

**A PRELIMINARY ASSESSMENT  
OF SUBAQUEOUS TAILINGS  
DISPOSAL IN ANDERSON LAKE,  
MANITOBA**

**MEND Project 2.11.1b**

**March 1990**

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# **A Preliminary Assessment of Subaqueous Tailings Disposal in Anderson Lake, Manitoba**

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**Prepared for and Funded by:**

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Mines and Petroleum Resources  
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## EXECUTIVE SUMMARY

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A preliminary field assessment of the effects of subaqueous disposal of tailings in Anderson Lake, Manitoba was conducted as part of the Mine Environment Neutral Drainage (MEND) program. The lake has received about 7.5 million tonnes of tailings since 1979 from the Snow Lake mill operated by Hudson Bay Mining & Smelting Co., Ltd. The mill processes copper-lead-zinc ore from four nearby underground mines. Tailings are discharged into the lake through a floating pipe, which is regularly moved to prevent tailings buildup.

The lake is a small, Precambrian Shield waterbody, with high biological productivity (meso to eutrophic conditions). Historically, it has been considered a dead lake due to the limited fisheries resources. The lake is essentially land-locked with minimal inflows and outflows. A dam with a control discharge structure has been installed at the outlet, and has increased lake area. However, due to tailings deposition, the overall lake volume has decreased. The lake is shallow (mean depth = 2.1 m) with a maximum depth of 6.7 m. No thermocline was observed in the water column, but dissolved oxygen concentrations were markedly decreased within 0.5 m of the bottom.

The lake is characterized by higher conductivity, dissolved solids, sulphate concentrations and increased hardness since tailings discharges have begun. The pH has generally decreased. Dissolved metal concentrations and turbidity have increased in the area near the discharge. Inflows from the Anderson mine area are characterized by low pH, high conductivity and dissolved solids, low alkalinity, high sulphate and reactive silicate concentrations, higher chloride concentrations and high dissolved metal concentrations.

Metal concentrations in the lake sediments have been greatly increased. The sediment stations near the outfall show metal levels comparable to fresh tailings samples. Stations where tailings have been deposited in the past are developing an organic layer that is biologically active. Detailed petrographic, X-ray diffraction (XRD), X-ray fluorescence (XRF), particle size and leaching analyses were performed to characterize the sediment and tailings.

Sediments were characterized into two major groups, those predominantly composed of tailings materials (the tailings, and Stations 1, 2, and 4) and those primarily composed of organic material (Stations 3, 5 and 7). XRD work indicated higher abundance of quartz, feldspar, pyrite, micas and calcite in the tailings dominated samples. The actual tailings were composed of 55 % pyrite, 4% pyrrhotite, 2% sphalerite and minor portions of hornblende, biotite, chlorite, carbonate and other silicates. Minor to trace amounts of chalcopyrite, arsenopyrite and galena were found. The amount of tailings estimated in the organic samples varied with the method used. The organic samples contained framboidal pyrite and fine specks of angular pyrite, while tailings dominated samples have similar compositions and grain size to the tailings and were virtually unmodified. Mineral compositions assumed from XRF analyses indicated the presence of various concentrations of quartz, plagioclase feldspar, micas, chlorite, and pyrite. The highest percentages of pyrite were found in the tailings and tailings-dominated samples.

Sequential extractions of a tailings-dominated sample (Station 2) indicated generally low metals availability, with most of the metals associated with the oxidizable and residual phases. These observations are in agreement with the high sulphide content of the sample. The results suggest that the metals are generally non-labile and that significant metal release would require strongly oxidizing and acidic conditions to exist. Present conditions in Anderson Lake are not conducive to such release; hence, the potential for metal transfer from sediments to the aqueous environment, in levels that are toxic, is considered to be minimal. With exception, however, was the behaviour of zinc. Due to the high total Zn concentrations, low releases of Zn occurring in the other phases indicated a potential for detectable release under natural conditions. Cadmium, copper, lead and nickel were also released in low quantities in phases other than the oxidizable and residual phases. Acid-base accounting of the tailings sample indicated a considerable potential for acid generation.

The biota of the lake were examined in considerable detail. Densities of benthic invertebrates were low but comparable to previous studies both in number and species composition. Phytoplankton densities and community structure characterize the lake as mesotrophic. Examination of past phytoplankton communities indicates that more eutrophic conditions existed prior to tailings deposition. Zooplankton densities were highly variable, but were generally lower near the tailings discharge. Zooplankton diversity is comparable to that observed in other Manitoba lakes. Aquatic vegetation of

the lake was mapped and samples collected for metal analyses. Metal levels in *Typha* were generally highest in a tailings seepage area, particularly for arsenic, cadmium, lead and zinc. Outside of the seepage area, concentrations of metals were low except for nickel. Fish sampling confirmed that the fishery resources was limited, as only brook sticklebacks (*Culaea inconstans*) were caught. Tissue concentrations in the stickleback suggest bioaccumulation of copper, lead and zinc. Metal levels in the fish were also significantly higher in populations from the tailings deposition area.

## SOMMAIRE

Dans le cadre du Programme de neutralisation des eaux de drainage dans l'environnement minier (NEDEM), les répercussions de l'élimination subaquatique de résidus miniers dans le lac Anderson au Manitoba ont fait l'objet d'une évaluation sur le terrain. Depuis 1979, environ 7,5 million de tonnes de résidus miniers ont été déversés dans ce lac par l'usine Snow Lake exploitée par la Compagnie minière et métallurgique de la Baie d'Hudson Ltée. Cette usine sert au traitement du minerai de cuivre/plomb/zinc tiré de sept mines souterraines du voisinage. Les résidus sont rejetés dans le lac au moyen d'un tuyau flottant, qui est déplacé régulièrement de façon à empêcher leur accumulation.

Ce lac, qui est une petite pièce d'eau du Bouclier précambrien, possède une activité biologique élevée (les conditions y sont mésotrophes ou eutrophes). Il y a longtemps qu'il est considéré comme mort vu le peu de poissons qu'on y rencontre. Le renouvellement de ses eaux est nul car il est entouré de terres et les débits d'entrée et de sortie sont minimaux. À la sortie du lac, on a construit un barrage permettant d'en régler le débit, ce qui a augmenté sa superficie. Toutefois, la sédimentation des résidus miniers a entraîné une diminution de son volume global. Ce lac est peu profond : en moyenne, 2,1 m et au maximum, 6,7 m. Aucune thermocline n'a été observée dans la colonne d'eau, mais on a noté que la concentration d'oxygène dissous augmentait d'une façon marquée à 0,5 m du fond.

Depuis qu'on a commencé d'y déverser des résidus miniers, ce lac se distingue des autres par une conductivité, des concentrations de matières solides dissoutes et de sulfates, et une dureté accrues; son pH a, en général, baissé; les concentrations de métal dissous et la turbidité ont augmenté près de la sortie. Les eaux provenant de la zone de la mine Anderson sont caractérisées par un pH bas, une conductivité élevée, une faible alcalinité et de fortes concentrations de matières solides dissoutes, de silicates réactifs, de sulfates et de métaux dissous, et des concentrations de chlorures supérieures.

Les concentrations de métaux dans les sédiments lacustres ont beaucoup augmenté. Au poste d'échantillonnage situé près de la décharge, les teneurs en métaux des sédiments sont comparables à celles des échantillons de résidus miniers frais. Aux postes où les dépôts miniers datent de longtemps, une couche organique biologiquement active est en train de se former. Des études pétrographiques et des analyses détaillées ont été effectuées pour caractériser les sédiments et les résidus miniers, tant par diffraction que par fluorescence des rayons X (DRX et FRX) et aussi bien d'après la taille des particules que les constituants des lixiviats.

Les sédiments ont été répartis en deux groupes principaux : ceux constitués surtout de matières appartenant aux résidus (les résidus eux-mêmes et les échantillons prélevés aux postes 1, 2 et 4) et ceux composés principalement de matières organiques (postes 3, 5 et 7). Des études par DRX ont montré des teneurs plus élevées en quartz, en feldspath, en pyrite, en micas et en calcite dans les échantillons constitués surtout de résidus. Les résidus eux-mêmes se composaient de pyrite (55 %), de pyrrhotite (4 %), de sphalérite (2 %) et, en faibles proportions, de hornblende, de biotite, de chlorite, de carbonates et d'autres types de silicates. On a aussi trouvé de faibles quantités jusqu'à des traces de chalcoppyrite, d'arsénopyrite et de galène. L'évaluation des quantités de résidus présentes dans les échantillons organiques varient selon la méthode d'analyse utilisée. Les échantillons organiques renfermaient de la pyrite framboïdale et de fins grains de pyrite angulaire. Quant aux échantillons constitués surtout de résidus, leur composition et leur granulométrie étaient semblables à celles des résidus et ils n'étaient à peu près pas modifiés. Les

analyses par FRX ont permis de proposer des compositions minérales correspondant à la présence de diverses concentrations de quartz, de plagioclases, de feldspath, de micas, de chlorite et de pyrite. Les proportions les plus élevées de pyrite ont été trouvées dans les résidus et les échantillons constitués surtout de résidus.

D'après les résultats de l'extraction séquentielle d'un échantillon constitué surtout de résidus (poste 2), les métaux sont généralement peu disponibles et se retrouvent la plupart du temps dans les phases oxydables et résiduelles. Ces observations sont compatibles avec les fortes teneurs en sulfures trouvées dans les échantillons. Il semblerait donc, en général, que les métaux sont non labiles et qu'il faudrait des conditions fortement oxydantes et acides pour qu'il y ait libération de quantités importantes de métaux. Les conditions qui prévalent dans le lac Anderson ne sont pas propices à ce phénomène; par conséquent, on considère minimale la probabilité que des teneurs toxiques en métaux passent des sédiments au milieu aqueux. Toutefois, le zinc est l'exception qui confirme la règle : en effet, étant donné les fortes concentration de Zn total présentes, l'observation d'un dégagement de faibles quantités de Zn dans les autres phases lors de l'extraction séquentielle indiquait la possibilité de libération de quantités décelables dans les conditions naturelles. En outre, de faibles quantités de cadmium, de cuivre, de plomb et de nickel étaient aussi libérées ailleurs que dans les phases oxydables et résiduelles. Le bilan acide-base des échantillons de résidus indiquait un fort potentiel générateur d'acide.

Le biote du lac fut étudié de façon fort détaillée. Les populations d'invertébrés benthiques étaient peu denses, mais comparables à celles observées lors d'études précédentes, tant au point de vue du nombre que des espèces qui les composaient. D'après la densité et la structure des populations de phytoplancton, le lac serait mésotrophe. L'examen des populations plus anciennes montre que des conditions plus eutrophes ont existé avant la sédimentation des résidus. La densité du zooplancton était fort variable, mais elle était généralement plus faible près des dépôts de résidus. La diversité du zooplancton était comparable à celle observée dans les autres lacs du Manitoba. On a dressé la carte de la végétation du lac et des échantillons ont été prélevés pour fins de dosage des métaux. Les teneurs en métaux en *Typha* étaient en général supérieures dans les zones d'infiltration des résidus, en particulier dans le cas de l'arsenic, du cadmium, du plomb et du zinc. À l'extérieur de ces zones, tous les métaux, à l'exception du nickel, étaient peu concentrés. L'échantillonnage des poissons a confirmé la limitation des ressources, car seules des épinoches à cinq épines (*Culaea inconstans*) furent capturées. En outre, les teneurs en métaux étaient aussi notablement plus élevées chez les poissons pêchés dans la zone de sédimentation des résidus.



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A number of people have made substantial contributions to this project. Clem Pelletier of Rescan Environmental Services Ltd. (Rescan) provided overall project coordination and senior review of the report. Bill Duncan (Rescan) and Shirley French were responsible for water quality sampling, sediment and core sampling, biota and lake morphology work.

Rescan personnel involved in various aspects of the project, included Paul Davidson who assisted with drafting and Janice Kukurudz who patiently wordprocessed this document. Bill Duncan, Gary Birch, Diane Howe and David Flather (Rescan) were responsible for reporting of this work.

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## **1 - Introduction**

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## 1.0 INTRODUCTION

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Surficial deposition of sulphide-bearing mine wastes has been a common disposal practice used by many mines. However, subsequent oxidation of the sulphidic waste can result in the generation of highly acidic drainage waters with concomitant leaching of heavy metals. The deleterious effects on the receiving environment associated with such practices are well documented. The need for environmentally safe, yet economically feasible, disposal of mine wastes has resulted in considerable efforts being directed toward identifying more benign disposal alternatives. Alternatives to land-based disposal of mine waste rock and tailings are based primarily on limiting the exposure of the material to oxygen and the inhibition of autotrophic iron and sulphide oxidizing bacteria. Subaqueous deposition of mine wastes has been identified as a particularly promising disposal alternative. In theory, underwater disposal of reactive mine wastes should suppress sulphide oxidation, however data in support of the above supposition, particularly for freshwater disposal, is sparse. Moreover, a dearth of information exists on the post-depositional chemical behaviour of submerged tailings and the associated impacts on the surrounding aquatic ecosystem. To alleviate these deficiencies in knowledge, a two-phase study of Anderson Lake was commissioned as part of the Mine Environment Neutral Drainage program. The initial phase was a preliminary assessment of existing lake conditions, while the second phase was to address, in more detail the geochemical conditions related to tailings disposal. Reported here are the results from this initial phase. As Anderson Lake is actively being used for subaqueous disposal of reactive mine wastes an opportunity existed for the examination of the early diagenetic behaviour of the submerged tailings as well as documenting changes to the associated biotic communities.

### 1.1 Objectives and Scope

Given the above identified gaps in knowledge concerning the efficacy of freshwater subaqueous disposal, the several fold objectives of the present study were as follows:

- To define the present environmental conditions of Anderson Lake;



- To review and compare the pre-depositional environment with the present in order to identify the impacts, if any, that occurred as a result of implementing subaqueous tailings disposal; and
- To evaluate the environmental stability of submerged tailings and assess their contribution, both present and future, to the metals loading in the biotic and aqueous environments.

The field and laboratory study designed to meet the above objectives included a general physical and chemical limnological survey, a biological survey to document the aquatic fauna and flora and geochemical analyses of lake sediments. Preliminary characterization of fresh and subaqueous tailings and sediments involved chemical, mineralogical, elemental, petrographic and particle size analyses. Particular attention was given to identifying mineralogical differences between deposited and fresh tailings in order to assess the stability of underwater tailings. Metals stability and partitioning between the sediment and aqueous-phase was examined through sequential multiple extractions. Although detailed sediment pore-water analyses was not in the scope of the present work, the second phase of the Anderson Lake study (spring 1990) will utilize such analyses to more clearly define the post-depositional reactivity of the tailings deposits.

### **1.2 Background**

Prior to tailings disposal which started in 1979, Anderson Lake was used as a water supply for the Anderson mine located adjacent to the lake. The lake presently receives drainage from the since shut-down Anderson mine area. Tailings have been used to build roads adjacent to the north side of the lake. Drainage from these tailings and from the mine site has become acidic affecting adjacent vegetation. Recreational use of the lake is, and has been, minimal as the lake has been regarded by local people as dead. A typical small, shallow Precambrian Shield lake, Anderson Lake has high productivity with a thick layer of organic muck covering the bottom sediments. The lake historically has contained few fish.

Several limnological surveys of varying degrees of detail were conducted on Anderson Lake prior to tailings deposition (Allard 1965, Munro and Ruggles 1977, Bridges 1977). Allard's study (1965) collected limited water quality, fisheries and benthic invertebrate

data as part of an assessment of the suitability of the lake for introduced exotic game fish. No fish were caught in gill nets, however, brook sticklebacks (*Culaea inconstans*) were caught using Rotenone. Dredge sampling indicated low numbers of invertebrates including amphipods, chironomids, *Chaoborus*, snails and sphaerid clams. Water quality analyses indicated the lake had an average pH of 6.8 to 7.4, dissolved oxygen levels ranging between 5.4 to 14.0 ppm, bicarbonate alkalinity (1.9 to 2.7 mg/L as CaCO<sub>3</sub>) and Secchi disk transparency of 1.3 m.

Hudson Bay Mining and Smelting Co. Ltd. (HBMS) carried out a baseline survey of the lake prior to tailings deposition (Bridges 1977). This survey examined physical and chemical limnology, benthos, zooplankton, phytoplankton, and fish. The lake was described as essentially land-locked, receiving minimal input from surface runoff, swamp drainage and precipitation. The maximum lake depth was given as 7.0 m, with a mean depth of 2.4 m, surface area of  $2.4 \times 10^6$  m<sup>2</sup> and a volume of  $5.8 \times 10^6$  m<sup>3</sup>. The shoreline length was 13.2 km with a shoreline development factor of 2.4. Sampling was carried out in May of 1977. Water quality analyses included pH (8.1 to 8.3 pH units), dissolved oxygen (9.9 to 11.1 ppm), conductivity (225 to 250  $\mu$ mhos/cm), turbidity (1.2 to 1.9 FTU), Secchi disk transparency (1.0 to 1.5 m), and other parameters (chloride, sulphate, S<sub>2</sub>O<sub>3</sub> and acidity/alkalinity). Six water stations were sampled for heavy metals (Cu, Zn, Fe, Pb, Ca, Cd, Mg, Ni and Co) and had concentrations similar to other Precambrian Shield lakes. Four bottom sediment stations were sampled and analyzed for heavy metal content (Al, Cu, Zn, Fe, Pb, Cd and Hg), silica and ignition loss.

A net tow revealed the presence of a plankton community dominated by rotifers and diatoms. Of the four stations sampled for benthic macroinvertebrates only one station had any invertebrates (13 chironomids). No fish were caught in the gill nets, but lake chub (*Couesius plumbeus*) and brook stickleback were caught in minnow traps.

The lake was classified as mesotrophic approaching eutrophic status and deemed to become more eutrophic due to natural causes. Due to the lack of fish, the lake had not been utilized for sporting purposes.

Another brief limnological survey was carried out by the Environmental Protection Service (EPS) as part of a federal government baseline study of potential impacts of tailings input (Munro and Ruggles 1977). Data collected included surface water chemistry, sediment chemistry and qualitative collections of benthic macroinvertebrates,

plankton and fish. Sampling was carried out on June 3, 1977. Water quality data included pH (7.5 to 8.1 pH units), conductivity (210  $\mu\text{mhos/cm}$ ), alkalinity (56 to 62 mg/L  $\text{CaCO}_3$ ), and other parameters. Heavy metal concentrations in the water were generally below detection limits except for iron, lead, and zinc. Limited sediment sampling was carried out and analyzed for heavy metals. Sediment metal concentrations were generally low with some elevation of zinc, cadmium and mercury concentrations near the mine seepage area. Benthic sampling revealed a greater diversity of macroinvertebrates in this study with 8 families represented. The dominant benthic organisms were *Chaoborus*, chironomids, snails and clams. Qualitative plankton sampling revealed more diversity of zooplankton and phytoplankton taxa than the early spring sampling by HBMS. Gill netting produced no fish but minnow traps caught large numbers of brook stickleback.

Since the start up of the Snow Lake mill in 1979, HBMS has conducted regular water quality surveys of Anderson Lake. These surveys were conducted two or more times per year between 1979 and 1985 for various selected parameters which regularly included pH, suspended solids, turbidity, sulphate, copper and zinc. Other parameters measured irregularly included thiosalts, acidity/alkalinity, dissolved oxygen, Secchi disk transparency, chloride, lead, nickel, cadmium, conductivity, and hydrogen sulphide. Sampling has occurred periodically since 1986 for metals, pH, and suspended solids.

The present study examined Anderson Lake, Manitoba, which currently receives high sulphide tailings from the Snow Lake mill operated by Hudson Bay Mining and Smelting Co. Ltd. (HBMS). The mill, rated at 3,450 mtpd, receives various copper-lead-zinc ores from four underground mines in the surrounding area. During the last decade, since 1979, about 7.5 million tonnes of tailings have been deposited into Anderson Lake.

Discharge to the lake is through a movable, floating Sclair pipe (30 cm diameter). The disposal location varies seasonally with shallower depths (3 m) being selected in the summer and greater depths in the winter (up to 6 m). This system prevents buildup of tailings in any one area and helps to maintain a water depth of 0.6 m over the deposited tailings. Tailings initially deposited in the lake maintained a 25 - 30° angle of repose, and did not readily disperse due to the quiescent lake conditions and the sharp drop from the discharge outfall. Initially, some mine waste and tailings built up above the lake surface and had to be moved in order to keep the deposits submerged.

## **2 - Study Area and Methods**

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## **2.0 STUDY AREA AND METHODS**

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### **2.1 Study Area**

The study area is located in central Manitoba (Figure 2-1) near the town of Snow Lake, Manitoba. Anderson Lake is approximately 2 km south of the townsite. Anderson Lake is an active subaqueous tailings disposal site receiving tailings through a moveable floating Sclair pipeline into approximately 3 to 6 m of water.

### **2.2 Sampling Stations**

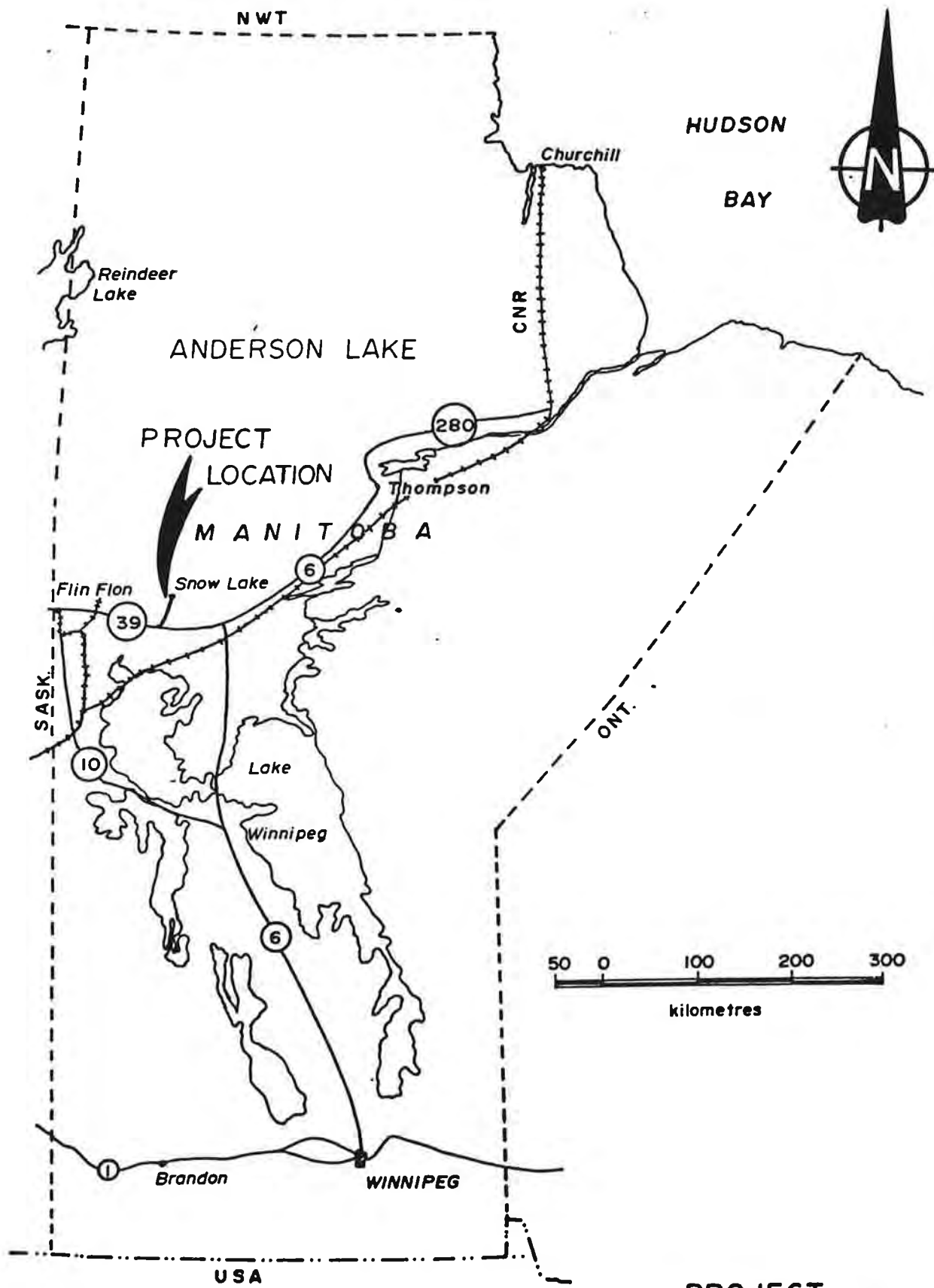
Eight primary stations (Station 1 to Station 8) were located along the central east-west axis of Anderson Lake (Figure 2-2). Water, sediment, benthos, zooplankton and phytoplankton were collected at each station, except for Station 8 where sediments and benthos were not collected as the bottom was composed of peat and twigs. Dissolved oxygen and temperature profiles and Secchi disk transparency were measured at each station. Seine netting was carried out at two sites (SN1 and SN2) on the north side of the lake. Four gill net sites (GN1 to GN4) were employed over the east side of the lake.

Three natural inflow Stations (I1 to I3) and five culvert Stations (C1, C2, C2A, C3 and C4) were sampled. Outflow from the lake is via a controlled discharge structure located in the dam at the east end of the lake. No discharge was occurring during the field trip because of drought conditions which have existed for several years prior to the study.

### **2.3 Study Methods**

#### **2.3.1 Lake Morphometry**

A bathymetric map of Anderson Lake was produced from echo soundings along defined transects using a Furuno Mark II depth sounder. From the soundings and bathymetric map, a number of morphometric parameters were determined including area, volume, length, mean breadth, mean depth, maximum depth, shoreline length and shoreline development factor (Hutchinson 1957). Lake volume was determined from measuring the area under the lake's hypsographic curve. The depth in the area of active discharge is highly variable and constantly changing making accurate contours in this area difficult

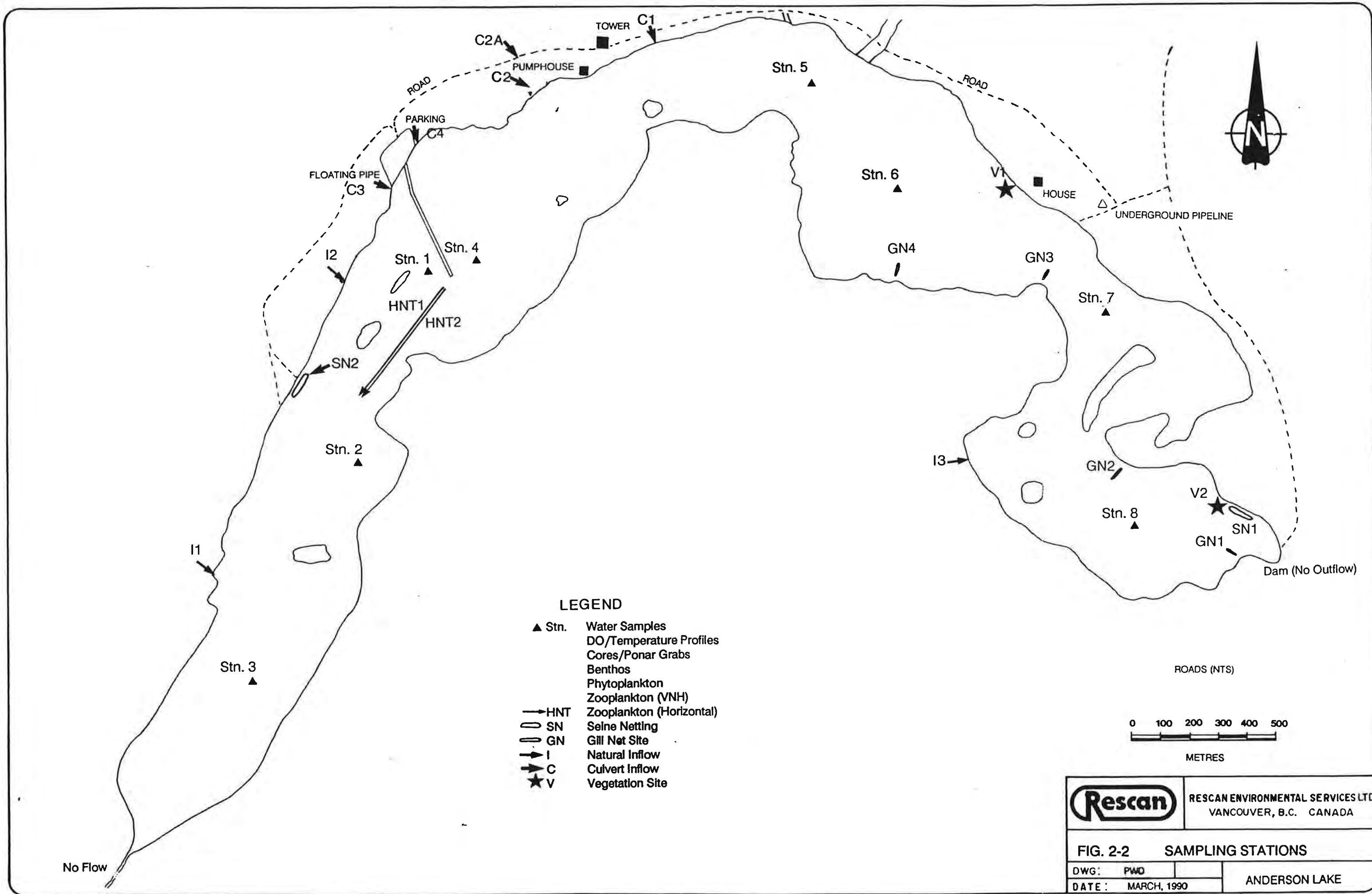


**PROJECT  
LOCATION MAP**

Figure 2-1



DB-20022



**LEGEND**

- ▲ Strn. Water Samples  
DO/Temperature Profiles  
Cores/Ponar Grabs  
Benthos  
Phytoplankton  
Zooplankton (VNH)  
Zooplankton (Horizontal)
- HNT Zooplankton (Horizontal)
- SN Seine Netting
- GN Gill Net Site
- I Natural Inflow
- C Culvert Inflow
- ★ V Vegetation Site

<b>Rescan</b>		RESCAN ENVIRONMENTAL SERVICES LTD. VANCOUVER, B.C. CANADA
<b>FIG. 2-2 SAMPLING STATIONS</b>		
DWG: PWD		ANDERSON LAKE
DATE: MARCH, 1990		

to illustrate. Muskeg islands have been formed of organic bottom sediments displaced by the weight of the dense tailings deposited in the lake. The location of these islands can also change over time.

### 2.3.2 Water Quality

Lake water samples were collected on August 28, 1989 at the eight primary stations (Figure 2-2) using a Teflon lined 5 L Go-Flow water sampler. Samples were taken at four (4) sample depths where possible (0.5 m below the surface, 1.7 m, 2.7 m and at the bottom). The 1 L polyethylene sample bottles and caps were rinsed with sample water prior to filling. Bottles were carefully filled to the top using a Teflon tube attached to the water sampler to minimize air contact. No preservatives were added to the 1 L bottles which were maintained at 4°C during shipping and handling. Grab water samples were collected from the inflow and culvert sites by submerging the sample bottle directly into the water flow. Rate of inflow (L/s) was measured by determining the time to fill a container of known volume.

Water samples were analyzed by Analytical Services Laboratories Ltd. (ASL) of Vancouver, B.C. Samples were analyzed for physical parameters including pH, specific conductivity, turbidity (NTU), total dissolved solids and total suspended solids (volatile and fixed), as well as anions and nutrients including alkalinity, sulphate, chloride, reactive silica, total phosphorus, nitrate/nitrite, ammonia, total dissolved nitrogen and total organic carbon using standard methods (APHA 1985).

Dissolved metals were analyzed by various atomic absorption and emission spectroscopy methods as follows:

- Inductively coupled argon plasma (ICP) emission spectroscopy for higher concentration elements
- Graphite furnace atomic absorption spectroscopy for low concentration element
- Hydride generation atomic absorption spectroscopy for arsenic
- Cold vapour atomic absorption spectroscopy for mercury



### 2.3.3 Sediment and Tailings

Sediment cores were collected at seven stations (Stations 1 to 7; Figure 2-2) on August 25, 1989 using an 8.8 cm OD lightweight gravity corer (Pedersen et al. 1985). Cores collected in the polycarbonate core liner were capped to retain interface water and sealed with tape. Cores were stored upright at 4°C during transportation and storage, and were subsequently processed at the University of British Columbia (UBC), Department of Oceanography, Vancouver, B.C. The top 2 - 3 cm of each core was removed, freeze-dried, mixed and split in half. One half was ground to -200 mesh in a tungsten carbide mill, while the other half was left intact.

Petrographic analysis for mineral identification of intact core samples using polished thin sections were performed by Dr. Jeff Harris, Harris Exploration Services Ltd., North Vancouver, B.C.

A multiple extraction leach test was performed on the intact core material from Station 2 by ASL. The test used was similar to those utilized in other aquatic studies (Forstner and Wittman 1983, Engler, Brannon and Rose 1974). In a multiple extraction, the mildest extraction is completed first, and the remaining solids are recovered by filtration and washed. Subsequent extractions are conducted until the sample has been subjected to an entire pre-determined series of extractants. The following extractants were used, and are identified in terms of their anticipated reaction with metals in the solids, as follows:

#### Water Soluble Phase

Distilled water extractant;

#### Exchangeable Cations

1 molar ammonium acetate at pH 7;

#### Weak Acid Soluble Phase

1 molar sodium acetate at pH 5;

#### Easily Reducible Phase

0.1 molar hydroxylamine hydrochloride + 0.01 molar nitric acid at pH 2;

#### Moderately Reducible Phase

0.2 molar ammonium oxalate + 0.2 molar oxalic acid at pH 3;

**Difficultly Reducible Phase**

0.5 molar sodium citrate + 0.1 molar sodium dithionite;

**Oxidizable Phase**

30% hydrogen peroxide + 1 molar ammonium acetate acidified to pH 2.5 with nitric acid;

**Total Extractable**

Nitric/perchloric/hydrofluoric acid digestion.

Selected ground core samples for X-ray diffractometry (XRD) analysis were pressed in a random orientation into a rigid disk held in an aluminum planchet. Disks were scanned using a Phillip PW1775 X-ray diffractometer at UBC. A curved graphite crystal monochromator, an automated divergent slit, a 1° scatter slit, a gas proportional counter and CuK $\alpha$  radiation were used in the analysis. XRD analysis was also performed on all samples by Cominco Exploration Research Laboratory, Vancouver, B.C. by Dr. J. Harris. Core samples were ground in acetone and dispersed on a glass slide. Samples were scanned using CuK $\alpha$  radiation at 24mA and 40kV. Scans extended from 2 $\theta$  angles of 4° to 60° for the tailings, Stations 1, 2 and 4; and from 4° to 34° for Stations 3, 5, 6 and 7.

Ground core samples were used for x-ray fluorescence analysis. X-ray fluorescence (XRF) analyses were performed at Cominco Exploration Research Laboratory, Vancouver, B.C. by Dr. J. Harris.

Carbon and nitrogen analysis were measured using Carlo-Erba 1106 CHN Elemental Analyzer at UBC in which the ground sample is combusted in a stream of oxygen and the evolved CO<sub>2</sub> and N<sub>2</sub> determined by thermal conductivity. Carbon measurements represent total carbon which includes carbonate carbon.

Sulphur analyses were done using a Carlo-Erba NA-1500 CNS Analyzer at UBC. The sample was combusted in oxygen and the SO<sub>2</sub> produced was detected by thermal conductivity. The high sulphur content of the samples swamped the N and C channels of the analyzer which required the analysis of these elements by the 1106 CHN instrument.

Bulk sediment samples were collected using a petite ponar dredge from the seven stations on August 26 and 27, 1989. The top 2 cm layer of sediment was collected for

particle size and metals analyses. Particle sizing analysis was performed by Golder and Associates Ltd., Vancouver, B.C. using a hygrometer method in accordance with ASTM designation D422-72 "Standard Methods for Particle-Size Analysis of Soils".

Metals analyses of the bulk sediments were performed by ASL. Sediments were homogenized and representative portions analyzed. Moisture was determined gravimetrically after drying the sample for 12 hours at 103 °C. Subsamples for metals were digested using a combination of nitric and hydrochloric acids, bulked to volume with deionized-distilled water and metals concentrations in the extract determined. Cadmium and lead were analyzed by direct flame atomic absorption spectrophotometry (AAS). Arsenic was determined by hydride generation AAS, while mercury was determined by cold vapour AAS. Aluminum, antimony, calcium, chromium, cobalt, copper iron, magnesium, manganese, molybdenum, nickel, vanadium and zinc were analyzed by ICP emission spectroscopy.

A sample of tailings slurry was collected from the end of the discharge pipe on August 26, 1989. The solid and liquid portions of the tailings slurry were separated and an analysis of the supernatant (as per section 2.3.2) and tailing solids performed. Tailing solids were analyzed for metals by ASL and petrographic, XRD and XRF analyses were completed by Dr. J. Harris as described above. Acid-base accounting analysis on the tailing solids was done by Chemex Laboratories Ltd., North Vancouver, B.C. Due to insufficient sample size, particle size analysis of the solids could not be completed.

### **2.3.4 Benthic Invertebrates**

Benthic invertebrate (benthos) samples were collected in triplicate on August 26 and 27, 1989 at seven stations (Stations 1 to 7, Figure 2-2) using a petite ponar dredge (0.023 m<sup>2</sup>). Samples were washed through a sieve bucket with a screen size of 253 μm. The retained material was preserved in a 10% buffered formalin solution. Benthos were counted and identified by R.D. Kathman Biological Consulting, Sidney, B.C. to the lowest practical taxonomic group.

### **2.3.5 Phytoplankton**

Phytoplankton samples were collected by bottle casts at 2 depths (0.5 m and 1.7 m) on August 28, 1989 at the eight primary stations (Figure 2-2). The 500 ml samples were

collected for phytoplankton identification were preserved with Lugol's solution. Additional samples were collected for chlorophyll *a* analysis; chlorophyll samples were filtered through a 45  $\mu\text{m}$  filter and preserved with a saturated  $\text{MgCO}_3$  solution. Filters were wrapped in aluminum foil and frozen. Analysis for chlorophyll *a* was completed by ASL using a spectrophotometer method (APHA 1985).

Quantitative phytoplankton analysis to the lowest possible taxonomic level was carried out by Aquametrix Research Ltd., Sidney, B.C. Samples were counted using Utermohl chambers. Organisms in ten fields of each sample were identified and counted under a 35 power objective lens. All count data have been expressed as cells/ml.

### 2.3.6 Zooplankton

Vertical net hauls for zooplankton collection were taken at the eight primary stations (Figure 2-2) on August 26 and 27, 1989 using a Wisconsin zooplankton net with a 12 cm diameter opening and mesh size of 64  $\mu\text{m}$ . Hauls were brought up from just off the bottom to the surface at a rate of 0.5 to 1 m/s. Two horizontal net tows approximately 500 m in length were taken at 1 and 2 m depths on August 28, 1989. The Wisconsin net was towed at constant velocity of approximately 1 m/s. Zooplankton samples were preserved in 10% buffered formalin.

Quantitative zooplankton analyses were performed by Sy-Tech Research Ltd., Sidney, B.C. Zooplankton were keyed to lowest practical taxonomic level using keys of Pennak (1978), Torke (1974), Torke (1976) and Ward and Whipple (1963).

### 2.3.7 Fish

Fish sampling was attempted in Anderson Lake from August 24 to 26, 1989 at four sites using sinking 2 inch stretch gill nets (45 m long). One gill net was set at each site for soak times of approximately 24 hours. No fish were caught in the nets. One grebe was inadvertently caught at site GN2 and frozen for subsequent analysis.

Seine netting using a 10 m long pole seine with 1/4 inch mesh was carried out on August 27 and 28, 1989. The two sites 40 to 50 m in length were sampled parallel to the shore to determine if smaller fish species were present. Only brook sticklebacks (*Culaea inconstans*) and a number of littoral invertebrates were caught.

At the laboratory, 2 to 3 whole fish (sticklebacks) from each seine haul were homogenized. The liver was removed from the grebe and also homogenized. Representative aliquots of homogenized tissue were digested using a combination of nitric acid and hydrogen peroxide. The resultant extracts were analyzed for metals as follows:

- Cadmium, copper, lead, nickel and zinc were analyzed by graphite furnace AAS with automatic background correction.
- Arsenic analyzed by hydride generation AAS.
- Mercury analyzed by cold vapour AAS after a potassium permanganate digestion.

### **3 - Results and Discussion**

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## 3.0 RESULTS AND DISCUSSION

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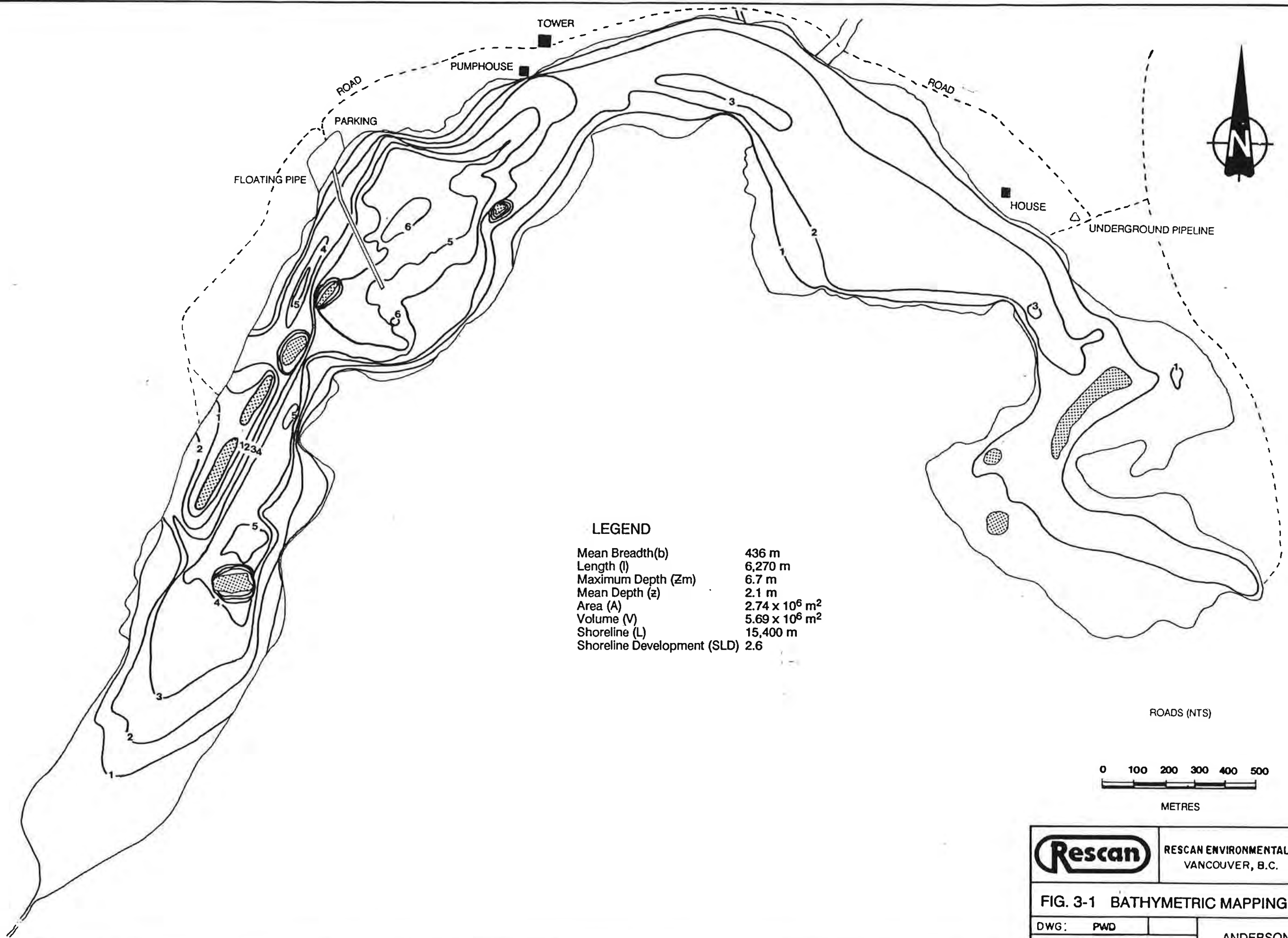
### 3.1 Lake Morphometry

Anderson Lake (Figure 3-1) is about 6.3 km long and 0.4 km wide. The lake is generally shallow (mean depth = 2.1 m) with a maximum depth of 6.7 m. A dam constructed at the lake's east end has increased the area from 2.41 to 2.74 x 10<sup>6</sup> m<sup>2</sup>, while the volume has decreased slightly from 5.8 to 5.69 x 10<sup>6</sup> m<sup>3</sup> since 1977 (Bridges 1977). The lake receives minimal inflows (exclusive of tailings discharges) and during the study no discharges were observed via the controlled outlet at the dam. The lake has 15.4 km of shoreline and shoreline development factor of 2.6 which is common to long narrow lakes. A shoreline development factor of 1.0 would indicate a circular lake (Hutchinson 1957).

### 3.2 Water Quality

Water column profiles of temperature, dissolved oxygen, turbidity, conductivity and pH indicate some differences between the eight lake stations related to proximity to tailings discharge and lake morphometry (Figures 3-2A and 3-2B). Turbidity was elevated at Stations 1 and 4 near the discharge but decreased to background levels at Stations 2 and 5. Conductivity was high throughout the lake and varied little with water depth or station location. This may have been because of low inflow rates and the lack of discharge due to drought conditions. The field pH was generally slightly acidic at all Stations except for Station 8 at the surface. Temperature profiles (Figures 3-2A and 3-2B; Appendix A) did not indicate the presence of a thermocline in the lake. This may be due to the shallow nature of the lake allowing the whole waterbody to be heated by conductance and subject to regular mixing. However, a slight clinograde oxygen curve was observed with decreasing oxygen concentrations within 0.5 m of the bottom (Figures 3-2A and 3-2B). The low oxygen levels near the bottom with absence of a thermocline indicated a high sediment oxygen demand. Anaerobic conditions were observed only at Station 1. Secchi disk transparency ranged from 0.5 m in the discharge plume to 1.95 m in areas outside the plume.

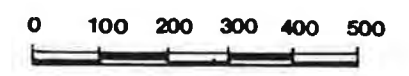
Previous studies prior to tailings deposition (Allard 1965, Munro and Ruggles 1977) did not indicate the presence of a thermocline in June. The limited dissolved oxygen data



**LEGEND**

Mean Breadth(b)	436 m
Length (l)	6,270 m
Maximum Depth (Zm)	6.7 m
Mean Depth (z)	2.1 m
Area (A)	$2.74 \times 10^6 \text{ m}^2$
Volume (V)	$5.69 \times 10^6 \text{ m}^3$
Shoreline (L)	15,400 m
Shoreline Development (SLD)	2.6

ROADS (NTS)



METRES



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VANCOUVER, B.C. CANADA

**FIG. 3-1 BATHYMETRIC MAPPING**

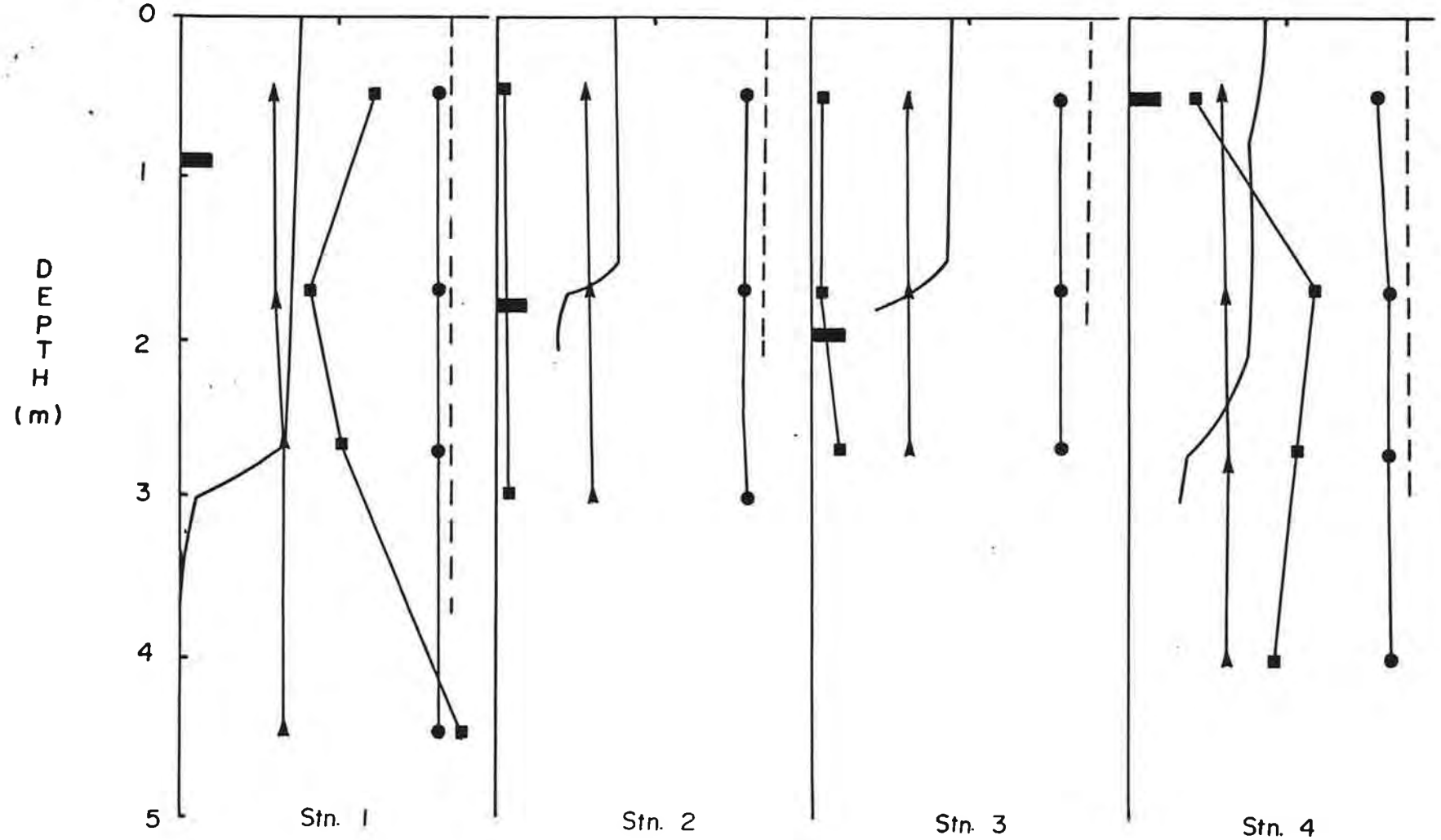
DWG: PWD  
DATE: MARCH, 1990

ANDERSON LAKE

DB-R0019



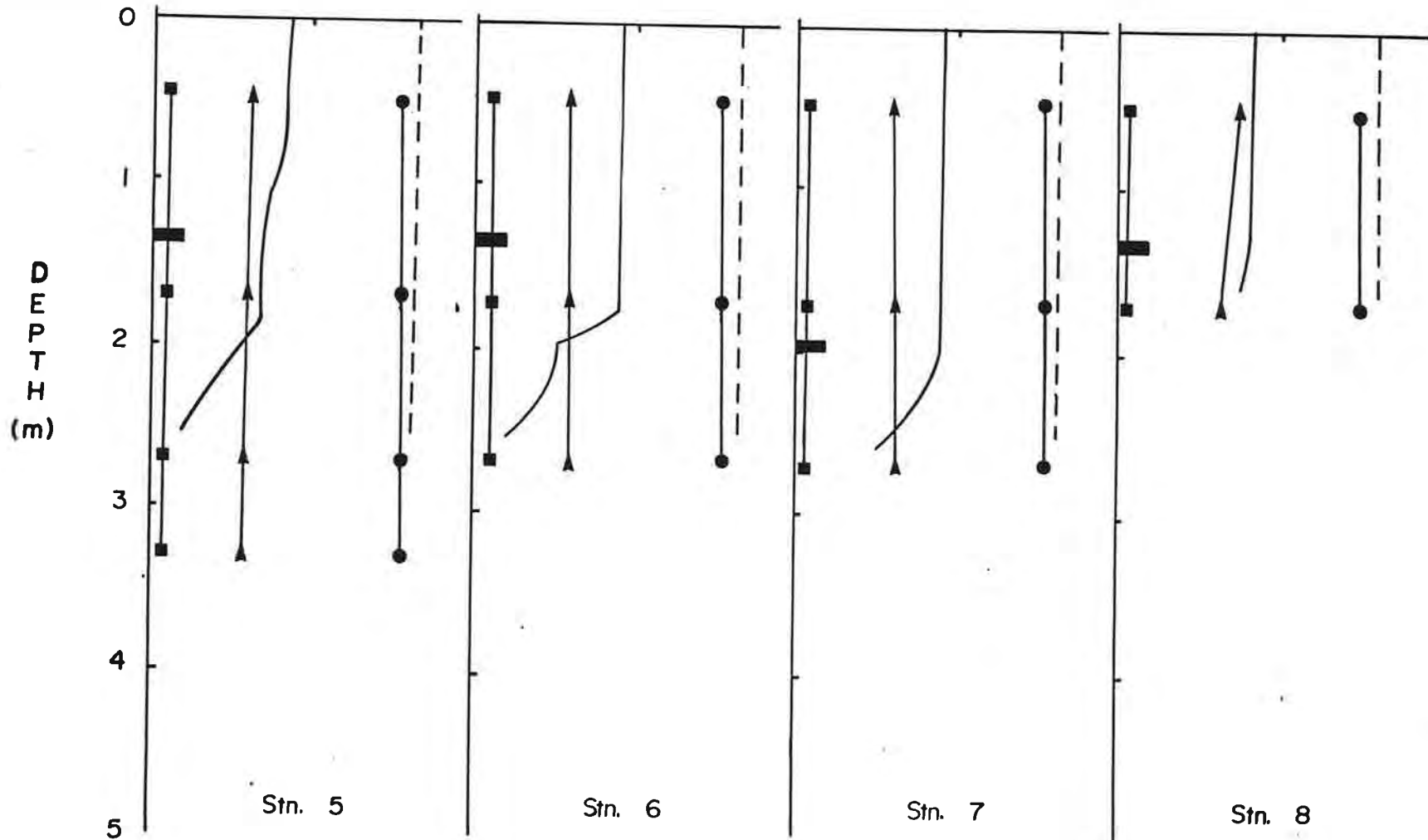
Conductivity	0	1000	0	1000	0	1000	0	1000
Turbidity	0	50	0	50	0	50	0	50
Temperature	}	}	}	}	}	}	}	}
ph								
Dissolved O <sub>2</sub>								



— Dissolved O<sub>2</sub> (mg/L)      —■— Turbidity (NTU)      ← pH  
 - - - Temperature (°C)      —●— Conductivity (µmhos/cm)      —■— Secchi (m)

WATER COLUMN PROFILE  
 ANDERSON LAKE  
 Figure 3-2A

Conductivity	0	1000	0	1000	0	1000	0	1000
Turbidity	0	50	0	50	0	50	0	50
Temperature	}							
ph								
Dissolved O <sub>2</sub>	0	10	0	10	0	10	0	10



— Dissolved O <sub>2</sub> (mg/L)	—■— Turbidity (NTU)	← pH
- - - Temperature (C)	—●— Conductivity (umhos/cm)	—■— Secchi (m)

**WATER COLUMN PROFILE**  
**ANDERSON LAKE**  
 Figure 3-2B

showed lower concentrations near the bottom but not anaerobic conditions. Secchi disk transparency ranged from 1.0 m to 1.5 m (Bridges 1977). Under ice cover, surface dissolved oxygen data in 1982 ranged from 2.8 to 6.5 mg/L and often a strong sulphide smell was indicated (HBMS file data).

The results of the water quality testing at the eight lake stations (Appendix B) showed similar water quality at all sampled sites with no consistent patterns with depth. The field pH was generally acidic ranging from pH 5.8 at the tailings discharge to pH 7.7 near the outlet (Station 8). Lab pH values were generally slightly more acidic, the two stations (Stations 1 and 4) nearest the discharge decreased by more than 2 pH units during transportation and storage. These two stations were characterized by low alkalinity. Alkalinity ranged from <1.0 mg/L at the discharge to 7.5 mg/L at Station 8. The whole lake was characterized by high conductivity, very high hardness, high dissolved solids and high sulphate. Chloride concentrations were highest near the tailings discharge and decreased slightly with distance from the discharge point (Table 3-1). Suspended solids, fixed volatile solids and turbidity were elevated at the tailings outfall, but decreased rapidly outside the discharge area.

Dissolved metals were highest at the outfall Stations and lowest near the lake outlet (Table 3-1). Dissolved concentrations of aluminum, arsenic, cadmium, copper, lead, manganese, and zinc were generally above detection levels. Aluminum, copper, lead and zinc concentrations frequently exceeded water quality guidelines (CCREM 1987) at Stations 1 through 7, while at Station 8 only aluminum levels were unacceptable (Table 3-1).

Lead concentrations were elevated only in the surface waters (0.5 m) at Stations 2 and 5 on either side of the discharge Stations 1 and 4. However, at discharge Stations 1 and 4 elevated lead concentrations were also found at lower depths, where tailings enter under pressure. The dispersion of lead on the surface may indicate an association with flotation materials in the tailings slurry.

Conditions of Anderson Lake prior to and after the initiation of tailings disposal (Table 3-2) indicate changes in water quality have occurred. The pH, while highly variable, has generally decreased in the lake. Conductivity and dissolved solids have increased five to eight fold. Sulphate concentrations have increased 10 to 20 fold. The water has

**Table 3-1**  
**Summary of Selected Water Quality Parameters - Maximum Values by Area in Anderson Lake - 1989**

Parameter	Inflow Area (Stns. 2 & 3)	Tailings Area (Stns. 1 & 4)	Mid-lake Area (Stns. 5, 6 & 7)	Outflow Area (Stn. 8)	CCREM (1987)
					Aquatic Life Guidelines <sup>a</sup>
pH (field)	5.8-6.2	5.9-6.4	5.8-6.4	6.2-7.5	6.5-9.0
Conductivity	1590	1660	1580	1530	none
Dissolved Solids	1370	1450	1370	1360	none
Suspended Solids	19.0	63.0	14.0	9.0	10
Turbidity	8.4	87.3	6.6	3.4	none
Alkalinity	4.29	<1.0	3.22	7.51	none
Hardness (calc)	807	813	797	805	none
Sulphate	841	847	837	774	none
Chloride	73.6	75.1	86.8	73.2	none
<b>Dissolved Metals</b>					
Aluminum	0.066	0.19	0.12	0.018	0.005
Arsenic	0.0015	0.0039	0.0012	0.0008	0.05
Cadmium	0.0006	0.0012	0.0007	<0.0002	0.0018
Copper	0.017	0.044	0.025	0.002	0.004
Iron	0.05	0.11	0.03	<0.03	0.3
Lead	0.038	0.046	0.052	<0.001	0.007
Manganese	0.19	0.19	0.18	0.070	none
Nickel	0.007	0.002	0.004	<0.001	0.15
Zinc	0.019	0.44	0.20	0.020	0.03

Results expressed as mg/L except for pH, Conductivity ( $\mu$ mhos/cm) and Turbidity (NTU).

<sup>a</sup> Adjusted for hardness as required.

**Table 3-2**  
**Summary of Selected Water Quality Parameters -**  
**Ranges Found in Previous Studies of Anderson Lake**  
**1977 - 1985**

Parameter	Before Tailings Discharge		After Tailings Discharge
	Munro & Ruggles (1977) June 2, 1977	Bridges (1977) May, 1977	HBMS Data Files 1979-1985 Lake-wide Averages
pH	7.4-8.1	8.1-8.3	4.78-7.7
Conductivity	210	225-250	946-1281
Dissolved Solids	180-214	-	-
Suspended Solids	<1-6	-	2-6
Turbidity	-	1.2-1.9	1.3-6.3
Alkalinity	56-62	60-64	14-58
Hardness	100-112	88-97	-
Sulphate	27-30	40-47	465-588
Chloride	14.7-19.1	18-24	-
<b>Total Metals</b>			
Arsenic	<0.02	0.003	-
Cadmium	<0.002	<0.01-0.03	<0.01-0.01
Copper	<0.02	<0.01-0.07	0.01-0.09
Iron	<0.02-0.13	0.10-0.24	-
Lead	<0.002-0.004	<0.01-0.04	<0.01-0.02
Manganese	-	0.04-0.06	-
Nickel	<0.03	<0.01	<0.01-0.01
Zinc	<0.005-0.019	<0.01-0.18	0.10-0.38

Results expressed as mg/L except for pH, Conductivity ( $\mu$ mhos/cm) and Turbidity (FTU).

changed from being moderately hard (approximately 100 mg/L CaCO<sub>3</sub>), to being very hard (approximately 800 mg/L CaCO<sub>3</sub>).

Comparison of metals concentrations prior to discharge is difficult due to differences in analytical techniques and detection limits, and the limited nature of the sampling programs. Previous results indicated the presence of arsenic, cadmium, copper, iron, lead, manganese and zinc at detectable levels. Copper, lead and zinc were apparently detected at concentrations as high or higher than found in the present study.

The water chemistry of the culverted and natural inflows into Anderson Lake (Appendix C) are highly variable. Sites which drain the mine area are characterized by low pH, high conductivity and dissolved solids, low alkalinity, high sulphate concentrations, higher chloride concentrations, high reactive silicate concentrations and high dissolved metal concentrations, particularly aluminum, copper, iron, manganese and zinc (Table C-1). The tailings discharge by comparison has a higher pH and alkalinity, higher suspended solids, higher reactive silicates and lower dissolved metal concentrations (Table C-2, D1 and D2). The natural inflows (Table C-2) show quality similar to streams and lakes found in Precambrian Shield areas (Bridges 1977; Wilson 1984).

### 3.3 Sediment and Tailings

Field descriptions of the sediments collected using the ponar dredge varied considerably between sample stations (Table 3-3). The stations near the present outfall (Station 1 and Station 4) showed no biological activity and appeared to be composed of tailings only. Biological activity was observed at Station 2 in the surface 0.5 cm layer over the older tailings. The other stations sampled had high organic content. Collected sediment samples varied in their particle size distribution (Table 3-4, Appendix D), however, Stations 4 and 7 had relatively consistent ratios of sand and silt but varied in the amount of clay sized material present.

Sample Stations 1 and 2 differed markedly from the other sediment samples in their relative abundances of sand and silt sized material. X-ray diffractometry analyses (Appendix E) of sediments from Stations 1, 2 and 4 contained more abundant quartz, feldspar, pyrite, micas and calcite than the organic samples from Stations 3 and 5. Station 7 did not contain any clay minerals and contained less quartz, feldspar and pyrite than any of the other samples. Stations 3, 5 and 7 all produced diffraction tracings with

Table 3-3

**Field Observations of Sediments Collected for Benthic Invertebrates,  
Metals Analyses and Particle Sizing - Anderson Lake**

Station Number	Date	Depth (m)	Field Observations
1	27/08/89	4.5 m	Straight tailings with no apparent biological activity; silver-grey in colour.
2	27/08/89	3.6 m	Top 0.5 cm brown in colour with biological activity; below is black-brown in colour.
3	27/08/89	2.9 m	Top 2.5 cm comprised of black muck; roots and organic debris in lower brown coloured layer.
4	26/08/89	6.7 m	Straight tailings with no apparent biological activity; silver grey to black in colour.
5	26/08/89	3.6 m	Surface layer is black over a black to brown layer with high organic and water content; slight sulphide smell.
6	26/08/89	3.6 m	Surface layer is black over a black to brown layer with high organic and water content; slight sulphide smell.
7	26/08/89	2.1 m	Mottled brown-black in colour with high organic content; strong sulphide smell.
8	26/08/89	-	No sample; bottom covered with dead peat and twigs.

**Table 3-4**  
**Particle Size Distribution for**  
**Anderson Lake Sediments**

Station	Sand (%)	Silt (%)	Clay (%)
1	20	75	5
2	10	80	10
3	60	35	5
4	70	25	5
5	70	20	10
6	70	25	5
7	75	25	<1

considerable noise and a broad hump of the continuous spectrum, presumably due to the presence of amorphous organic material. Petrographic analysis of tailings and sediment samples indicated two main types, the tailings-dominated and the organic sediments (Appendix F). The tailings sample (ALT) consists of about 55% pyrite, 4% pyrrhotite, 2% sphalerite and minor portions of hornblende, biotite, chlorite, carbonate and other silicates. Submerged sediment samples from Stations 1, 2 and 4 (samples AL-1, AL-2 and AL-4) were similar in composition and grain size to the tailings and have been virtually unmodified. No evidence for sulphide oxidation was observed. The samples included a few percent of organic material with optically estimated total sulfide contents ranging from 28-44%. The general mineralogical character was consistent and dominated by pyrite with pyrrhotite and sphalerite the principal accessories. Minor to trace amounts of chalcopyrite, arsenopyrite and galena were also found. The non-tailings stations (Stations 3, 5, 6 and 7) consisted predominantly of fragments of organic materials including diatom frustules. The samples also contained up to 3% sulphides and similar levels of clastic silicates (primarily quartz). The sulphides were primarily pyrite as angular specks in the size range 2-15 microns. This material (pyrites and quartz) likely represents the fines fractions of the tailings being incorporated into the accumulating organisms. Stations 3 and 5, closest to the tailings outfall, contained an estimated 5-7% of this material, whereas Station 6 and 7 contained much less. These four Stations also contained traces of pyrite in framboidal form. Photomicrograph plates are presented with detailed captions for each sample (Plates 3-1 to 3-10).



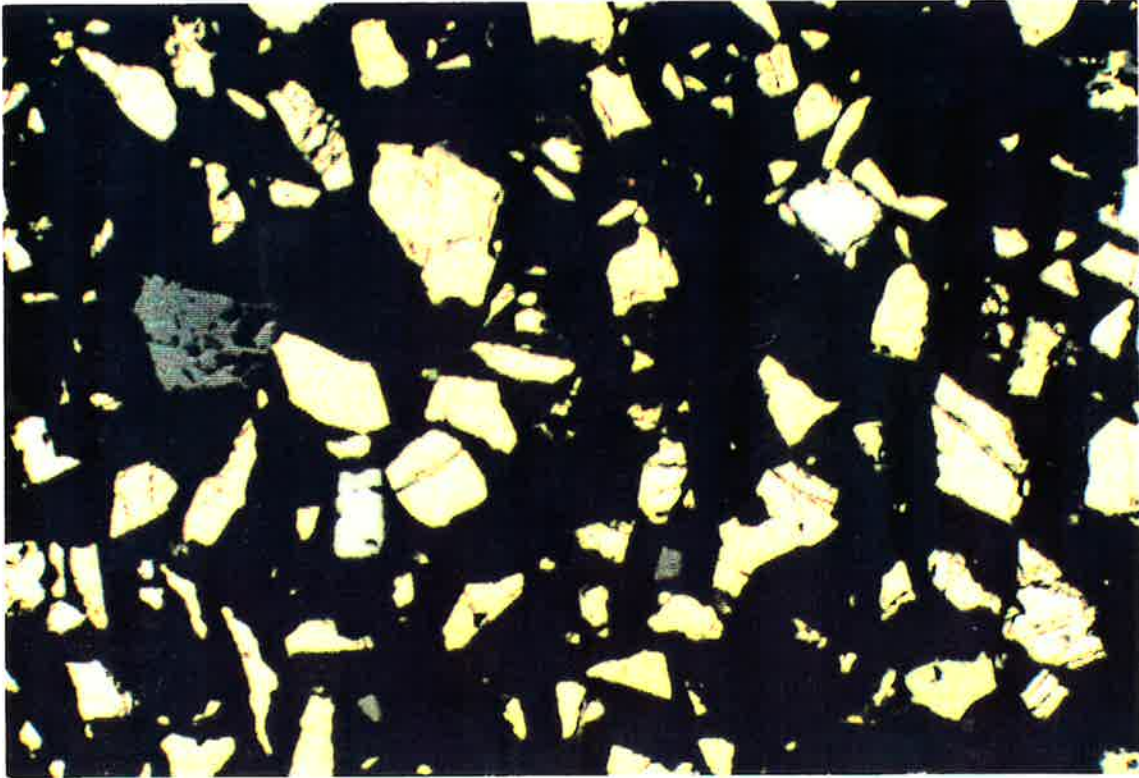


Plate 3-1: Photomicrograph of fresh tailings (ALT) using reflective light (Scale 1 cm = 42 microns). The dominant, cream-coloured constituent is pyrite and the occasional, slightly browner grains are pyrrhotite (bottom right) dark grey grains are sphalerite (left center); white grain is arsenopyrite (upper right); and the light bluish grey, rectangular grain is galena (lower left centre).

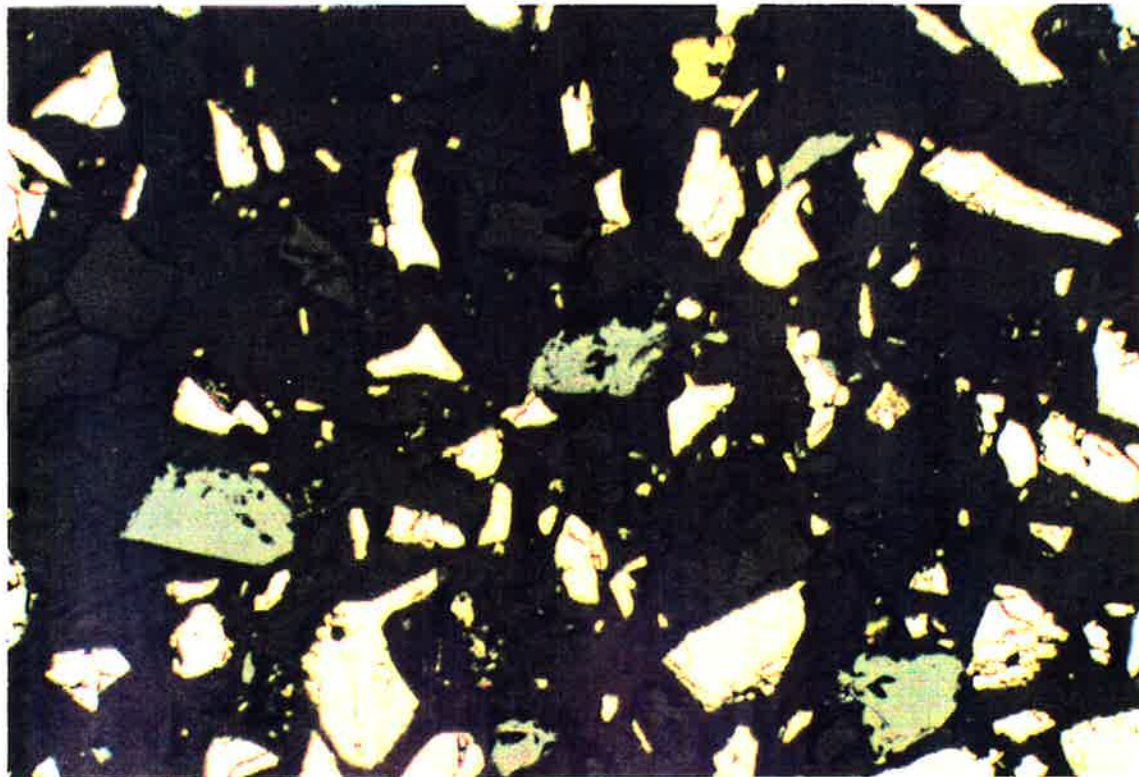


Plate 3-2: Photomicrograph of fresh tailings (ALT) using reflective light (Scale 1 cm = 42 microns). Note the relatively abundant sphalerite (medium grey) and gangue (very dark grey) as compared to Plate 3-1. Grains are sharply angular and quite coarse.





Plate 3-3: Photomicrograph of Station 1 sediments (AL-1) using reflective light (Scale 1 cm = 42 microns). Fresh pyrite (light cream colour) and gangue are found. Field included two sphalerite grains (grey) and occasional small brown grains of pyrrhotite. Note smaller particle size than in tailings.



Plate 3-4: Photomicrograph of Station 2 sediments (AL-2) using reflective light (Scale 1 cm = 42 microns). Fresh pyrite (light cream colour) and pyrrhotite (slightly browner grains) are seen. Note higher abundance of gangue than Station 1.



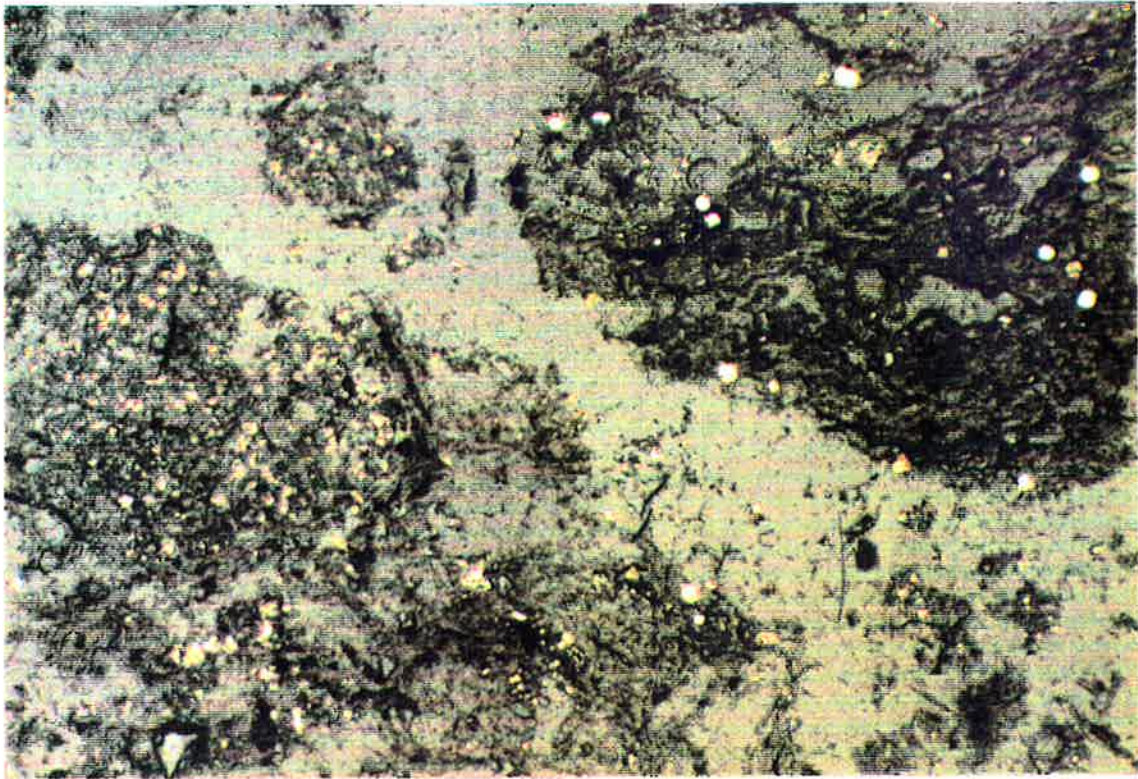


Plate 3-5: Photomicrographs of Station 3 sediments (AL-3) using reflective light (Scale 1 cm = 42 microns). Field composed of mats of loosely consolidated/fibrous organic material with incorporated sulphides (bright specks). Specks in lower left are sulphides with rare angular silicate grains. Note framboidal pyrite in upper right.

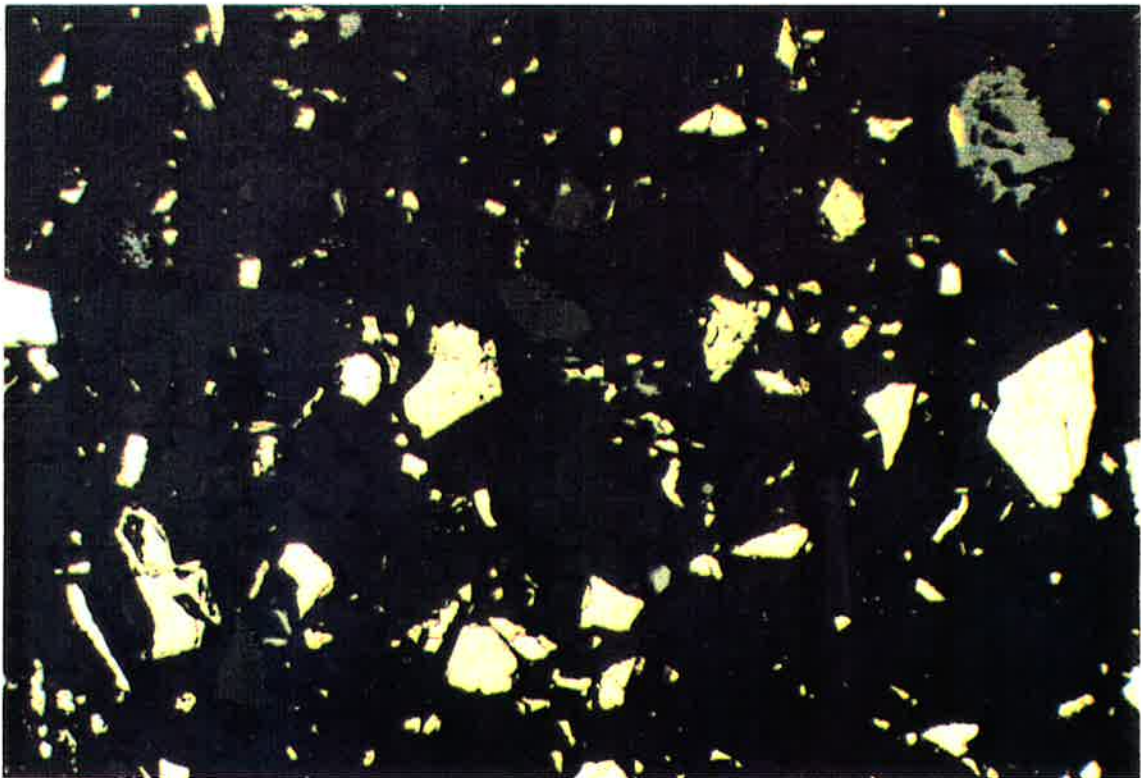


Plate 3-6: Photomicrograph of Station 4 sediments (AL-4) using reflective light (Scale 1 cm = 42 microns). Note similarity to Stations 1 and 2 and the tailings. Higher fines are noted compared to tailings sample.



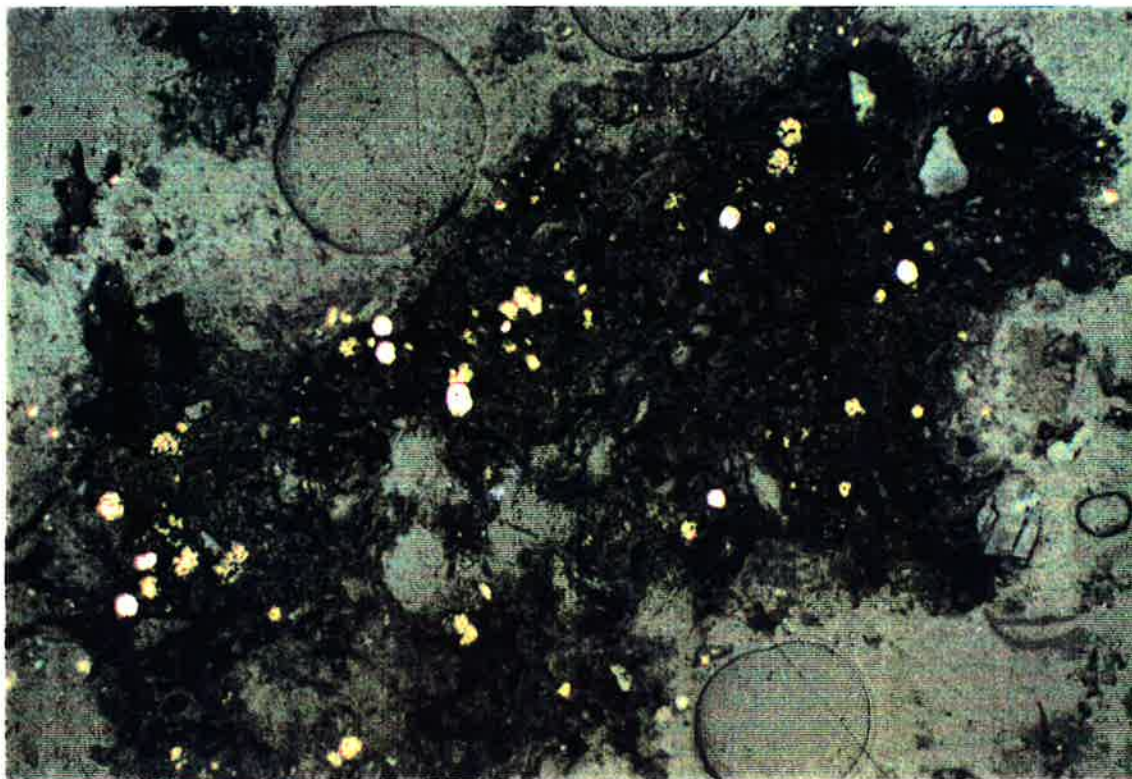


Plate 3-7: Photomicrograph of Station 5 sediments (AL-5) using reflective light (Scale 1 cm = 42 microns). Sample containing organic mat with high concentration of pyrite framboids and occasional angular grains of quartz trapped within the darker organic material.

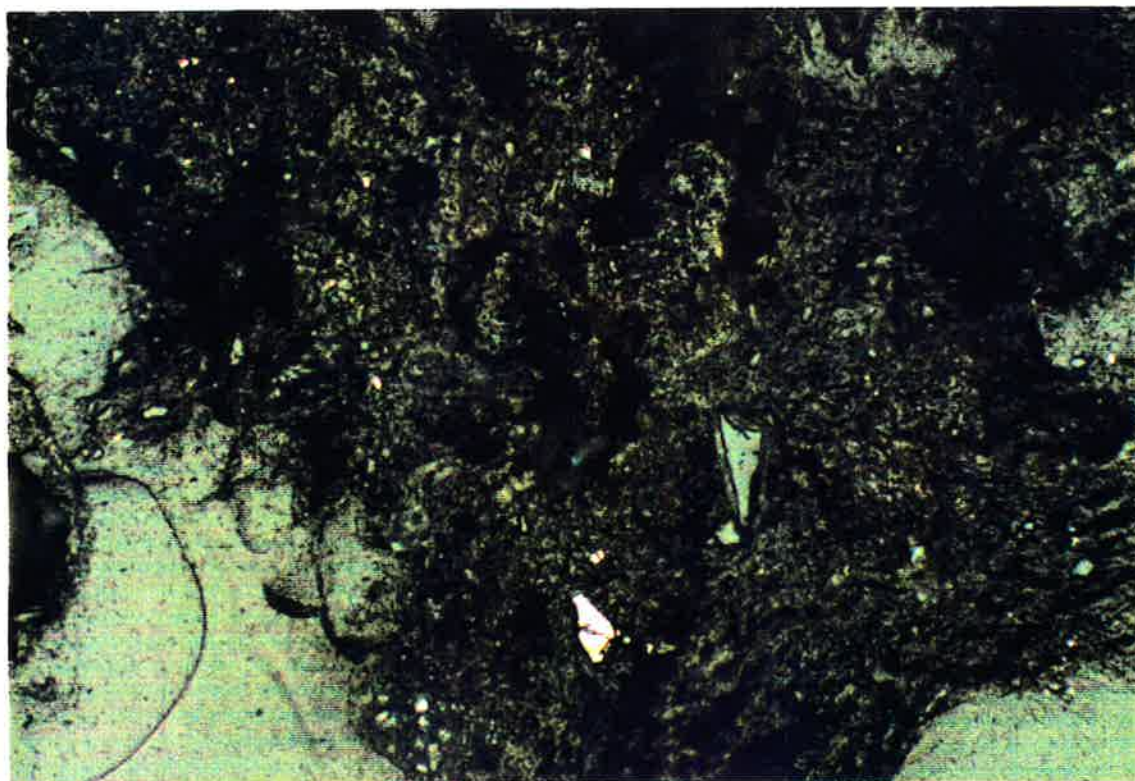


Plate 3-8: Photomicrograph of Station 6 sediments (AL-6) using reflective light (Scale 1 cm = 42 microns). Sample contains organic material with only traces of sulphides (sparsely scattered bright specks). Note single, angular coarse pyrite grain of centre bottom and grey shard like quartz grain in the organic mat.



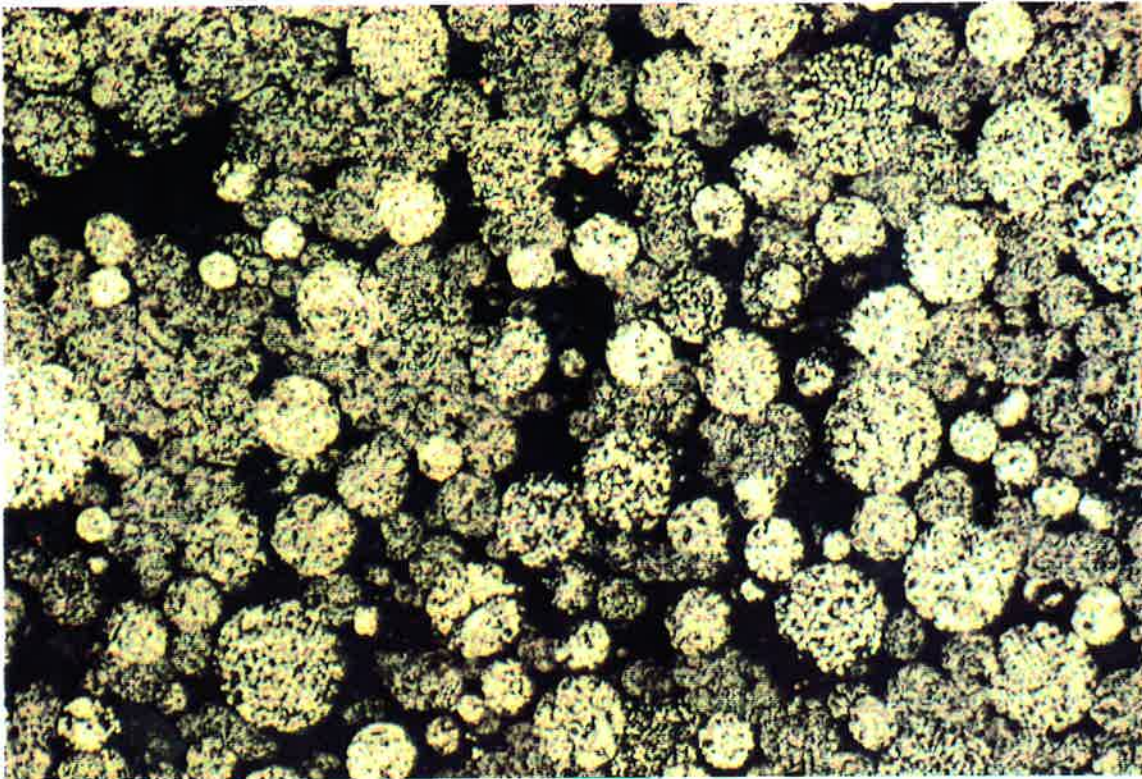


Plate 3-9: Photomicrograph of Station 6 sediments (AL-6) using reflective light (Scale 1 cm = 21 microns). Higher magnification showing detailed structure of pyrite framboids. Framboids being made up of clusters of individual granules, 1-2 microns in size.

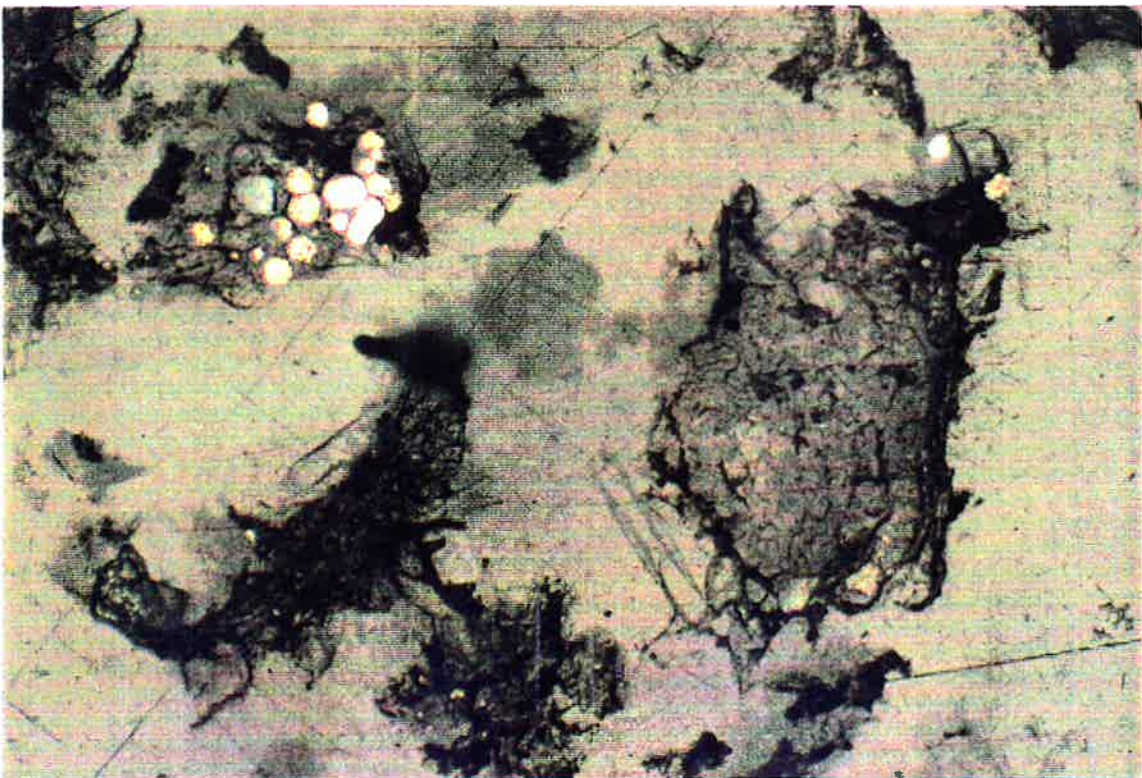


Plate 3-10: Photomicrograph of Station 7 sediments (AL-7) using reflective light (Scale 1 cm = 42 microns). Brown organic material with sub opaque areas possible representing hydrated ferric oxides. Pyrite present in framboidal form only.

X-ray fluorescence analyses (XRF) of the sediments and tailings for major constituents and % loss on ignition (LOI) are presented in Table 3-5. The average percentages of lithophile elements are expressed in conventional oxide form. The data can be recalculated to provide an approximation of the most likely mineralogical composition. This is done by assuming that the  $\text{Na}_2\text{O}$  (plus part of the  $\text{CaO}$ ) is combined with the  $\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$  as plagioclase feldspar; the  $\text{MgO}$  (plus part of the  $\text{Fe}_2\text{O}_3$ ) is combined with  $\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$  as chlorite; the  $\text{K}_2\text{O}$  is combined with  $\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$  as the micas (sericite and muscovite) and with the addition of some Fe for biotite; and the S is combined with Fe as pyrite and pyrrhotite. Unused silica is assumed to be free quartz. The remainder is presumably made of organic matter, combined  $\text{H}_2\text{O}$ , excess Fe as  $\text{Fe}(\text{OH})_3$ , other sulphides, carbonates, etc. Thus the average compositions of the samples are given in Table 3-6.

Comparisons between calculated mineralogical composition (XRF) and the petrographic analyses show minor discrepancies in tailings and tailing rich sediment samples with more pronounced differences in the organically dominated sediments. The total mineral content of the organic samples (AL-3, AL-5, AL-6 and AL-7) determined optically was 5% while XRF indicated 47.3%. The petrographic results based on visual observations may have under-estimated the mineral content. The organics, while occupying a large proportion of the field, likely were substantially less dense than the mineral material present and hence their contribution over-estimated. Also the silica component (determined by XRF) may have included the portion of the organic debris formed by diatom frustules and thus XRF may have over-estimated clastic silicates (mineral content) of the organic sediments. The samples showed substantial amounts of  $\text{Al}_2\text{O}_2$  and  $\text{Na}_2\text{O}$  suggesting plagioclase is major component of the gangue material. This material is difficult to distinguish optically from quartz in particulate material. Thus it is likely the optically determined quartz is a mixture of quartz and plagioclase in various proportions. Analyzed levels of  $\text{K}_2\text{O}$  and  $\text{MgO}$  indicated the presence of micas and chlorite at far higher levels than were determined optically in the organic samples.

Total carbon, nitrogen and sulphur analyses of sediment core samples were in agreement with XRD analyses with the tailings (Stations 1, 2 and 4) containing the highest percentage of sulphur-S as compared to the organic samples (Table 3-7). The C:N ratio of the organic samples (Station 3, 5, 6 and 7) was approximately 11 (S.D.  $\pm$  0.75) and relatively consistent between samples. The diffraction tracings of tailings



**Table 3-5**

**X-Ray Fluorescence (XRF) Analysis of Top 2 cm Layer of Sediments in Anderson Lake  
(Values as %)**

Sample ID	CaO	K <sub>2</sub> O	P <sub>2</sub> O <sub>5</sub>	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	MgO	Na <sub>2</sub> O	Fe <sub>2</sub> O <sub>3</sub>	TiO <sub>2</sub>	MnO	Ba	LOI	% Total
AL Tailings	1.04	0.44	0.05	16.11	4.1	2.08	0.74	49.29	0.17	0.08	0.02	20.93	95.06
AL-1(1)	2.75	1.16	0.07	33.71	9.93	3.57	1.07	32.68	0.36	0.18	0.01	9.43	94.95
AL-2(2)	2.34	1.15	0.07	34.28	9.06	3.19	0.90	35.16	0.27	0.16	0.01	11.5	98.11
AL-4(4)	2.21	1.01	0.07	31.01	8.67	3.43	1.11	35.96	0.29	0.15	0.01	14.3	98.22
Mean	2.4	1.1	0.07	33.0	9.2	3.4	1.0	34.6	0.31	0.16	0.01	11.7	-
AL-3(3)	2.20	0.96	0.17	27.16	6.62	1.78	0.70	12.09	0.24	0.06	0.02	46.5	98.50
AL-5(5)	2.22	1.34	0.16	31.51	8.38	1.82	1.10	8.05	0.32	0.04	0.03	44.5	99.47
AL-6(6)	3.08	0.97	0.13	25.76	5.44	1.16	0.67	4.94	0.24	0.03	0.02	56.32	98.77
AL-7(7)	2.79	1.04	0.11	29.25	5.74	1.05	0.68	2.61	0.25	0.03	0.03	56.1	99.69
Mean	2.6	1.1	0.14	28.4	6.5	1.4	0.8	6.9	0.26	0.04	0.03	50.8	-

() Indicates station number

**Table 3-6**

**Calculated Mineral Compositions using XRF analyses. (Values as %)**

Sample Group	Quartz	Plagioclase	Micas	Chlorite	Pyrite	Remainder
Tailings	3.3	9.2	8.0	7.2	52.3	20.00
AL-1, AL-2, AL-3	11.8	14.2	8.7	11.8	41.0	12.5
AL-3, AL-5, AL-6, AL-7	15.2	10.8	8.7	4.6	8.0	52.7

**Table 3-7**

**Total Carbon, Nitrogen, and Sulphur (Dry Weight %) in Surface Sediments (Top 2 cm) from Anderson Lake Core Samples**

Station	Carbon (%C)	Nitrogen (%N)	Sulphur (%S)
1	0.59	0.02	19.8
2	0.95	0.06	19.5
3	20.5	1.99	7.79
4	0.62	0.03	25.5
5	19.3	1.71	4.60
6	25.1	2.19	2.93
7	27.8	2.29	1.42

sediments (Stations 1, 2 and 4), indicated that little or no amorphous material was present and specifically, amorphous hydroxides of Al and Fe were not present.

Acid base accounting of the fresh tailings sample (ALT) indicated the total sulphur to be 27.3% comprised of 26.8% sulphide-S and 0.42% sulphate-S. The paste pH of ALT was pH 5.8. The neutralization potential was determined to be 9 tons CaCO<sub>3</sub> per 1000 tons of material compared to the maximum potential acidity based on total sulphur content of 853 tons CaCO<sub>3</sub> per 1000 tons of material. No carbonates were determined in the sample. The tailings are considered to have significant acid generation potential.



Metal analyses of the top 2 cm of the sediments indicated high metal levels at Stations 1 to 5 (Table 3-8). Specifically, Cu, Hg, Pb, and Zn were elevated above the levels reported in the baseline studies of Munro and Ruggles (1977) and HBMS (1977) conducted on Anderson Lake. Levels of As, Pb, Hg, and Zn were highest in sediments from Stations 1, 2 and 4 whereas Station 3 had the highest concentration of Cu (Table 3-8). Arsenic analyses were not performed for the 1977 baseline studies, however, arsenic was highly elevated in the sediment samples collected near the tailings outfall (Stations 1, 2 and 4 in Figure 2-2; Table 3-8) as compared to sediment at Stations 6 and 7 located at the eastern section of the lake. Metals are known to accumulate in the finer fractions of sediments (Forstner and Wittmann 1983), partially resulting from the increase in adsorption capacity associated with the greater surface area and electrical charge of the finer grained material. Although metal analyses were performed on the bulk sample, the higher percentage of finer material in the samples from Stations 1 and 2 may partially explain the observed elevated levels of the metals of concern.

The methodology used for the sequential extraction of sediment from Station 2 is outlined in Section 2.3.3. Eight (8) different extractions were used to assist with the determination of the metal associations with this sediment. Although the discussion below deals with several metals of environmental concern, some general comments can be made regarding the expected speciation of metal forms in the tailings sediment.

The concentration of metals in the water-soluble phase is typically quite low, representing only those ions which are loosely bound to the surface of the sediments. Similarly the exchangeable cation phase which represents those metals adsorbed to the surfaces of sediment by electrostatic or coulombic forces, usually does not have a large proportion of metals associated with it. Nonetheless, cation exchange is an important metal scavenging mechanism and maybe more significant in sediments with high clay content. However, because the positively charged metals are relatively weakly held to the surfaces they can be easily exchanged by other cations. The use of excess ammonium ions in the extractant effectively displaces these weakly held metals from the surface exchange sites.

The weak acid soluble phase is generally resigned to carbonates, whereby the metal ions are liberated by the dissolution of metal carbonate or host carbonate at pH 5.0 with the subsequent release of CO<sub>2</sub>. Some Cu, Zn and Fe(II) oxides and hydroxides are also marginally soluble at this pH.

Table 3-8

Metals Analysis of Sediment (Top 2 cm) and Tailing Samples  
from Anderson Lake Collected, August 26 and 27, 1989

Element	Detection Limit	Sampling Station									Fresh Tailings	
		Station 1	Station 2	Station 3	Station 4	Station 5	Station 5 <sup>1</sup>	Station 6	Station 7	Old Tailings Zone B (SN2)	A	B
Aluminum %	0.005	1.65	1.45	2.44	1.84	1.98	2.07	1.71	2.21	0.89	0.80	0.81
Antimony	15	<	<	<	<	<	<	<	<	<	<	<
Arsenic <sup>2</sup>	0.02	701	1190	157	1044	195	188	49	65	832	1780	1630
Cadmium <sup>2</sup>	0.10	8.39	13.0	9.63	4.54	5.43	5.92	1.79	3.71	18.5	21.4	26.0
Calcium %	0.005	0.29	0.78	1.68	0.58	2.26	2.27	1.79	2.37	0.64	0.09	0.13
Chromium	2.0	14.4	2.39	42.8	8.15	33.5	42.1	33.9	41.9	1.2	9.2	8.2
Cobalt	2.0	115	309	71.5	179	34.5	29.8	12.3	19.8	187	69.7	81.9
Copper	1.0	1000	1570	2000	1078	886	878	323	521	1739	2390	2100
Iron %	0.005	10.6	14.7	6.46	10.8	4.34	4.17	2.05	2.67	10.09	8.01	9.05
Lead <sup>2</sup>	2.0	371	146	371	161	291	261	89.4	138	501	586	843
Magnesium	0.005	1.29	1.02	0.93	1.69	0.75	0.75	0.60	0.72	0.63	0.81	0.83
Manganese	0.50	585	577	377	535	234	230	177	220	360	352	337
Mercury <sup>2</sup>	0.005	1.68	1.97	1.07	1.88	0.35	0.27	0.13	0.17	3.35	2.61	4.15
Molybdenum	5.0	<	<	<	<	<	<	<	<	<	<	<
Nickel	2.0	8.56	10.7	22.2	8.19	27.8	39.7	20.2	36.1	1.8	8.0	8.9
Vanadium	2.0	21.6	16.9	28.8	13.7	<	<	27.5	31.9	13.7	12.7	12.8
Zinc	0.10	4440	6660	2670	2770	1610	1670	484	957	9876	12800	13100

Results are expressed in milligrams per dry kilogram of sediment except where otherwise stated.

< = Less than detection limit stated

% = Percent weight basis (w/w)

1 = Duplicate

2 = Parameters analyzed by specific atomic absorption spectrophotometry techniques.

The easily and moderately reducible phases will include primarily amorphous manganese and ferric oxides and hydroxides, respectively. Their solubility is greatly increased in acid solution following the reduction from the higher to lower oxidation state. Heavy metals such as As, Cr, Cu, Cd and Pb which co-precipitated with these amorphous hydroxides or are covalently bound to their surface would be liberated simultaneously.

The difficulty reducible phase is often termed the non-silicate iron phase and includes those crystalline forms of ferric and manganese oxides and hydroxides (e.g.  $\beta$ -FeOOH). Metals which have co-precipitated or participated in lattice substitutions would be released during this extraction.

The oxidizable phase includes species which are rendered soluble in acid solution by oxidation with hydrogen peroxide. Most metal sulphides and organic metal compounds are included in this category.

Sequential extraction results for Station 2 are presented in Appendix G and Figure 3-3. The sampling and storage of the sediments, and the actual extraction method used did not exclude the potential for atmospheric oxidation of the sample to occur. Thus the results indicate the potential for release, not actual *in situ* release, from the sediments. Station 2 is located in an older area of tailings deposition but petrographic analysis indicate similar general composition and grain size to the fresh tailings. However, a lower percentage of sulphides were found.

The water quality data did not provide any clear evidence of metal release from the sediments. The extraction results (Appendix G and Figure 3-3) also indicated that the majority of metal was unavailable, being released primarily from the oxidizable and residual phases. High releases of Ni (21%) were noted in the water-soluble phase but the Ni concentration was low in the sample. Moderate releases (from 5-20% of the total releases) of Cd (9%) and Mn (8%) and minor releases (<5% of the total releases) of cobalt and zinc also occurred in this phase. Minor releases of Cd, Pb and Mn occurred in the exchangeable phase. As previously stated, the water-soluble and exchangeable phases represent loosely bound metals that maybe readily released to surface waters (Forstner and Wittmann 1983). The weak acid soluble phase had moderate releases of Pb (10%) with minor releases of Cd, Cu and Zn. Petrographic analysis indicated little or no carbonates in the sediments.

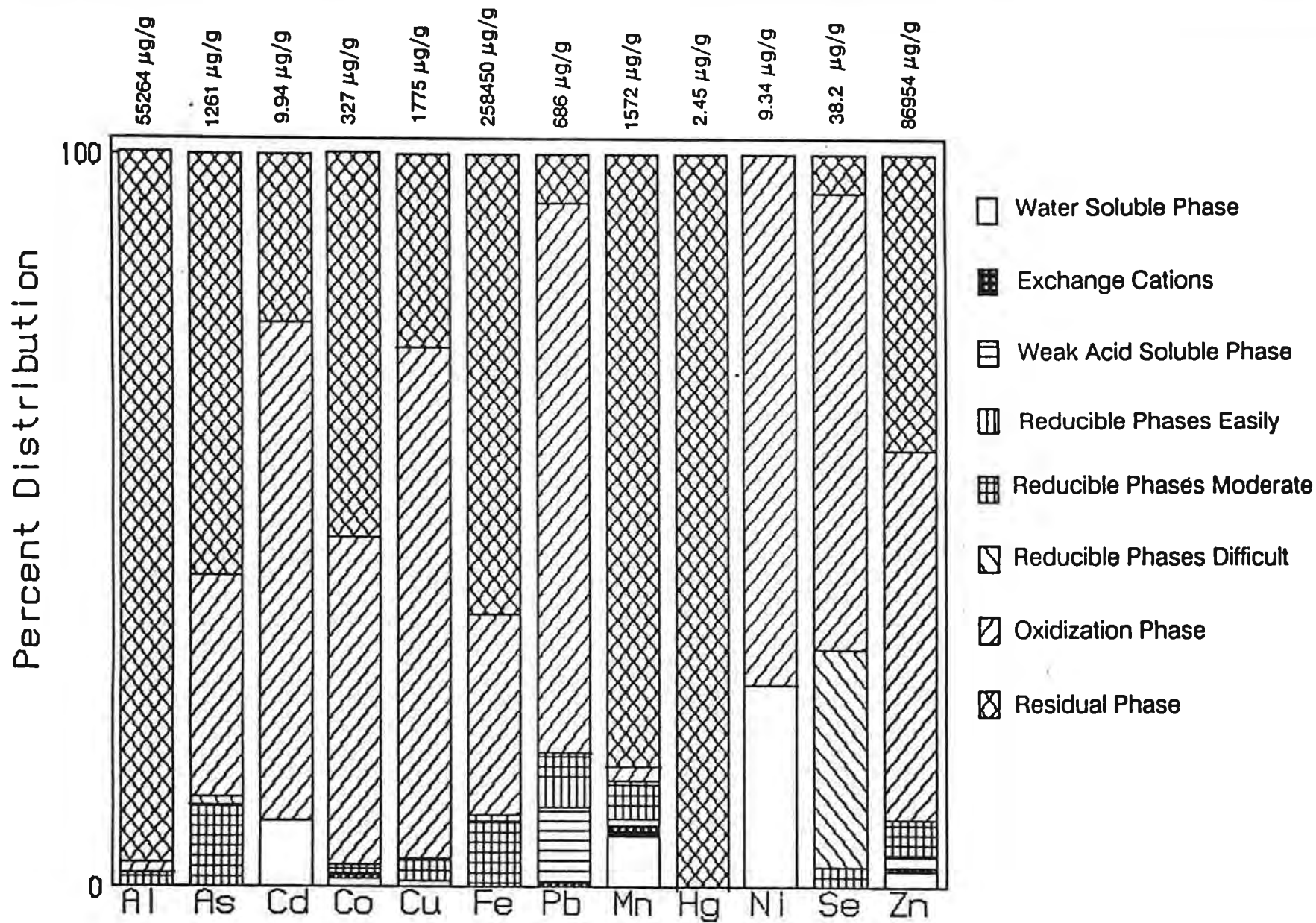


FIGURE 3-3 SEQUENTIAL EXTRACTION OF ANDERSON LAKE SEDIMENTS

Only minor releases of Pb, Mn and Zn occurred in the easily reducible phase. While moderate releases of As (14%), Ni (14%) and Fe (9%) and minor releases of Al, Cu, Pb, Mn, Se and Zn occurred in the moderately reducible phase. The difficultly reducible phase (non-silicate iron phase) had high releases of Se (31%) with minor releases of As.

The oxidizable phase generally represents organic compounds of metals but will also include most metal sulphides. The high releases of metals in this phase suggest metal-sulfide associations and is supported by the high sulphide content of this sample. High releases of As (34%), Cd (67%), Co(49%), Cu (72%), Fe (35%), Pb (74%), Ni (66%), Se (61%) and Zn (54%) occurred with comparatively minor releases of Al and Mn.

The residual phase was characterized by high releases of Al (96%), As (52%), Co (48%), Cu (24%), Fe (54%), Mn (82%), Mg (100%) and Zn (37%) and moderate releases of Cd (16%), Pb (74%) and Se (5%).

A summarization of extraction results for surface sediments (Duplicate A, Appendix G), by metals is as follows:

**Aluminum** displayed low availability in all extractants and was mainly found in the residual phase. Total aluminum concentration was very high in the sample (48,710  $\mu\text{g/g}$ ).

**Arsenic** was most available in the residual phase followed by the oxidizable (as a sulphide) and moderately reducible phases. This latter observation is explainable as As adsorbs readily to Fe hydroxides (Pierce and Moore 1982). The total arsenic concentration was elevated in the sample (1,360  $\mu\text{g/g}$ ).

**Cadmium** was released primarily in the oxidizable phase with some releases in other extractant phases excluding the reducible phases. The total concentrations of cadmium in the sample was 14.8  $\mu\text{g/g}$ .

**Cobalt** was associated primarily with the residual and oxidizable phases. A moderate level of cobalt was found in the sample (366  $\mu\text{g/g}$ ).

**Copper** was associated primarily with the oxidizable phase probably as a sulphide and, to lesser extent with the residual phase. Total copper concentration was high (1788  $\mu\text{g/g}$ ).

**Iron** was released primarily in the residual and oxidizable phases and to a lesser extent the moderately reducible phase. This would indicate that very little of the

iron is present as oxides or hydroxides. Total iron content of the sample was very high (265,000  $\mu\text{g/g}$ ).

**Lead** was primarily released in the oxidizable phase, likely from the sulphide form (galena), and to lesser extents from the weak acid soluble and residual phases. Lead content was elevated in the sample (640  $\mu\text{g/g}$ ).

**Manganese** was released in all extractants but was primarily released in the residual phase and to a lesser extent the water soluble phase. A moderate concentration of manganese was noted in the sample (1430  $\mu\text{g/g}$ ).

**Mercury** was detected only in the residual fraction and its total concentration in the sample was 2.45  $\mu\text{g/g}$ .

**Nickel** was released primarily in the oxidizable phase followed by moderate releases in the water soluble and moderately reducible phases. Total nickel concentration was low in the sample (16.0  $\mu\text{g/g}$ ).

**Selenium** was released primarily in the oxidizable phase followed by the difficulty reducible phase from a total sample concentration of 55  $\mu\text{g/g}$ .

**Zinc** was associated primarily with the oxidizable phase (likely as a sulphide) and residual phase, with minor releases of zinc in most of the other extractants. The total zinc concentration of the sample was high (8907  $\mu\text{g/g}$ ), and a considerable amount of zinc was released in the water soluble phase (271  $\mu\text{g/g}$ ).

Most metals (Al, As, Cd, Cu, Co, Fe, Pb, Mn, Ni, Se, Hg and Zn) were released in highest quantities in the oxidizable and residual phases indicating the sample was relatively inert. Smaller releases of some metals (As, Fe, Ni and others to lesser degree) occurred in the moderate reducible phases. While only a small percentage of the Zn was water-soluble, the high Zn concentrations in the sediment resulted in considerable Zn concentrations in the various extracts. Cadmium and cobalt were also released in small quantities in the water-soluble phase. Small quantities of Cd, Cu, Pb and Zn were released in the exchangeable and weak acid soluble phases. It is likely that many of the metals were present as metal sulphides and therefore potentially soluble only upon oxidation. Present lake conditions appear to preclude the possibility for substantial sulphide oxidation. In support, mineralogical analyses of submerged tailings sediments indicated that sulphide oxidation was not occurring. Moreover, the relative absence of

secondary minerals, such as Fe and Mn oxides and hydroxides, attests to the lack of post-depositional oxidation.

### 3.4 Biota

#### 3.4.1 Benthic Invertebrates

The invertebrate taxa of Anderson Lake are presented in Table 3-9. In the profundal zone, Stations 1, 2, 3, 4 and 7 were dominated by dipteran (chironomids and *Chaoborus punctipennis*) larvae, while Stations 5 and 6 were dominated by pelecypod freshwater clams (Table 3-10). The mean number of invertebrates ranged from 109 individuals/m<sup>2</sup> near the outfall to 1622 individuals/m<sup>2</sup> at Station 6, with a mean lake density of 519 individuals/m<sup>2</sup>.

The densities of the non-impacted sites and the mean lake density are higher than those found in two oligotrophic Manitoba lakes, Trout and Cliff Lakes, near Flin Flon, Manitoba (Wilson 1984). The benthic community was also dominated by clams and chironomid larvae and had densities ranging from 19 to 1165 individuals/m<sup>2</sup> with mean lake densities of 385 and 351 individuals/m<sup>2</sup> for Trout and Cliff Lakes, respectively. *Chaoborus* larvae were less abundant in these lakes.

Higher mean densities of profundal benthos were found in Southern Indian Lake in northern Manitoba ranging from 3227 to 5592 individuals/m<sup>2</sup> (Weirs and Rosenberg 1984). Benthos were comprised of four main taxa: Diptera (mainly chironomids), Amphipoda, Oligochaeta and Pelecypoda (mainly sphaerid clams). Mandy Lake, studied as part of the MEND program (Rescan 1990), had a slightly higher lake-wide mean density of 533 individuals/m<sup>2</sup> compared to Anderson Lake, the invertebrate community was dominated by oligochaetes (tubercid worms) and dipteran larvae (chironomids and *Chaoborus punctipennis*).

Previous studies on Anderson Lake prior to tailings deposition have also found generally low numbers of benthic invertebrates with similar species present (Allard 1965, Munro and Ruggles 1977, Bridges 1977). Mean densities ranged from 144 to 444 individuals/m<sup>2</sup>. However, one site had a density of over 5000 individuals/m<sup>2</sup> (Munro and Ruggles 1977). The community was dominated by dipteran larvae (chironomids and

Table 3-9

Species and Taxa List of Littoral and  
Profundal Benthic Invertebrates  
Found in Anderson Lake

## INSECTA

## ODONATA

Deshnidae

*Aeshna*

## HEMIPTERA

Notonectidae

*Notonecta*

Belostomatidae

*Lethocerus*

## TRICHOPTERA

Phryganeidae

*Agrypnia*

## DIPTERA

Tipulidae

*Prionocera*

Chaoboridae

*Chaoborus (Sayomyia) punctipennis*

Chironomidae

*Procladius**Chironomus**Cryptochironomus**Glyptotendipes**Tanytarsus*

## MOLLUSCA

## GASTROPODA

## LYMNOPHILA

Lymnaeidae

*Lymnaea stagnalis**Stagnicola elodes*

## PELECYPODA

## SPHAERIACEA

Sphaeriidae

*Musculium* prob. *securis**Sphaerium*



Table 3-10

**Counts of Profundal Benthic Invertebrates from Anderson Lake, Manitoba,  
August 26, 1989**

Taxa	Ponar Samples																				
	1-1	1-2	1-3	2-1	2-2	2-3	2-4	3-1	3-2	3-3	4-2	4-3	5-1	5-2	5-3	6-1	6-2	6-3	7-1	7-2	7-3
<b>Insecta</b>																					
<b>Trichoptera</b>																					
<b>Phryganeidae</b>																					
<i>Agrypnia</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
<b>Diptera</b>																					
<b>Chaoboridae</b>																					
<i>Chaoborus (Sayomyia) punctipennis</i> : larvae	9	0	7	1	4	1	6	9	14	3	3	0	0	0	0	0	1	0	0	1	0
<b>Chironomidae</b>																					
<i>Procladius</i> sp.	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0
<i>Chironomus</i> sp.	1	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	0	1	8	0	0
<i>Cryptochironomus</i> sp.	0	0	0	1	0	1	3	0	0	1	0	0	0	0	0	0	1	1	0	0	0
<i>Glyptotendipes</i> sp.	0	0	0	1	2	4	12	5	3	0	0	0	0	0	0	0	0	0	0	0	0
<i>Tanytarsus</i> sp.	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<b>Mollusca</b>																					
<b>Pelecypoda</b>																					
<b>Sphaeriacea</b>																					
<b>Sphaeriidae</b>																					
<i>Musculium</i> prob. <i>securis</i>	0	0	0	0	0	0	0	4	0	4	0	2	1	14	10	20	41	44	0	0	1
<i>Sphaerium</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	1	0	0	0	0
<b>Total Number of Taxa</b>	<b>3</b>	<b>0</b>	<b>1</b>	<b>3</b>	<b>2</b>	<b>4</b>	<b>4</b>	<b>4</b>	<b>2</b>	<b>3</b>	<b>1</b>	<b>1</b>	<b>2</b>	<b>2</b>	<b>1</b>	<b>1</b>	<b>4</b>	<b>5</b>	<b>1</b>	<b>1</b>	<b>1</b>
<b>Total Number of Individuals</b>	<b>11</b>	<b>0</b>	<b>7</b>	<b>3</b>	<b>6</b>	<b>7</b>	<b>23</b>	<b>19</b>	<b>17</b>	<b>8</b>	<b>3</b>	<b>2</b>	<b>2</b>	<b>18</b>	<b>10</b>	<b>20</b>	<b>44</b>	<b>48</b>	<b>8</b>	<b>1</b>	<b>1</b>
<b>Total Number of Taxa by Site</b>	<b>3</b>			<b>5</b>				<b>4</b>			<b>2</b>		<b>3</b>			<b>6</b>			<b>3</b>		
<b>Mean Number of Individuals by Site</b>	<b>6.0</b>			<b>9.8</b>				<b>14.6</b>			<b>2.5</b>		<b>10</b>			<b>37.3</b>			<b>3.3</b>		
<b>Mean Number/m<sup>2</sup></b>	<b>261</b>			<b>426</b>				<b>635</b>			<b>109</b>		<b>435</b>			<b>1622</b>			<b>143</b>		

*Chaoborus* sp.) in the west end of the lake, and freshwater clams (Sphariidae) at the east end, as in the present study.

The variability in community composition and numbers of benthic invertebrates results from the heterogeneity of the lake bottom and the differing feeding and habitat requirements of the different species. For example, pelecypod clams feed primarily on particulate detritus and microzooplankton of the sediments, while *Chaoborus* larvae are carnivorous and feed on pelagic zooplankton and small benthic animals (Wetzel 1975). The areas sampled for benthos varied in depth and substrate characteristics ranged from primarily tailings to rich organic muck (Table 3-3), while at Station 8, peat and twigs were encountered.

The present study indicates a possible impact on the benthos near the outfall stations (Stations 1 and 4) which may be due to smothering of the bottom by fresh tailings. Station 2, away from the outfall on older tailings, showed the development of a thin surface layer of organics and had a higher density of benthic invertebrates. Thus, once tailings deposition is halted near Stations 1 and 4, the density of the benthic invertebrates will likely increase over time as an organic layer develops. Other stations in the lake had higher organic content in the sediments.

Littoral invertebrates were collected incidentally when seining for fish (Table 3-11). They included additional representatives from three additional orders and five families (Aeshnidae, Notonectidae, Belostomatidae, Tipulidae and Lymaeidae). These aquatic invertebrates are not necessarily associated with the sediments and are common species found in littoral zones. Further seining with finer mesh nets would likely increase the number of species collected from littoral habitats.

### 3.4.2 Phytoplankton

The various phytoplankton taxa collected in Anderson Lake are presented in Table 3-12. Chlorophyll *a* values (Appendix H) were lowest at the outfall Stations 1 and 4 (0.67 mg/m<sup>3</sup>), probably as a result of high turbidity and corresponding low light transmittance, and increased with distance from outfall to a maximum at Station 8 (10.1 mg/m<sup>3</sup>). Phytoplankton densities followed a similar though less distinct pattern.

The phytoplankton taxa and densities encountered (Appendix H) are indicative of mesotrophic conditions (Wetzel 1975). The presence of high numbers of diatoms

Table 3-11

Littoral Benthic Invertebrates from Anderson Lake, Manitoba,  
August 26, 1989

Taxa	Seine #1	Seine #2
Insecta		
Odonata		
Aeshnidae		
<i>Aeshna</i> sp.	4	0
Hemiptera		
Notonectidae		
<i>Notonecta</i> sp.	1	2
Belostomatidae		
<i>Lethocerus</i> sp.	0	1
Diptera		
Tipulidae		
<i>Prionocera</i> sp.	1	0
Mollusca		
Gastropoda		
Lymnophila		
Lymnaeidae		
<i>Lymnaea stagnalis</i>	8	0
<i>Stagnicola eldoes</i>	0	1
Total Number of Taxa	5	3
Total Number of Individuals	15	4

Table 3-12

**Classification of Taxa Encountered from  
Phytoplankton Samples from Anderson Lake**

DIVISION CHRYSOPHYCOPHYTA	DIVISION CHLOROPHYCOPHYTA
CLASS BACILLARIOPHYCEAE	ORDER TETRASPORALES
ORDER PENNALES	<i>Gloeocystis</i> sp. indet.
<i>Asterionella formosa</i>	ORDER CHLOROCOCCALES
<i>Fragellaria crotonensis</i>	<i>Crucigenia tetrapedia</i>
<i>Synedra radians</i>	ORDER CHLORELLALES
<i>Tabellaria fenestrata</i>	<i>Ankistrodesmus convolutus</i>
ORDER CENTRALES	<i>Ankistrodesmus falcatus</i>
<i>Coscinodiscus subtilus</i>	<i>Coelastrum microsporum</i>
CLASS CHRYSOPHYCEAE	<i>Dictyosphaerium pulchellum</i>
ORDER OCHROMONADALES	<i>Kirchneriella obesa</i>
<i>Dinobryon divergens</i>	<i>Quadrigula</i> sp. indet.
CLASS XANTHOPHYCEAE	<i>Scenedesmus bijuga</i>
ORDER MISCHOCOCCALES	<i>Scenedesmus quadricauda</i>
<i>Ophiocytium</i> sp. indet.	ORDER VOLVOCALES
DIVISION EUGLENOPHYCOPHYTA	FAMILY CHLAMYDOMONADACEAE
ORDER EUGLENALES	<i>Chlamydomonadaceae</i> spp. indet.
<i>Phacus</i> sp. indet.	ORDER ULOTRICHALES
<i>Phacus</i> sp. 2	Chlorophyte filament
<i>Trachelomonas</i> sp.	ORDER ZYGNEMATALES
DIVISION PYRRHOPHYCOPHYTA	FAMILY ZYGNEMATAACEAE
ORDER PERIDINIALES	<i>Spondylosium</i> sp. indet.
<i>Peridinium</i> sp. indet.	<i>Zygnemetales</i> sp. indet.
DIVISION CRYPTOPHYCOPHYTA	ORDER OEDOGONIALES
<i>Cryptomonas</i> sp. indet.	<i>Oedogonium</i> sp. indet.

(Bacillariophyceae), particularly *Fragelaria crotonensis* and *Synedra*, the abundance of green algae species (Chlorophyta), such as *Scenedesmus*, and the presence of dinoflagellates (Pyrrophyta), such as *Peridinium*, are typical of mesotrophic to eutrophic conditions. No taxa were present in unusually high numbers, although *Synedra radians* did reach moderately high numbers at Station 8. The average phytoplankton density of Anderson Lake was 4346 cells/ml compared to average densities of 7.5 and 12.8 cells/ml in Trout and Cliff Lakes, respectively (Wilson 1984). Trout and Cliff Lakes are oligotrophic to ultra-oligotrophic lakes near Flin Flon, Manitoba that were dominated by diatoms with a virtual absence of chlorophytes.

Mandy Lake, a second Manitoba lake studied as part of the MEND program (Rescan 1990), had a slightly higher average phytoplankton density of 6714 cells/ml with higher densities of blue-greens and euglenophytes. Phytoplankton were evenly distributed throughout Mandy Lake and chlorophyll *a* values were higher, ranging from 12.8 to 22.9 mg/m<sup>3</sup>.

Previous studies of Anderson Lake (Bridges 1977, Munro and Ruggles 1977) showed the lake to be dominated by diatoms, especially *Melosira granulata*, and other eutrophic indicator species such as blue-green algae (Cyanophyta), including *Anacystis*, *Anabena*, and *Amphanizomenon*, and dinoflagellates, including *Peridinium* and *Ceratium*. The presence of these additional indicator species, particularly the blue-green algae suggest Anderson Lake was more eutrophic prior to tailings discharge. Presently the lake has nitrogen values in eutrophic range and phosphorus in the meso-eutrophic range (Wetzel 1975), while Trout and Cliff Lakes had nitrogen values in ultra-oligotrophic range and phosphorus in the oligo-mesotrophic range.

### 3.4.3 Zooplankton

A reasonably diverse zooplankton community was found at Anderson lake (Table 3-13). The community was dominated by rotifers (Rotatoria), cladocerans (Cladocera), and copepods (Copepoda), with minor representation of trematode flatworms (Turbellaria), ostracods (Ostracoda; small, bivalved crustaceans) and chironomids (Diptera). Densities of rotifers, cladocerans and copepods were generally highest at the east end of the lake (Stations 7 and 8) or furthest from the tailings outfall. The lowest abundance was found at the west end of the lake (Station 3; 1441 individuals/m<sup>3</sup>), with the maximum at the east end (Station 8; 80,000 individuals/m<sup>3</sup>). Mandy Lake had

**Table 3-13**

**Anderson Lake - Density of Zooplankton Captured in Vertical and Horizontal Tows (individuals/m<sup>3</sup>)**

Station Number	1	2	3	4	5	
Date	27/08/89	27/08/89	27/08/89	26/08/89	26/08/89	
Depth (m)	4.6	3.7	3.0	3.7	3.7	
Time	10:00	10:40	11:30	19:24	19:00	
Tow	VNH	VNH	VNH	VNH	VNH	
Volume (m <sup>3</sup> )	0.475	0.39	0.311	0.322	0.407	
Split	0.125	0.5	0.5	0.25	0.25	
<b>TAXON</b>						
TURBELLARIA	17	0	0	0	0	
ROTATORIA						
Testudinellidae	118	0	0	199	59	
Asplanchnidae	51	0	6	149	0	
<i>Keratella</i> sp.	876	149	225	708	541	
CLADOCERA						
<i>Diaphanosoma brachyurum</i>	51	67	39	335	177	
<i>Bosmina longirostris</i>	51	36	0	62	79	
<i>Kurzia latissima</i>	0	0	0	25	0	
<i>Alona costata</i>	51	0	19	12	0	
Cladoceran embryos	0	5	0	0	0	
COPEPODA						
<i>Diaptomus oregonensis</i> Vlf	0	56	26	62	216	
VIm	0	15	19	0	39	
V	0	56	58	161	275	
<i>Diaptomus tyrelli</i> Vlf	0	0	6	0	0	
Calanoid Copepodites						
IV	168	149	51	174	344	
III	168	164	77	261	295	
II	286	154	116	236	246	
I	152	31	26	99	39	
Cyclopoids	I-IV	808	200	225	621	1563
Copepod nauplii		640	359	373	770	1101
OSTRACODA	0	0	0	0	0	
INSECTA						
Chironomid larvae	0	0	0	12	0	
<b>TOTALS (individuals/m<sup>3</sup>)</b>	<b>3436</b>	<b>1441</b>	<b>1267</b>	<b>3888</b>	<b>4973</b>	

VNH = Vertical net haul  
 HNH = Horizontal net haul

**Table 3-13 (cont'd)**

Station Number	6	7	8	HNT1	HNT2	
Date	26/08/89	26/08/89	26/08/89	28/08/89	28/08/89	
Depth (m)	3.7	0.9	0.7	1	2	
Time	18:15	18:02	17:30	17:02	17:18	
Tow	VNH	VNH	VNH	HNH	HNH	
Volume (m <sup>3</sup> )	0.407	0.102	0.068	6.78	6.78	
Split	0.25	0.0625	0.0625	0.0625	0.0313	
<b>TAXON</b>						
TURBELLARIA	0	0	0	0	0	
ROTATORIA						
Testudinellidae	0	1725	0	5	9	
Asplanchnidae	197	13490	4706	0	5	
<i>Keratella</i> sp.	570	4392	22588	340	297	
CLADOCERA						
<i>Diaphanosoma brachyurum</i>	432	3294	6353	42	146	
<i>Bosmina longirostris</i>	128	941	1882	0	0	
<i>Kurzia latissima</i>	0	0	0	0	0	
<i>Alona costata</i>	0	471	0	5	9	
Cladoceran embryos	10	0	706	0	0	
COPEPODA						
<i>Diaptomus oregonensis</i> Vlf	29	1412	1176	5	24	
VIm	49	627	941	5	28	
V	668	1412	6353	19	136	
<i>Diaptomus tyrelli</i> Vlf	0	0	0	0	0	
Calanoid Copepodites						
IV	668	3137	5176	101	179	
III	226	4392	6353	85	137	
II	118	2039	2824	50	160	
I	10	0	1882	76	127	
Cyclopoids	I-IV	816	5490	2353	85	94
Copepod nauplii		1052	6902	16706	101	94
OSTRACODA	10	0	0	0	0	
INSECTA						
Chironomid larvae	0	0	0	0	0	
<b>TOTALS (individuals/m<sup>3</sup>)</b>	<b>4983</b>	<b>49724</b>	<b>80000</b>	<b>918</b>	<b>1447</b>	

VNH = Vertical net haul  
 HNH = Horizontal net haul

zooplankton densities ranging from 17,513 to 32,536 individuals/m<sup>3</sup> that were more randomly distributed than observed in Anderson Lake (Rescan 1990).

Rotifer densities were generally low (Wetzel 1975) ranging from 0.15 to 27.3 individuals/L and included representatives from two families, Testudinellidae and Asplanchidae (*Keratella* sp.). The density of cladocerans ranged from 0.06 to 8.9 individuals/L, while copepods ranged from 0.98 to 43.8 individuals/L. The higher densities found at the east end of Anderson Lake were comparable to those found in Southern Indian Lake, Manitoba with densities ranging from 10 to 200 individuals/L, and average site densities from 40 to 76 individuals/L (Patalas and Salki 1974). Mandy Lake had rotifer densities ranging from 8.2 to 22.5 individuals/L, cladoceran densities ranging from 2.7 to 7.1 individuals/L and copepod densities ranging from 5.2 to 9.1 individuals/L (Rescan 1990).

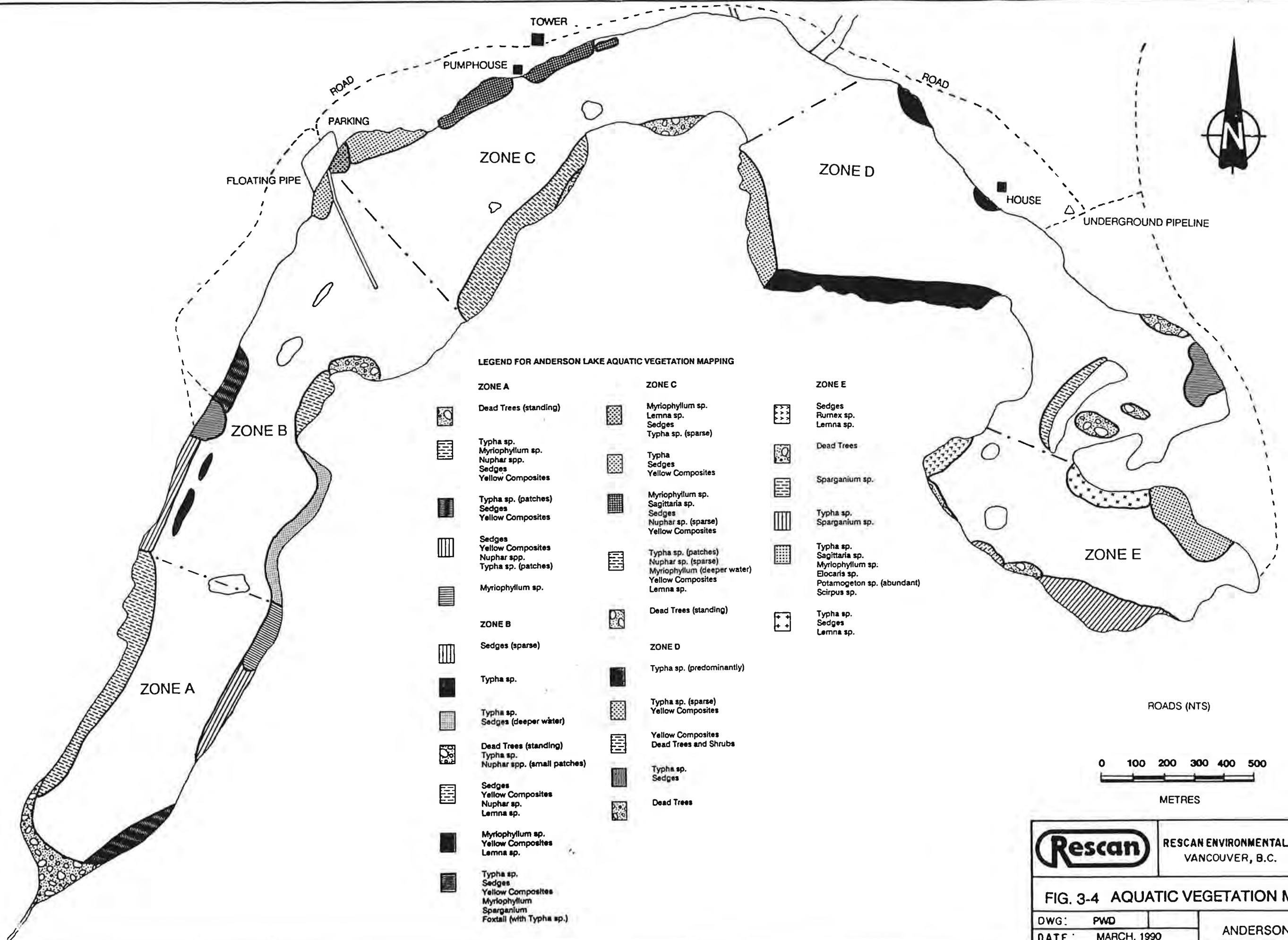
The higher zooplankton densities observed in Anderson Lake at Stations 7 and 8, particularly of rotifers may be due to the shallower depth (Wetzel 1975) or lower metal concentrations of these stations. Deniseger et al. (1988) found decreasing zooplankton (cladocerans and copepods) in Buttle Lake as the mine area was approached and metal concentrations in the water increased. The metal concentrations, while not lethal, may be stressing the zooplankton populations.

Qualitative sampling of zooplankton prior to discharge at Anderson Lake (Bridges 1977; Munro and Ruggles 1977) demonstrated a slightly more diverse zooplankton community than currently present. However, dominant species have been similar in all studies to date and included rotifers (*Keratella* spp., *Asplancha* sp.), cladocera (*Bosmina* sp.) and copepods (*Diaptomus* spp.).

### 3.4.4 Aquatic Vegetation

Aquatic vegetation is well established in most of the littoral zones of Anderson lake (Figure 3-4). The littoral zone has minimal aquatic vegetation on the north side of the lake in Zones C and D where acidic drainage is leaching from the reactive tailings used to build the adjacent road (Plate 3-11). Common genera of the littoral zone included *Typha*, *Myriophyllum*, *Potamogeton*, *Sparganium*, *Sagittaria*, *Scirpus*, and various sedges (Plates 3-12 and 3-13).





DB-R0019

	<b>RESCAN ENVIRONMENTAL SERVICES LTD.</b> VANCOUVER, B.C. CANADA	
	<b>FIG. 3-4 AQUATIC VEGETATION MAPPING</b>	
DWG: PWD	ANDERSON LAKE	
DATE: MARCH, 1990		



Plate 3-11: Road located adjacent to Anderson Lake built from mine tailings (Zone C).



Plate 3-12: Littoral vegetation at east end of Anderson Lake showing *Potamogeton* spp. and *Sagittaria* sp. (Zone E).



Many areas of dead trees exist around the lake, particularly at each end of the lake. The dead trees are likely the result of flooding from the dam that was built across the outlet. The rising water levels saturated the root zones and covered areas of peat, particularly at the east end. These areas are now dominated by *Typha* sp., as are several muskeg islands formed in Zone B by bottom sediments displaced by denser tailings (Plate 3-14).

Metal analyses of aquatic vegetation (Table 3-14) found 2 to 40x higher levels of arsenic, cadmium, lead and zinc in *Typha* sp. in a tailing seepage area in Zone D (Site V1) compared to samples collected at the east end of the lake (Site V2). The largest increases occurred for arsenic, followed by cadmium, lead, zinc and copper with the lowest increase at Site V1. However, mercury concentrations were similar, and nickel concentrations were higher at Site V2. *Potamogeton* sp. was collected from Site V2 only and had comparatively low metal concentrations (except for nickel) for this species.

Aquatic vegetation from Mandy Lake generally had higher or comparable metal concentrations in their tissue than observed in Anderson Lake (Rescan 1990). The aerial leaves of *Typha* sp. growing on submerged tailings in Mandy Lake had higher levels of arsenic, cadmium, copper, mercury and zinc and comparable concentrations of lead and nickel versus *Typha* sp. collected from a tailings seepage area in Anderson Lake. *Potamogeton* sp. collected from an uncontaminated site in Mandy Lake were comparable to those found in an uncontaminated site in Anderson Lake, except for nickel (3.75  $\mu\text{g/g}$  - dry weight) which was higher in Anderson Lake (Forstner and Wittman 1983).

### 3.4.5 Fish

Gill netting was unsuccessful in Anderson Lake, which is consistent with the lack of gill netting success observed during previous studies of the system (Allard 1965, Bridges 1977, Munro and Ruggles 1977). Beach seining at the two sites in the lake (SN1 and SN2; Figure 2-2) provided samples of brook stickleback (*Culaea inconstans*). Stickleback were also captured in Anderson Lake by Allard (1965) and Bridges (1977) prior to tailings deposition. Unlike other workers on Anderson Lake, Bridges (1977) also caught lake chub using minnow traps. The absence of chub among the samples collected for this project may be related to the fishing methods used, however, chub spawning performance can be impaired by high copper levels in surface waters and the



Plate 3-13: Littoral vegetation on the N.W. end of Anderson Lake showing *Typha*, sedges, yellow composites, and foxtails (Zone B).



Plate 3-14: Muskeg islands in area of old tailings with abandoned tailings pipe (Zone B).

**Table 3-14**

**Metal Analyses of Anderson Lake Aquatic Vegetation**

Site	Date	Site Description	Plant Species	Tissue Samples	Metal ( $\mu\text{g/g}$ - dry weight)						
					As	Cd	Cu	Pb	Hg	Ni	Zn
V1	27/08/89	Tailings seepage area on north side (Zone D) in area of dead brush	<i>Typha</i> sp.	Leaves	1.10	0.13	3.68	1.50	0.030	0.50	39.1
V2	27/08/89	East end of lake (Zone E) near the dam	<i>Typha</i> sp.	Leaves	<0.025	0.080	3.10	0.25	0.030	2.50	17.4
					<0.025	0.055	2.65	0.25	0.030	2.50	16.6
			<i>Potamogeton</i> sp.	Leaves, stems	6.00	0.29	16.1	2.05	0.035	3.75	100

chub population may have been lost due to copper contamination associated with tailings deposition (Demayo and Taylor 1981).

Seining was difficult due to the bottom topography, vegetation and debris, and resulting set efficiency was poor. Catch per unit data were not, therefore, collected. The samples taken were limited to those collected for tissue metals analysis; no biological data was collected.

The results of metal analyses are presented in Table 3-15, and included the levels present on the liver of an accidentally caught grebe. Metal levels in the grebe liver were generally lower than those observed in the sticklebacks. To allow comparison to other studies, tissue metals concentrations in Anderson Lake fish were converted from analytical dry weight (Table 3-15) to wet weight by applying a factor of 0.2. Of the metals analyzed for in fish tissue, copper, lead and zinc were found at higher than expected background levels and were probably bioaccumulated, directly or indirectly, from the tailings source.

Freshwater fishes in Canada have been reported to contain <0.5 ppm wet weight of arsenic (Munro 1976). In Manitoba lakes impacted by mine operations, average arsenic levels of 0.02-0.47 ppm wet weight (Rescan 1989). Arsenic levels in stickleback from Anderson Lake ranged from 0.052-0.066 ppm wet weight. These levels are lower than maximum background levels reported in Canada, and are well below the level currently considered safe for human consumption in Canada (3.5 ppm As - wet weight, Canadian Guidelines for Chemical Contaminants in Fish and Fish Products).

Cadmium concentrations in whole fish samples from Lakes Superior, Michigan and Erie are reported as <0.14 ppm wet weight (Lucas et al. 1970). The cadmium concentrations in Anderson Lake stickleback were 0.04-0.118 ppm wet weight, or within the background range reported. In other studies of Manitoba lakes, both affected and unaffected by tailings deposition, most fish tissue samples showed below detectable levels of cadmium (<0.1 ppm) on average (Rescan 1989, Rescan 1990).

In dressed lake whitefish samples from non-contaminated Moose Lake, Manitoba, copper levels average 0.5 ppm wet weight (Uthe and Bligh 1971). Whole fish samples from the Great Lakes, however, contain as much as 2.7 ppm Cu wet weight in trout perch (*Percopsis omiscomaycus*) from Lake Michigan (Lucas et al. 1970). In fish from Manitoba lakes contaminated by mine tailing releases or stockpile drainage, the average

**Table 3-15****Metal Analyses of Anderson Lake  
Sticklebacks (wholefish) and Grebe (liver)**

Sample Date	Species	Location	Tissue Type	Metal ( $\mu\text{g/g}$ - dry weight)						
				As	Cd	Cu	Pb	Hg	Ni	Zn
25/08/89	Grebe (Bird)	GN2	Liver	0.16	0.031	20.8	<0.050	0.16	0.18	104
27/08/89	Stickleback	SN1	3 whole fish	0.26	0.20	12.6	0.65	0.059	1.18	199
28/08/89	Stickleback	SN2	2 whole fish	0.33	0.59	28.8	8.37	0.26	1.83	340

copper content in fish tissues ranged from 0.15-0.91 ppm wet weight, while maximum concentrations ranged from 0.3-2.0 ppm Cu wet weight (Rescan 1989). Tissue copper concentrations in stickleback from Anderson Lake ranged from 2.52-5.76 ppm wet weight. While the lower measurement is comparable to background whole fish levels from the Great Lakes, both measurements are greater than the levels observed in other impacted Manitoba lakes.

Lead is a highly toxic metal, and is usually found at background levels of <0.5 ppm wet weight in fish muscle in Canada (Demayo et al. 1980). The Canadian guideline for edible fish is 0.5 ppm Pb wet weight. In fish from Manitoba lakes affected by mine tailings, average lead concentrations of up to 0.87 ppm wet weight or maximum of up to 2.5 ppm Pb wet weight have been reported (Rescan 1989). Lead concentrations in stickleback from Anderson Lake ranged from 0.13-1.67 ppm wet weight. The lower concentration is probably within background levels, while the higher measurement suggests bioaccumulation associated with the tailings. The higher concentration was from a sample collected at seine site SN2, located near the tailings outfall, while the lower measurement is for fish from site SN1, which was located near the outlet of the lake.

Metals are bioaccumulated by fish, especially omnivorous fish such as stickleback. Stickleback are also highly territorial at least during the summer, and populations at the same sites may be locally resident. This would explain the significantly higher tissue metal levels observed at site SN2 compared to those for site SN1 (Figure 2-2, Table 3-15). This is especially the case for lead which was found at a concentration 13x greater in stickleback from SN2 compared to those sampled at SN1.

The Canadian limit on mercury in edible fish and fish products is 0.5 ppm wet weight. Background levels of tissue mercury concentrations in fish are usually <0.5 ppm wet weight (Reeder et al. 1979). The tissue mercury concentrations observed in fish from Anderson lake are <0.052 ppm wet weight, and well within the background range found in Canada.

In fish from Manitoba lakes affected by mine tailings, tissue nickel concentrations of up to 2.0 ppm wet weight have been observed (Rescan 1989). Background levels in non-impacted Manitoba lakes, while usually <0.5 ppm Ni wet weight, were observed to be as



high as 1.8 ppm. Tissue nickel concentrations in Anderson Lake stickleback (0.24-0.34 ppm Ni wet weight) are within these background concentrations.

Zinc is an essential element that is bioaccumulated to quite high levels, especially by omnivorous or bottom dwelling fishes, and particularly in the liver (Taylor and Demayo 1980). Tissue concentrations of up to 48 ppm wet weight have been reported in Great Lakes fish (Lucas et al. 1970). The Canadian standard for human consumption of fish is 100 ppm Zn (Taylor and Demayo 1980). In other Manitoba lakes, fish tissue samples show average zinc concentrations ranging from 3.72-6.53 ppm wet weight, and maximums of 4.5-18.3 ppm Zn wet weight (Rescan 1989). Zinc concentrations in fish tissue from Anderson Lake are very high at 40-68 ppm wet weight, probably due to the high zinc content in the tailings (Table 3-8).

## **4 - Conclusions**

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## 4.0 CONCLUSIONS

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As would be expected, present tailings discharges are adversely affecting water quality near the outfall and to a lesser extent in the whole lake. Conductivity, hardness, dissolved solids and sulphate levels have increased since the inception of tailings disposal. Levels of dissolved lead, copper and zinc have also increased and frequently exceed water quality guidelines, although metal concentrations generally decreased with distance away from the outfall. In contrast, concentrations of Al were elevated throughout the lake. Although highly variable, the pH of the lake has generally decreased. Drainage from the exposed mine tailings adjacent to Anderson Lake is also adversely affecting lake water quality. The relative contribution of these acidic seepages to the reduction in water quality has not been addressed.

The petrographic and mineralogical examination of submerged and fresh tailings indicated that the samples had a high sulphide content, mostly as pyrite, and that little post-depositional oxidation of the sulphides had occurred. Sequential extraction of a tailings-rich sediment sample indicated that metals were primarily in a sulphide form and, hence, not readily available. However, very high zinc concentrations in the sediment resulted in significant quantities of easily extractable zinc in the leachate. Some oxidation of the sample could have occurred prior to, and during, the extraction procedure which may have contributed to the zinc solubility.

Benthic invertebrate densities were generally lowest near the outfall but were comparable to densities observed prior to tailings deposition. Spatial distribution of the species and species composition followed similar patterns to pre-depositional studies. It is apparent that although natural sediments near the outfall are initially smothered by the tailings discharge, over time, a veneer of organic material is deposited allowing benthic communities to re-establish.

Phytoplankton taxa and densities were generally indicative of mesotrophic conditions and were lowest near the tailings outfall.

The zooplankton community was reasonably diverse with the highest densities being found furthest from the outfall stations where metal concentrations in the water were

the lowest. Past studies, while not quantitative, suggest that a more diverse zooplankton community may have existed prior to lake disposal of tailings.

The aquatic vegetation is well established in most littoral areas of the lake, except where acidic drainage from an adjacent road (constructed of tailings) has impacted the vegetation.

The fisheries resources of the lake have always been limited, possibly due to winter kills and/or restricted stream access to the lake. Metal levels were higher in fish near the tailings outfall, particularly for Cu, Pb and Zn. The high Zn concentrations in the fish correspond to the high levels observed in the sediments.

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**Dissolved Oxygen and Temperature  
Profiles for Anderson Lake at  
Eight Stations**

Table A-1

Station	1		2		3		4	
Date	28/08/89		28/08/89		28/08/89		28/08/89	
Time	14:50		15:05		15:40		14:05	
Secchi (m)	0.9*		1.8		1.95		0.53*	
Max z (m)	5.0		3.3		2.9		4.4	
	DO	TEMP	DO	TEMP	DO	TEMP	DO	TEMP
	(mg/L)	(°C)	(mg/L)	(°C)	(mg/L)	(°C)	(mg/L)	(°C)
<b>Depth (m)</b>								
0.25	7.6	17.2	8.7	17.5	9.2	17.4	8.3	17.2
0.50	7.6	17.2	8.7	17.3	9.1	17.5	7.8	17.2
0.75	7.5	17.2	8.4	17.5	8.8	17.5	7.6	17.2
1.00	7.4	17.2	8.6	17.3	8.6	17.5	7.5	17.2
1.25	7.4	17.2	8.5	17.3	8.9	17.3	7.6	17.2
1.50	7.2	17.2	7.8	17.2	8.8	16.8	7.5	17.2
1.75	7.2	17.2	4.5	17.2	4.8	16.7	7.6	17.2
2.00	7.2	17.2	4.3	17.0			7.4	17.2
2.25	7.2	17.2					7.4	17.2
2.50	7.0	17.2					5.8	17.2
2.75	6.6	17.2					3.8	17.2
3.00	0.8	17.2					3.6	17.2
3.25	0.4	17.2						
3.50	Variable Bottom						Variable Bottom	

\* Murky-tailings discharges

Table A-2

Station	5		6		7		8	
Date	28/08/89		28/08/89		28/08/89		28/08/89	
Time	12:15		11:30		10:55		9:45	
Secchi (m)	1.35		1.35		1.95		1.35	
Max z (m)	3.4		3.2		2.8		1.6	
	DO	TEMP	DO	TEMP	DO	TEMP	DO	TEMP
	(mg/L)	(°C)	(mg/L)	(°C)	(mg/L)	(°C)	(mg/L)	(°C)
Depth (m)								
0.25	8.4	16.8	8.9	16.5	9.0	16.5	8.5	16.0
0.50	8.4	16.8	8.9	16.5	9.0	16.5	8.6	16.0
0.75	8.1	16.5	8.6	16.5	9.0	16.5	8.6	16.0
1.00	7.8	16.5	8.8	16.5	9.0	16.5	8.5	16.0
1.25	7.3	16.5	8.8	16.5	9.0	16.5	8.6	16.0
1.50	7.3	16.5	8.9	16.5	8.9	16.3	7.5	16.0
1.75	7.0	16.5	9.0	16.5	8.6	16.1		
2.00	5.5	16.5	5.2	16.7	8.6	16.1		
2.25	4.0	16.5	4.4	16.7	7.7	16.1		
2.50	2.4	16.5	2.2	16.7	5.4	16.1		
2.75								
3.00	Soft Muck		Soft Muck					
3.25								
3.50								

**Anderson Lake - Water Quality Data  
for Lake Stations**

Table B-1

Site Number	AL 1A	AL 1B	AL 1C	AL 1D
Date Sampled	Aug 28/89	Aug 28/89	Aug 28/89	Aug 28/89
Time	14:40	14:35	14:23	14:16
Depth (m)	0.5	1.7	2.7	4.5
<b>Physical Tests</b>				
pH (field)	6.0	6.2	6.4	6.5
pH (lab)	3.82	3.78	3.72	3.74
Conductivity	1610.	1640.	1630.	1660.
Dissolved Solids	1420.	1430.	1430.	1430.
Suspended Solids	50.0	27.0	44.0	63.0
Fixed Volatile Solids	9.0	8.0	10.0	8.0
Turbidity	63.5	42.3	53.2	87.3
<b>Anions &amp; Nutrients</b>				
Alkalinity	<1.0	<1.0	<1.0	<1.0
Sulphate	769.	811.	828.	820.
Chloride	66.1	75.1	74.0	73.3
T-Phosphorous	0.009	0.012	0.011	0.009
NO <sub>3</sub> /NO <sub>2</sub>	0.43	0.43	0.44	0.47
Ammonia	0.85	0.89	0.91	0.96
T-Dissolved Nitrogen	1.33	1.26	1.36	1.43
TOC	5.5	5.4	5.4	5.1
Silicate	1.2	1.7	1.8	2.1
<b>Dissolved Metals</b>				
Aluminum	0.19	0.22	0.18	0.19
Arsenic	0.0032	0.0029	0.0030	0.0039
Cadmium	0.0009	0.0009	0.0009	0.0010
Copper	0.042	0.040	0.038	0.042
Iron	0.09	0.09	0.09	0.10
Lead	0.042	0.034	<0.001	<0.001
Manganese	0.18	0.18	0.17	0.17
Mercury	<0.00005	<0.00005	<0.00005	<0.00005
Nickel	<0.001	0.002	<0.001	<0.001
Silver	<0.0001	<0.0001	<0.0001	<0.0001
Zinc	0.39	0.38	0.40	0.38
Calcium	302.	299.	292.	302.
Magnesium	16.5	17.5	17.1	16.9
Potassium	19.1	19.7	19.1	19.2
Sodium	39.8	38.4	39.6	42.3

Results expressed as milligrams per litre except for pH, Conductivity ( $\mu$ mhos/cm), and Turbidity (NTU).

< = Less than

T = Total

NO<sub>3</sub>/NO<sub>2</sub> = Nitrate/nitrite nitrogen

TOC = Total Organic Carbon

Table B-2

Site Number	AL 2A	AL 2B	AL 2C
Date Sampled	Aug 28/89	Aug 28/89	Aug 28/89
Time	14:56	15:07	15:20
Depth (m)	0.5	1.7	3.0
<b>Physical Tests</b>			
pH (field)	5.8	6.0	6.0
pH (lab)	5.34	5.67	5.53
Conductivity	1590.	1560.	1550.
Dissolved Solids	1360.	1370.	1350.
Suspended Solids	1.0	6.0	4.0
Fixed Volatile Solids	1.0	6.0	3.0
Turbidity	3.4	4.1	4.4
<b>Anions &amp; Nutrients</b>			
Alkalinity	3.22	4.29	3.22
Sulphate	729.	814.	841.
Chloride	73.6	73.3	72.5
T-Phosphorous	0.016	0.031	0.043
NO <sub>3</sub> /NO <sub>2</sub>	0.32	0.34	0.33
Ammonia	0.80	0.81	0.82
T-Dissolved Nitrogen	1.16	1.16	1.12
TOC	5.8	6.0	6.2
Silicate	1.2	1.1	1.1
<b>Dissolved Metals</b>			
Aluminum	0.063	0.061	0.066
Arsenic	0.0014	0.0015	0.0013
Cadmium	0.0006	0.0004	0.0002
Copper	0.016	0.014	0.016
Iron	<0.03	<0.03	<0.03
Lead	0.038	0.004	0.005
Manganese	0.19	0.19	0.19
Mercury	<0.00005	<0.00005	<0.00005
Nickel	0.001	0.002	0.003
Silver	<0.0001	<0.0001	<0.0001
Zinc	0.19	0.18	0.17
Calcium	295.	297.	286.
Magnesium	17.0	16.7	16.5
Potassium	18.8	18.6	18.4
Sodium	39.9	41.7	38.9

Results expressed as milligrams per litre except for pH, Conductivity ( $\mu$ mhos/cm), and Turbidity (NTU).

< = Less than

T = Total

NO<sub>3</sub>/NO<sub>2</sub> = Nitrate/nitrite nitrogen

TOC = Total Organic Carbon

Table B-3

Site Number	AL 3A	AL 3B	AL 3C
Date Sampled	Aug 28/89	Aug 28/89	Aug 28/89
Time	15:50	15:42	15:35
Depth (m)	0.5	1.7	2.7
<b>Physical Tests</b>			
pH (field)	6.2	6.2	6.2
pH (lab)	5.59	5.58	5.73
Conductivity	1550.	1550.	1560.
Dissolved Solids	1350.	1350.	1350.
Suspended Solids	5.0	2.0	23.0
Fixed Volatile Solids	5.0	2.0	19.0
Turbidity	3.3	3.0	8.4
<b>Anions &amp; Nutrients</b>			
Alkalinity	3.22	3.22	4.29
Sulphate	761.	707.	774.
Chloride	73.5	70.2	70.4
T-Phosphorous	0.11	0.022	0.12
NO <sub>3</sub> /NO <sub>2</sub>	0.35	0.37	0.37
Ammonia	0.78	0.74	0.72
T-Dissolved Nitrogen	0.95	1.02	1.03
TOC	5.9	6.0	6.1
Silicate	1.3	1.2	1.3
<b>Dissolved Metals</b>			
Aluminum	0.030	0.049	0.051
Arsenic	0.0013	0.0013	0.0011
Cadmium	0.0004	0.0006	0.0004
Copper	0.012	0.017	0.015
Iron	0.05	0.03	<0.03
Lead	0.004	0.003	0.003
Manganese	0.18	0.18	0.18
Mercury	<0.00005	<0.00005	<0.00005
Nickel	<0.001	0.001	0.007
Silver	<0.0001	<0.0001	<0.0001
Zinc	0.16	0.18	0.18
Calcium	292.	286.	287.
Magnesium	17.1	17.0	16.8
Potassium	18.8	19.9	18.7
Sodium	40.1	40.0	41.2

Results expressed as milligrams per litre except for pH, Conductivity ( $\mu$ mhos/cm), and Turbidity (NTU).

< = Less than

T = Total

NO<sub>3</sub>/NO<sub>2</sub> = Nitrate/nitrite nitrogen

TOC = Total Organic Carbon

Table B-4

Site Number	AL 4A	AL 4B	AL 4C	AL 4D
Date Sampled	Aug 28/89	Aug 28/89	Aug 28/89	Aug 28/89
Time	14:02	13:52	13:46	13:40
Depth (m)	0.5	1.7	2.7	0.5
<b>Physical Tests</b>				
pH (field)	5.9	6.1	6.3	6.4
pH (lab)	3.89	3.63	3.66	3.64
Conductivity	1580.	1660.	1650.	1640.
Dissolved Solids	1400.	1450.	1440.	1430.
Suspended Solids	22.0	41.0	42.0	54.0
Fixed Volatile Solids	11.0	17.0	16.0	24.0
Turbidity	21.5	58.8	52.1	46.7
<b>Anions &amp; Nutrients</b>				
Alkalinity	<1.0	<1.0	<1.0	<1.0
Sulphate	812.	846.	844.	847.
Chloride	73.0	72.8	73.1	73.3
T-Phosphorous	0.088	0.020	0.018	0.013
NO <sub>3</sub> /NO <sub>2</sub>	0.40	0.43	0.44	0.43
Ammonia	0.88	0.92	0.97	0.96
T-Dissolved Nitrogen	1.26	1.39	1.58	1.69
TOC	5.4	5.4	5.5	5.6
Silicate	1.4	2.0	1.5	2.0
<b>Dissolved Metals</b>				
Aluminum	0.092	0.087	0.085	0.084
Arsenic	0.0016	0.0026	0.0032	0.0028
Cadmium	0.0012	0.0010	0.0009	0.0010
Copper	0.042	0.044	0.044	0.044
Iron	0.08	0.09	0.11	0.10
Lead	0.026	0.003	0.044	0.046
Manganese	0.19	0.19	0.19	0.19
Mercury	<0.00005	<0.00005	<0.00005	<0.00005
Nickel	<0.001	<0.001	0.001	0.002
Silver	<0.0001	<0.0001	<0.0001	<0.0001
Zinc	0.37	0.43	0.44	0.44
Calcium	298.	290.	293.	298.
Magnesium	17.7	17.3	17.2	17.0
Potassium	19.3	19.4	19.1	19.2
Sodium	42.2	40.1	39.2	40.2

Results expressed as milligrams per litre except for pH, Conductivity ( $\mu$ mhos/cm), and Turbidity (NTU).

< = Less than

T = Total

NO<sub>3</sub>/NO<sub>2</sub> = Nitrate/nitrite nitrogen

TOC = Total Organic Carbon



Table B-5

Site Number	AL 5A	AL 5B	AL 5C	AL 5D
Date Sampled	Aug 28/89	Aug 28/89	Aug 28/89	Aug 28/89
Time	12:10	12:02	11:55	11:48
Depth (m)	0.5	1.7	2.7	3.3
<b>Physical Tests</b>				
pH (field)	6.1	6.0	5.9	5.8
pH (lab)	5.38	5.58	5.42	4.94
Conductivity	1580.	1580.	1580.	1580.
Dissolved Solids	1370.	1370.	1370.	1370.
Suspended Solids	5.0	4.0	5.0	14.0
Fixed Volatile Solids	5.0	4.0	5.0	14.0
Turbidity	6.1	6.6	5.7	5.6
<b>Anions &amp; Nutrients</b>				
Alkalinity	3.22	3.22	3.22	1.07
Sulphate	804.	795.	778.	837.
Chloride	75.4	73.6	74.7	73.5
T-Phosphorous	0.10	0.019	0.090	0.007
NO <sub>3</sub> /NO <sub>2</sub>	0.38	0.37	0.36	0.39
Ammonia	0.65	0.69	0.71	0.82
T-Dissolved Nitrogen	1.01	0.95	1.00	1.92
TOC	6.0	6.2	6.1	6.2
Silicate	<1.0	1.1	1.1	1.1
<b>Dissolved Metals</b>				
Aluminum	0.076	0.12	0.097	0.10
Arsenic	0.0010	0.0012	0.0011	0.0009
Cadmium	0.0003	0.0003	0.0004	0.0003
Copper	0.015	0.015	0.017	0.025
Iron	<0.03	<0.03	0.03	<0.03
Lead	0.052	0.003	0.004	0.007
Manganese	0.18	0.16	0.17	0.17
Mercury	<0.00005	<0.00005	<0.00005	<0.00005
Nickel	<0.001	<0.001	0.004	<0.001
Silver	<0.0001	<0.0001	<0.0001	<0.0001
Zinc	0.16	0.16	0.17	0.20
Calcium	277.	287.	291.	290.
Magnesium	16.9	17.4	17.5	17.8
Potassium	19.0	18.9	19.2	19.1
Sodium	39.6	37.7	37.9	38.6

Results expressed as milligrams per litre except for pH, Conductivity ( $\mu$ mhos/cm), and Turbidity (NTU).

< = Less than

T = Total

NO<sub>3</sub>/NO<sub>2</sub> = Nitrate/nitrite nitrogen

TOC = Total Organic Carbon

Table B-6

Site Number	AL 6A	AL 6B	AL 6C
Date Sampled	Aug 28/89	Aug 28/89	Aug 28/89
Time	11:25	11:13	11:05
Depth (m)	0.5	1.7	2.7
<b>Physical Tests</b>			
pH (field)	6.0	6.1	6.0
pH (lab)	5.22	5.35	4.94
Conductivity	1570.	1550.	1560.
Dissolved Solids	1370.	1360.	1360.
Suspended Solids	5.0	3.0	8.0
Fixed Volatile Solids	5.0	3.0	8.0
Turbidity	6.5	5.5	5.4
<b>Anions &amp; Nutrients</b>			
Alkalinity	2.12	3.22	1.07
Sulphate	794.	790.	769.
Chloride	68.7	71.2	74.6
T-Phosphorous	0.011	0.009	0.010
NO3/NO2	0.43	0.43	0.64
Ammonia	0.53	0.71	0.43
T-Dissolved Nitrogen	0.96	1.04	1.05
TOC	6.2	6.4	6.4
Silicate	<1.0	<1.0	<1.0
<b>Dissolved Metals</b>			
Aluminum	0.090	0.088	0.095
Arsenic	0.0010	0.0008	0.0008
Cadmium	0.0003	0.0007	<0.0002
Copper	0.011	0.012	0.011
Iron	<0.03	<0.03	<0.03
Lead	0.001	0.001	0.002
Manganese	0.17	0.18	0.18
Mercury	<0.00005	<0.00005	<0.00005
Nickel	<0.001	<0.001	0.001
Silver	<0.0001	<0.0001	<0.0001
Zinc	0.15	0.16	0.14
Calcium	285.	290.	290.
Magnesium	17.5	17.0	16.9
Potassium	19.4	18.8	18.6
Sodium	37.3	36.5	37.4

Results expressed as milligrams per litre except for pH, Conductivity ( $\mu$ mhos/cm), and Turbidity (NTU).

< = Less than

T = Total

NO3/NO2 = Nitrate/nitrite nitrogen

TOC = Total Organic Carbon

Table B-7

Site Number	AL 7A	AL 7B	AL 7C	AL 8A	AL 8B
Date Sampled	Aug 28/89	Aug 28/89	Aug 28/89	Aug 28/89	Aug 28/89
Time	10:24	10:32	10:45	9:41	9:30
Depth (m)	0.5	1.7	2.7	0.5	1.5
<b>Physical Tests</b>					
pH (field)	6.2	6.3	6.4	7.7	6.5
pH (lab)	5.01	4.97	4.93	6.04	6.20
Conductivity	1580.	1560.	1560.	1520.	1530.
Dissolved Solids	1380.	1380.	1370.	1360.	1360.
Suspended Solids	4.0	10.0	13.0	9.0	8.0
Fixed Volatile Solids	4.0	10.0	12.0	9.0	8.0
Turbidity	3.0	6.4	4.2	3.4	3.2
<b>Anions &amp; Nutrients</b>					
Alkalinity	1.07	1.07	1.07	6.38	7.51
Sulphate	819.	813.	816.	785.	774.
Chloride	72.6	86.8	80.8	73.2	70.6
T-Phosphorous	0.007	0.012	0.004	0.016	0.018
NO <sub>3</sub> /NO <sub>2</sub>	0.62	0.66	0.65	0.45	0.44
Ammonia	0.42	0.32	0.35	0.005	<0.005
T-Dissolved Nitrogen	1.03	1.02	1.03	0.66	0.68
TOC	6.3	6.5	5.6	5.8	5.8
Silicate	<1.0	<1.0	<1.0	<1.0	<1.0
<b>Dissolved Metals</b>					
Aluminum	0.053	0.050	0.054	0.017	0.018
Arsenic	0.0009	0.0008	0.0008	0.0008	0.0008
Cadmium	<0.0002	<0.0002	0.0005	<0.0002	<0.0002
Copper	0.009	0.010	0.009	0.002	0.002
Iron	<0.03	<0.03	<0.03	<0.03	<0.03
Lead	<0.001	<0.001	<0.001	<0.001	<0.001
Manganese	0.17	0.17	0.17	0.064	0.070
Mercury	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
Nickel	<0.001	<0.001	<0.001	<0.001	<0.001
Silver	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Zinc	0.13	0.13	0.14	0.020	0.020
Calcium	289.	301.	289.	292.	290.
Magnesium	17.4	17.7	18.3	18.5	18.1
Potassium	19.6	19.2	19.3	18.5	19.0
Sodium	37.3	35.9	37.7	37.0	37.2

Results expressed as milligrams per litre except for pH, Conductivity ( $\mu$ mhos/cm), and Turbidity (NTU).

< = Less than

T = Total

NO<sub>3</sub>/NO<sub>2</sub> = Nitrate/nitrite nitrogen

TOC = Total Organic Carbon

**Anderson Lake Inflows  
Water Chemistry Data**

Table C-1

Site Number	C1	C 2	C2A	C3	C4
Date Sampled	Aug 27/89	Aug 27/89	Aug 28/89	Aug 27/89	Aug 27/89
Flow (L/S)	4.5	18	1.5	3.0	3.0
<b>Physical Tests</b>					
pH (lab)	2.56	2.50	5.67	6.75	2.38
Conductivity	2980.	3260.	480.	255.	388.
Dissolved Solids	2190.	2450.	420.	230.	340.
Suspended Solids	733	179	56.0	4.0	18.0
Fixed Volatile Solids	243	28.0	39.0	4.0	12.0
Turbidity	1420	204	121	8.6	5.3
<b>Anions &amp; Nutrients</b>					
Alkalinity	<1.0	<1.0	12.7	44.6	<1.0
Sulphate	1630.	1770.	213.	81.3	108.
Chloride	25.8	44.2	5.4	4.6	4.2
T-Phosphorous	0.22	<0.001	0.53	0.25	0.028
NO <sub>3</sub> /NO <sub>2</sub>	0.27	0.005	<0.005	0.005	0.015
Ammonia	0.41	0.38	<0.005	<0.005	<0.005
T-Dissolved Nitrogen	1.11	1.43	0.67	0.72	0.70
TOC	14.0	9.5	42.8	30.0	32.5
Silicate	9.6	7.5	18.0	10.4	10.2
<b>Dissolved Metals</b>					
Aluminum	72.2	45.0	0.57	0.58	0.31
Arsenic	0.51	0.34	0.0009	0.0008	0.0006
Cadmium	0.044	0.032	0.0092	0.0017	0.0003
Copper	7.18	7.32	0.17	0.18	0.073
Iron	88.4	176.	1.07	1.50	0.19
Lead	<0.001	<0.001	0.001	0.001	0.001
Manganese	4.06	4.31	0.37	0.18	0.014
Mercury	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
Nickel	<0.001	0.081	0.009	0.042	0.009
Silver	0.0002	0.0002	<0.0001	<0.0001	<0.0001
Zinc	24.3	29.2	4.28	0.63	0.098
Calcium	144.	195.	48.1	28.9	46.9
Magnesium	128.	111.	24.9	13.0	18.3
Potassium	5.53	8.90	3.39	1.44	2.30
Sodium	8.27	16.7	3.58	2.61	3.49

Results expressed as milligrams per litre except for pH, and Conductivity ( $\mu$ mhos/cm), and Turbidity (NTU).

< = Less than

T = Total

NO<sub>3</sub>/NO<sub>2</sub> = Nitrate/nitrite nitrogen

TOC = Total Organic Carbon

Table C-2

Site Number	I1	I2	I3	B1	Tailings D1	Tailings D2
Date Sampled	Aug 27/89	Aug 27/89	Aug 27/89	Aug 27/89	Aug 26/89	Aug 26/89
Flow (L/s)	3.0	12.0	9	-	-	-
<b>Physical Tests</b>						
pH (lab)	7.02	6.53	6.58	5.38	6.75	5.92
Conductivity	67.1	126.	105.	1440.	1480.	1410.
Dissolved Solids	50.	110.	90.	1250.	1290.	1230.
Suspended Solids	5.3	1.0	1.0	5.0	58300.	7420.
Fixed Volatile Solids	5.3	1.0	1.0	5.0	8230.	1330.
Turbidity	2.1	1.6	3.3	2.7	16200.	930.
<b>Anions &amp; Nutrients</b>						
Alkalinity	35.0	25.8	21.5	3.22	34.3	7.51
Sulphate	1.3	26.7	17.0	673.	665.	634.
Chloride	0.7	2.1	2.5	66.1	93.3	92.4
T-Phosphorous	0.082	0.020	0.005	0.004	0.32	0.40
NO3/NO2	0.24	0.033	0.005	0.72	0.030	0.47
Ammonia	<0.005	<0.005	<0.005	0.21	1.30	1.54
T-Dissolved Nitrogen	1.13	0.88	0.72	1.03	2.33	2.54
TOC	22.0	37.8	45.6	7.7	4.6	5.0
Silicate	3.8	9.5	10.6	1.5	14.8	18.4
<b>Dissolved Metals</b>						
Aluminum	0.054	0.096	0.22	0.036	0.009	0.017
Arsenic	<0.0001	0.0003	0.0006	0.0013	0.0026	0.017
Cadmium	<0.0002	<0.0002	<0.0002	<0.0002	0.0016	0.0048
Copper	0.003	0.002	0.003	0.005	0.004	0.028
Iron	0.17	0.11	0.11	<0.03	<0.03	<0.03
Lead	0.003	<0.001	<0.001	0.001	0.017	0.006
Manganese	<0.005	<0.005	<0.005	0.096	1.16	1.05
Mercury	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
Nickel	0.004	<0.001	<0.001	<0.001	0.008	0.027
Silver	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Zinc	<0.005	<0.005	<0.005	0.078	2.77	2.97
Calcium	9.20	17.1	14.1	257.	224.	217.
Magnesium	2.43	6.22	5.78	14.7	29.7	25.7
Potassium	0.60	1.38	0.46	16.9	14.3	14.2
Sodium	0.78	1.44	1.27	34.2	47.9	46.9

Results expressed as milligrams per litre except for pH, and Conductivity ( $\mu$ mhos/cm), and Turbidity (NTU).

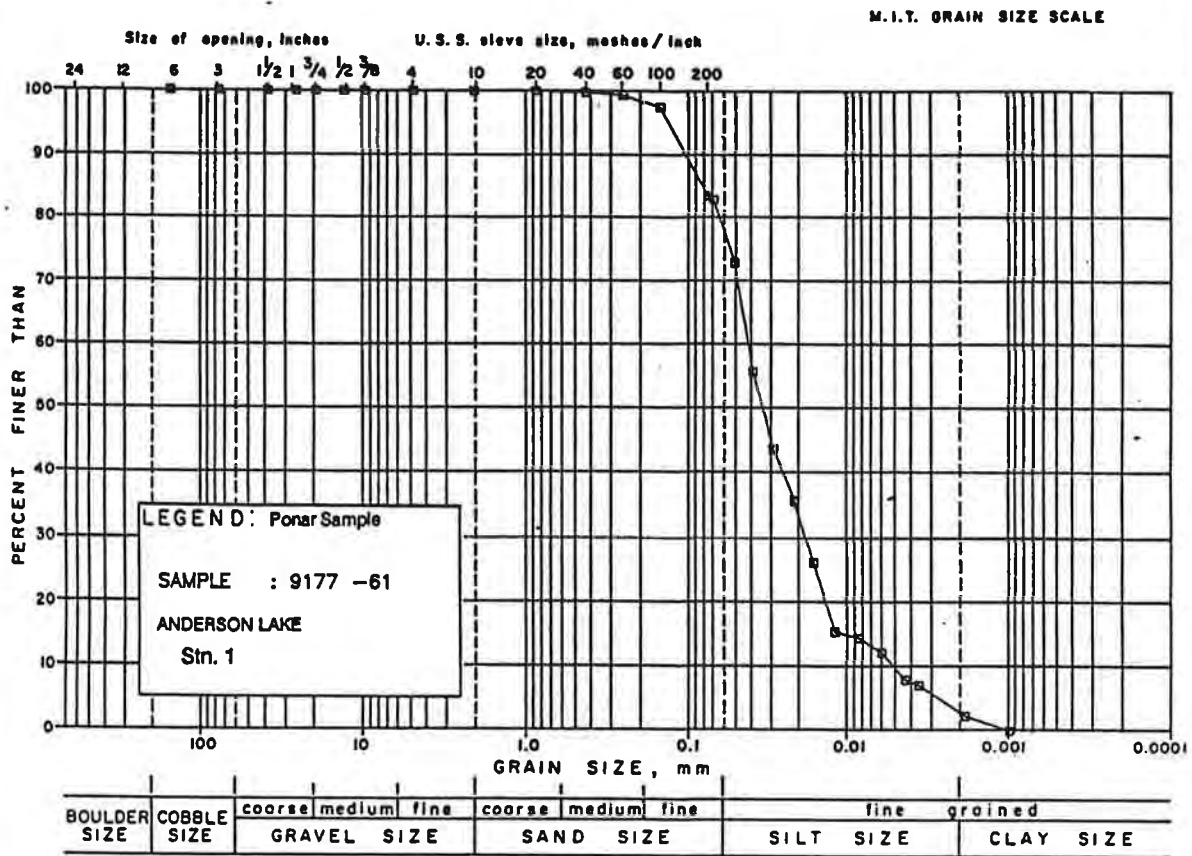
< = Less than

T = Total

NO3/NO2 = Nitrate/nitrite nitrogen

TOC = Total Organic Carbon

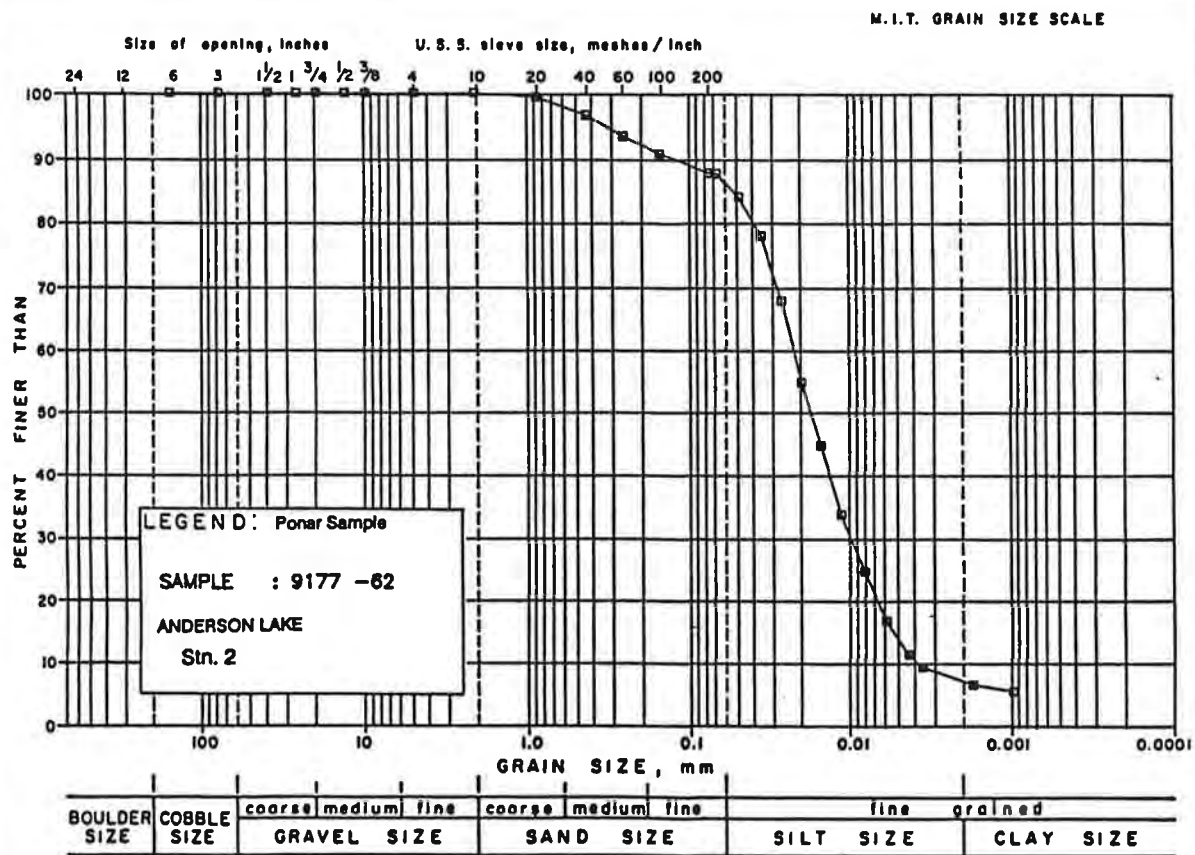
**Particle Size Analysis of  
Top 2 cm Layer of Sediments**



GRAIN SIZE DISTRIBUTION

Figure D 1

Golder Associates

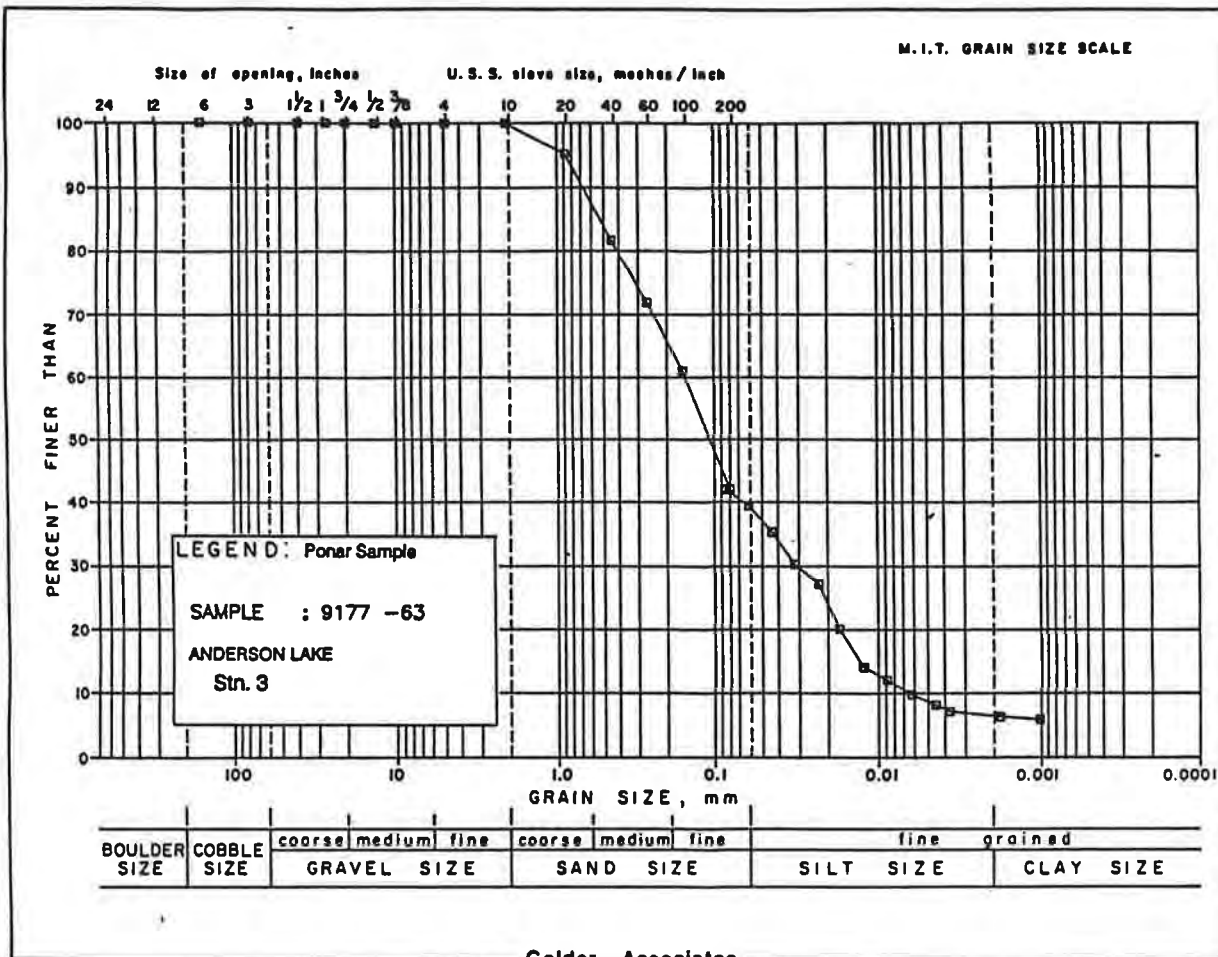


GRAIN SIZE DISTRIBUTION

Figure D 2

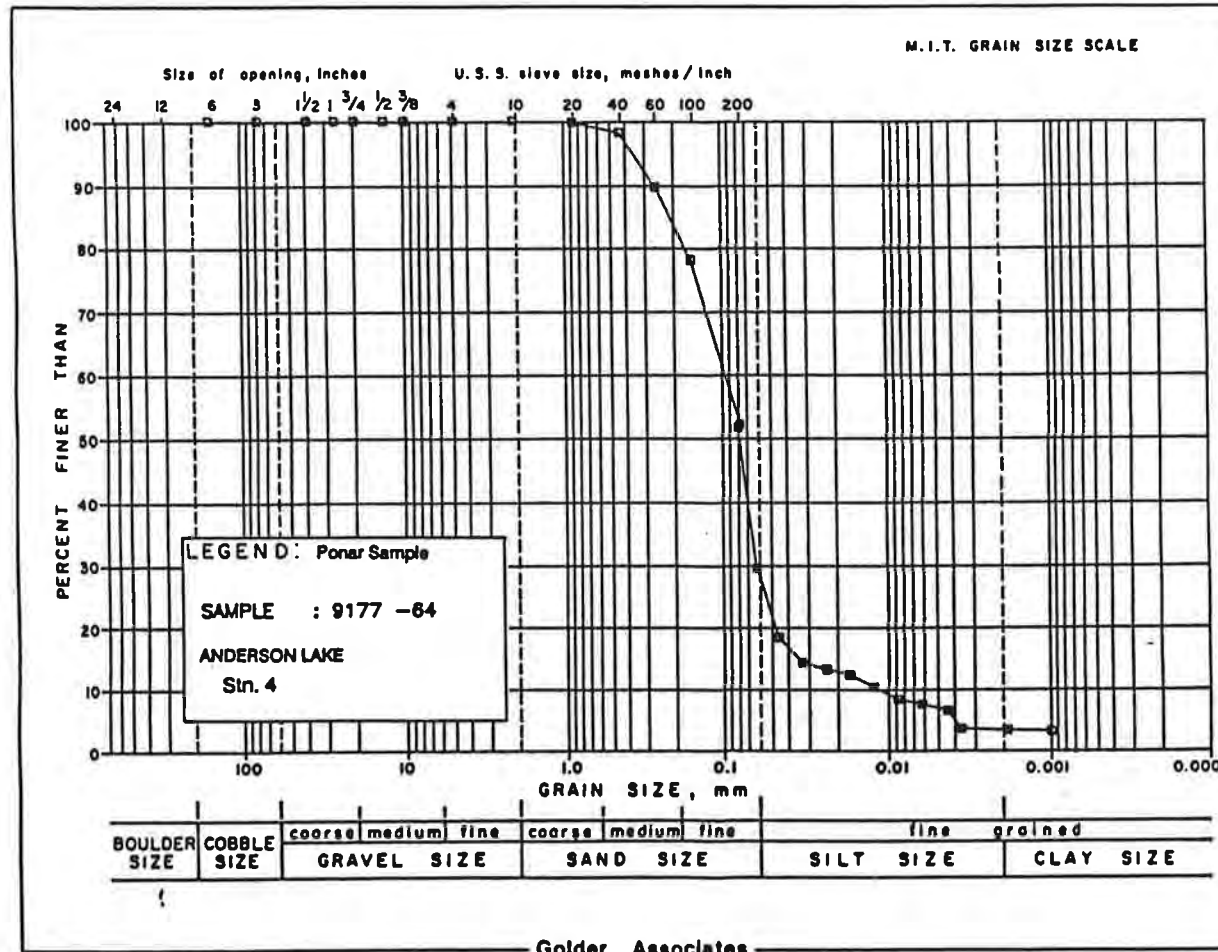
Golder Associates





GRAIN SIZE DISTRIBUTION

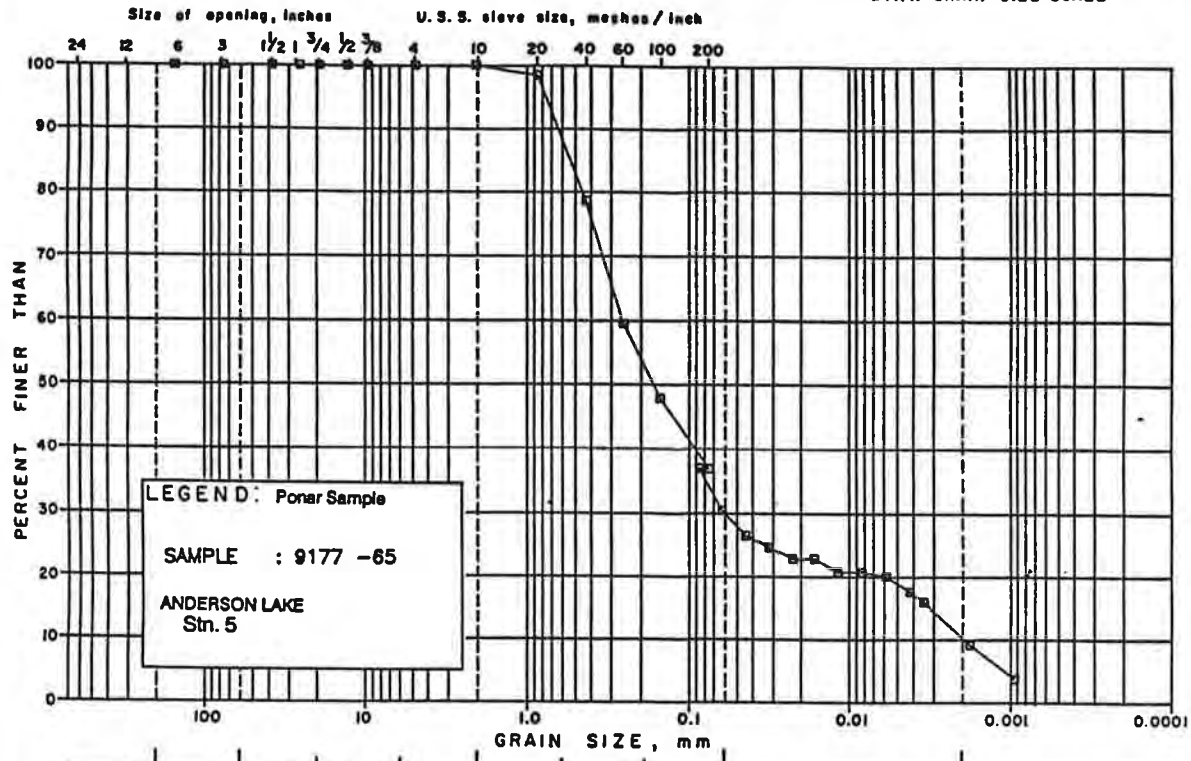
Figure D 3



GRAIN SIZE DISTRIBUTION

Figure D 4

M.I.T. GRAIN SIZE SCALE



LEGEND: Ponar Sample  
 SAMPLE : 9177 -65  
 ANDERSON LAKE  
 Stn. 5

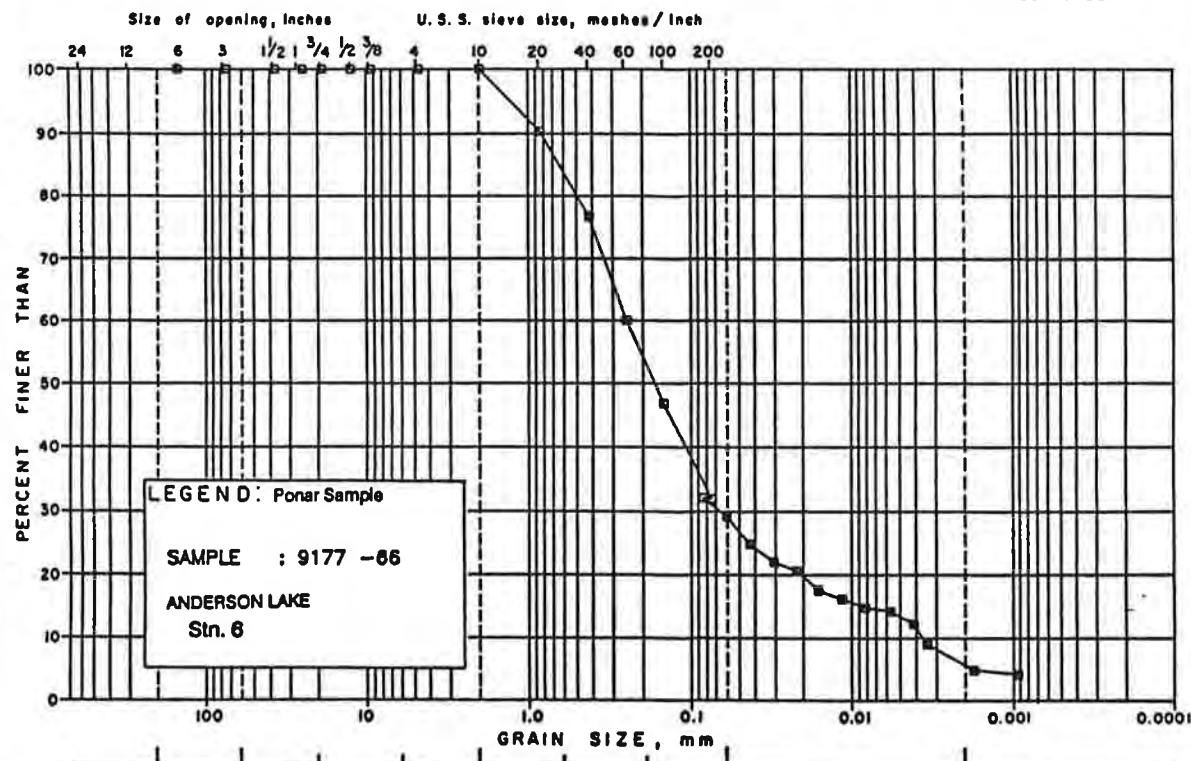
BOULDER SIZE	COBBLE SIZE	coarse GRAVEL SIZE	medium GRAVEL SIZE	fine GRAVEL SIZE	coarse SAND SIZE	medium SAND SIZE	fine SAND SIZE	SILT SIZE	CLAY SIZE
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GRAIN SIZE DISTRIBUTION

Figure D 5

Golder Associates

M.I.T. GRAIN SIZE SCALE



LEGEND: Ponar Sample  
 SAMPLE : 9177 -66  
 ANDERSON LAKE  
 Stn. 6

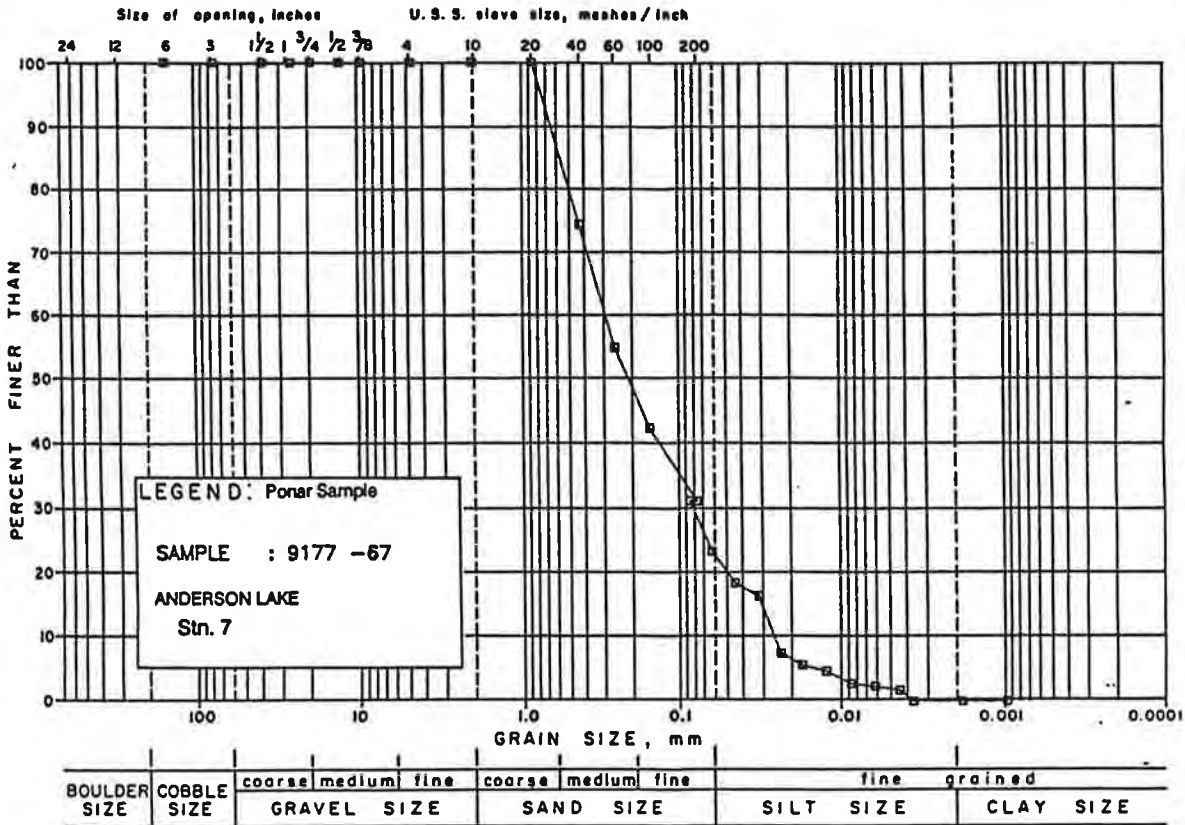
BOULDER SIZE	COBBLE SIZE	coarse GRAVEL SIZE	medium GRAVEL SIZE	fine GRAVEL SIZE	coarse SAND SIZE	medium SAND SIZE	fine SAND SIZE	SILT SIZE	CLAY SIZE
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GRAIN SIZE DISTRIBUTION

Figure D 6

Golder Associates

M.I.T. GRAIN SIZE SCALE

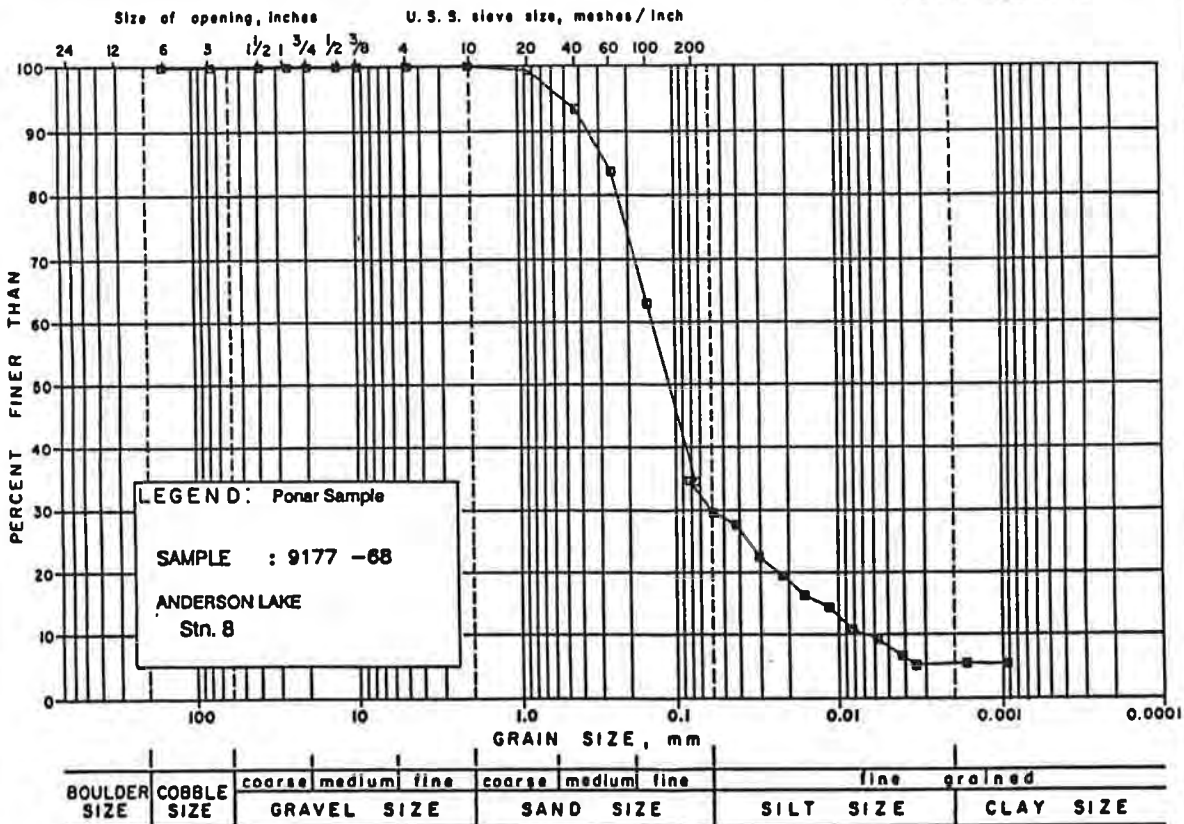


GRAIN SIZE DISTRIBUTION

Figure D 7

Golder Associates

M.I.T. GRAIN SIZE SCALE



GRAIN SIZE DISTRIBUTION

Figure D 8

Golder Associates

**XRD Analysis of  
Top 2 cm Layer of Sediments**

Table E-1

Station (Sample)	Minerals Present (UBC)	Mineral Present (Cominco)
Stn. 1 (AL-1)	Quartz Pyrite Feldspar (Albite) Clay (Muscovite) Clay (Chlorite) Calcite, minor amounts	Quartz Pyrite Chlorite Sericite
Stn. 2 (AL-2)	Quartz Pyrite Feldspar (Albite) Clay (Muscovite) Clay (Chlorite) Calcite, minor amounts	Quartz Pyrite Chlorite Sericite
Stn. 3 (AL-3)	Quartz Pyrite Feldspar (Albite) Clay (Chlorite), minor amounts Clay (Muscovite), trace amounts Calcite, trace amounts	Quartz Pyrite Chlorite Sericite
Stn. 4 (AL-4)	Quartz Pyrite Feldspar (Albite) Clay (Muscovite) Clay (Chlorite) Calcite, minor amounts	Quartz Pyrite Chlorite Sericite
Stn. 5 (AL-5)	Quartz Feldspar (Albite) Pyrite Clay (Chlorite), trace amounts Calcite, trace amounts	Quartz Pyrite
Stn. 6 (AL-6)	Not Done	Quartz Chlorite Sericite
Stn. 7 (AL-7)	Quartz Feldspar (Albite) Pyrite, minor amounts	Quartz Pyrite
Tailings (ALT)	Not Done	Quartz Pyrite Chlorite Sericite

### Sample: AL Tailings

Constituent	Estimated Mode (%)
Pyrite	55
Pyrrhotite	4
Sphalerite	2.5
Chalcopyrite	0.5
Galena	0.3
Arsenopyrite	0.7
Magnetite	0.5
Quartz	25
Hornblende	4
Epidote	3
Carbonate	2
Other silicates	2.5

This product has a predominant particle size range of 20 - 170 microns. A very minor proportion is in the range 5 - 20 microns, and there are scattered, coarser grains up to 250 microns in size.

It is a sulfide-rich tailings, in which pyrite is by far the dominant component. Pyrrhotite and dark brown (Fe-rich) sphalerite are the principal sulfide accessories. There is also very minor chalcopyrite, galena and arsenopyrite.

The sulfide particles are almost entirely liberated from the gangue, and there is also a very high order of liberation between the individual sulfide species. Very occasional fine-grained intergrowth of the minor sulfide components with pyrite or with each other is observed.

The sulfides are fresh, and consist of sharply defined, angular to sub-angular particles. The low proportion of slimes-sized particles (<20 microns) is notable.

The gangue constituents appear to be predominantly quartz, with minor accessory proportions of hornblende, epidote, carbonate and other silicates (chlorite, sericite, biotite, garnet [?], etc.).

## Sample: AL-1

Constituent	Estimated Mode (%)
Pyrite	28
Pyrrhotite	8
Sphalerite	1.5
Chalcopyrite	0.5
Arsenopyrite	0.5
Galena	trace
Quartz	53
Hornblende	3
Chlorite	2
Sericite)	2
Biotite)	
Organics	1.5

This sample has a predominant particle size range of 2 - 80 microns. It is of notably smaller average size than the AL Tailings, and it is estimated that at least 50% of the material is <45 microns in size. Grain shapes are strikingly angular, and often elongate, splintery or shard-like.

The sulfides are principally pyrite, with accessory pyrrhotite and sphalerite, and minor chalcopyrite and arsenopyrite. All are present as liberated grains.

The sulfides appear fresh and unoxidized.

The gangue is largely quartz (possibly including a small proportion of plagioclase), plus minor amounts of hornblende, chlorite and sericite and/or biotite. A few quartz particles reach 120 microns in size.

This material appears to be a tailings, similar to that represented by the previous sample (AL Tailings), but having a lower ratio of sulfides to gangue, and a smaller average particle size. There is no recognizable component of natural mineral sediment.

Occasional flocs of micron-sized sulfides cemented by isotropic brown material probably represent sulfide slimes intermingled with organic ooze.

**Sample: AL-2**

Constituent	Estimated Mode (%)
Pyrite	20
Pyrrhotite	8
Sphalerite	1
Chalcopyrite	trace
Quartz	64
Hornblende	2
Biotite	1
Chlorite	1
Organics	3

This sample shows similar general features to the previous one (AL-1), but is slightly finer-grained overall, and has a lower percentage of total sulfides.

The particle size range is about 2 - 70 microns, with the bulk of the material (particularly the sulfide component) in the <math>-35</math> micron range. Clumps of sulfide slimes cemented by brown organic material are significantly more common than in AL-1

The majority of the sulfide particles are of sharply angular to elongate or splintery form.

The ratio of pyrrhotite to pyrite appears distinctly higher than in AL-1, though it is not easy to discriminate reliably between the two minerals at the smaller particle sizes.

The sulfide particles appear fresh and unoxidized.

**Sample: AL-3**

Constituent	Estimated Mode (%)
Organic Material	94
Framboidal Pyrite	1
Sulfide Dust	2
Quartz	2
Sericite	1

This sample is of strikingly different type to the previous ones.



**Petrographic Analysis of  
Top 2 cm Layer of Sediments**

It consists of ragged clumps of contorted/fibrous or crustified/cellular, translucent, brown, isotropic material which is clearly a form of organic (animal and vegetable) trash. It not uncommonly includes discrete, discoidal and segmented forms of obvious biogenic origin (diatoms, etc.).

The brown material incorporates wisps and clumps of sub-opaque, white material having optical properties similar to leucoxene (hydrated  $\text{TiO}_2$ ). This is almost certainly an artifact of the slide preparation process, being  $\text{Al}_2\text{O}_3$  polishing powder trapped in the porous unconsolidated organic material.

Rare, individual, angular quartz grains, up to 25 microns in size, are seen incorporated in the brown organic matrix, and there are scattered, minute flecks of possible sericite, but the abundance of clastic mineral material overall is strikingly low. Note, however, that the XRD scan includes a variety of peaks, suggesting a more substantial content of crystalline phases, so possibly the thin section is non-representative.

Apparently this sample (sediment from 0 - 2 cm) represents the organic ooze on a lake bottom which is not a site of active clastic deposition. It is, however, possible that the organic material is a surface veneer overlying true sediments.

Notwithstanding the nature of the sample, there is a minor, but significant, content of sulfides. These are of two distinct textural types.

One consists of minute, angular grains, 1 - 5 microns in size, occurring as flocculated aggregates and as more or less sparsely disseminated specks incorporated within the organic material. Occasional individual angular sulfide grains up to 15 microns in size, are also seen.

Estimation of the abundance and constituent mineral proportions in sulfides of this size range is very difficult. However, the fine sulfide dust clearly resembles the coarser sulfides of the previous samples (AL tailings, and AL-1 and 2), in that it consists predominantly of pyrite, with minor pyrrhotite and sphalerite - though the proportion of chalcopyrite appears somewhat higher. It probably represents hydrologically transported, slimes-sized material from the main tailings dumping area.

The other sulfide type consists of spheroidal clusters and more or less compact fromboids of pyrite, 5 - 20 microns in diameter. These occur as scattered individuals,

sometimes together with included dust of the previous type, and sometimes alone in the organic matrix. This is probably biogenically deposited, and may, in fact, represent a product of partial bacterial reworking of the clastic sulfides.

**Sample: AL-4**

Constituent	Estimated Mode (%)
Pyrite	37
Pyrrhotite	8
Arsenopyrite	trace
Sphalerite	1.5
Chalcopyrite	trace
Galena	trace
Quartz	47
Hornblende	2
Biotite	2
Chlorite	1
Carbonate	trace
Organics	1

This sample has a particle size range of 2 - 120 microns. It is of similar type to AL-1 and 2, and consist of discrete, angular grains of liberated fresh sulfides and crystalline silicates.

Sulfides in this sample are coarser and relatively more abundant than in the comparable tailings-rich samples, AL-1 and AL-2, but show similar mineral proportions.

The gangue is, as in the other samples, predominantly quartz with minor hornblende, biotite etc. The presence of carbonate was noted, but it is very minor.

This sample is largely free of the brown organic phase and/or of organic-cemented sulfide slimes. It probably represents a site of recent tailings dumping.

**Sample: AL-5**

Constituent	Estimated Mode (%)
Organic Material	93
Quartz	5
Sulfide Dust	2
Pyrite framboids	trace

This sample is composed predominantly of organic trash and ooze.

The predominant component is the brown, streaky/clumpy, translucent phase (see description of AL-3), often with biogenic skeletal. A few recognizable wood fragments are present.

Sporadic, angular quartz grains, 20 - 150 microns in size, are relatively common, embedded in the organic material.

Sulfides are seen as sparse disseminations of included angular dust, of grain size 2 - 10 microns. There are also rare, discrete, angular pyrite grains, 20 - 50 microns in size.

A few grains of the framboidal type of pyrite were noted, but it is much less evident than in AL-3.

**Sample: AL-6**

Constituent	Estimated Mode (%)
Organic Material	99.5
Quartz	trace
Sulfide Dust	trace
Pyrite framboids	trace

This sample consist of essentially 100% organic trash.

Other components are confined to very rare, small, angular quartz grains, traces of micron-sized sulfide dust and very rare pyrite framboids.

This sample appears to represent a portion of the lake bed where the contribution of transported tailings material is virtually nil.

Note that, although framboidal pyrite individuals are generally very rare in this sample, the slide includes a single fragment, 0.7 x 0.5 mm in size, of compact, aggregated framboidal pyrite. The presence of such material suggests that significant localized accumulation of secondarily reworked S is taking place in this lake.

Note that this sample contains the lowest percentage of non-organic components (silicates and clastic sulfides) of all the suite.

**Sample: AL-7**

Constituent	Estimated Mode (%)
Organic Material	99
Quartz	1
Pyrite framboids	trace

This sample is essentially identical to AL-6. It consists almost entirely of organic trash, with abundant biogenic skeletal.

Sparsely scattered, individual, angular grains of quartz, to 75 microns in size, are seen, but micron-sized clastic sulfide dust is virtually absent. Rare, individual pyrite framboids, 10 - 30 microns in size, are, however, seen.

**Sequential Extraction Results of  
Top 2 cm of Sediments**

Table G-1

**Sequential Multiple Extraction of Surface  
Sediments (top 2 cm) from Anderson Lake (Site AL-2)  
Anderson Lake Duplicate A**

Parameter	Detection Limit ( $\mu\text{g/g}$ )	Water Soluble Phase	Exchange Cations	Weak Acid Soluble Phase	Reducible Phases			Oxidizable Phase	Residual Phase	Mass Balance ( $\mu\text{g/g}$ )	Total Digestion
					Easily	Moderate	Difficult				
Aluminum	4.00	<	<	59.2	49.8	1076	43.5	1225	52810	55264	48710
	%	0.0	0.0	0.1	0.1	1.9	0.1	2.2	95.6	100.0	
Arsenic	4.00	<	<	<	<	170	15.4	426.5	650	1261	1360
	%	0.0	0.0	0.0	0.0	13.5	1.2	33.8	51.5	100.0	
Cadmium	0.20	0.93	0.40	0.36	<	<	<	6.7	1.55	9.94	14.8
	%	9.4	4.0	3.6	0.0	0.0	0.0	67.4	15.6	100.0	
Cobalt	0.30	5.0	0.78	1.30	0.84	2.63	<	161	155	327	366
	%	1.5	0.2	0.4	0.3	0.8	0.0	49.3	47.5	100.0	
Copper	0.20	<	3.1	18.1	<	49.8	<	1275.0	429.0	1775.0	1788.0
	%	0.0	0.2	1.0	0.0	2.8	0.0	71.8	24.2	100.0	
Iron	0.50	18.1	<	520	1380	22450	2082	91500	140500	258450	265000
	%	0.0	0.0	0.2	0.5	8.7	0.8	35.4	54.4	100.0	
Lead	1.00	<	7.5	71	26.6	22.1	<	510	49.3	686	640
	%	0.0	1.1	10.3	3.9	3.2	0.0	74.3	7.2	100.0	
Manganese	0.10	122	20.2	10.9	28.2	46.7	6.3	42.8	1295	1572	1430
	%	7.8	1.3	0.7	1.8	3.0	0.4	2.7	82.4	100.0	
Mercury	0.010	<	<	<	<	<	<	<	2.45	2.45	2.10
	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	
Nickel	0.40	1.92	<	<	<	1.27	<	6.1	<	9.34	16.0
	%	20.5	0.0	0.0	0.0	13.6	0.0	65.9	0.0	100.0	
Selenium	0.04	0.06	0.06	0.06	0.06	1.12	12.0	23.2	1.65	38.2	55.0
	%	0.2	0.2	0.2	0.2	2.9	31.4	60.7	4.3	100.0	
Zinc	0.10	271	58	141	96	278	<	4795	3315	8954	8907
	%	3.0	0.6	1.6	1.1	3.1	0.0	53.6	37.0	100.0	

Results are expressed as micrograms per dry gram of sediment followed by % of total. Molybdenum and silver were not detectable in the sample.

Table G-1 (Cont'd)

Sequential Multiple Extraction of Surface  
Sediments (top 2 cm) from Anderson Lake (Site AL-2)  
Anderson Lake Duplicate B

Parameter	Detection Limit (µg/g)	Water Soluble Phase	Exchange Cations	Weak Acid Soluble Phase	Reducible Phases			Oxidizable Phase	Residual Phase	Mass Balance (µg/g)	Total Digestion
					Easily	Moderate	Difficult				
Aluminum	4.00	<	<	59	48	1087	44.5	638	56000	57875	48710
	%	0.0	0.0	0.1	0.1	1.9	0.1	1.1	96.8	100.0	
Arsenic	4.00	<	<	<	<	148	15.6	382	750	1295	1360
	%	0.0	0.0	0.0	0.0	11.4	1.2	29.5	57.9	100.0	
Cadmium	0.20	0.63	<	<	<	<	<	4.68	1.55	6.86	10.0
	%	9.2	0.0	0.0	0.0	0.0	0.0	68.2	22.6	100.0	
Cobalt	0.30	4.40	0.80	1.18	0.78	2.48	<	133	160	303	366
	%	1.5	0.3	0.4	0.3	0.8	0.0	43.9	52.9	100.0	
Copper	0.20	<	3.0	18.8	<	53.1	<	1260.0	470.0	1804.9	1788.0
	%	0.0	0.2	1.0	0.0	2.9	0.0	69.8	26.0	100.0	
Iron	0.5	17.5	<	515	1370	22650	2145	70500	165000	262197	265000
	%	0.0	0.0	0.2	0.5	8.6	0.8	26.9	62.9	100.0	
Lead	1.00	<	8.1	74	28.6	25.1	<	550	46.4	733	640
	%	0.0	1.1	10.2	3.9	3.4	0.0	75.1	6.3	100.0	
Manganese	0.10	110	21.4	11.7	28.6	46.3	6.6	29.5	1275	1529	1430
	%	7.2	1.4	0.8	1.9	3.0	0.4	1.9	83.4	100.0	
Mercury	0.010	<	<	<	<	<	<	<	2.45	2.45	2.10
	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	
Nickel	0.40	2.00	<	<	<	<	<	5.20	<	7.20	16
	%	27.8	0.0	0.0	0.0	0.0	0.0	72.2	0.0	100.0	
Selenium	0.04	0.06	0.06	0.08	0.06	1.02	12.0	25.6	2.10	41.0	62.0
	%	0.1	0.1	0.2	0.1	2.5	29.3	62.5	5.1	100.0	
Zinc	0.10	219	54	141	95	300	<	4190	3400	8399	8907
	%	2.6	0.6	1.7	1.1	3.6	0.0	49.9	40.5	100.0	

Results are expressed as micrograms per dry gram of sediment followed by % of total. Molybdenum and silver were not detectable in the sample.



**Chlorophylla a and Quantitative  
Phytoplankton Data (cells/ml)  
for Anderson Lake**

Table H-1

Site	1-A	1-B	2-A	2-B
Date	28/08/89	28/08/89	28/08/89	28/08/89
Time	14:44	14:35	14:56	15:00
Depth (m)	0.5	1.7	0.5	1.7
<b>Chlorophyll a (mg/m<sup>3</sup>)</b>	0.79	0.75	1.80	2.63
<b>Taxa</b>				
<i>Asterionella formosa</i>	-	-	-	-
<i>Coscinodiscus</i> sp.	-	-	-	-
<i>Fragellaria crotonensis</i>	12.3	-	24.52	-
<i>Fragellaria leptostauron</i>	-	-	-	-
<i>Synedra radians</i>	332.1	269.7	723.3	821.4
<i>Tabellaria fenestrata</i>	-	-	-	-
<i>Ankistrodesmus convolutus</i>	-	6.13	-	18.39
<i>Ankistrodesmus falcatus</i>	-	6.13	61.3	30.65
Chlamydomonadaceae spp. indet.	258.3	73.56	318.8	1134
<i>Chlorophyta</i> sp. (filament)	2595	-	-	-
<i>Chlorophyta</i> sp. 2 (filament)	1095	-	-	-
<i>Coelastrum microsporum</i>	-	-	-	6.13
<i>Crucigenia tetrapedia</i>	24.6	12.26	24.52	69.43
<i>Dictyosphaeria</i> sp.	-	-	-	251.3
<i>Gloeocystis</i> sp.	-	-	-	-
<i>Kirchneriella obesa</i>	12.3	-	-	-
<i>Oedogonium</i> sp.	-	-	-	-
<i>Ophiocytium</i> sp.	-	-	12.26	-
<i>Phacus</i> sp.	-	-	6.13	-
<i>Phacus</i> sp. 2	-	-	-	-
<i>Quadralinga</i> sp.	61.5	-	134.9	104.2
<i>Scenedesmus bijuga</i>	24.6	49.04	98.08	98.08
<i>Scenedesmus quadricauda</i>	24.6	12.26	61.3	61.3
<i>Spondylosium</i> sp.	-	-	-	-
<i>Zygnemetales</i> sp.	-	-	-	-
<i>Chroococcus</i> sp.	98.4	-	49.04	42.91
<i>Merismopedia punctata</i>	-	-	-	-
<i>Spirolina</i> sp.	-	-	-	-
<i>Trachelomonas</i> cyst?	-	-	-	-
<i>Dinobryon divergens</i>	61.5	55.17	496.5	373.9
<i>Peridinium</i> sp.	-	6.13	6.13	6.13
<i>Cryptomonas</i> sp.	-	12.26	12.26	18.39
<b>Total</b>	<b>4600.</b>	<b>497.</b>	<b>2029.</b>	<b>3036.</b>

Table H-2

Site	3-A	3-B	4-A	4-B
Date	28/08/89	28/08/89	28/08/89	28/08/89
Time	15:50	15:42	14:02	13:52
Depth (m)	0.5	1.7	0.5	1.7
<b>Chlorophyll a (mg/m<sup>3</sup>)</b>	2.55	3.64	0.94	0.67
<b>Taxa</b>				
<i>Asterionella formosa</i>	-	12.26	-	-
<i>Coscinodiscus</i> sp.	-	-	-	-
<i>Fragellaria crotonensis</i>	18.39	3.13	-	-
<i>Fragellaria leptostauron</i>	-	-	-	-
<i>Synedra radians</i>	980.8	1361	766.3	557.8
<i>Tabellaria fenestrata</i>	-	-	-	-
<i>Ankistrodesmus convolutus</i>	12.26	-	-	6.13
<i>Ankistrodesmus falcatus</i>	30.65	12.26	42.91	6.13
Chlamydomonadaceae spp. indet.	1079	3273	373.9	355.5
<i>Chlorophyta</i> sp. (filament)	-	-	-	-
<i>Chlorophyta</i> sp. 2 (filament)	-	-	-	-
<i>Coelastrum microsporum</i>	12.26	-	-	-
<i>Crucigenia tetrapedia</i>	49.04	6.13	12.26	6.13
<i>Dictyosphaeria</i> sp.	-	-	-	-
<i>Gloeocystis</i> sp.	-	-	-	-
<i>Kirchneriella obesa</i>	-	-	-	-
<i>Oedogonium</i> sp.	-	-	-	-
<i>Ophiocytium</i> sp.	-	6.13	-	-
<i>Phacus</i> sp.	-	-	18.39	-
<i>Phacus</i> sp. 2	-	-	-	12.26
<i>Quadralinga</i> sp.	134.9	171.6	67.43	6.13
<i>Scenedesmus bijuga</i>	98.08	232.9	110.3	24.52
<i>Scenedesmus quadricauda</i>	98.08	49.04	24.52	-
<i>Spondylosium</i> sp.	-	-	-	-
<i>Zygnemetales</i> sp.	6.13	-	-	-
<i>Chroococcus</i> sp.	-	6.13	-	-
<i>Merismopedia punctata</i>	-	-	-	-
<i>Spirolina</i> sp.	-	-	-	-
<i>Trachelomonas</i> cyst?	-	-	-	-
<i>Dinobryon divergens</i>	245.2	827.6	91.95	-
<i>Peridinium</i> sp.	36.78	6.13	12.26	-
<i>Cryptomonas</i> sp.	73.56	24.52	79.69	-
<b>Total</b>	<b>2875.</b>	<b>5991.</b>	<b>1600.</b>	<b>975.</b>

Table H-3

Site	5-A	5-B	6-A	6-B
Date	28/08/89	28/08/89	28/08/89	28/08/89
Time	12:10	12:02	11:25	11:13
Depth (m)	0.5	1.7	0.5	1.7
<b>Chlorophyll a (mg/m<sup>3</sup>)</b>	3.09	1.72	3.42	2.60
<b>Taxa</b>				
<i>Asterionella formosa</i>	-	-	-	-
<i>Coscinodiscus</i> sp.	-	-	-	-
<i>Fragellaria crotonensis</i>	-	36.78	36.78	12.26
<i>Fragellaria leptostauron</i>	-	-	-	-
<i>Synedra radians</i>	2237	2078	2103	1980
<i>Tabellaria fenestrata</i>	-	6.13	12.26	-
<i>Ankistrodesmus convolutus</i>	-	6.13	18.39	73.56
<i>Ankistrodesmus falcatus</i>	36.78	6.13	30.65	49.04
Chlamydomonadaceae spp. indet.	1079	1024	8030	1134
<i>Chlorophyta</i> sp. (filament)	-	-	-	-
<i>Chlorophyta</i> sp. 2 (filament)	-	-	-	-
<i>Coelastrum microsporum</i>	-	-	24.52	-
<i>Crucigenia tetrapedia</i>	49.04	49.04	110.3	104.2
<i>Dictyosphaeria</i> sp.	-	-	-	24.52
<i>Gloeocystis</i> sp.	24.52	257.9	220.7	24.52
<i>Kirchneriella obesa</i>	-	-	-	-
<i>Oedogonium</i> sp.	-	-	-	-
<i>Ophiocytium</i> sp.	6.13	-	6.13	-
<i>Phacus</i> sp.	-	-	-	-
<i>Phacus</i> sp. 2	-	-	-	-
<i>Quadrilinga</i> sp.	61.3	61.3	12.26	61.3
<i>Scenedesmus bijuga</i>	208.4	183.9	294.2	214.6
<i>Scenedesmus quadricauda</i>	36.78	134.9	24.52	110.3
<i>Spondylosium</i> sp.	-	-	6.13	-
Zygnemetales sp.	-	-	-	-
<i>Chroococcus</i> sp.	61.3	-	-	85.82
<i>Merismopedia punctata</i>	-	-	-	-
<i>Spirolina</i> sp.	-	-	-	-
<i>Trachelomonas</i> cyst?	-	-	-	-
<i>Dinobryon divergens</i>	61.3	122.6	79.69	514.9
<i>Peridinium</i> sp.	6.13	12.26	-	12.26
<i>Cryptomonas</i> sp.	61.3	55.17	85.82	171.6
<b>Total</b>	<b>3929.</b>	<b>4034.</b>	<b>11,095.</b>	<b>4573.</b>

Table H-4

Site	7-A	7-B	8-A	8-B
Date	28/08/89	28/08/89	28/08/89	28/08/89
Time	10:24	10:32	9:40	9:30
Depth (m)	0.5	1.7	0.5	1.5
<b>Chlorophyll a (mg/m<sup>3</sup>)</b>	3.26	3.57	10.1	6.86
<b>Taxa</b>				
<i>Asterionella formosa</i>	-	-	-	-
<i>Coscinodiscus</i> sp.	9.39	-	-	-
<i>Fragellaria crotonensis</i>	178.4	-	169.0	-
<i>Fragellaria leptostauron</i>	-	12.26	-	7.51
<i>Synedra radians</i>	2366	3016	10920	10086
<i>Tabellaria fenestrata</i>	-	-	9.39	45.06
<i>Ankistrodesmus convolutus</i>	-	-	37.56	-
<i>Ankistrodesmus falcatus</i>	46.95	12.26	46.95	97.63
Chlamydomonadaceae spp. indet.	563.4	2311	610.4	413.1
<i>Chlorophyta</i> sp. (filament)	-	-	-	-
<i>Chlorophyta</i> sp. 2 (filament)	-	-	-	-
<i>Coelastrum microsporum</i>	-	-	9.39	-
<i>Crucigenia tetrapedia</i>	103.3	98.08	75.12	15.02
<i>Dictyosphaeria</i> sp.	-	-	-	-
<i>Gloeocystis</i> sp.	-	-	75.12	-
<i>Kirchneriella obesa</i>	-	-	-	-
<i>Oedogonium</i> sp.	-	-	18.78	7.51
<i>Ophiocytium</i> sp.	-	-	-	-
<i>Phacus</i> sp.	-	-	-	-
<i>Phacus</i> sp. 2	-	-	28.17	-
<i>Quadralinga</i> sp.	-	-	72.12	-
<i>Scenedesmus bijuga</i>	225.4	208.4	2995	2298
<i>Scenedesmus quadricauda</i>	169.0	85.82	469.5	375.5
<i>Spondylosium</i> sp.	-	-	-	-
Zygnemetales sp.	-	-	-	-
<i>Chroococcus</i> sp.	197.2	49.04	46.95	-
<i>Merismopedia punctata</i>	-	-	75.12	90.12
<i>Spirolina</i> sp.	-	-	-	7.51
<i>Trachelomonas cyst?</i>	-	-	18.78	-
<i>Dinobryon divergens</i>	347.4	208.4	103.3	52.57
<i>Peridinium</i> sp.	9.39	6.13	37.56	60.08
<i>Cryptomonas</i> sp.	84.51	55.17	272.3	383.0
<b>Total</b>	<b>4300.</b>	<b>3775.</b>	<b>16,091.</b>	<b>13,901.</b>