Lake, using the sedimentation trap data and Fix's equation to evaluate the zinc distribution in this report.

- The results of the enclosure itself in Mud lake were not encouraging after the first application of the potato waste. This is not unexpected as a cover should be constructed for the enclosure. The construction of a cover will be not a simple task, since iron precipitation of such a structure is difficult to predict which will affect the floatation and the cattail growth in these harsh conditions. Unfortunately extensive discussion with Hoey, at A Quality contracting delayed the installation of such a cover in 1994/1995.

! The phosphate rock treatment in Boomerang lake is giving sings of being effective. The literature suggest phosphate applications to lakes which had been acidified by atmospheric acidification, as an effective means to increase pH in the lake. These new literature reports along with the visual observation of the absence of an iron encrustment on the sedimentation traps , suggest that the project is developing technically the correct direction. At present one can not differentiate between the precipitation rates of the fall season, which are generally lower than those of the summer. Furthermore the increased iron loading from the Backfill Raise ditch have to be considered , in obtaining a measure of the true reduction in iron cycling achieved.

! The EM survey at the mine / mill site did not produce new anomalies compared to 1992 . The survey suggests that essentially with the possible exception of two small anomalies on the mine site, all other plumes of contaminated ground water/surface waters, are migrating towards Boomerang Lake. The two anomalies of concern, migrating towards Confederation lake have decreased in intensity drastically . The decrease is interpreted to be due to but may be related to decrease in ground water flow through this area due to the construction of the Backfill Raise Diversion Ditch.

8.2 Acidic Drainage Remediation Options

The overall conclusion of the 1995 work was that a broader view had to be taken in 1996 in order to address the remedial options for the site in the near future. Some of these options are identified here as part of the conclusions, since they will guide to a large degree the activities in 1996 and 1997. Remediation options that could be considered for application at the South Bay tailings site, to reduce or eliminate the discharge of acidic drainage from the site are listed below in related groups:

! **Flooding the Tailings by e.g.:**

1- natural precipitation, or
2- pumping from Boomerang Lake

Moving the Tailings e.g. to:

3-1 Boomerang Lake
3-2 Underground

These options are given for completeness but will not be considered further given the evaluation carried out in 1993/1994 which produced a potential fall back position for site remediation, but leaves the undesirable economic expenditures without assurances of a sustainable solution to the problem.

! **Plugging Subsurface Pathways by e.g.:**

1- grouting, or
2- bacterial biomass, or
3- slurry cut-off wall, or
4- artificial permafrost

Grouting and slurry cut-off walls are likely not only uneconomic options, but also non sustainable options, as the terrain is very difficult to access for construction purposes, due to the floating muskeg in the northern part of the drainage basin. As a first cut a hydrological evaluation is recommended to be carried out to address surface and ground water diversion of freshwater away from the tailings area. In addition the source of the surface water in Decant pond should be delineated clearly .

A second option to be pursued in 1996 , is the evaluation of the feasibility of in-situ treatment of ground water seepage, referred to as the option under bacterial biomass generation. This option is particularly attractive, since it might also be relevant as an option to consider for the Mine/mill site and the underground mine workings. .

- **Covering the Tailings by e.g.:**
  1- vegetation, or
  2- impermeable geofabric, or
  3- clay cover, or
  4- graduated cover (Swedish process)

  Reducing Hydraulic Conductivity of the Tailings by e.g.:
  4-1 Application of $Ca(OH)2$, or
  4-2 Application of $Ba(OH)2$

Essentially all covers have one objective to reduce the permeability of water falling onto the tailings area infitrating into the tailings. . It is recommended that any of these cover options is first evaluated with respect to the hydrological implications, since water from the sky has to go somewhere. This is particularly important in relation to Decant pond , where the source of surface water has to be addressed.