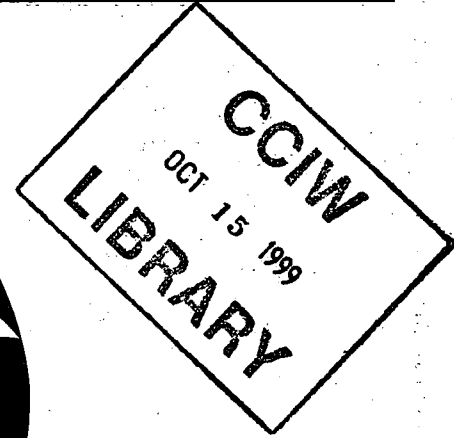


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**EFFECTS OF SUBAQUEOUS GOLD MINE  
TAILINGS ON LARDER LAKE ECOSYSTEM**

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G.E.M. Hall Z. Kezhun and R.D. Coker

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## **Effects of Subaqueous Gold Mine Tailings on Larder Lake Ecosystem**

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## MANAGEMENT PERSPECTIVE

Metal mine tailings and waste rock are a source of contaminants in the environment. Toxic elements transported from land-disposed mine tailings and waste rock in dissolved or particulate form affect the quality of surface and ground waters, the health of terrestrial and aquatic biota, and become transported by air from the disposal site into the surrounding environment. Subaqueous disposal of the tailings and waste rock has been considered an option for permanent storage of these materials. Recent studies on evaluation of the impact of the subaqueous tailings on the environment dealt only with the geochemistry of the tailings and chemistry of the overlying waters. A multidisciplinary study was carried out in Larder Lake, northern Ontario, to evaluate the suitability of the lake for subaqueous disposal of gold mine tailings. The study included determination of the limnological regime and quality of water, bottom sediments and sediment pore water in the lake. Obtained results were used in the assessment of the health of biota in the lake.

The results showed that Larder Lake is a typical well stratified temperate lake with sufficient concentrations of dissolved oxygen to support aquatic life. However, it was found that primary production in the lake was lower than predicted from the phosphorus-chlorophyll relation compared to other similar temperate freshwater lakes. The inhibition of primary production was attributed to high concentrations of dissolved trace elements, particularly Cu, in the lake water. High concentrations of As, Cu, Ni, Cr and Zn in bottom sediments across the lake indicated transport of the subaqueous tailings deposited along the north shore and in the northeast arm of the lake. The concentrations of Zn, Cu, Ni and Fe were greater in the bottom than in the surface waters suggesting migration of these elements from the sediments and subaqueous tailings into the overlying water. This observation was supported by the results showing high concentrations of the elements in sediment pore water. The concentrations of these elements in the sediments exceeded the "Severe Effect Levels" given in the Ontario Ministry of the Environment and Energy (OMEE) sediment quality guidelines. Determination of chemical forms of trace elements in the sediments showed that considerably large quantities of the elements were easily available. The benthic invertebrate community in Larder Lake was severely impaired: it was either non-existent or represented by extremely low densities of organisms. The results of testing of sediment toxicity showed a widespread toxicity to *Tubifex tubifex* in Larder Lake. The survival and reproduction rates of *T. tubifex* indicated a long-term, i.e., over 28 days, chronic toxicity. It was concluded that relatively high concentrations of easily available Cu, Zn and Ni in sediments and high concentrations of As, Cu, Ni and Zn in sediment pore water and lake water contributed to the observed sediment toxicity.

The Ontario Ministry of Environment and Energy data and results of this study showed that the concentrations of As, Cu, Pb, Ni and Zn in the effluent from the tailing pond into Larder Lake were lower than those given in the Metal Mining Liquid Effluent

Regulations. However, continuous loadings of As, Cu, Ni and Zn in the tailing pond effluent eliminated the benthic invertebrate community in Larder Lake. These findings suggested that the Metal Mining Liquid Effluent Regulations should rather be based on the loadings of deleterious substances to the receiving aquatic environment than on their concentrations in the mine effluents. Further, the results of the study showed deterioration of the aquatic ecosystem by leaching different metals and trace elements from land-disposed metal mine tailings and suggested the development of new techniques for the disposal of the tailings.

Further, the results of the investigation showed that temperate, stratified, relatively shallow lakes, such as Larder Lake, are not suitable for subaqueous disposal of metal mine tailings. Transport of contaminants from the tailings across the lake, destruction of the benthic community and depressed primary production in Larder Lake were the major indicators of the negative effects on the lake's ecosystem. The results of the study suggested that thermally stratified temperate lakes with regular overturn and subsequent mixing of contaminants leached from the tailing particles are not suitable for disposal of mine tailings. However, it has to be noted that the tailings on the bottom of Larder Lake were previously disposed on the land and therefore partially oxidized. Further studies need to be carried out on the effects of disposed anoxic tailings on the ecosystem of a thermally stratified temperate lake. On the other hand, conditions of permanently chemically stratified lakes or man-made reservoirs should be considered for subaqueous disposal of mine tailings. In a chemically stratified water body, a chemocline will prevent the migration of contaminants into surface waters. In addition, such water bodies have an almost non-existent benthic community in bottom sediments. Therefore it appears that subaqueous disposal of metal mine tailings into deep, chemically stratified lakes or man-made reservoirs may be harmless to the biota in the surface waters and to the benthic community on the bottom of the lake.

## *FOREWORD*

This report contains unpublished original data from a study conducted over a period of three years (1990 - 1992). None of the information contained herein is to be cited or quoted or used in any way without the written permission of the authors.

Furthermore, the interpretation of results presented in the report are to be regarded as tentative pending completion of the research project and full assessment of the effects of mine tailings on the Larder Lake ecosystem.

The study is a part of the project on assessment of effects of mining activities on aquatic ecosystems in Canada carried out by the scientists of the Sediment/Water Interaction Project, Lakes Research Branch, National Water Research Institute, Burlington, Ontario. The field work was carried out by the authors of the report with the help of Mr. M. Mawhinney, and Ms. J. Vaive. Ms. K. Lantagne provided invaluable assistance in the preparation of this report.

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## SUMMARY AND CONCLUSIONS

1. An investigation was carried out to evaluate the effects of gold mine tailings deposited on the bottom of Larder Lake, Ontario, on the lake's ecosystem. Larder Lake is located in the Precambrian Shield of northern Ontario about 15 km east of Kirkland Lake, and 19 km west of the Ontario-Québec border. There is an operating gold mine at the northeast corner of the lake. The lake has a surface area of 37 km<sup>2</sup> with a mean and maximum depth of 12.3 and 33.5 m, respectively. The lake receives water from land drainage, four major creeks and the outflow from the gold mine tailings pond located on the north shore. The lake's outflow is via the Larder River which joins a system of lakes and rivers in the area. Surface water from the area will eventually flow into the Ottawa River.

2. Water and bottom sediments were sampled at thirty-eight sampling stations in the lake in August 1990, 1991, and 1992, to determine the limnological features of the lake, geochemistry of the bottom sediments, benthic community structure and toxicity of the sediments to benthic organisms. Barber and Raven Lakes, in the vicinity of Larder Lake, were used as control sites in the study. Conductivity and pH were determined in water samples collected at the thirty-eight sampling stations. Profiles of temperature, pH, conductivity and concentrations of dissolved O<sub>2</sub> were obtained at six sampling stations in Larder Lake and at five stations in the control sites. The concentrations of nutrients, chlorophyll *a*, trace elements and major ions were determined in water collected 1 m below the water surface and 1 m above the lake bottom. Particle size distribution, concentrations of major and trace elements and benthic community structure were determined in surficial sediments collected at the thirty-seven sampling stations in the lake. The toxicity of the bottom sediments were tested in the laboratory using *Tubifex tubifex* reproductive bioassay.

3. Thermal stratification of Larder Lake was typical of a well stratified temperate lake, with epilimnion and thermocline thickness between 5 to 7 m and 2 to 4 m,

respectively, and surface water temperature between 17.5 and 19.8°C during the sample period in August. The remainder of the water column consisted of hypolimnion with water temperatures between 4 and 9°C. The thermocline in Raven Lake, which was used as a control site, was 1 to 2 m deeper than in Larder Lake, most likely due to a greater exposure to winds. Generally, the concentrations of dissolved oxygen in Larder Lake water were greater than 6.5 mg/L across the lake.

4. Primary production in Larder Lake was lower than predicted from the phosphorus-chlorophyll relation and compared to other similar temperate freshwater lakes. The inhibition of primary production was attributed to high concentrations of dissolved trace elements, particularly Cu, in Larder Lake water. The results of the study showed that about 67% of dissolved Cu was in a readily available form in the lake water. In the Larder Lake water column, light transmission increased from the surface towards the bottom. On the other hand, the light transmission decreased towards the lake bottom in the control lake. In addition, the light transmission in Larder Lake surface water was about 10% less than in the control lake. The results indicated transport of particles from the tailing pond outlet and resuspension of subaqueous tailings and their transport across Larder Lake.

5. The concentrations of dissolved Na, K, Ca, SO<sub>4</sub> and Cl in water were similar across Larder Lake. However, they were more than 2 times greater than those in the downstream control lake. The results showed that the water quality in Larder Lake was greatly affected by the outflow from the tailing pond on the north shore of the lake.

6. The concentrations of dissolved Zn, Cu, Ni and Fe were greater in the bottom than in the surface water in Larder Lake. The results suggested migration of these elements from the bottom sediments into overlying water. The concentration of dissolved trace elements particularly, As, Cu, Ni, Zn and Cr, in Larder Lake water were 3 to 7 times greater than those in the downstream control lake. The greatest concentrations of

dissolved trace elements were found in the tailing pond outlet and were up to 17 times greater than those in the lake water. The concentrations of dissolved As, Ni, and Cu in Larder Lake water were 2, 2 and 4 times greater, respectively, than the "Lowest Effect" concentrations given by the Department of the Environment (DOE) guidelines for the protection of freshwater life. Mean concentrations of dissolved trace elements were lower than their analytical detection limits in all streams in the vicinity of Larder Lake and in the control lake upstream of Larder Lake. However, the concentrations of dissolved Zn, Co, Cd, As, and Ni were greater than the detection limit in the water of the downstream control lake. The results indicated transport of the contaminants from Larder Lake downstream into adjacent surface water bodies.

7. The concentrations of trace elements, particularly As and Ni, in sediment pore water collected in Larder Lake were considerably greater than those in the control lakes. The concentrations of As, Cu, Ni, Zn and Pb in pore water collected from the topmost 5 cm layer of the sediments were up to 110 times greater than those given as "Lowest Effect" concentrations for freshwater biota life.

8. The results indicated an outstanding geochemical character of surficial sediments along the north shore of Larder Lake at the outlet from the tailing pond. According to their geochemical composition and visual observations, the sediments at this area consisted mainly of mine tailings. The results suggested that the quality of the sediments in the northeast arm and north-central part of the lake, in the vicinity of the submerged tailings, was greatly affected by the contaminants in the tailings and by those in the outflow from the tailing pond. The concentrations of trace elements, i.e., As, Cu, Ni, Cr and Zn, in most of the surficial sediments collected in Larder Lake exceeded the "Severe Effect Levels" given in the OMEE guidelines. There was no relationship between particle size and the concentrations of the trace elements in the sediments. However, significant correlation was found between the concentrations of As, Cu, Ni, Pb and Zn and organic matter in the sediments. The results of the determination of chemical forms of different elements in the sediments showed that

Cu was mainly associated with organic matter. Readily available fraction of Cu, Zn and Ni represented 0.2, 1.5 and 7.2% of their total concentrations in the sediments, respectively. Consequently, a considerable quantity of Ni, i.e., about 50  $\mu\text{g/g}$ , was in the readily available form in the sediments. The results indicated a restriction of migration of trace elements from sediment pore water into overlying lake water by Fe-oxides.

9. Concentration profiles in the sediments indicated an increase of several trace elements, particularly As, Ni, Zn and Cu, towards the sediment surface. The increase started at the 3 to 4 cm sediment depth and indicated input of tailing particles from the tailing pond into the lake, particularly during the collapse of the tailing pond dike. Calculated enrichment factors showed that As concentrations increased up to 30 times and Cu and Ni up to 55 and 45 times, respectively, above the background concentrations in the Larder Lake surficial sediments.

10. The benthic invertebrate community in Larder Lake was severely impaired. It was either non-existent or represented by extremely low densities, such as 1-2 organisms per 100  $\text{cm}^2$ . The results suggested a possible relationship between the absent benthic organisms and the distance from the subaqueous tailings. The difference between the presence and absence of the benthic organisms could not be discriminated by the examined sediment characteristics. The results of testing of sediment toxicity to *Tubifex tubifex* showed widespread toxicity in Larder Lake. The survival and reproductive rates of *T. tubifex* indicated a long-term, i.e., >28 days, chronic toxicity. It was concluded that the relatively high concentrations of available trace elements, particularly Ni, in the sediments and high concentrations of As, Cu, Ni and Zn in sediment pore water and lake water contributed to the observed sediment toxicity.

11. The Ontario Ministry of Environment and Energy data and results of this study showed that the concentrations of As, Cu, Pb, Ni and Zn in the effluent from the

tailing pond into Larder Lake were lower than those given in the Metal Mining Liquid Effluent Regulations. However, the concentrations of As, Cu, Ni and Zn in Larder Lake bottom sediments have been elevated by the continuous loading through the effluent from the tailing pond to a level which is intolerable to benthic organisms. The absence of benthic invertebrate community has a negative effect on Larder Lake ecosystem. Further, these findings confirm results of previous studies on effects of mining on the environment which showed deterioration of aquatic environment by leaching different metals and trace elements from land-disposed mine tailings. The results of this study suggested that the Metal Mining Liquid Effluent Regulations should be based rather on the loadings of deleterious substances to the receiving aquatic environment than on their concentrations in the mine effluents.

12. The results of the investigation showed that temperate stratified lakes, such as Larder Lake, are not suitable for subaqueous disposal of metal mine tailings. Destruction of the benthic community and depressed primary production in Larder Lake were the major indicators of the negative effects on the lake's ecosystem. However, it has to be noted that the tailings on the bottom of Larder Lake were previously disposed on the land and therefore partially oxidized. Further studies need to be carried out on the effects of disposed anoxic tailings on the ecosystem of a thermally stratified temperate lake. The results of the study further suggested that ideal conditions for subaqueous disposal of mine tailings would be a water body with a sufficiently deep layer of anoxic water to prevent the oxidation of the tailings and migration of toxic trace elements into the water column. Further, a permanently chemically stratified water body will be more suitable than a thermally stratified lake with a regular overturn and subsequent mixing of contaminants leached from the tailings on the bottom of the lake into the water column. On the other hand, tailings disposed on the bottom of a chemically stratified lake or man-made reservoir will be isolated from the surface waters. Consequently, a negligible migration of toxic trace elements through the chemocline should not affect the primary production in the surface water of a permanently chemically stratified water body. Further, deep,



chemically stratified lakes have almost a non-existent benthic community in bottom sediments and therefore the effects of subaqueous disposal of mine tailings into such lakes would not need to be considered on benthic organisms.

## ABBREVIATION TABLE

Abbreviation	Description
TSM	Total Suspended Matter
ISM	Inorganic Suspended Matter
OSM	Organic Suspended Matter
LOI	Loss on Ignition
CHLA	Chlorophyll <i>a</i>
CHLA.U	Chlorophyll <i>a</i> (uncorrected)
CHLA.C	Chlorophyll <i>a</i> (corrected)
POC	Particulate Organic Carbon
C-ORG	Total Organic Carbon
PN	Particulate Nitrogen
TP	Total Phosphorus
TPP	Total Particulate Phosphorus
TFP	Total Filtered Phosphorus
SRP	Soluble Reactive Phosphorus
SOP	Soluble Organic Phosphorus
NO <sub>3</sub>	Nitrate
NO <sub>2</sub>	Nitrite
DIC	Dissolved Inorganic Carbon
DOC	Dissolved Organic Carbon
Cl	Chloride
SO <sub>4</sub>	Sulphate
SiO <sub>2</sub>	Silica

## 1. INTRODUCTION

Mobilization of different metals and trace elements from tailings and waste rock generated by metal mining has a potential for long-term environmental implication after active mining has ceased (Mudroch and Capobianco, 1979, 1980; Mudroch and Clair, 1986; Allan and Mudroch, 1989). Results of many studies showed negative effects of metal mine tailings and waste rock on terrestrial and, particularly, aquatic environment (Nriagu *et al*, 1982; Nriagu, 1983; Allan, 1988). Different elements transported from the tailings disposed on land in dissolved or particulate form affect the quality of ground- and surface waters, the health of terrestrial and aquatic biota, and become transported by air from the disposal site into surrounding environment. Acid production in tailings and waste rock disposed on land is the result of the oxidation of sulphide minerals. Under low pH, different elements in the tailings and waste rock become solubilized and transported into the environment.

Subaqueous disposal of the tailings and waste rock has been considered an option for permanent storage of these materials. Under specific conditions, mine tailings and waste rock disposed on the bottom of lakes or oceans may not release toxic elements into the overlying water in concentrations which would affect the lacustrine or marine ecosystem. Recently, few studies have been carried out to evaluate the behaviour of different elements in mine tailings disposed on the bottom of lakes and oceans (Pedersen, 1983, 1984, 1985), and evaluate the impact of the subaqueous tailings on the environment. However, these studies dealt only with geochemistry and mineralogy of the tailings, and chemistry of the overlying lake or ocean water and pore water extracted from the tailings. No comprehensive study was carried out to evaluate the effects of the subaqueous tailings on lacustrine or marine biota, particularly benthic organisms, the resuspension and transport of the tailings from the disposal site, and chemical forms of the elements in the tailings and potential for their release into the overlying waters. However, a proper technology for subaqueous disposal of metal mine tailings and waste rock can not be developed

without the assessment of their impact on lacustrine and marine ecosystems under different environmental conditions.

A multidisciplinary study was carried out to investigate the processes affecting the potential of subaqueous mine tailings for long-term degradation of an aquatic ecosystem. Factors considered in the study included natural biogeochemistry of the receiving environment, physico-chemical processes affecting the solubility or precipitation of different elements in tailings deposited on lake bottom, the presence of the elements, particularly As, Cu, Zn, Cr, Ni, Co and S in the tailings, hydrological and limnological conditions of the lake which may affect biological and chemical processes involved in solubilization of the elements of interest, and the health of biota, particularly benthic organisms, on the bottom of the lake. The objective of the study was to evaluate a lake suitable for subaqueous disposal of metal mine tailings and waste rock.

Following a careful survey of lakes in Ontario containing metal mine tailings on the bottom, Larder Lake in the vicinity of Kirkland Lake, Ontario, was chosen for the study (Figure 1). The tailings on the bottom of Larder Lake originate from a gold mine on the northeast shore of the lake. A continuous outflow from the tailing pond into Larder Lake was a recognized disadvantage which may affect the results of the study. On the other hand, the study was designed mainly to investigate the physical behaviour of the subaqueous tailings, the processes affecting the availability and release of different elements in the tailings and effects of the tailings on benthic organisms on the bottom of the lake. Further, a controlled outflow with a known chemical composition from land-disposed tailings into the lake was more desirable than an uncontrolled or unknown seepage from tailings disposed along the shore of other lakes in Ontario which were considered for the study. Different parts of the study were carried out in August 1990, 1991 and 1992. August was considered most suitable study period mainly for the sampling in evaluation of biological activity such as benthic community structure and primary production in the lake. The analytical

methods used in the determination of the concentration of major and trace elements in water and sediment samples collected in Larder Lake and two other lakes used as a control enabled analysis for about forty-five parameters. However, only selected parameters were used in the interpretation of the results. The non-used part of the data was kept for future studies of the area.

## 2. MATERIALS AND METHODS

### Study Area

Larder Lake is located in Northern Ontario, at latitude 48° 05' and longitude 79° 38', 19 km west of the Ontario-Québec border (Figure 1). The lake is situated in the Precambrian Shield, with a surface area of 37 km<sup>2</sup>, and a water content of 45x10<sup>7</sup> m<sup>3</sup>. Larder Lake has a mean and a maximum depth of 12.3 and 33.5 m, respectively. The perimeter of the shore line is 73.7 km. The geology of the drainage basin consists mainly of a conglomerate of sandstone, mudstone, marble, chert, iron formation, and related magnitites. Small areas of siltstone, shale, and orgillite, were found to the east of the lake. Larder Lake is divided into three morphologically different areas: the west and east arms and the main central basin (Figure 2). The lake receives water from land drainage, four major creeks and the outflow from the gold mine tailings pond (Figure 3). The Larder Lake outflow is through the Larder River, which flows into the southern end of Raven Lake (Figure 2). Surface waters from this area will eventually flow into the Ottawa River. Raven Lake and Barber Lake were used as "control" lakes due to their similar geomorphological conditions and absence of effects of mining activities on the lakes.

Gold mining at Larder Lake commenced in 1938 (Gordon *et al.*, 1979), and the tailings were disposed into the Upper Tailing Area (Figure 3) which was a low-lying wetland draining into the lake (Canadian Mining Journal, 1951). The tailings gradually extended to the Lower Tailing Area (Figure 3) along the north shore of Larder Lake.

In 1970, construction of a dike created a tailing pond in the Lower Tailing Area (Ontario Ministry of the Environment and Energy). According to information from staff members of the mining company at Larder Lake, the dike wall collapsed in the 1970's releasing large amounts of tailings into the lake. Further small slumps of tailings from the tailing pond into the lake occurred in May 1983. Released tailings generated a large fan-shaped layer of tailings on the bottom of the lake, extending to a distance of approximately 50 m from the outflow from the tailing pond.

### **Sampling, Sample Preparation and Analytical Methods**

Thirty-eight sampling stations were established in Larder Lake for collecting water and sediment and in situ measurements. Seven additional sampling stations were located along a transect from the tailing pond outlet towards offshore (Figure 2).

#### Water

At thirty-eight Larder Lake sampling stations, surface to bottom profiles of temperature and light transmissions in water were recorded, using a combined transmissometer-electronic-bathythermograph (TEBT) system. A HYDROLAB Profiling System (Model, Data Sonde<sub>R</sub> 3) was used for recording continuous profiles of pH, temperature, specific conductivity (COND) and dissolved oxygen concentrations (DO) from the water surface to the lake bottom, at six stations in Larder Lake and four stations in Raven Lake. The HYDROLAB recorder was allowed to reach and record down to the sediment water interface to detect any gradients that may have existed below the sampling depth of 1 m above bottom. In addition, pH, COND, and F were measured at the thirty-eight Larder Lake stations, at 1 m below the water surface and 1 m above bottom, using a Van Dorn bottle for sample collection (Rosa *et al.*, 1991). Collected samples were analyzed at lab temperature, using the Cole Palmer Analyzer, Model 5800-05 for measuring pH and COND, and Orion ion-selective electrode for measuring the concentrations of F. At all sampling stations a YSI oxygen meter was used to measure in situ DO.

Water samples for particulate and soluble nutrient analysis were collected by Van Dorn bottle from thirteen stations in Larder Lake and one station in both Raven and Barber Lakes. At each station two samples were collected, one at 1 m below water surface and the second at 1 m above the lake bottom. Particulate organic carbon and nitrogen (POC, PN), chlorophyll *a* (CHLA), corrected and uncorrected (CHLA.C, CHLA.U) for phyophyten, total filtered and unfiltered phosphorus (TFP, TP) and total organic carbon (C-ORG) were determined according to Philbert and Traversy (1974). Total particulate phosphorus (TPP) was calculated from the difference between TP and TFP. For the determination of total suspended matter (TSM) the samples were filtered, using precombusted (500°C) and pre-weighed Whatman GF/C glass fibre filters (approximate pore size 1-2  $\mu\text{m}$ ). The filters were then dried at 100°C for 3 hours to obtain the dry weight of the TSM. The inorganic suspended matter (ISM), gravimetrically measured after the sample was combusted at 500°C for 2.5 hours. Organic suspended matter (OSM) was calculated from the difference between TSM and ISM.

For the determination of major ions and trace elements, two water samples from two depths, 1 m below water surface and 1 m above lake bottom, were collected at thirty-eight sampling stations in Larder Lake (Figure 2). Water samples were collected at seven additional sampling stations in Larder Lake. The stations, labelled with the LT notation, were located on a transect from the tailing pond outflow towards offshore (Figure 2). Further, water samples were collected at three stations in Raven Lake. All water samples for the determination of major ions and trace elements were collected using a Van Dorn bottle and analyzed for forty-four parameters at the laboratory of Geological Survey of Canada, Ottawa. One of the two samples collected at each depth was filtered and acidified for the determination of dissolved elements. The second sample was left unacidified and filtered for the determination of concentration of major ions. The filtration of the samples was carried out in the field within a few hours of collection using Millipore glass filtration apparatus, with 0.45  $\mu\text{m}$  cellulose acetate filters. The samples were acidified with 50

$\mu\text{l}$  of Ultrex  $\text{HNO}_3$ . All samples were sent to the laboratory in Ottawa as quickly as possible and stored at  $4^\circ\text{C}$  until analyzed.

Air-acetylene AAS was used in the determination of the concentrations of Na, K, Ca and Mg. Cesium at 0.1% concentrations was used as an ionization buffer and La at 0.5% concentration was used as a releasing agent. Ion chromatography was used to determine  $\text{NO}_2\text{-N}$ ,  $\text{NO}_3$ ,  $\text{PO}_4$ , Br,  $\text{SO}_4$  and Cl concentrations, according to the method described by Smee *et al* (1978).

Hydrid formation technique was used to determine the concentrations of As, Sb, Te, Bi, and Se using  $\text{NaBH}_4$  as the initial reductant. Arsenic was reduced in a second process with KI and ascorbic acid prior to analysis by quartz tube atomic absorption spectrometry (AAS). The reported concentrations represent As(III) and As(V). Hydrochloric acid was used to reduce Sb, Te, and Bi which were then determined by inductively coupled plasma mass spectrophotometry (ICP-MS). The results represent concentrations of these elements in their inorganic forms. Sub-samples for the determination of Se were digested with  $\text{K}_2\text{S}_2\text{O}_8$  prior to the reduction by 6M HCl and analyzed by ICP-MS. The concentrations of Se, represented total Se in organic and inorganic forms. Aluminum, Ti, V, Co, Ni, Cu, Zn, Y, Cd, In, La, Ce, Pr, Nd, Sm, Eu, Tb, Gd, Dy, Ho, Er, Tm, Yb, Lu, Pb, U, Mn and Fe were determined by ICP-MS following a 10-fold preconcentration using an automated procedure.

The bio-available portions of Cu, Zn, Pb and Cd in the water samples were determined in the field by Anodic Stripping Voltametry (AVS), according to Hall and Vaive (1993). Free ions were determined after chelation on a Metapac CC-1 resin, prepared by Dionex.

#### Sediment pore water

The samples of sediment pore water, were collected at twelve sampling stations in Larder Lake and at one station in both Raven and Barber Lakes. Bottom



sediments were sampled using a modified Kajak-Brinkhurst corer. Sediment sections of 0 to 5 cm and 5 to 10 cm sediment depth were extruded from the core liner under nitrogen atmosphere and separately squeezed to collect the pore water. A squeezer assembly, designated by Kalil and Goldhaber (1973), was used for collecting the pore water. During the process, the pore water was separated from the sediment by a 0.45  $\mu\text{m}$  millipore filter. The pore water squeezed from the individual sediment sections was collected in vials pre-acidified with 0.4% Ultrex  $\text{HNO}_3$  and stored at 4°C prior to the analysis. The time between sample collection and termination of squeezing was less than 5 hours. The major ions and trace elements were determined by ICP-MS.

### Bottom Sediments

Surficial sediment samples were collected at thirty-six sampling stations in Larder Lake (Figure 2) using a miniponar grab sampler. The sampler encloses an area of 232  $\text{cm}^2$  to an average depth of 5 cm. Collected sediments were placed in a glass tray, homogenized with a plastic spoon and transferred to plastic vials. Samples were stored at 4°C in the field and freeze dried in the laboratory prior to grinding and chemical analysis. At five of the thirty-six sampling stations (stations 7, 17, 26, 27 and 34), a modified Kajak Brinkhurst corer was used to obtain sediment cores for the determination of concentrations profiles of major and trace elements in the sediments. The cores were subsampled into 1 cm vertical sections. Sample preparation and analysis of the individual sections were similar to those used for the surficial sediments described above. The concentrations of major elements (Si, Al, Fe, Mg, Ca, K, Na, Ti, P, Mn and P) and trace elements (As, Cu, Co, Cr, Ni, Pb, V and Zn) in sediment samples were determined by x-ray fluorescence spectrometry (Mudroch, 1985). The precision of the analysis was determined by analyzing five pellets made from a homogenized sediment sample. Relative deviations for major elements in sediment samples can be expected at the following levels:  $\text{SiO}_2$  2%,  $\text{K}_2\text{O}$  and  $\text{Al}_2\text{O}_3$  4%,  $\text{Fe}_2\text{O}_3$  and  $\text{CaO}$  2%,  $\text{MgO}$  and  $\text{Na}_2\text{O}$  10%. Absolute deviations of 0.01% to 0.02% were found for  $\text{MnO}$ ,  $\text{TiO}_2$ , and  $\text{P}_2\text{O}_5$ . Generally, the coefficient of variation for trace elements was less than 10% and continuously declining with increased trace

element concentrations in the samples. The accuracy of the analyses was verified by running Canadian reference standards Syenite SY-2 and soils SO-2 and SO-4 and comparing the analytical results with the stated reference values for major and trace elements.

Particle size distribution was determined on wet sediment samples using the sedigraph method (Duncan and LaHaie, 1979). Data was expressed as percent of sand, silt and clay in the sample. Loss on ignition (LOI) was determined by heating dry sediment at 450°C to constant weight, i.e., approximately three hours.

#### Benthic invertebrates

Sediment sampling for the determination of benthic invertebrate community structure was conducted using a modified Kajak Brinkhurst corer. A Plexiglas core tube with an inside diameter of 6.6 cm was used in the corer. Only the top 10 cm of the cores were sampled. Thus, one core sampled an area of 34.2 cm<sup>2</sup> with the volume of 342 cm<sup>3</sup>. Benthic community structure was examined at 35 sampling stations in Larder Lake. At each station a sample was composed of three cores. Each core was extruded into a plastic whirl-pak bag. Sediment sieving for the benthic organisms were conducted in the field. Samples were sieved through 500 µm mesh. The residues on the sieve were preserved in 4% formalin for sorting and identification in the laboratory.

Sediment toxicity was examined at 35 sampling stations in Larder Lake. Sediment samples for the testing were collected using the miniponar grab sampler. One grab sample was collected at each station. The sediments were transferred to a 4 L plastic container with a plastic liner. Samples were stored on ice in the field, and at 4°C in the laboratory prior to testing. The storage period ranged from 100-180 days. Earlier experiments (Reynoldson *et al*, 1991) have shown storage up to 168 days did not effect test results. Toxicity was estimated using the *T. tubifex* reproductive bioassay (Reynoldson *et al*, 1991), which use the numbers of cocoons

and young produced by four sexually mature worms as an indicator of sediment toxicity. The method was described by Reynoldson *et al* (1991). For each station, five laboratory replicates were tested. The tests were conducted at 22.5°C ( $\pm 1^\circ\text{C}$ ), and test sediments were pre-treated by sieving through 250  $\mu\text{m}$  mesh to remove indigenous organisms.

Detection limits

Parameter	Detection Limit in Water	Parameter	Detection Limit in Sediment
TSM	10 $\mu\text{g/L}$	SiO <sub>2</sub>	0.01%
ISM	10 $\mu\text{g/L}$	TiO <sub>2</sub>	0.01%
OSM	10 $\mu\text{g/L}$	Al <sub>2</sub> O <sub>3</sub>	0.01%
LOI	0.1%	Fe <sub>2</sub> O <sub>3</sub>	0.01%
CHLA	0.1 $\mu\text{g/L}$	MnO	0.01%
CHLA.U	0.1 $\mu\text{g/L}$	MgO	0.01%
CHLA.C	0.1 $\mu\text{g/L}$	CaO	0.01%
POC	10 $\mu\text{g/L}$	Na <sub>2</sub> O	0.01%
PN	2 $\mu\text{g/L}$	K <sub>2</sub> O	0.01%
TP	0.2 $\mu\text{g/L}$	P <sub>2</sub> O <sub>5</sub>	0.01%
TPP	0.1 $\mu\text{g/L}$		
TFP	0.2 $\mu\text{g/L}$		
SRP	0.2 $\mu\text{g/L}$		
SOP	0.1 $\mu\text{g/L}$		
NO <sub>3</sub>	10 $\mu\text{g/L}$		
NO <sub>2</sub>	50 $\mu\text{g/L}$		
DIC	100 $\mu\text{g/L}$		
DOC	100 $\mu\text{g/L}$		
Cl	50 $\mu\text{g/L}$		
SO <sub>4</sub>	20 $\mu\text{g/L}$		
SiO <sub>2</sub>	20 $\mu\text{g/L}$		

Detection limits cont'd

Parameter	Detection Limit in Water	Detection Limit in Sediment
As	0.15 µg/L	5 µg/g
Sb	0.2 µg/L	5 µg/g
Zn	3 µg/L	1 µg/g
Cu	5 µg/L	1 µg/g
Ni	15 µg/L	1 µg/g
Fe	20 µg/L	0.01%
Ba	1 µg/L	1 µg/g
Sr	1 µg/L	1 µg/g
Bi	0.2 µg/L	5 µg/g
Cd	2 µg/L	0.2 µg/g
Co	15 µg/L	1 µg/g
Mn	10 µg/L	1 µg/g
Pb	20 µg/L	2 µg/g
F	15 µg/L	NA
Na	100 µg/L	0.01%
K	100 µg/L	0.01%
Ca	100 µg/L	0.01%
Mg	100 µg/L	0.01%
S	NA	10 µg/g
Al	10 µg/L	0.01%
V	1 µg/L	1 µg/g
Li	1 µg/L	NA
Sc	NA	5 µg/g
Cr	1 µg/L	1 µg/g
Hg	0.005 µg/L	5 µg/kg

NA = Not Analyzed

## Statistical Methods

### Water and sediment pore water

Data matrices for the concentrations of major ions and trace elements in surface and bottom lake water and in the pore water were generated. Mean, standard deviation, median and range of concentrations were calculated for each parameter in each matrix. Simple linear correlation analysis was performed between and among parameters according to Spiegel (1961). Statistical difference between concentration means in different water samples was determined by t-test analysis according to Spiegel (1961). Cluster analysis and principal component analysis were used to determine the homogeneity of bottom and surface water chemistry in Larder and Raven Lakes.

### Sediments and benthic invertebrates

Major objectives of this study were to determine spatial patterns in the geochemistry of sediments in Larder Lake, particularly the distribution of tailings materials, and to determine the impact of sub-aqueous tailings on the biota in the lake. The large sampling grid and the number of variables made a multivariate statistical approach the most appropriate for both pattern analyses and relating any effects of sediment variables on the biota. Data were stored in three matrices, one for physico-chemical characteristics of sediments the second for benthic community structure, and the third for sediment toxicity results. Structural pattern and spatial relationship between sites were established by ordination, i.e., principle component analysis, and cluster analysis, i.e., K-means and average linkage clustering. Data were standardized for cluster analysis of toxicity data and sediment chemistry and physics. Relationship between site groupings based on effects on biota and sediment characteristics were investigated using multiple discriminant analysis (MDA). Data were stored using Lotus 123 version 2.3. Analysis of the data was carried out using the SYSTAT statistical package (Wilkinson, 1990).

### 3. RESULTS AND DISCUSSION

#### Water Chemistry

##### Temperature structure, light transmission and thermal stratification depths

From the onset of thermal stratification to fall overturn, there are many physical processes/mechanisms that influence the distribution of biological and chemical parameters in lakes. Special caution must be exercised when correlating chemical and biological data, with the variability of thermal stratification depths, and water temperatures, since they may both directly or indirectly affect ambient nutrient concentrations. The thermal stratification of Larder Lake was typical to temperate freshwater lakes (Prepas and Trew, 1983) (Table 1, Figure 4). Thermal layers were well established in mid-August, with light transmission increasing toward the lake bottom at most of the stations, (Table 1, Figure 5). In contrast, in Raven Lake, which was used a control site, the light transmission decreased toward the lake bottom. The mean light transmission in Larder Lake surface water was about 10% lower than that in Raven Lake. This may be due to the greater quantities of suspended particles transported from tailing pond outlet and by resuspension of subaqueous tailings and their transport across the lake.

The amount of organic matter produced in a lake sinks through the water column. The portion which does not decay in the water column settles on the lake bottom. Decaying organic matter at the sediment surface can consume the oxygen in the hypolimnion. In Larder Lake, this consumption was minimal due to a low organic matter content in surficial sediments as shown in Table 2. Therefore high concentration of dissolved oxygen was found in the lake's hypolimnion during the sounding period (Tables 3 and 4). Relatively high concentrations of dissolved trace elements in the water column indicated that any measurable oxygen demand may be due to chemical (COD) rather than biological demand (BOD) (Table 5).

pH, temperature, conductivity and concentrations of dissolved O<sub>2</sub> in the water columns

Continuous water column depth profiles of pH, temperature, COND and DO in Larder Lake are shown in Figures 6 to 17. Both Larder and Raven Lakes were thermally stratified during the sampling period. The thermal layers were typical of a well stratified temperate lake, with epilimnion and thermocline thickness between 5 to 7 m, and 2 to 4 m, respectively, and surface water temperatures between 17.5 and 19.8°C. The remainder of the water column consisted of a cold, 5-9°C hypolimnion. The thermocline of Raven Lake was 1 to 2 m deeper than in Larder Lake, most likely due to greater exposure of the lake to prevailing winds.

In Larder and Raven Lakes, pH, temperature and COND all decreased with water depth (Figures 6 to 17). Since both COND and pH were temperature dependent, the lowest values were recorded at levels closest to the lake bottom where the temperature was the lowest. Larder Lake water had pH ranges from 8.2, at the surface, to 7.6, at the bottom. Raven Lake surface to bottom pH ranged from 8.0 to 6.9, respectively.

The COND results in Larder Lake ranged from 99 to 102  $\mu\text{s}/\text{cm}$  at the surface, and 79 to 88  $\mu\text{s}/\text{cm}$  at the lake bottom. In Raven Lake the COND at stations 1 and 2 were approximately 48  $\mu\text{s}/\text{cm}$  at the surface and 32  $\mu\text{s}/\text{cm}$  at the lake bottom, which was a factor of two decrease from Larder to Raven Lake. Station 3 in Raven Lake, which was downstream from Larder River inlet (Figure 2), had a 15% greater COND than that at stations 1 and 2. COND recorded at the Larder River inlet to Raven Lake over an one hour period (Figure 12) displayed values of 98  $\mu\text{s}/\text{cm}$ , similar to the values recorded in Larder Lake surface water. The increase in conductivity observed at station 3 in Raven Lake may have been due to the transport of major ions and trace elements from Larder Lake to Raven Lake via the Larder River.

Larder and Raven Lakes DO profiles were typical of those in well stratified

temperate lakes. The DO concentrations in water were greater than 6.5 mg/L at all stations, with the exception of station 30 in Larder Lake and station 3 in Raven Lake, which exhibited minimum concentrations of 4.7 and 2.0 mg/L, respectively, in the water at the sediment/water interface. Both lakes illustrated a minimum DO in the thermocline (Figures 7, 8, 10, 13, 14 and 16). These results were also typical of stratified temperate lakes. However, the DO minimum were less pronounced than in other lakes and may be attributed to the lack of decaying organic matter trapped in the thermocline zone of Larder and Raven Lakes (Hargrave, 1975). Generally, the high DO concentrations in Larder Lake may be due to the low primary productivity and consequently low levels of organic matter in the bottom sediment. Any observed oxygen depletion in both lakes may be more likely attributed to chemical rather than biological oxygen demand. In addition, the oxygen concentrations were determined very close to the sediment/water interface using the HYDROLAB Profiling System. Therefore, any oxygen depletion ( $O_2$ -saturation < 100%) may be only localized near the bottom of the lake at few areas.

### Nutrients

Water quality problems may arise in any water-body, if the nutrient concentrations exceed certain levels which promote excessive algal production. Generally, increased levels of phosphorus, nitrogen, and carbon in the lake water, have been inextricably related to biological productivity. Although many elements and compounds are required for biosynthesis, nitrogen and phosphorus have long been considered to be the principal limiting nutrients for primary production. In addition, there was evidence that organic carbon may also limit production in some situations. The concentration of nutrients and chlorophyll *a* are shown in Table 6. In general, all particulate nutrient concentrations were low, with the exception of POC, PN and TP (Table 6). Larder Lake was a brown water lake, and the high DOC and POC were probably due to the humic acids the lake receives from the drainage basin. The high concentrations of POC relative to OSM were most likely due to the humic acids adsorbed onto the organic particulate and detected as organic carbon. In clear water



lakes the OSM/POC ratios are in the 8 to 12 range; in Larder Lake this ratio was < 1.

The concentration of  $\text{NO}_3$  in Larder Lake water ranged from 1.1 to 2.3 mg/L. The concentrations of  $\text{NO}_2$  were all less than 0.05 mg/L. The main source of nitrate was from the tailing pond outlet, with concentrations of 12.5 mg/L. In Raven Lake the concentration of  $\text{NO}_3$  ranged from 0.26 to 0.48 mg/L and concentrations of  $\text{NO}_2$  were less than 0.05 mg/L. It can be expected that nitrogen will not be a limiting nutrient with such supply of nitrate to Larder Lake. This supports the fact that the low production may be due to other reasons rather than nutrient limitations.

The mean concentration of TP and total filtered phosphorus, TFP, were equal for the two layers, epilimnion and hypolimnion (0.019 - 0.20) and 0.012 mg.L<sup>-1</sup>, respectively. The particulate phosphorus fraction, TPP (TP - TFP) was 20% higher in the hypolimnion (0.0083) than in the epilimnion. In Raven Lake, these phosphorus forms, i.e., TP, TFP & TPP, were considerably lower, 0.0075, 0.0050 and 0.0020 mg.L<sup>-1</sup>, respectively, than in Larder Lake. These lower phosphorus levels reflect better the low CHLA concentrations observed in Raven Lake.

Generally, POC and CHLA have the greatest vertical stratification and year-to-year variability, of all the parameters (Prepas and Trew, 1983). Table 6, shows the mean POC concentration and CHLA in epilimnion and hypolimnion in Larder Lake. Greater concentrations of POC occurred in the epilimnion. The concentrations in the hypolimnion were less variable than those in the epilimnion. However, the concentrations of POC in the epilimnion and hypolimnion were not statistically different.

The CHLA, CHLA-C and CHLA-U, concentrations are shown in Table 6. Mean concentrations of CHLA in the epilimnion and hypolimnion were statistically different. The amount of CHLA, indicative of algae production, was greater in the epilimnion, which was a part of the euphotic zone. Differences in concentrations between

epilimnion and hypolimnion may also be due to thermocline particulate retention (13% for POC), reported by Rosa (1985) and for subsurface maximum of chlorophyll, usually found in the thermocline region (Dobson, 1984).

The concentrations of all particulate nutrients were generally very low, with the exception of organic carbon and phosphorus. TSM concentrations were relatively very low, from 1 to 1.2 mg/L, of which 60 % was organic matter (Table 6). The productivity of Larder Lake and Raven Lake (control) was compared to Precambrian Shield lakes (Prepas and Trew, 1983) by using chlorophyll *a* measurements and relating chlorophyll levels to TP levels (Figure 18). Phosphorus-chlorophyll regression plots for the epilimnion (Figure 18, Top), show a typical positive slope for the shield lakes for CHLA.U. The data from Raven Lake showed a good fit with the shield lakes. On the other hand, the data from Larder Lake indicated lower primary production than predicted by the regression line. Data obtained in Raven Lake for CHLA.U at 1 m below the water surface, fits with the shield lakes data rather than the Larder Lake data (Figure 18). Given the phosphorus concentrations of Raven Lake, the shield lakes regression equation would clearly predict the CHLA.U concentration within 10%. However, the prediction for the concentrations in Larder Lake of CHLA.U were different from the results obtained in the study. This implies that biological predictors in Larder Lake do not follow the expected pattern and seems to be inhibited, based on its TP levels. CHLA.C measured in the epilimnion (1 m below water surface), was very low, (0.2 to 1.8  $\mu\text{g/l}$ ) or below detection limits (DL), (Table 6). The results indicated that primary production, particularly during the sampling period, was abnormally low. According to Molot and Dillon (1991), the total chlorophyll-phosphorus relationship for 15, "nutrient limited", central Ontario lakes (Figure 19) can be expressed as:

$$\text{Chl}_{\text{epi}} = 0.329\text{TP}_{\text{epi}} + 0.606$$

The relationship was established by linear regression using data collected over a 12

year period. Based on this relationship the total CHLA (CHLA.U) concentration in Larder Lake water should be in the range of 5 to 7.0  $\mu\text{g/l}$ . Chlorophyll concentrations in surface water in Raven Lake were 1  $\mu\text{g/l}$ , which is common in oligotrophic lakes. Based on lake classification models and concentrations of carbon and phosphorus, the total chlorophyll concentrations of Larder Lake should range between 5 and 7  $\mu\text{g/l}$ . However, the CHLA concentration in surface water was only 1.6  $\mu\text{g/l}$ , a factor of 4 to 5 lower than predicted.

As shown below, benthic organisms activities were suppressed due to the degradation of bottom sediments caused by tailings deposited on the bottom of Larder Lake. The low primary production may be attributed to a number of effects. The presence of bio-available Cu in the lake in concentrations of 10.9  $\mu\text{g/L}$ , was most likely affecting the primary production.

#### Dissolved major ions and trace elements

The concentrations of major ions and trace elements in water are shown in Tables 7 to 10. Median, mean and range of dissolved trace elements concentrations are shown in Table 11. The concentrations of dissolved major ions were similar in surface and bottom water across Larder Lake. Small increase in concentrations of  $\text{SO}_4$  existed in the northeast arm at station 27 (Table 7, Figure 20). There was no thermal stratification of water at this station. The results suggested an input of  $\text{SO}_4$  from the bottom sediment or from the outflow of Bear Creek at this part of Larder Lake. The concentration of Na, K, Ca, Mg,  $\text{SO}_4$  and Cl were considerably greater in Larder Lake than in Raven Lake water (Tables 7 and 8) The results showed that the water quality in Larder Lake was greatly affected by the outflow from the tailing pond on the north shore of the lake.

The concentrations of dissolved As, Sb, Ba and Sr in the surface water exceeded those in the bottom water. On the other hand, concentrations of Zn, Cu, Ni and Fe were greater in the bottom water than in the surface water in Larder Lake

(Table 12). The results suggested migration of Zn, Cu, Ni and Fe from the sediments into overlying water. At station 16, anomalously high concentrations of dissolved Ni and Zn existed in the bottom water. The concentrations of dissolved trace elements in Raven Lake water were 3 to 7 times lower than in Larder Lake (Tables 9 and 10). The concentrations of dissolved As, Ni and Cu in Larder Lake water were 2, 2, and 4 times greater, respectively, than the Lowest Effect (LE) guidelines (McNeely *et al.*, 1979) for the protection of freshwater life (Figure 21). Mean concentrations of trace elements were lower than detection limits in all the streams and in Barber Lake (Table 5), upstream of Larder Lake.

The concentrations of dissolved Zn, Co, Cd, As and Ni were greater than the detection limits in Raven Lake water. The concentrations of dissolved As and Ni in Raven Lake were greatest at station 3, which was downstream from the inflow of the Larder River (Figure 3). The concentrations of dissolved Ni in the bottom waters in Raven Lake at station 3 were within the same range as those in Larder Lake (Table 10). The concentrations of the five above trace elements were below detection limit in the water samples collected in Barber Lake. The results indicated an input of trace elements from Larder to Raven Lake water, particularly to the southern part of the lake, downstream of the Larder River inflow (Figure 3).

Statistical analyses of water chemistry in Larder Lake using the concentrations of eight parameters (As, Sb, Zn, Cu, Ni, Fe, Ba and Sr) indicated relatively homogeneous surface and bottom water mass in the lake. However, at few areas the bottom water contained greater concentrations of some elements, particularly dissolved Fe and Ni, than in the rest of the lake. Greatest concentrations of dissolved Fe ( $57.7 \mu\text{g/L}$ ) were found in the bottom water at the sampling stations located in the vicinity of the tailing pond outflow. At this area, the concentrations of Fe in bottom sediments were also greater than in the rest of the lake. The results suggested migration of Fe from the sediments into the bottom waters. Greatest mean concentrations of dissolved Ni ( $55.8 \mu\text{g/L}$ ) existed in the bottom water in the centre

of the lake. Chemical speciation of trace elements (Figure 22) showed that about 10% of Ni in bottom sediments in the centre of the lake was in an exchangeable form. Therefore the high concentrations of Ni in the bottom water at this part of the lake may reflect migration of Ni from the sediments into overlying water. Mean concentrations of dissolved Fe in surface water in the northeast arm and eastern part of Larder Lake were greater than in the rest of the lake. The results indicated an inflow of water containing Fe into the northeast arm of the lake.

In the multivariate analyses, the difference in the concentrations of dissolved Ni and Fe in Larder Lake surface and bottom waters separated the sampling stations into different groups (Figures 23 and 24). Low concentrations of all eight parameters in Raven Lake water separated clearly Raven Lake water chemistry from that of Larder Lake (Figures 23 and 24).

The greatest concentrations of dissolved trace elements were found in the tailing pond outlet (Table 5). The concentration ratios (Enrichment Index), between the tailing pond outlet and Larder Lake, for dissolved As, Cu, Ni, Zn, and Pb (Table 13), ranged from 6 to 17. The effluent flow and the concentrations of As, Cu, Ni, Zn and Pb in the effluent have been monitored by the Ministry of the Environment and Energy (OMEE, 1993). In 1992 (Figure 25), the greatest flow and recorded loading were during the month of July (OMEE, 1993). The mean annual loadings of Ni, As, Cu, Zn and Pb were 2249, 1224, 685, 211 and 153 kg, respectively. The mean effluent concentrations of soluble Cu, Ni, and Zn entering Larder Lake from the tailing pond outlet were 450, 1000, and 240  $\mu\text{g/l}$ , respectively, for 1991 and 1992, (OMEE, 1993). The mean in-lake concentrations based on the average of surface and bottom water samples for the 38 sampling stations were 16.2, 44.8, and 6.6  $\mu\text{g/l}$  for Cu, Ni, and Zn, respectively, (Table 5). Larder Lake has a volume of 456 million  $\text{m}^3$ , (MNR, personal communication). Based on the above loadings and lake volume, the soluble in-lake concentrations of Cu, Ni, and Zn would increase at a rate of approximately 10 % per year. This calculation assumes that there would be no metal

transformation from the soluble to the particulate phase. If the assumption is made that one half of the soluble metals entering Larder Lake would undergo phase transformation through adsorption and/or chemical reactions, then the in-lake concentration increase of the soluble component would be 5% per year. This implies that one half of the metal loadings would be removed from the water column by sedimentation processes. This would correspond to a loading of 340, 1125, and 105 kg/yr of Cu, Ni, and Zn to the sediments in Larder Lake. This loading would be an underestimate, since the particulate fraction entering the lake through the tailing pond outlet and other sources, has not been taken into account. Dividing the particulate loading by the lake area, the net accumulation of Cu, Ni, and Zn in the bottom sediments is 9, 24 and 3 mg/m<sup>2</sup>/yr, based on the 1989 to 1992 data, collected by OMEE, and NWRI.

The Ontario Ministry of Environment and Energy data and results of this study showed that the concentrations of As, Cu, Pb, Ni and Zn in the effluent from the tailing pond into Larder Lake were lower than those given in the Metal Mining Liquid Effluent Regulations (Environment Canada, 1992). However, Larder Lake continues to receive high concentrations of trace elements from the tailings disposed in the tailing pond. The concentration of these elements in the lake water were already about 5 to 24 times greater than the background concentrations measured in Barber Lake. The Enrichment Index between the tailing pond outlet and Barber Lake for the above dissolved trace elements ranged between 24 and 407 (Table 13). If trace element indices (TEI) were calculated by dividing the ambient concentrations by the given guidelines for aquatic life (Conc/LE), the concentrations of As, Cu, Ni, Zn, and Pb in the water at 1 m above the lake bottom were between < 1 and 39 times greater than those given in the DOE guidelines for the lowest effect on freshwater biota (Table 14). In Larder Lake, the greatest trace element indices for water was for As, followed by Cu, Ni, Zn, and Pb.

## Sediment Pore Water Chemistry

Results of sediment pore water analyses are presented in Table 15. In Larder Lake, the concentrations of trace elements in pore water were 2 to 20 times greater than those in the lake water (Tables 9 and 10). These differences were not uncommon, even in uncontaminated lakes, and were observed often for many naturally occurring trace elements and nutrients (Carignan and Nriagu, 1985). In Larder Lake, the concentration of trace elements, particularly As and Ni in the sediment pore water were much greater than in the control lakes. The differences in the concentrations between the control lakes and Larder Lake were statistically different for many elements, with the exception of Cu. The concentrations of all trace elements in the sediment pore water were 10 times greater in Larder Lake than in other lakes, such as Jack of Clubs Lake, British Columbia, which has also been contaminated by effluents from gold mining activities (Mudroch *et al.*, 1993). Spatial distribution of As, Cu, Ni, and Zn in sediment pore water in Larder Lake water are compared to guidelines in Figure 26. When trace element indices were calculated by dividing the ambient concentrations in the lake by the concentrations given in the guidelines for aquatic life (Conc/LE), the concentrations of As, Cu, Ni, Zn, and Pb in sediment pore water were 1 to 110 times greater than lowest effect concentrations for freshwater biota life DOE guidelines (McNeely, *et al.*, 1979) .

## Sediment Chemistry

### Horizontal distribution of major and trace elements

Surface sediment samples collected at thirty-seven sampling stations in Larder Lake were analyzed to determine the concentrations of major and trace elements and particle size distribution. The results of the analysis are shown in Tables 2, 16 and 17. Using PCA and cluster analysis enabled to distinguish four groups of sediments of similar geochemical character. Median, mean and ranges of concentrations of major and trace elements in surficial sediments are shown in Table 18.

The clustering of sediment samples by major elements generally produced a similar pattern to that obtained by the clustering by trace elements. Four stations, nos.

21 to 24, along the north shore of the lake represented one group (Figure 27). This group of sediments contained the lowest mean concentrations of organic matter, i.e., 3.6%, from all sediments collected in the lake. In addition, the sediments in this group contained the greatest mean concentrations of Fe and Ca, i. e., 7.5% and 15.4%, respectively. The results indicated the presence of subaqueous tailings deposited at this area with Fe originating from arsenopyrite in the tailings. High concentrations of Ca most likely originated from liming the tailing pond to reduce the acid drainage. With the exception of sampling station no. 1, sediments from all stations in the west arm belonged to the second group together with the sediments from a large part of the centre of the lake, and with two stations in the farthest end of the northeast part of the lake (Figure 27). The sediments in this group contained the greatest concentrations of organic matter in the lake. The results suggested that the trace elements in the sediments at these areas may become associated with organic compounds and become more toxic to the biota living at the bottom of the lake. Sediments collected at stations nos. 18, 20, 25 and 26, in the vicinity of the subaqueous tailings (Figure 27) formed the third group. The group also included sediments at station 13 in the southwest part of the lake. These sediments contained the second greatest concentrations of Fe, Ca and organic matter, and the greatest concentrations of Mg. The results indicated transport of tailing particles deposited along the north shore with subsequent mixing of the particles with the lake sediments with high concentrations of organic matter. The last group was represented by sediments from stations nos. 34 to 37 located along the southeast shore of the lake, and from station 1 in the most west part of the lake. Sediments at these stations contained the lowest concentrations of Fe, and appeared to be least affected by the major elements originating from the transport of tailing particles in the lake.

The division into clusters by using the concentrations of trace elements, i. e., As, Pb, Zn, Cu, Ni, Co, Cr, V and S, separated Larder Lake bottom sediments into four groups. The first group contained sediments from sampling stations nos. 21 to 24. These stations were located along the north shore of the lake in the vicinity of the



outlet from the tailing pond. Mean concentration of S in the sediments at these stations was 11,800  $\mu\text{g/g}$ , and exceeded many times that in the rest of the sediment in the lake. High concentrations of S indicated the presence of the submerged tailings at this area. The second group contained sediments from the following 18 sampling stations in the lake: all five stations, nos. 25 to 29, located in the northeast arm, seven stations, nos. 10, 18, 20, 30, 31, 32 and 17, in the centre of the lake, four stations, nos. 13 to 16, in the southern part of the lake, and three stations, nos. 4, 7 and 8, in the west arm of the lake (Figure 28). Mean concentrations of As, Zn, Cu, Ni and Cr in the sediments belonging to this group were the greatest in the lake. This indicated a widespread contamination of sediments by trace elements from the tailings across the entire lake. In addition, the mean concentration of S in the sediments in this group was the second greatest, i. e., 2,900  $\mu\text{g/g}$  S, in Larder Lake bottom sediments. This suggested a dispersion of the sulphur-containing tailing particles across the lake. The third group contained sediments from 10 sampling stations in the lake. Three of the stations, nos. 2, 3 and 5, were in the west arm of the lake. The rest of the stations, nos. 11, 12, 19, 33, 34, 35 and 37 were generally in the centre of the lake (Figure 28). Mean concentrations of As, Ni and Cr in the sediments belonging to this group were among the greatest in the lake bottom sediments. However, the mean concentration of S was among the lowest in the sediments across the lake. The results suggested the input of As, Ni and Cr into the bottom sediments at these stations by different processes, such as adsorption, precipitation, etc., than by the transport of tailing particles across the lake. The fourth group contained sediments from 3 sampling stations, nos. 1 and 6, located in the west arm of the lake, and no. 36 in the southeast corner of the lake. The concentrations of all trace elements in the sediments at these stations were the lowest in the lake and indicated the least affected areas of the lake by mining activities.

In summary, it was found that the surficial sediments along the north shore at the outlet from the tailing pond had an outstanding geochemical character. According to their composition and visual observations, they consisted mainly of mine tailings.

The results indicated that the sediments in the northeast arm and north-central part of the lake, in the vicinity of the submerged tailings, were greatly affected by the contaminants in the tailings and by those in the outflow from the tailing pond. The concentrations of trace elements in most of the surficial sediments collected in Larder Lake exceeded the "Severe Effect Levels" given in the sediment guidelines prepared in 1992 by the Ontario Ministry of the Environment and Energy (Table 19). There was no relationship between particle size and concentration of the trace elements in the sediments. However, there was a significant correlation ( $P < 0.05$ ) between five trace elements (As, Cu, Ni, Pb and Zn) and organic matter content, as measured by LOI. On the other hand, the amount of variance explained by LOI ranged from 62% for Pb to 14% for Zn.

#### Concentration profiles of major and trace elements

Sediment cores were obtained from stations 7, 17, 26, 27, and 34 in Larder Lake to evaluate the changes of sediment geochemistry and input trace elements. The concentration profiles of major and trace elements in the sediments are presented in Tables 20 and 21, respectively.

With few exceptions, the concentration profiles of major elements suggested deposition of geochemically similar material on the bottom of Larder Lake. The exceptions were elevated concentrations of  $\text{Fe}_2\text{O}_3$  and  $\text{TiO}_2$ , at the surface of the sediments core collected at all stations. Further, elevated concentrations of MgO existed at the surface of cores collected at stations 7, 17, 26 and 27. The concentrations of CaO were lower at the surface than in the rest of the cores. The pattern of the concentration profiles of  $\text{Fe}_2\text{O}_3$ ,  $\text{TiO}_2$ , MgO and CaO corresponded to that of most of the trace elements (Table 20), and indicated that the source of these elements was the mine tailings.

Concentration profiles clearly indicated an increase of several trace elements, particularly As, Ni, Zn and Cu, towards the sediment surface. The increase which

started at the 3 to 4 cm sediment depth was observed in all five sediment cores, and reflected the inputs of the trace elements from the gold mining activities. Assuming an annual sedimentation rate of 2 to 3 mm in the lake, the major inputs of trace elements to Larder Lake commenced in the 1970's. This time corresponds to the collapse of the tailing pond dike on the north shore of the lake. The greatest concentrations of Ni, Cu and Zn and As in the top 4 cm of sediment cores supported the indication that these elements entered Larder Lake as tailing particles. In addition, the trace elements were transported in dissolved form through the Tailing Pond Outlet. Concentration profiles of trace elements at stations 7 and 27 are shown in Figure 29. The greatest concentrations of all determined trace elements at the sediment surface were found at station 27 (Figure 3).

Enrichment factor of trace elements in the sediment cores was calculated by dividing their concentrations, at each depth interval by the background concentrations i.e., the lowest concentrations of each element in the sediment profile. The enrichment factors are shown in Table 22. The greatest enrichment factor of all trace elements existed for As, followed by Cu, Ni, Zn, Cr, Co, and Pb,. Vanadium had the lowest enrichment factor. Lead showed a consistent gradual increase towards the sediment surface, with enrichment factor between 3 and 4. None of the concentration profiles for all trace elements showed a decrease at the surface. This indicated that loadings of trace elements to bottom sediments, continue in Larder Lake.

The results of the chemical speciation of trace elements in a sediment core from Larder Lake showed that Cu in the sediments was mainly associated with organic matter. Zinc, Mn and Ni were associated mainly with iron oxides. Iron was present mainly as oxide and associated with the residual, i.e., least available, fraction in the sediment (Figure 22). Readily available fraction of Cu, Zn and Ni represented 0.2, 1.5 and 7.2% of the total concentrations in the sediments, respectively. These concentrations represent a considerable amount of readily available Cu, Zn and Ni. For example, 50  $\mu\text{g/g}$  of Ni were in the readily available form in the sediments. The results

suggested that the presence of Fe-oxides in the surficial sediments and oxic bottom waters restricted migration of the trace elements in sediment pore water into the lake waters. A similar phenomenon was found in Jack of Clubs Lake, B.C., containing considerably elevated concentrations of As, Cu, and Pb in sediment pore water and Fe-oxides in surficial sediments (Mudroch *et al.*, 1993).

Distribution of trace elements in the sediment profile indicated different sources of sediments in the past. The results suggested that sediment above 14 cm sediment depth originated mainly from tailings transported into Larder Lake from the tailing pond. The sediments below 18 cm depth is mainly from natural sources in the lake drainage basin. The sediments between 14-18 cm depth are a mixture of the two sediment. A relationship existed between the concentrations of Cu, Pb, Zn and Cd and organic matter at different sediment depths.

### **Benthic Community Structure**

Results showed few benthic invertebrates at any of the thirty five stations. At two stations, 22 and 23, samples were not obtained as the substrate was too firm to be collected. No benthic organisms were found at eighteen sampling stations in the lake. From the 45 sampling units taken at the remaining 15 stations, the following number of organisms were found: three oligochaetes, five nematodes, seven amphipods and sixteen chironomid larvae. At all but one of the 15 sites at which organisms were found, the maximum density was 100 organisms/m<sup>2</sup> (two individuals from 3 replicates). The only sampling station with a greater density of organisms was station 28 (Figure 30), where the density was 200 organisms/m<sup>2</sup>. This station was located at the mouth of one of the larger tributaries in the northeast arm of the lake.

Given the paucity of the benthic community, it was difficult to interpret spatial patterns. However, examination of the distribution of the sampling stations where species were absent does show a possible relationship with proximity to the tailings. The boundary of the sampling stations where no fauna was found extends along the

north-east shore and out from the subaqueous tailings area. The smaller eastern basin, particularly its most east side, was devoid of organisms. In attempt to relate these observations to sediment characteristics, the sites were grouped as having benthic organisms present or absent. Multiple discriminant analysis was then used to relate these groupings to sediment characteristics. This was carried out using the variables shown to be important by ordination in discriminating spatial differences in the sediment as well as with variables that are known to be important in structuring benthic communities, such as particle size and organic matter content. Three separate analyses were carried out using the concentrations of major and trace elements and physical parameters.

None of the analyses suggested a relationship between the presence or absence of invertebrates and the range in values of the examined sediment characteristics. This was evident from the low values for the canonical correlation and the high values for Lambda. This does not mean that the absence of a benthic community was unrelated to high levels of sediment contaminants, such as different trace and major elements, as a lake wide phenomenon. Rather, the differences between presence and absence cannot be discriminated by the sediment characteristics examined. Examination of sediment toxicity may provide evidence that sediment contamination or other factors were responsible for the absence of a thriving benthic invertebrate community in Larder Lake.

### **Sediment Toxicity**

As described above the benthic community in Larder Lake was severely impaired: it was either non-existent or represented by extremely low densities (1-2 organisms per 100 cm<sup>2</sup>). To determine whether this finding was related to sediment toxicity, directly or through other mechanisms, the toxicity associated with bulk sediments was estimated.

Sediment samples were obtained at 35 sampling stations (Figure 2) for

laboratory determination of sediment-associated toxicity as estimated by reproduction in the aquatic oligochaete *Tubifex tubifex*. Using five test endpoints the number of adults, empty cocoons, full cocoons, small young and large young, the spatial pattern in sediment toxicity was determined at the 35 stations using cluster analysis (K means) and ordination (PCA). The dendrogram in Figure 31 from the cluster analysis shows the first division to be a simple station group (group 4), station number 28, off the large cluster. Station 28, located at the mouth of Bear Creek, had the greatest young production (Table 23). The next division occurred by a small cluster (group 1 with 2 sampling stations) splitting off from the large group (group 2). The large group 2 then divides into two clusters of a similar size. Beyond these four clusters separation appears to be into small groups. Therefore, the four cluster solution was used.

Transposition of these clusters in ordination space showed a good discrimination on the first two principle components (Figure 31). These two components explain more than 74% of the variance between the sites. The most toxic sites, group 1, showed high adult mortality i.e., >50%, and very little young production (Table 23). The least impacted site, group 4, had the greatest number of large young and the highest overall production, although considerably lower than the control sediment (Table 23). Except for sediment from group 1, sampling station showed some ability to reproduce. However, the reproduction was suppressed, particularly in the 17 stations comprising Group 2. On the other hand, none of the sediment from the sample stations demonstrated acute toxicity. Examination of spatial pattern in the toxicity data (Figure 32) showed no apparent relationship with the tailings material. The two most toxic sites (Group 1 - stations 7 and 14) were widely separated, being located in the east basin and southern part of the main lake basin (Figure 32), and do not relate to either sediment pattern (Figures 27 and 28) or the observed community structure (Figure 30). The two large clusters (group 2 and group 3) which show distinctly different levels of reproduction both in numbers of cocoons and young produced (Table 23) do not appear to have any spatial pattern.

Discriminant analysis was used to determine what relationship existed between observations on sediment toxicity and sediment characteristics. Simple variables (particle size and LOI) were used first to determine whether the differences in sediment toxicity were a result of basic differences in sediment particle size or food availability. Results of MDA analysis of the relationship of the toxicity groups with sediment characteristics showed seven sediment variables: % clay, Al, Pb, Mn, % silt, K and Zn to discriminate between the groupings created by toxicity test endpoints. These variables predicted correctly 77.1% of the sample stations. However, the differences in the sediment variables in the four groups was small (Table 24). The increased toxicity in group 1 stations may be related to the greater concentrations of Zn and Pb. The most notable feature of the sediment toxicity was that it was widespread, that the station with the least toxicity was the only station with an existing benthic community (station 28), and that at most stations *T. tubifex* can survive and reproduce. This suggested that chronic toxicity was either longer term i.e., > 28 days or possibly related to water column effects. Results showed that the standing crop of phytoplankton as estimated by chlorophyll concentration was extremely low for the observed phosphorus levels. We suspect that water column toxicity may be an explanation for the observed results. This would explain the lake wide absence of a benthic community and the apparently low level of primary production. Sediments may have been the original vector as trace element levels were high. The results of the chemical speciation showed considerably greater concentrations of available Ni in the sediments. In addition, leaching of trace elements from the sediments could have been one of the primary cause of the toxicity to the lake biota. Further, concentrations of Cu, Pb and Zn in the sediment pore and lake water exceed guidelines for the protection of aquatic life, most likely contributed to the observed sediment toxicity.

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Table 1.

DEPTH OF THERMAL STRATIFICATION AND LIGHT TRANSMISSION IN LARDER LAKE AND RAVEN LAKE WATER						
STATION	DEPTHS (m)			LIGHT TRANSMISSION (%)		
	Epilimnion	Hypolimnion	Bottom	Epilimnion	Hypolimnion	Bottom
L 1	5.2	5.2	5.2	69	69	69
L 2	7	10	15	74.6	76.4	73.6
L 3	7.4	9.8	15.5	67	76	73.2
L 4	7.6	9.1	20.8	58	52	69.6
L 5	7.3	9.3	17.2	72.8	74.8	70
L 6	7.6	7.6	7.6	72.8	72.8	72.8
L 7	6.5	9	25.5	66.6	70	71.2
L 8	7.6	10.1	26.5	73.8	75.6	73
L 9	6.6	10.3	28.5	74.2	77.2	76
L 10	7.2	9.4	27.2	76	76.8	77.6
L 11	6.5	9	9	76	72	72
L 12	6.5	12.8	12.8	72	71.6	71.6
L 13	8.2	11.1	29.5	72.4	76	78
L 14	8	9.4	20.5	73	74.4	74
L 15	8.4	11	21.8	73.6	76.6	73.8
L 16	7.3	10.3	14.6	72.4	75.2	73.8
L 17	7	10.6	36	73	76.2	78
L 18	7	9.8	31.2	73.8	74.2	78.8
L 19	6	9.9	25	68.8	76	78
L 20	7	9.3	36	72	75.6	76.8
L 21	7	10.1	36	66	63.2	79.4
L 22	7.5	9.5	33	77.2	77.6	76.8
L 23	8.2	8.6	12.5	76.2	76.6	78.2
L 24	7.5	9	17.9	75.4	75.8	75.2
L 25	8.4	9.8	17.4	74.4	72.8	71.2
L 26	6.1	10	13.5	75.6	76.8	76.4
L 27	5.9	8	8	75.2	77	77
L 28	1.3	1.3	1.3	73	73	73
L 29	6.4	11	11	76	74.4	74.4
L 30	7.5	9.3	16.1	74.6	77	76.2
L 31	6.6	9.6	18	75.2	76	60
L 32	7	9.8	17.9	53	71.2	72
L 33	6.8	6.8	6.8	73.8	73.8	73.8
L 34	7.1	7.1	7.1	74	74	74
L 35	5.9	5.9	5.9	72.2	72.2	72.2
L 36	6.3	6.3	6.3	73	73	73
L 37	5	5	5	68.2	68.2	68.2
L 38	6.3	6.3	6.3	70	70	70
LT 2	5	5	5	73	73	73
LT 3	8.1	8.1	8.1	74.2	74.2	74.2
LT 4	6	11.8	11.8	70	77.2	77.2
LT 5	6	10.8	16.5	72.4	74	78.8
LT 6	7.5	10.1	21	76.6	77.6	80
LT 7	7	9.9	19	75.6	68	79.6
R 1	7.5	12.5	28.4	80.8	83.6	79.4
R 2	6.5	9.9	23.6	82.4	82.4	80
R 3	3.9	8.5	12	78.2	77	69

Table 2.

CONCENTRATION OF MAJOR ELEMENTS IN LARDER LAKE SURFICIAL SEDIMENTS (0 to 5cm)

STN	SiO <sub>2</sub> %	Al <sub>2</sub> O <sub>3</sub> %	Fe <sub>2</sub> O <sub>3</sub> %	MgO %	CaO %	Na <sub>2</sub> O %	K <sub>2</sub> O %	TiO <sub>2</sub> %	MnO %	P <sub>2</sub> O <sub>5</sub> %	S ug/g	LOI %
L1	64.63	13.02	4.80	2.44	2.50	2.12	2.08	0.52	0.09	0.17	1700	6.33
L2	56.57	12.48	11.37	2.82	1.96	1.88	2.14	0.69	0.70	0.30	850	9.81
L3	58.73	13.03	9.26	2.68	2.18	1.89	2.24	0.61	0.50	0.25	1050	9.43
L4	61.07	13.17	7.57	2.80	2.09	1.95	2.23	0.60	0.09	0.14	3003	11.12
L5	60.31	12.98	8.06	2.62	2.27	1.92	2.22	0.54	0.35	0.20	1100	9.18
L6	55.19	14.01	12.16	3.48	2.66	1.99	2.81	0.55	0.29	0.19	400	6.26
L7	57.86	13.23	9.66	3.17	2.01	2.07	2.20	0.62	0.11	0.15	5000	9.58
L8	55.87	12.75	10.84	4.59	2.05	2.06	2.04	0.72	0.15	0.19	2892	9.38
L10	57.16	13.50	9.96	3.73	2.02	1.91	2.32	0.60	0.23	0.20	2203	8.76
L11	58.43	13.68	8.70	3.35	2.09	2.10	2.24	0.68	0.23	0.17	700	5.9
L12	57.43	13.81	10.07	3.18	2.34	2.05	2.42	0.69	0.59	0.20	700	8.27
L13	52.76	12.23	13.14	5.47	2.24	2.21	1.79	0.79	0.37	0.19	2400	8.99
L14	60.20	13.50	8.65	3.27	2.02	2.17	2.26	0.68	0.09	0.18	2000	8.04
L15	61.62	13.80	7.48	3.03	2.13	2.17	2.32	0.57	0.09	0.14	2000	8.28
L16	60.19	13.59	8.51	3.04	2.15	2.23	2.27	0.65	0.24	0.16	1500	7.77
L17	54.54	12.56	10.60	4.99	2.25	1.95	2.06	0.65	0.19	0.16	3068	7.93
L18	49.40	11.04	13.14	7.66	3.73	1.95	1.54	0.76	0.29	0.15	3051	6.19
L19	57.41	13.65	11.46	3.52	2.26	2.36	2.29	0.52	0.23	0.21	600	5.64
L20	50.97	11.52	12.46	7.14	3.65	1.94	1.70	0.75	0.19	0.14	4582	7.46
L21	47.86	10.37	15.00	4.72	6.73	2.80	1.02	0.90	0.23	0.12	11000	3.71
L22	45.91	10.02	15.25	5.40	7.30	2.86	0.88	0.97	0.23	0.11	12000	3
L23	45.77	9.85	15.10	5.33	7.88	2.78	0.87	0.92	0.24	0.11	13000	3.57
L24	46.31	10.17	15.19	5.59	7.06	2.83	0.91	0.94	0.23	0.11	12000	4.43
L25	50.27	10.92	13.58	6.69	4.24	2.35	1.34	0.80	0.22	0.12	4710	5.98
L26	52.95	11.95	12.48	6.56	2.20	1.92	1.84	0.69	0.27	0.14	2000	9.34
L27	60.76	11.06	8.48	4.03	2.38	2.33	1.41	0.60	0.11	0.11	1800	4.98
L28	56.78	9.44	9.95	4.02	4.99	2.15	1.10	0.85	0.16	0.11	6000	6
L29	58.31	13.05	9.96	3.53	1.88	2.20	2.04	0.64	0.27	0.16	800	7.81
L30	59.79	13.16	8.67	3.52	1.98	2.13	2.16	0.63	0.13	0.18	2500	8.62
L31	58.78	13.30	9.46	3.58	1.84	2.15	2.19	0.64	0.16	0.16	2500	8.69
L32	57.65	13.30	10.43	3.77	1.70	2.21	2.12	0.72	0.17	0.19	2100	8.29
L33	59.61	13.64	8.19	3.27	2.25	2.31	2.26	0.58	0.27	0.15	400	5.96
L34	64.68	12.71	4.82	2.59	2.60	2.38	1.94	0.58	0.08	0.13	900	6.27
L35	61.38	13.08	6.64	2.79	2.27	2.22	2.06	0.61	0.16	0.15	900	4.9
L36	63.72	13.17	5.56	2.66	2.42	2.33	2.06	0.58	0.13	0.13	500	4.06
L37	64.60	12.83	7.02	2.51	2.55	2.44	1.99	0.59	0.14	0.14	400	5.17

LOI = loss on ignition at 500 C

Table 3.

TEMPERATURE, pH, DISSOLVED O2 CONCENTRATION, TRANSMISSION, AND CONDUCTIVITY IN LARDER LAKE AND RAVEN LAKE WATER, AT 1 m BELOW THE SURFACE					
STATION	TEMP °C	pH	DO mg/L	TRANS %	COND* uMO
L 1	18.6	7.6	8.95	75	
L 2	19.8	8.17	8.65	73	130
L 3	19.5	8.04	9.2	72	120
L 4	19.5	7.88	9.0	70	120
L 5	19.5	7.98	8.85	70	120
L 6	19.8	7.82	8.8	74	130
L 7	19.2	7.85	8.7	72	130
L 8	19.5	7.95	8.75	70	130
L 9	19.5	8.00	8.7	72	120
L 10	19.0	7.54	8.4	74	120
L 11	19.6	7.38	8.75	73	130
L 12	19.0	7.45	8.75	73	130
L 13	18.8	7.60	8.75	72	120
L 14	18.2	7.51	8.4	72	120
L 15	18.6	7.42	8.45	73	120
L 16	18.7	7.40	8.50	72	120
L 17	19.0	7.73	8.75	73	120
L 18	19.5	8.04	8.75	70	120
L 19	19.2	7.32	8.75	73	120
L 20	19.6	7.88	8.75	73	120
L 21	19.5	8.05	8.75	70	130
L 22	18.4	7.64	8.90	75	120
L 23	19.5	7.76	8.8	72	120
L 24	19.8	7.74	8.9	71	120
L 25	19.5	7.71	8.9	72	120
L 26	18.7	7.62	8.9	74	120
L 27	18.7	7.65	9.0	73	130
L 28	18.5	7.67	8.95	76	130
L 29	18.7	7.64	8.90	76	130
L 30	18.6	7.70	8.8	76	120
L 31	18.4	7.64	8.7	72	120
L 32	18.4	7.66	8.75	75	120
L 33	19.2	7.73	8.9	70	120
L 34	19.0	7.50	8.5	71	120
L 35	18.2	7.68	8.9	72	120
L 36	18.2	7.70	8.8	73	130
L 37	18.1	7.76	8.8	73	120
L 38	17.5	7.56	8.9	72	130
R 2	18.4	7.29	8.75	82	50

\*COND measured at room temperature

Table 4.

THERMAL STRUCTURE, TEMPERATURE, pH, DISSOLVED O2 CONCENTRATION, TRANSMISSION AND CONDUCTIVITY IN LARDER LAKE AND RAVEN LAKE WATER AT 1m ABOVE BOTTOM						
STATION	THERMAL STRUCT.	TEMP °C	pH	DO mg/L	TRANS %	COND* uMO
L 1	ISO	18.0	7.6	9.0	72	120
L 2	STR	9.2	7.29	8.90	71	120
L 3	STR	7.8	7.31	8.9	75	120
L 4	STR	6.5	7.31	8.0	69	120
L 5	STR	7.3	7.20	8.85	73	120
L 6	ISO	19.0	7.79	8.8	74	120
L 7	STR	6.2	7.54	9.6	73	120
L 8	STR	6.2	7.44	9.5	76	120
L 9	STR	5.6	7.48	9.9	76	120
L 10	STR	6.5	6.93	9.6	48	120
L 11	STR	13.0	7.16	8.5	76	120
L 12	STR	8.1	6.96	8.75	73	120
L 13	STR	5.8	7.16	9.8	79	120
L 14	STR	7.7	6.76	9.1	75	120
L 15	STR	7.5	6.70	8.6	75	120
L 16	STR	8.7	6.71	8.85	75	120
L 17	STR	5.1	7.22	9.5	88	120
L 18	STR	5.2	7.50	9.8	79	120
L 19	STR	6.2	6.76	9.9	78	120
L 20	STR	5.0	7.26	9.4	78	120
L 21	STR	5.0	7.32	9.05	79	130
L 22	STR	5.1	6.81	10.1	82	120
L 23	STR	8.0	7.20	9.4	78	120
L 24	STR	7.6	7.11	9.3	76	120
L 25	STR	7.6	7.03	8.8	75	120
L 26	STR	8.7	6.93	8.7	76	130
L 27	ISO	16.4	7.32	9.0	78	130
L 29	STR	9.6	6.90	8.75	76	130
L 30	STR	7.0	6.88	9.05	78	120
L 31	STR	6.4	6.86	8.2	76	130
L 32	STR	6.6	6.84	8.2	75	120
L 33	ISO	18.2	7.73	8.9	70	120
L 34	ISO	18.5	7.50	8.2	73	130
L 35	ISO	18.2	7.65	8.9	72	120
L 36	ISO	18.2	7.65	8.7	73	120
L 37	ISO	18.10	7.76	8.9	68	120
L 38	ISO	17.8	7.42	8.9	69	120
R 2	STR	5.3	7.02	9.2	81	50

ISO= Isothermal

STR= Stratified

\*COND measured at room temperature

Table 5.

MEAN CONCENTRATION OF DISSOLVED MAJOR IONS AND TRACE ELEMENTS IN WATER SAMPLES FROM LARDER LAKE, TAILINGS POND OUTLET, RAVEN LAKE, BARBER LAKE, CREEK INLETS, SPRING WATER AND MINE PITS

PARAMETER	Larder Lake	Trail.pond outlet	LT1-LT3	Raven Lake	Barber Lake	Creek Inlets	Spring Water	Mine-pits	detection limit & units
	MEAN	MEAN	MEAN	MEAN	Lake	MEAN	Water	MEAN	
Conductivity	132.30	436.00	137.70	62.70	80.3	158.05	446.0	408.00	0.10 UMO
pH	7.48	8.09	7.43	7.02	7.38	7.53	7.96	7.67	0.01
CaCO3	33.02	80.40	33.30	12.92	18.5	58.50	17.8	123.57	.1 mg/L
F	37.84	56.50	36.33	38.33	28.00	49.50	62.00	64.00	15 ug/L
SO4	17.59	89.95	18.98	9.88	NA	4.16	11.10	139.00	0.02 mg/L
ORG-C	6.31	NA	6.29	6.51	NA	NA	NA	NA	0.2 mg/L
As	23.34	390.97	30.03	3.85	0.96	0.54	5.13	81.47	0.15 ug/L
Bi	0.02	DL	DL	DL	DL	DL	DL	DL	0.2 ug/L
Sb	3.48	59.72	4.31	0.52	DL	DL	DL	1.01	0.2 ug/L
Na	4.39	43.58	4.66	1.96	4.04	2.83	7.71	3.56	.1 mg/L
K	0.80	5.78	0.86	0.46	0.35	0.50	0.93	1.10	.1 mg/L
Ca	13.64	31.65	14.18	6.41	7.90	21.09	24.15	25.95	.1 mg/L
Mg	4.31	4.74	4.30	1.97	1.75	5.50	13.80	14.66	3 ug/L
Zn	6.60	36.50	4.67	1.33	DL	1.10	DL	9.00	3 ug/L
[Zn]	5.41	NA	NA	DL	DL	DL	DL	2.90	1 ug/L
Cu	16.23	166.00	16.33	1.50	DL	DL	DL	DL	5 ug/L
[Cu]	10.96	62.05	9.70	DL	DL	DL	DL	DL	2 ug/L
Pb	21.00	DL	21.00	DL	DL	DL	DL	DL	20 ug/L
Ni	44.79	714.00	43.33	13.67	DL	DL	DL	DL	15 ug/L
Co	1.68	98.00	DL	2.50	DL	DL	DL	5.00	15 ug/L
Cd	0.13	DL	DL	0.33	DL	DL	DL	DL	2 ug/L
Mn	0.24	40.00	DL	DL	DL	11.00	650.00	569.33	10 ug/L
Fe	24.49	187.00	46.00	16.17	51.00	120.50	94.00	1383.33	20 ug/L
Ba	9.20	42.60	9.77	5.83	9.4	17.18	67.5	33.80	1 ug/L
Sr	52.93	217.30	54.70	25.82	34.8	76.35	251.6	188.13	1 ug/L

NA= Not analysed  
 DL = less than or detection limit  
 [] = readily available portion



**Table 6.**

CONCENTRATIONS OF POC, PN, CHLA.U, CHLA.C, TP, TFP, DOC, TSM, ISM & OSM IN LARDER LAKE AND RAVEN LAKE WATER, AT 1m BELOW THE SURFACE										
STATION	POC mg/L	PN mg/L	CHLA.U ug/L	CHLA.C ug/L	TP mg/L	TFP mg/L	DOC mg/L	TSM mg/L	ISM mg/L	OSM mg/L
L 2	1.59	0.133	1.4	0.8	0.0184	0.0155	5.88	0.80	0.00	0.80
L 4	3.50	0.380	1.7	1.5	0.0194	0.0111	NA	0.93	0.07	0.87
L 7	1.71	0.170	1.2	1.1	0.0178	0.0112	6.42	1.33	0.13	1.20
L 10	1.77	0.175	1.5	1.4	0.0181	0.0110	5.96	1.20	0.00	1.20
L 16	1.88	0.245	2.3	1.8	0.0184	0.0115	6.36	3.70	0.20	3.50
L 17	1.29	0.133	1.5	1.1	0.0192	0.0111	6.03	0.85	0.15	0.69
L 19	1.94	0.200	1.7	1.4	0.0192	0.0116	NA	1.00	0.40	0.60
L 21	2.13	0.240	1.9	1.5	0.0189	0.0110	NA	1.17	0.00	1.17
L 26	0.34	0.048	1.8	1.2	0.0200	0.0154	6.38	1.71	0.00	1.71
L 27	0.39	0.048	1.6	0.8	0.0210	0.0140	6.33	0.92	0.00	0.92
L 30	1.42	0.180	1.0	0.4	0.0187	0.0123	NA	1.24	1.00	0.24
L 34	1.67	0.304	2.2	2.0	0.0182	0.0107	6.13	1.00	0.00	1.00
L 37	1.46	0.169	0.7	0.2	0.0180	0.0120	NA	NA	NA	NA
Mean	1.62	0.187	1.6	1.2	0.0189	0.0122	6.19	1.32	1.16	1.16
R2	0.82	0.100	1	0.8	0.0072	0.0058	6.32	0.57	0.007	0.05

NA = Not Analysed

CONCENTRATIONS OF POC, PN, CHLA.U, CHLA.C, TP, TFP, DOC, TSM, ISM & OSM IN LARDER LAKE AND RAVEN LAKE WATER, AT 1m ABOVE BOTTOM										
STATION	POC mg/L	PN mg/L	CHLA.U ug/L	CHLA.C ug/L	TP mg/L	TFP mg/L	DOC mg/L	TSM mg/L	ISM mg/L	OSM mg/L
L 2	1.33	0.108	0.5	0.2	0.0177	0.0111	NA	0.96	0.00	0.96
L 4	2.20	0.195	0.5	0.4	0.0177	0.0092	NA	1.13	0.33	0.80
L 7	1.96	0.175	0.5	0.3	0.0178	0.0102	6.10	0.50	0.00	0.50
L 10	2.65	0.233	0.8	0.7	0.0184	0.0115	6.60	1.20	0.00	1.20
L 16	1.54	0.140	0.6	0.4	0.0191	0.0103	6.47	1.10	0.00	1.10
L 17	2.50	0.175	0.4	0.2	0.0208	0.0118	6.54	1.00	0.00	1.00
L 19	1.79	0.310	0.4	0.3	0.0213	0.0108	NA	1.50	0.10	1.40
L 21	1.30	0.940	1.3	0.5	0.0314	0.0136	NA	NA	NA	NA
L 26	0.48	0.032	0.5	DL	0.0204	0.0133	6.43	1.23	0.15	1.08
L 27	0.38	0.044	1.0	0.4	0.0219	0.0143	6.67	1.85	0.77	1.08
L 30	1.85	0.245	0.1	DL	0.0175	0.0117	NA	1.07	0.14	0.93
L 34	1.24	0.160	2.0	1.9	0.0183	0.0125	6.16	0.92	0.33	0.58
L 37	1.45	0.168	0.7	0.2	0.0181	0.0123	NA	1.00	0.29	0.71
Mean	1.59	0.225	0.7	0.5	0.02	0.0117	6.42	1.12	0.18	0.95
R2	0.47	0.04	DL	DL	0.0078	0.0042	6.9	0.71	0.04	0.5

DL = less than or detection limit  
NA = Not Analysed

Table 7.

CONCENTRATIONS OF DISSOLVED F, Na, K, Ca, Mg, SO <sub>4</sub> AND Cl IN LARDER LAKE AND RAVEN LAKE WATER, AT 1m BELOW THE SURFACE							
STATION	F ug/L	Na mg/L	K mg/L	Ca mg/L	Mg mg/L	SO <sub>4</sub> mg/L	Cl mg/L
L 1	39	4.54	0.83	13.71	4.30	17.8	5.27
L 2	38	4.54	0.79	13.29	4.24	17.9	5.11
L 3	37	4.53	0.85	13.36	4.29	18.0	5.27
L 4	36	4.44	0.78	13.48	4.27	17.8	5.10
L 5	36	4.38	0.79	13.41	4.30	17.6	5.05
L 6	36	4.46	0.79	13.48	4.29	18.2	5.19
L 7	34	4.35	0.78	13.34	4.24	18.1	5.04
L 8	35	4.44	0.81	13.50	4.29	18.1	5.00
L 9	41	4.47	0.78	13.53	4.34	18.1	4.92
L 10	39	4.54	0.81	13.40	4.32	18.2	4.89
L 11	38	4.47	0.79	13.30	4.34	18.2	5.18
L 12	38	4.49	0.79	13.41	4.32	18.2	4.90
L 13	38	4.49	0.79	13.41	4.34	18.3	5.07
L 14	41	4.50	0.79	13.89	4.32	18.3	5.12
L 15	39	4.44	0.79	13.65	4.27	18.3	5.08
L 16	39	4.41	0.81	13.77	4.32	18.2	4.99
L 17	38	4.44	0.81	13.74	4.35	18.4	4.98
L 18	40	4.49	0.81	13.82	4.34	18.3	5.15
L 19	38	4.54	0.84	13.86	4.35	18.3	4.99
L 20	38	4.46	0.79	13.80	4.32	18.4	5.13
L 21	38	4.47	0.79	13.74	4.34	18.3	5.05
L 22	37	4.56	0.88	13.70	4.32	18.3	5.04
L 23	47	4.62	0.83	13.86	4.37	18.6	5.15
L 24	37	4.51	0.81	13.88	4.38	18.6	5.19
L 25	39	4.65	0.81	13.97	4.38	18.6	5.41
L 26	40	4.35	0.79	13.91	4.34	18.6	5.08
L 27	37	4.46	0.83	13.92	4.44	19.1	5.24
L 28	37	4.44	0.84	13.99	4.44	19.0	5.33
L 29	38	4.47	0.81	14.04	4.38	18.9	5.15
L 30	37	4.43	0.79	13.84	4.35	18.3	5.01
L 31	37	4.41	0.78	13.95	4.38	18.2	4.98
L 32	42	4.43	0.81	13.88	4.34	18.4	5.19
L 33	39	4.29	0.79	13.89	4.34	18.2	5.03
L 34	39	4.24	0.78	13.86	4.32	18.1	5.06
L 35	49	4.27	0.79	13.88	4.34	18.0	4.89
L 36	39	4.24	0.79	13.91	4.30	18.0	4.94
L 38	42	4.20	0.78	13.93	4.30	18.0	4.95
LT 1	36	5.02	0.94	14.35	4.30	19.4	5.18
LT 3	39	4.46	0.84	14.05	4.30	18.5	4.94
LT 5	34	4.29	0.81	13.98	4.24	18.2	4.96
LT 7	34	4.24	0.79	14.01	4.27	18.2	4.94
R 1	40	2.10	0.47	6.73	2.06	10.0	1.83
R 2	39	2.03	0.47	6.69	2.04	10.1	1.77
R 3	38	2.34	0.51	8.01	2.44	11.5	2.36

Table 8.

CONCENTRATIONS OF DISSOLVED F, Na, K, Ca, Mg, SO <sub>4</sub> AND Cl IN LARDER LAKE AND RAVEN LAKE WATER, AT 1m ABOVE THE BOTTOM							
STATION	F ug/L	Na mg/L	K mg/L	Ca mg/L	Mg mg/L	SO <sub>4</sub> mg/L	Cl mg/L
L 1	38	4.49	0.83	13.54	4.29	17.9	5.04
L 2	36	4.26	0.78	13.05	4.15	18.1	4.93
L 3	36	4.30	0.78	13.16	4.15	17.2	4.89
L 4	35	4.21	0.81	12.96	4.07	16.7	4.87
L 5	35	4.15	0.79	12.96	4.11	17.3	4.96
L 6	36	4.38	0.81	13.50	4.30	18.0	5.06
L 7	35	4.29	0.78	13.11	4.18	17.6	4.83
L 8	35	4.37	0.78	13.24	4.23	17.7	4.93
L 9	39	4.40	0.78	13.23	4.35	17.9	4.89
L 10	36	4.51	0.79	13.14	4.27	17.8	5.14
L 11	38	4.49	0.81	13.29	4.35	18.2	5.01
L 12	37	4.35	0.79	13.05	4.26	17.8	5.02
L 13	37	4.38	0.78	13.13	4.27	18.1	5.02
L 14	39	4.41	0.79	13.60	4.23	17.9	4.97
L 15	39	4.37	0.81	13.46	4.30	17.8	5.07
L 16	38	4.29	0.81	13.47	4.29	18.0	5.00
L 17	38	4.35	0.78	13.47	4.27	18.0	4.93
L 18	37	4.38	0.78	13.60	4.34	18.0	4.96
L 19	37	4.41	0.81	13.52	4.32	17.8	5.09
L 20	38	4.40	0.79	13.74	4.40	18.1	5.08
L 21	38	4.44	0.79	13.88	4.44	17.9	5.04
L 22	38	4.34	0.79	13.66	4.30	18.4	5.10
L 23	38	4.35	0.78	13.53	4.29	18.0	5.02
L 24	37	4.24	0.78	13.65	4.32	17.9	4.90
L 25	40	4.26	0.79	13.76	4.37	17.9	5.02
L 26	38	4.24	0.79	13.70	4.34	17.9	5.13
L 27	37	4.43	0.83	13.97	4.40	18.6	5.10
L 29	36	4.27	0.79	13.62	4.30	17.9	4.75
L 30	36	4.30	0.79	13.60	4.29	17.8	4.95
L 31	35	4.35	0.78	13.65	4.34	17.8	5.02
L 32	40	4.23	0.78	13.68	4.30	17.6	4.81
L 33	40	4.30	0.79	13.92	4.34	18.1	5.07
L 34	39	4.23	0.79	13.89	4.34	18.2	5.07
L 35	38	4.27	0.79	13.89	4.34	18.2	5.04
L 36	39	4.34	0.79	13.93	4.32	18.1	4.96
L 37	39	4.34	0.81	14.07	4.37	18.1	4.98
L 38	38	4.27	0.79	14.07	4.32	18.1	4.85
LT 3	34	4.49	0.79	14.13	4.29	18.6	5.13
LT 5	34	3.99	0.76	13.70	4.17	17.5	4.98
R 1	39	1.75	0.43	5.52	1.71	9.1	1.44
R 2	37	1.75	0.43	5.57	1.72	9.0	1.45
R 3	37	1.80	0.45	5.91	1.82	9.3	1.58

Table 9.

CONCENTRATIONS OF DISSOLVED As, Sb, Zn, Cu, Ni, Fe, Ba AND Sr IN LARDER LAKE AND RAVEN LAKE, AT 1m BELOW THE SURFACE IN ug/L								
STATION	As	Sb	Zn	Cu	Ni	Fe	Ba	Sr
L 1	23.59	3.66	DL	13	16	DL	9.6	51.0
L 2	23.80	3.35	11	12	26	DL	9.5	52.7
L 3	21.59	3.00	16	16	22	DL	9.5	53.2
L 4	21.75	3.28	3	17	22	34	9.1	53.1
L 5	24.15	3.53	DL	13	49	40	9.7	53.4
L 6	21.94	3.45	12	17	52	DL	9.5	51.7
L 7	22.18	3.50	DL	14	39	30	9.1	51.0
L 8	22.01	3.57	4	17	30	DL	9.2	53.3
L 9	22.46	3.41	4	17	58	42	9.5	52.6
L 10	24.49	3.80	4	16	32	29	9.4	54.4
L 11	23.70	3.66	4	17	45	26	9.4	53.2
L 12	22.99	3.50	3	16	50	25	9.3	54.1
L 13	22.51	3.49	5	14	51	DL	9.1	52.5
L 14	24.26	3.81	4	17	38	DL	9.2	53.4
L 15	24.44	3.60	5	21	47	DL	9.1	52.4
L 16	23.44	3.33	3	17	48	DL	9.4	52.6
L 17	22.90	3.57	4	16	46	41	9.4	55.3
L 18	22.71	3.20	5	14	46	DL	9.3	52.2
L 19	24.40	3.30	6	17	42	27	9.6	53.8
L 20	24.13	3.41	5	16	45	24	9.4	53.4
L 21	23.70	3.55	6	17	32	21	8.9	53.6
L 22	22.84	3.57	7	19	45	28	8.7	52.6
L 23	26.25	3.84	6	14	27	DL	9.1	51.1
L 24	24.89	3.49	DL	18	31	DL	9.0	56.8
L 25	25.05	3.62	4	19	36	29	9.5	53.7
L 26	24.36	3.52	4	16	40	DL	9.5	55.2
L 27	24.48	3.33	5	15	66	DL	9.8	53.6
L 28	26.51	3.94	4	16	59	DL	9.3	54.9
L 29	25.85	3.74	4	16	65	DL	9.1	53.8
L 30	23.90	3.49	4	18	54	DL	9.3	53.1
L 31	23.78	3.48	4	14	51	DL	9.2	55.7
L 32	23.50	3.64	6	14	40	DL	9.2	54.2
L 33	22.80	3.40	10	13	57	25	9.5	54.0
L 34	24.18	3.57	3	10	60	DL	9.3	54.0
L 35	23.11	3.32	4	11	49	35	9.2	53.6
L 36	23.00	3.33	DL	14	56	28	9.2	52.5
L 38	24.65	3.92	3	14	42	27	9.1	54.7
LT 1	33.09	4.87	7	17	60	47	10.3	56.6
LT 3	26.99	3.92	3	15	36	35	9.5	53.9
LT 5	24.80	3.44	3	14	34	68	9.3	55.6
LT 7	24.18	3.68	4	12	43	27	9.2	54.6
R 1	4.05	0.83	DL	DL	DL	26	5.8	26.6
R 2	4.49	0.58	4	DL	DL	DL	6.1	26.3
R 3	7.82	1.03	DL	DL	17	DL	6.4	31.6

DL = less than or detection limit

Table 10.

CONCENTRATIONS OF DISSOLVED As, Sb, Zn, Cu, Ni, Fe, Ba AND Sr IN  
LARDER LAKE AND RAVEN LAKE, AT 1m. ABOVE BOTTOM IN ug/L

STATION	As	Sb	Zn	Cu	Ni	Fe	Ba	Sr
L 1	23.85	3.61	4	12	DL	28	9.5	52.3
L 2	21.47	3.22	9	17	20	25	9.0	50.5
L 3	20.28	3.04	14	18	40	41	8.8	49.8
L 4	18.33	2.69	10	17	21	51	9.6	50.5
L 5	21.82	3.17	7	18	34	22	9.3	50.0
L 6	22.36	3.57	4	17	48	25	9.5	52.5
L 7	21.37	3.21	8	17	35	28	8.7	51.2
L 8	20.96	3.35	10	18	43	34	8.8	51.1
L 9	20.90	3.36	9	19	55	30	8.6	51.8
L 10	22.83	3.41	9	19	56	29	8.7	51.3
L 11	23.08	3.43	5	18	45	DL	9.5	51.1
L 12	20.88	3.15	9	16	41	34	8.7	52.0
L 13	21.24	3.46	9	16	60	DL	8.7	52.0
L 14	23.24	3.56	10	23	53	34	9.0	50.6
L 15	23.10	3.41	11	20	50	25	9.1	51.9
L 16	21.70	3.31	29	21	135	DL	9.1	52.9
L 17	22.02	3.52	10	17	52	45	8.4	53.1
L 18	21.22	3.32	10	19	48	44	8.8	51.2
L 19	22.52	3.34	9	17	49	35	8.8	52.0
L 20	22.97	3.44	17	20	40	30	8.6	53.3
L 21	21.89	3.44	12	20	47	DL	8.8	53.9
L 22	27.27	3.52	14	19	49	331	9.1	52.6
L 23	22.46	3.68	9	19	22	27	9.3	54.0
L 24	22.73	3.58	8	19	33	36	9.1	52.4
L 25	22.63	3.43	10	18	24	33	9.1	52.7
L 26	21.97	3.21	8	18	28	34	9.0	51.3
L 27	23.18	3.48	4	15	65	35	9.2	53.9
L 29	22.82	3.72	7	14	58	DL	9.0	50.9
L 30	22.31	3.52	8	15	62	DL	8.9	53.2
L 31	21.92	3.09	10	21	76	40	9.2	53.6
L 32	21.79	3.10	10	15	75	DL	9.5	53.9
L 33	25.06	4.04	4	10	70	DL	9.5	53.6
L 34	24.53	3.46	3	15	48	30	9.3	53.5
L 35	23.72	3.24	DL	15	62	26	9.2	53.5
L 36	23.15	3.11	4	13	40	24	9.3	52.7
L 37	23.02	3.17	4	14	42	DL	9.4	53.1
L 38	24.73	3.37	5	14	43	DL	9.1	53.7
LT 3	30.02	4.13	4	17	34	56	9.5	53.6
LT 5	21.88	3.36	8	14	32	66	9.0	53.2
R 1	1.99	0.30	DL	DL	DL	25	5.5	23.0
R 2	1.74	0.39	4	DL	DL	DL	5.6	22.7
R 3	3.01	DL	DL	DL	65	46	5.6	24.7

DL = less than or dection limit

**Table 11.**

MEDIAN, MEAN, STANDARD DEVIATION (S.D.) AND RANGE OF DISSOLVED TRACE ELEMENTS IN LARDER LAKE WATER, AT 1M BELOW THE SURFACE								
ELEMENT	As	Sb	Zn	Cu	Ni	Fe	Ba	Sr
MEDIAN	23.70	3.50	4.00	16.00	45.00	28.00	9.30	53.40
MEAN	23.68	3.52	5.38	15.54	43.62	30.06	9.30	53.42
S.D.	1.17	0.20	2.89	2.26	12.17	6.02	0.22	1.25
RANGE								
MIN	21.59	3.00	3.00	10.00	16.00	21.00	8.70	51.00
MAX	26.51	3.94	16.00	21.00	66.00	42.00	9.80	56.80

MEDIAN, MEAN, STANDARD DEVIATION (S.D.) AND RANGE OF DISSOLVED TRACE ELEMENTS IN LARDER LAKE WATER, AT 1M ABOVE THE BOTTOM								
ELEMENT	As	Sb	Zn	Cu	Ni	Fe	Ba	Sr
MEDIAN	22.55	3.41	9.00	17.50	48.00	30.00	9.10	52.45
MEAN	22.47	3.37	8.97	17.11	49.14	43.56	9.06	52.26
S.D.	1.48	0.23	4.61	2.67	20.20	56.79	0.30	1.20
RANGE								
MIN	18.33	2.69	3.00	10.00	20.00	22.00	8.40	49.80
MAX	27.27	4.04	29.00	23.00	135.00	331.00	9.60	54.00

**Table 12.**

MEAN CONCENTRATIONS AND STANDARD DEVIATION (SD) OF TRACE ELEMENTS IN SEDIMENTS AND WATERS OF LARDER LAKE								
ELEMENT	As	Sb	Zn	Cu	Ni	Fe	Ba	Sr
SEDIMENT (ug/g)								
MEAN	29.85	660.38	272.29	409.07	518.15	44.98	628.22	163.36
SD	13.61	338.54	84.69	210.23	200.64	12.64	431.95	77.97
WATER AT 1m ABOVE BOTTOM (ug/L)								
MEAN	22.47	3.37	8.97	17.11	49.14	43.56	9.06	52.26
SD	1.48	0.23	4.61	2.67	20.20	56.79	0.30	1.20
WATER AT 1M BELOW SURFACE (ug/L)								
MEAN	23.68	3.52	5.38	15.54	43.62	30.06	9.30	53.42
SD	1.17	0.20	2.89	2.26	12.17	6.02	0.22	1.25
DIFFERENCE BETWEEN 1m ABOVE BOTTOM AND 1m BELOW SURFACE (ug/L)								
B-S	-1.21	-0.15	3.59	1.57	5.52	13.50	-0.24	-1.16
SD	2.30	0.93	3.87	3.14	8.05	11.21	1.02	2.21

Table 13.

TRACE ELEMENTS RATIOS, BASED ON THE WATER CONCENTRATION MEANS IN LARDER LAKE,  
RAVEN LAKE, BARBER LAKE AND TAILINGS POND OUTLET

Metals	Dilution Index					Enrichment Index				
	B/S	R/S	L/S	TPO/S	R/B	L/B	TPO/B	TPO/L		
As	2	10	50	99	4	24	407	17		
Cu	1	1	7	66	1	16	66	10		
Ni	1	3	6	80	3	6	95	16		
Zn	1	2	4	24	2	5	24	6		

R = Raven Lake (Control Lake Downstream)      S = Streams  
 B = Barber Lake (Control Lake Upstream)      L = Larder Lake  
 TPO = Tailings Pond Outlet

Table 14.

TRACE ELEMENT INDICES IN WATER FROM LARDER LAKE, RAVEN LAKE,  
BARBER LAKE, TAILINGS POND OUTLET AND AREA STREAMS

Metals	LEL	TPO	Larder L.	Raven L.	Barber L.	Streams
As	1	39	2	*	*	*
Cu	1	33	3	*	*	*
Ni	1	29	2	*	*	*
Zn	1	1.2	*	*	*	*
Pb	1	*	7	*	*	*

\* = Value is less than " 1 "  
 Indices (Conc./LE): calculated from mean concentrations

TPO = Tailings Pond Outlet



Table 15.

CONCENTRATIONS OF MAJOR IONS AND TRACE ELEMENTS IN SEDIMENT PORE WATER  
LARDER LAKE, RAVEN LAKE, AND BARBER LAKE\*

Major Ions and Trace Elements (ug/L)										
Elements	Zn	Cd	Pb	Cr	V	Co	Cu	Li	Sr	Ni
Detec. limit	1	1	5	1	1	1	1	1	1	2
Lake/Station										
L37	27	1	DL	1	1	1	31	1	64.7	50
L16	84	1	DL	7	7	8	58	2	69.4	54
L4	81	1	7	2	4	4	19	1	57	40
L27	73	1	DL	10	8	3	17	6	131	8
L30	131	1	13	4	3	13	135	1	93	155
L20	149	1	DL	6	3	5	64	2	80.1	90
L7	81	1	5	2	3	15	49	1	59.8	91
L34	80	1	DL	4	4	7	110	1	59.7	84
L19	73	1	DL	8	3	8	38	1	85.1	149
L20	57	1	DL	2	2	7	26	2	109	72
L17	85	1	DL	6	4	11	21	1	68.6	98
L27	99	1	DL	15	5	4	66	2	104	52
R1	22	DL	DL	1	1	1	52	DL	69.2	2
B1	27	DL	5	3	DL	4	78	1	69.4	39

Major Ions and Trace Elements (mg/L)									
Elements	Al	Ba	Fe	Mn	Ca	Mg	Na	K	As
Detec. limit	0.01	0.001	0.001	0.001	0.1	0.1	0.2	0.2	0.001
Lake/Station									
L37	0.49	0.0181	0.404	0.0794	19.7	5.6	5	1.3	0.126
L16	1.61	0.0309	3.45	1.49	19.4	5.4	5.4	1.5	0.681
L4	0.29	0.0272	1	0.414	17.2	4.2	4.3	1.4	0.349
L27	4.7	0.0787	3.73	8290	40.3	17	6.5	2.6	0.156
L30	0.7	0.0868	2.51	0.753	24.5	6.5	5	1.4	0.363
L20	0.83	0.0163	2.27	0.553	24.8	8.1	5.3	1.2	0.49
L7	0.28	0.0184	1.93	1.29	17.6	4.6	5.2	1.2	1.351
L34	0.84	0.0249	1.25	0.147	18.3	5.4	4.7	1.2	0.151
L19	0.82	0.0257	2.41	1.19	31.6	10.6	5	1.1	0.442
L20	0.23	0.0305	1.47	0.555	34.1	10.5	5.9	1.4	0.49
L17	0.55	0.0273	2.68	1.21	20.4	5.7	5.1	1.7	0.749
L27	1.06	0.0247	3.55	0.309	36.1	18.4	5.3	1.5	0.156
R1	0.393	0.0397	1.67	0.884	16.8	3.2	8.3	0.6	0.01
B1	0.746	0.0485	2.03	14.9	16.7	4.2	3.2	0.9	0.02

\* SEDIMENT PORE WATER, collected by squeezing the top most 5cm of bottom sediment  
DL = less than or detection limit

Table 16.

CONCENTRATIONS OF Pb, As, Zn, Cu, Ni, Co, Cr AND V IN LARDER LAKE SURFICIAL SEDIMENTS (0 to 5 cm) IN ug/g								
STATION	Pb	As	Zn	Cu	Ni	Co	Cr	V
L1	18	90	122	106	151	13	119	59
L2	61	1607	370	847	878	67	560	145
L3	53	924	299	626	718	53	310	105
L4	54	576	280	570	642	45	283	94
L5	58	707	287	622	628	48	216	87
L6	16	103	120	72	118	39	155	101
L7	41	1107	425	713	615	45	469	137
L8	37	681	363	577	650	49	953	191
L10	28	457	224	166	406	35	694	136
L11	25	640	199	287	439	36	517	129
L12	28	331	182	160	325	38	376	130
L13	38	1511	405	875	900	62	1419	273
L14	47	655	330	526	531	43	444	118
L15	30	334	218	253	388	31	331	96
L16	42	661	279	591	628	44	353	114
L17	29	546	332	358	551	44	1023	186
L18	21	942	350	491	750	52	1778	290
L19	15	341	151	147	271	37	430	127
L20	22	558	384	484	704	55	1509	254
L21	16	685	354	381	306	63	493	272
L22	15	563	277	282	277	59	672	312
L23	13	407	275	177	234	58	544	308
L24	15	812	300	283	326	64	720	314
L25	19	890	299	515	735	61	1445	294
L26	23	1062	325	483	821	58	1633	255
L27	16	680	201	227	530	38	629	144
L28	16	715	254	329	540	50	475	181
L29	36	1019	325	531	650	49	729	157
L30	31	656	250	378	474	41	543	125
L31	36	781	271	426	527	42	643	143
L32	55	940	438	818	791	55	835	182
L33	26	585	194	304	500	39	445	114
L34	32	509	207	399	432	36	290	91
L35	23	340	176	269	461	24	215	74
L36	18	151	113	116	228	24	153	74
L37	22	209	226	338	530	23	215	70

**Table 17.**

PARTICLE SIZE ANALYSIS AND LOI IN SURFICIAL SEDIMENTS (0-5cm) IN %				
STATION	GRAVEL	SAND	SILT	CLAY
L1	0	1.51	74.43	24.05
L2	0	0.33	41.74	57.93
L3	0	0.73	49.79	49.48
L4	0	2	30.48	67.52
L5	0	2.08	44.92	53
L6	1.34	24.68	21.78	52.2
L7	0	0.44	36.69	62.86
L8	0	0.75	31.79	67.46
L10	0	2.11	40.31	57.58
L11	0	3.47	44.01	52.52
L12	0	7.12	36.14	56.73
L13	0	0.74	36.27	62.99
L14	0	0.9	29.08	70.02
L15	0	0.66	31.91	67.43
L16	0	0.55	37.82	61.62
L17	0	0.63	35.15	64.21
L18	0	0.37	41.22	58.41
L19	0.5	22.06	17.69	59.76
L20	0	0.33	46.17	53.5
L21	0	0.34	67.52	32.14
L21/20cm	0	0.16	68.88	30.95
L22	0	0.32	0	0
L23	0	0.03	70.97	29
L23/5cm	0	0.17	82.71	17.12
L24	0	1.16	61.69	37.16
L25	0	0.16	51.87	47.98
L26	0	0.34	37.09	62.57
L27	0.82	47.69	26.19	25.31
L28	0.62	13.26	72	14.12
L29	0	2.3	42.13	55.57
L30	0	0.39	34.28	65.33
L31	0	0.52	36.23	63.25
L32	0	0.46	0	0
L33		11.7	27.54	60.76
L34	0	0.71	30.93	68.36
L35	0	3.99	34.86	61.15
L36	8.2	9.28	38.72	43.8
L37	0	2.99	60.08	36.93
<b>MEDIAN, MEAN, STANDARD DEVIATION AND            RANGE FOR SURFICIAL SEDIMENTS (0-5cm)            (n=37)</b>				
FRACTION	GRAVEL	SAND	SILT	CLAY
MEDIAN	0	0.74	37.82	56.73
MEAN	0.34	4.63	43.64	51.41
SD	1.42	9.41	15.20	14.97
RANGE				
MIN	0	0.03	17.69	14.12
MAX	1.34	24.68	74.43	70.02

Table 18.

MEDIAN, MEAN, STANDARD DEVIATION AND RANGE OF MAJOR ELEMENTS IN LARDER LAKE SURFICIAL SEDIMENTS												
ELEMENT	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	MgO	CaO	Na <sub>2</sub> O	K <sub>2</sub> O	TiO <sub>2</sub>	MnO	P <sub>2</sub> O <sub>5</sub>	S	
MEDIAN	58.12	13.03	9.96	3.52	2.26	2.10	2.07	0.65	0.23	0.16	2000	
MEAN	56.82	12.49	10.10	3.99	2.97	2.20	1.93	0.68	0.23	0.16	3119.7	
S.D.	5.22	1.27	2.81	1.39	1.66	0.27	0.48	0.12	0.13	0.04	3428.6	
RANGE												
MIN	45.77	9.44	4.80	2.44	1.70	1.88	0.87	0.52	0.08	0.11	400	
MAX	64.68	14.01	15.25	7.66	7.88	2.86	2.81	0.97	0.70	0.30	13000	

MEDIAN, MEAN, STANDARD DEVIATION AND RANGE OF TRACE ELEMENTS IN LARDER LAKE SURFICIAL SEDIMENTS										
ELEMENT	Pb	As	Zn	Cu	Ni	Co	Cr	V		
MEDIAN	25.50	655.50	278.00	379.50	530.00	44.50	529.00	136.50		
MEAN	29.85	660.38	272.29	409.07	518.15	44.98	628.22	163.36		
S.D.	13.61	338.54	84.69	210.24	200.64	12.64	431.95	77.97		
RANGE										
MIN	13.00	90.30	113.40	71.70	118.20	13.10	118.80	58.50		
MAX	61.00	1607.00	438.00	87.00	900.00	67.00	1778.00	314.00		

**Table 19.**

Mean concentrations of trace elements in four groups of sediments in Larder Lake in  $\mu\text{g/g}$

	As	Cu	Co	Cr	Pb	Zn	Ni
Group 1	608	277	63	586	14	289	289
Group 2	764	487	47	858	32	312	621
Group 3	655	411	40	391	34	237	530
Group 4	114	98	25	142	17	118	165

OMEE sediment guidelines<sup>1</sup>

Lowest effect level	6	16	—	26	31	120	16
Sever effect level	33	110	—	110	250	820	75

<sup>1</sup> Persaud et al., 1992

Table 20.

CONCENTRATION PROFILES OF MAJOR ELEMENTS IN LARDER LAKE SEDIMENT CORES IN %										
STATION/ DEPTH (cm)	SiO2	TiO2	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	P2O5	
L7	0-1	52.4	0.5	12.7	9.7	2.6	1.7	2.0	2.0	0.6
L7	1-2	54.7	0.6	14.3	8.3	4.2	1.4	2.3	2.2	0.3
L7	2-3	55.7	0.7	15.3	7.4	4.4	1.4	2.5	2.5	0.1
L7	3-4	54.7	0.6	14.0	8.3	3.0	2.0	2.4	2.5	0.1
L7	4-5	58.2	0.5	14.0	6.3	2.7	2.0	2.3	2.5	0.2
L7	5-6	57.7	0.5	13.9	5.5	2.5	1.9	2.1	2.4	0.2
L7	6-7	58.4	0.5	13.7	5.3	2.5	2.0	2.2	2.4	0.2
L7	7-8	59.1	0.5	13.7	5.3	2.4	1.9	2.1	2.3	0.2
L7	8-9	58.3	0.5	13.6	5.2	2.4	2.0	2.1	2.4	0.3
L7	9-10	58.9	0.5	13.6	5.3	2.5	2.0	2.1	2.4	0.3
L7	10-12	59.0	0.5	13.7	5.3	2.4	1.9	2.1	2.3	0.3
L17	1-2	55.2	0.6	14.0	8.0	3.2	1.7	2.5	2.3	0.1
L17	2-3	53.7	0.7	14.0	10.1	3.5	1.4	2.7	2.2	0.1
L17	3-4	52.1	0.8	14.1	11.5	3.9	1.2	3.0	2.0	0.1
L17	4-5	49.7	0.8	13.7	10.4	5.8	2.4	2.9	1.9	0.2
L17	5-6	46.4	0.6	12.7	9.3	8.9	3.6	2.0	1.6	0.1
L17	6-7	46.0	0.6	12.8	9.2	8.9	3.5	1.8	1.7	0.1
L17	7-8	54.3	0.5	14.2	8.8	4.2	1.5	2.0	2.4	0.1
L17	8-9	55.1	0.5	14.2	7.0	3.9	1.9	2.1	2.7	0.2
L17	9-10	57.8	0.5	14.2	6.6	2.9	2.0	2.2	2.6	0.2
L17	10-12	58.8	0.5	14.0	5.9	2.6	2.0	2.2	2.6	0.2
L17	12-14	58.3	0.5	13.9	5.7	2.5	2.0	2.2	2.4	0.2
L26	1-2	53.9	0.8	14.0	10.7	4.3	1.4	3.0	1.8	0.0
L26	2-3	52.2	0.6	13.4	11.2	6.2	1.3	2.3	1.9	0.2
L26	3-4	51.8	0.5	12.8	9.2	7.5	1.8	1.9	2.0	0.2
L26	4-5	52.6	0.5	13.6	7.6	7.6	2.5	2.0	2.4	0.1
L26	5-6	55.7	0.5	13.6	7.0	3.9	2.2	2.1	2.3	0.2
L26	6-7	59.6	0.6	13.9	5.9	2.8	2.4	2.5	2.4	0.2
L26	7-8	61.6	0.6	14.1	5.4	2.5	2.4	2.4	2.4	0.2
L26	8-9	59.9	0.5	13.8	5.0	2.2	2.2	2.3	2.3	0.2
L26	9-10	60.6	0.5	13.8	5.0	2.4	2.3	2.4	2.4	0.2
L26	10-12	59.7	0.5	13.8	5.1	2.4	2.3	2.3	2.3	0.3
L26	12-14	59.4	0.5	13.9	5.1	2.4	2.2	2.3	2.4	0.3
L27	1-2	55.1	0.7	11.8	10.1	5.5	1.8	2.5	1.6	0.0
L27	2-3	51.5	0.6	11.6	10.5	6.7	2.4	2.3	1.6	0.1
L27	3-4	48.4	0.6	10.4	10.2	8.1	3.9	1.9	1.5	0.1
L27	4-5	52.2	0.5	11.1	7.7	6.7	4.3	2.2	1.7	0.1
L27	5-6	67.9	0.4	12.3	3.7	1.9	2.5	2.8	1.9	0.1
L27	6-7	70.7	0.4	12.0	2.9	1.5	2.4	3.0	1.9	0.1
L27	7-8	72.2	0.4	12.1	2.9	1.4	2.5	3.1	1.8	0.1
L27	8-9	72.1	0.4	12.3	2.8	1.4	2.4	3.1	1.9	0.1
L27	9-10	73.2	0.4	12.4	2.9	1.5	2.5	3.2	1.9	0.1
L27	10-12	72.0	0.4	12.8	3.6	1.4	2.5	3.2	1.9	0.1
L27	12-14	71.5	0.5	12.5	3.0	1.6	2.6	3.2	2.0	0.1
L34	1-2	59.3	0.6	14.3	6.9	2.7	1.9	2.6	2.3	0.1
L34	2-3	58.2	0.6	14.4	7.2	3.3	1.8	2.6	2.5	0.1
L34	3-4	60.8	0.6	14.5	6.2	2.8	2.1	2.5	2.5	0.1
L34	4-5	61.5	0.5	13.1	6.4	2.2	2.3	2.5	2.4	0.3
L34	5-6	64.4	0.5	13.7	4.5	2.2	2.4	2.6	2.4	0.2
L34	6-7	65.6	0.6	13.8	4.4	2.2	2.5	2.7	2.4	0.2
L34	7-8	64.8	0.5	13.4	4.3	2.1	2.4	2.6	2.4	0.2
L34	8-9	64.9	0.5	13.1	4.1	2.0	2.5	2.7	2.3	0.2
L34	9-10	66.1	0.5	13.6	4.2	2.1	2.6	2.8	2.3	0.2
L34	10-12	64.7	0.5	13.5	4.4	2.1	2.5	2.7	2.3	0.2
L34	12-14	64.6	0.6	14.1	4.6	2.2	2.6	2.7	2.4	0.2

Table 21.

CONCENTRATION PROFILES OF TRACE ELEMENTS IN LARDER LAKE SEDIMENT CORES IN ug/g										
STATION/ DEPTH (cm)	Sc	V	Cr	Co	Ni	Cu	Zn	As	Pb	
L7 0-1										
L7 1-2	10.0	96.0	456.0	69.0	887.0	892.0	522.0	945.0	81.0	
L7 2-3	10.0	86.0	438.0	71.0	791.0	661.0	797.0	680.0	61.0	
L7 3-4	7.0	55.0	166.0	50.0	383.0	348.0	598.0	808.0	48.0	
L7 4-5	6.0	54.0	108.0	23.0	117.0	97.0	205.0	400.0	35.0	
L7 5-6	6.0	52.0	92.0	22.0	63.0	32.0	120.0	138.0	31.0	
L7 6-7	6.0	52.0	92.0	20.0	63.0	32.0	119.0	105.0	31.0	
L7 7-8	6.0	51.0	90.0	20.0	61.0	28.0	112.0	56.0	28.0	
L7 8-9	6.0	52.0	90.0	19.0	58.0	27.0	109.0	37.0	26.0	
L7 9-10	6.0	53.0	93.0	19.0	59.0	28.0	109.0	31.0	27.0	
L7 10-12	6.0	50.0	88.0	17.0	60.0	28.0	105.0	29.0	23.0	
L17 1-2	10.0	92.0	245.0	101.0	724.0	968.0	664.0	828.0	89.0	
L17 2-3	11.0	103.0	295.0	102.0	753.0	1036.0	574.0	>2000	86.0	
L17 3-4	13.0	136.0	375.0	72.0	950.0	1251.0	494.0	>2000	76.0	
L17 4-5	13.0	137.0	534.0	58.0	950.0	1290.0	347.0	1186.0	56.0	
L17 5-6	12.0	128.0	807.0	43.0	805.0	325.0	272.0	265.0	36.0	
L17 6-7	12.0	127.0	818.0	47.0	806.0	311.0	324.0	248.0	40.0	
L17 7-8	8.0	75.0	397.0	58.0	941.0	276.0	290.0	210.0	45.0	
L17 8-9	7.0	64.0	255.0	32.0	355.0	107.0	199.0	141.0	40.0	
L17 9-10	6.0	58.0	130.0	23.0	135.0	60.0	143.0	122.0	34.0	
L17 10-12	6.0	58.0	97.0	20.0	75.0	36.0	127.0	56.0	33.0	
L17 12-14	7.0	58.0	91.0	21.0	64.0	31.0	117.0	46.0	30.0	
L26 1-2	14.0	136.0	474.0	94.0	1305.0	1062.0	462.0	1718.0	63.0	
L26 2-3	13.0	126.0	702.0	61.0	1136.0	560.0	331.0	1979.0	49.0	
L26 3-4	12.0	103.0	709.0	46.0	852.0	259.0	294.0	843.0	39.0	
L26 4-5	10.0	79.0	600.0	50.0	748.0	167.0	276.0	207.0	38.0	
L26 5-6	7.0	58.0	236.0	33.0	276.0	59.0	171.0	65.0	35.0	
L26 6-7	6.0	55.0	107.0	20.0	82.0	34.0	122.0	38.0	30.0	
L26 7-8	6.0	55.0	86.0	19.0	61.0	27.0	108.0	40.0	27.0	
L26 8-9	6.0	50.0	78.0	17.0	55.0	24.0	96.0	28.0	21.0	
L26 9-10	6.0	51.0	79.0	17.0	56.0	25.0	95.0	24.0	21.0	
L26 10-12	6.0	53.0	83.0	18.0	59.0	26.0	99.0	27.0	22.0	
L26 12-14	6.0	54.0	85.0	18.0	60.0	27.0	105.0	22.0	21.0	
L27 1-2	13.0	96.0	425.0	79.0	1095.0	543.0	337.0	1487.0	50.0	
L27 2-3	13.0	107.0	542.0	69.0	975.0	304.0	284.0	1342.0	43.0	
L27 3-4	13.0	89.0	544.0	50.0	652.0	155.0	228.0	1140.0	36.0	
L27 4-5	DL	60.0	362.0	36.0	407.0	95.0	171.0	334.0	31.0	
L27 5-6	DL	29.0	75.0	11.0	66.0	18.0	60.0	27.0	19.0	
L27 6-7	DL	25.0	43.0	8.0	32.0	11.0	42.0	23.0	15.0	
L27 7-8	DL	24.0	39.0	7.0	28.0	9.0	37.0	14.0	12.0	
L27 8-9	DL	25.0	38.0	7.0	28.0	9.0	38.0	24.0	12.0	
L27 9-10	DL	25.0	37.0	7.0	26.0	8.0	37.0	11.0	11.0	
L27 10-12	DL	25.0	36.0	7.0	26.0	8.0	36.0	10.0	11.0	
L27 12-14	DL	26.0	39.0	8.0	25.0	10.0	39.0	5.0	12.0	
L34 1-2	9.0	77.0	189.0	94.0	862.0	976.0	356.0	897.0	65.0	
L34 2-3	6.0	87.0	359.0	70.0	1067.0	712.0	263.0	1079.0	53.0	
L34 3-4	DL	58.0	204.0	35.0	689.0	212.0	191.0	474.0	35.0	
L34 4-5	DL	45.0	76.0	23.0	268.0	47.0	115.0	276.0	27.0	
L34 5-6	DL	45.0	70.0	16.0	88.0	34.0	106.0	16.0	27.0	
L34 6-7	DL	43.0	66.0	16.0	67.0	24.0	86.0	8.0	25.0	
L34 7-8	DL	41.0	63.0	15.0	55.0	20.0	81.0	DL	25.0	
L34 8-9	DL	41.0	64.0	15.0	50.0	19.0	78.0	11.0	24.0	
L34 9-10	DL	39.0	60.0	13.0	44.0	18.0	72.0	7.0	21.0	
L34 10-12	DL	40.0	62.0	13.0	45.0	19.0	74.0	13.0	17.0	
L34 12-14	5.0	43.0	67.0	14.0	48.0	20.0	78.0	7.0	19.0	

DL = less than or detection limit

Table 22.

ENRICHMENT FACTOR FOR TRACE ELEMENTS IN LARDER LAKE										
STATION/ DEPTH (cm)	Sc	V	Cr	Co	Ni	Cu	Zn	As	Pb	
L7 1-2	1.7	1.9	5.2	4.1	14.8	31.9	5.0	32.6	3.5	
L7 2-3	1.7	1.7	5.0	4.2	13.2	23.6	7.6	23.4	2.7	
L7 3-4	1.2	1.1	1.9	2.9	6.4	12.4	5.7	27.9	2.1	
L7 4-5	1.0	1.1	1.2	1.4	2.0	3.5	2.0	13.8	1.5	
L7 5-6	1.0	1.0	1.0	1.3	1.1	1.1	1.1	4.8	1.3	
L7 6-7	1.0	1.0	1.0	1.2	1.1	1.1	1.1	3.6	1.3	
L7 7-8	1.0	1.0	1.0	1.2	1.0	1.0	1.1	1.9	1.2	
L7 8-9	1.0	1.0	1.0	1.1	1.0	1.0	1.0	1.3	1.1	
L7 9-10	1.0	1.1	1.1	1.1	1.0	1.0	1.0	1.1	1.2	
L7 10-12	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	
L17 1-2	1.4	1.6	2.7	4.8	11.3	31.2	5.7	18.0	3.0	
L17 2-3	1.6	1.8	3.2	4.9	11.8	33.4	4.9	43.5	2.9	
L17 3-4	1.9	2.3	4.1	3.4	14.8	40.4	4.2	43.5	2.5	
L17 4-5	1.9	2.4	5.9	2.8	14.8	41.6	3.0	25.8	1.9	
L17 5-6	1.7	2.2	8.9	2.0	12.6	10.5	2.3	5.8	1.2	
L17 6-7	1.7	2.2	9.0	2.2	12.6	10.0	2.8	5.4	1.3	
L17 7-8	1.1	1.3	4.4	2.8	14.7	8.9	2.5	4.6	1.5	
L17 8-9	1.0	1.1	2.8	1.5	5.5	3.5	1.7	3.1	1.3	
L17 9-10	0.9	1.0	1.4	1.1	2.1	1.9	1.2	2.7	1.1	
L17 10-12	0.9	1.0	1.1	1.0	1.2	1.2	1.1	1.2	1.1	
L17 12-14	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	
L26 1-2	2.3	2.5	5.6	5.2	21.8	39.3	4.4	78.1	3.0	
L26 2-3	2.2	2.3	8.3	3.4	18.9	20.7	3.2	90.0	2.3	
L26 3-4	2.0	1.9	8.3	2.6	14.2	9.6	2.8	38.3	1.9	
L26 4-5	1.7	1.5	7.1	2.8	12.5	6.2	2.6	9.4	1.8	
L26 5-6	1.2	1.1	2.8	1.8	4.6	2.2	1.6	3.0	1.7	
L26 6-7	1.0	1.0	1.3	1.1	1.4	1.3	1.2	1.7	1.4	
L26 7-8	1.0	1.0	1.0	1.1	1.0	1.0	1.0	1.8	1.3	
L26 8-9	1.0	0.9	0.9	0.9	0.9	0.9	0.9	1.3	1.0	
L26 9-10	1.0	0.9	0.9	0.9	0.9	0.9	0.9	1.1	1.0	
L26 10-12	1.0	1.0	1.0	1.0	1.0	1.0	0.9	1.2	1.0	
L26 12-14	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	
L27 1-2	4.3	3.7	10.9	9.9	43.8	54.3	8.6	297.4	4.2	
L27 2-3	4.3	4.1	13.9	8.6	39.0	30.4	7.3	268.4	3.6	
L27 3-4	4.3	3.4	13.9	6.3	26.1	15.5	5.8	228.0	3.0	
L27 4-5	1.0	2.3	9.3	4.5	16.3	9.5	4.4	66.8	2.6	
L27 5-6	1.0	1.1	1.9	1.4	2.6	1.8	1.5	5.4	1.6	
L27 6-7	1.0	1.0	1.1	1.0	1.3	1.1	1.1	4.6	1.3	
L27 7-8	1.0	0.9	1.0	0.9	1.1	0.9	0.9	2.8	1.0	
L27 8-9	1.0	1.0	1.0	0.9	1.1	0.9	1.0	4.8	1.0	
L27 9-10	1.0	1.0	0.9	0.9	1.0	0.8	0.9	2.2	0.9	
L27 10-12	1.0	1.0	0.9	0.9	1.0	0.8	0.9	2.0	0.9	
L27 12-14	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	
L34 1-2	1.8	1.8	2.8	6.7	18.0	48.8	4.6	128.1	3.4	
L34 2-3	1.2	2.0	5.4	5.0	22.2	35.6	3.4	154.1	2.8	
L34 3-4	0.6	1.3	3.0	2.5	14.4	10.6	2.4	67.7	1.8	
L34 4-5	0.6	1.0	1.1	1.6	5.6	2.4	1.5	39.4	1.4	
L34 5-6	0.6	1.0	1.0	1.1	1.8	1.7	1.4	2.3	1.4	
L34 6-7	0.6	1.0	1.0	1.1	1.4	1.2	1.1	1.1	1.3	
L34 7-8	0.6	1.0	0.9	1.1	1.1	1.0	1.0	0.7	1.3	
L34 8-9	0.6	1.0	1.0	1.1	1.0	1.0	1.0	1.6	1.3	
L34 9-10	0.6	0.9	0.9	0.9	0.9	0.9	0.9	1.0	1.1	
L34 10-12	0.6	0.9	0.9	0.9	0.9	1.0	0.9	1.9	0.9	
L34 12-14	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	



**Table 23.**

GROUPING VARIABLE STATISTICS (MEAN AND S.D.) FOR FOUR CLUSTER SOLUTION OF SEDIMENT TOXICITY IN LARDER LAKE

Variable	Gp. 1 (n=2)	Gp. 2 (n=17)	Gp. 3 (n=15)	Gp.4(n=1)	Reference Sediment
Adults	1.9 (0.7)	4.0 (0.2)	4.0 (0.2)	4.0	4.0 (0.0)
Empty Cocoons	3.6 (1.4)	6.6 (3.0)	14.8 (3.1)	16.0	23.2 (2.0)
Full Cocoons	9.8 (12.7)	2.4 (3.8)	10.3 (3.3)	15.6	18.2 (1.3)
Small Young	1.0 (0.8)	13.6 (7.5)	34.6 (9.2)	31.4	60.8 (11.5)
Large Young	0.0 (0.0)	0.3 (0.5)	1.5 (1.1)	15.2	44.8 (5.3)
Total Cocoons	13.4 (11.3)	9.1 (4.2)	25.1 (4.9)	31.6	41.4 (0.9)
Total Young	1.0 (0.8)	13.8 (7.6)	36.1 (9.5)	41.6	105.6 (12.2)

**Table 24.**

MEAN VALUES OF BIOASSAY END-POINTS AND IMPORTANT SEDIMENT VARIABLE FROM (MDA) IN FOUR TOXICITY GROUPS AND A REFERENCE SEDIMENT

Variable	Ref	Gp 1	Gp 2	Gp 3	Gp 4
T. cocoon	43.4	13.4	9.1	25.1	31.6
T. young	96.6	1.0	13.9	36.1	46.6
Clay	19.5	66.4	55.0	43.9	14.1
Silt	74.8	32.9	39.4	38.5	72
Al <sub>2</sub> O <sub>3</sub>	7.0	13.4	12.5	12.5	9.4
MnO	0.1	0.1	0.3	0.2	0.2
K <sub>2</sub> O	1.8	2.2	1.9	1.9	1.1
Pb	25.8	43.7	26.7	32.9	16.0
Zn	96.6	377.4	261.8	277.8	254.4



Figure 1. Location of the study area

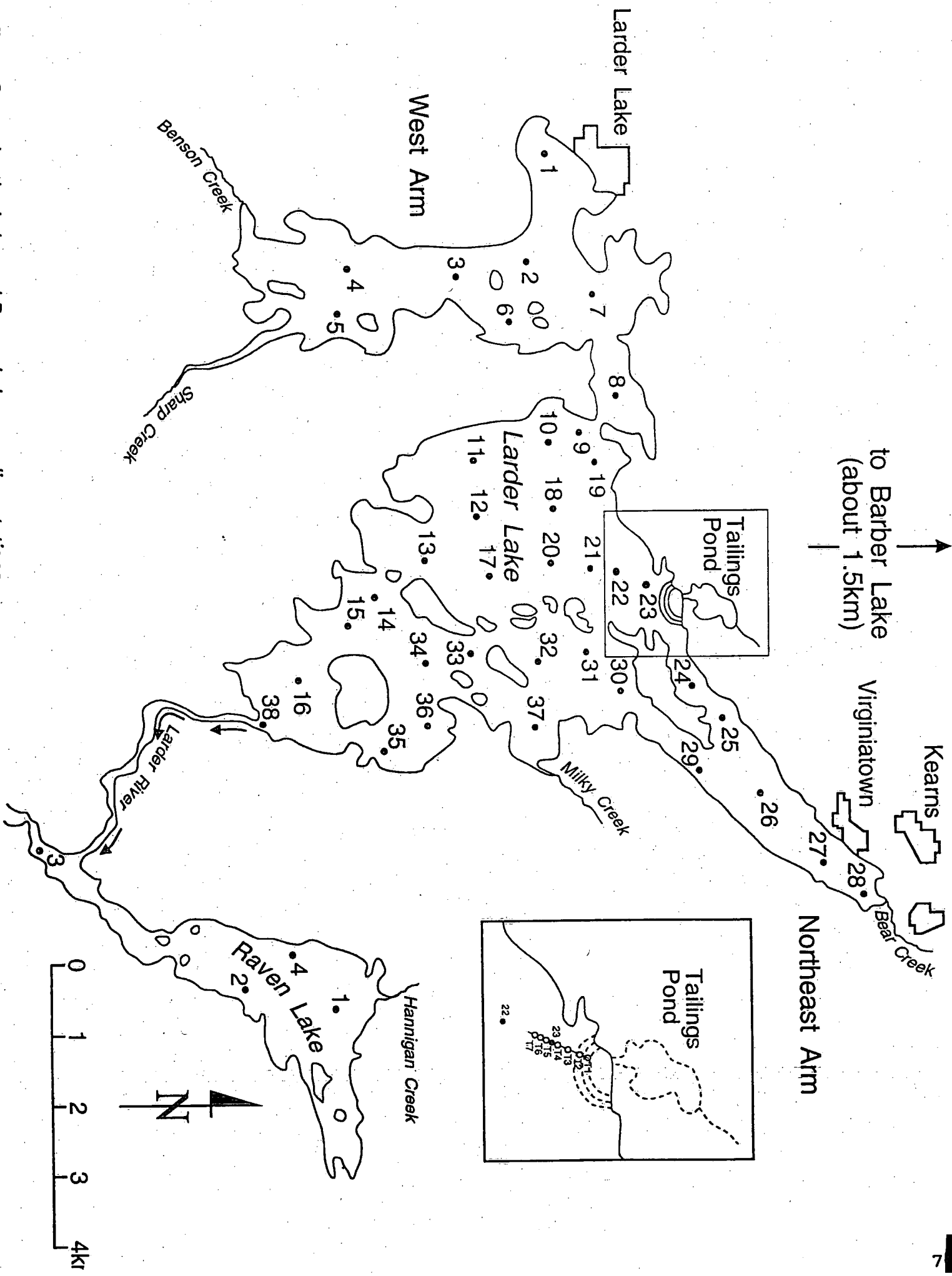
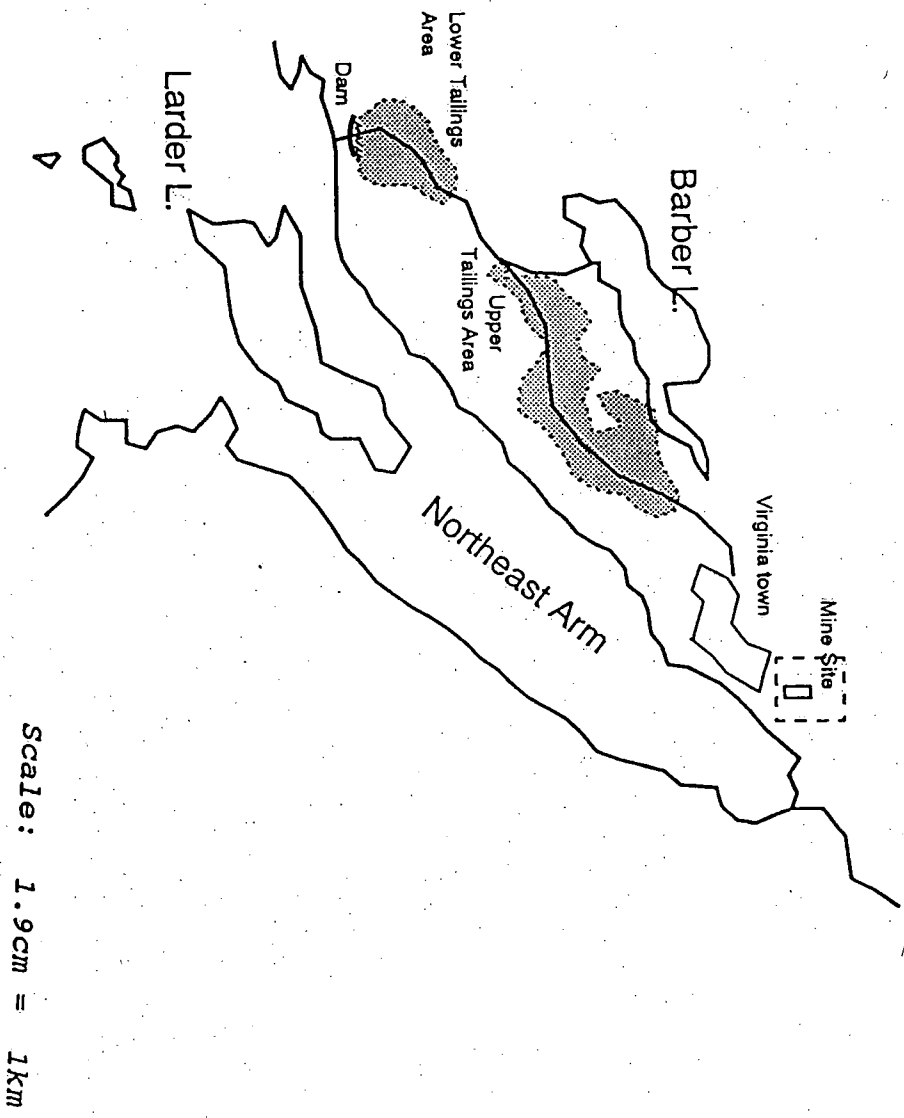


Figure 2. Larder Lake and Raven Lake samolimo stations

Figure 3.

Lower and Upper Tailings Ponds relative to Larder Lake and Barber Lake



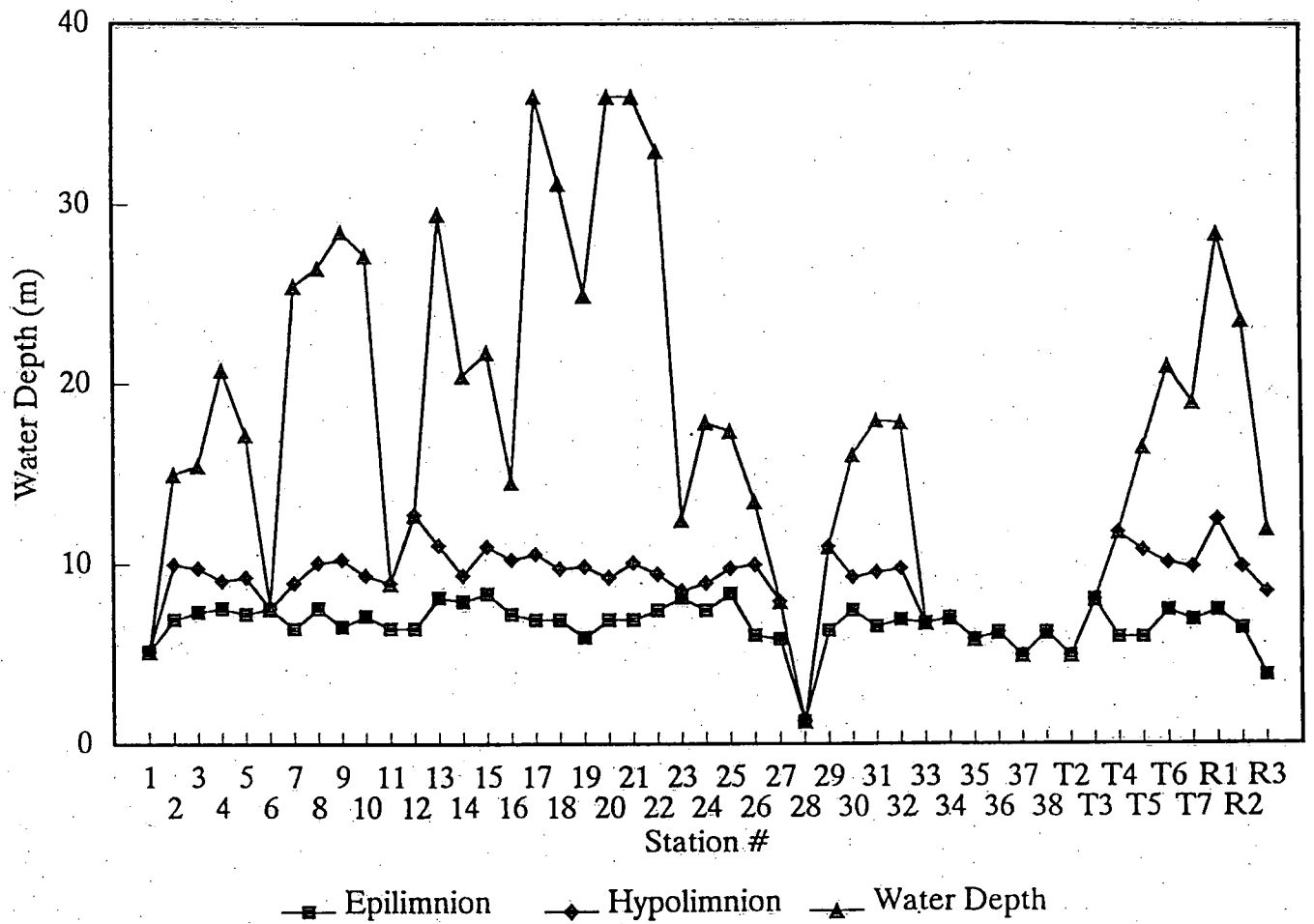
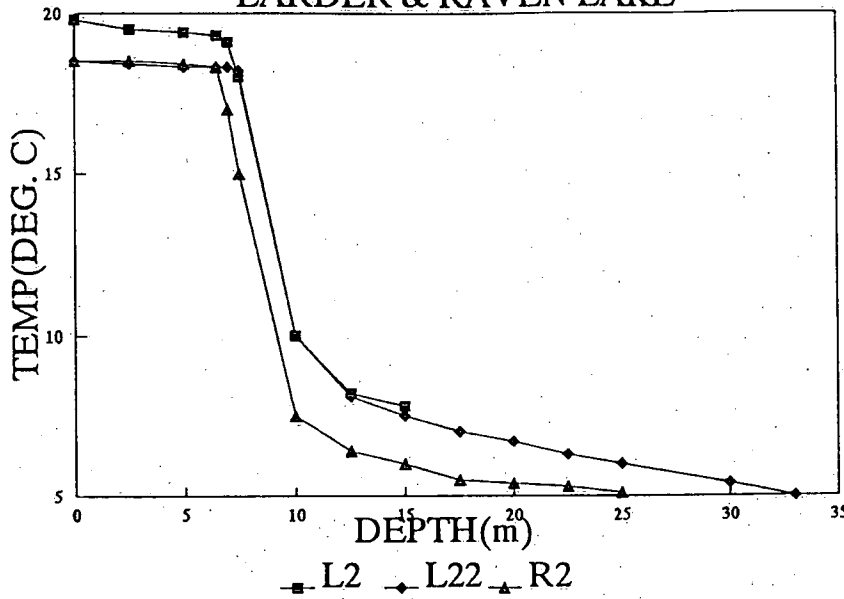


Figure 4. Thermal structure in Larder Lake and Raven Lake

# TEMPERATURE PROFILE

## LARDER & RAVEN LAKE



### STATION L2

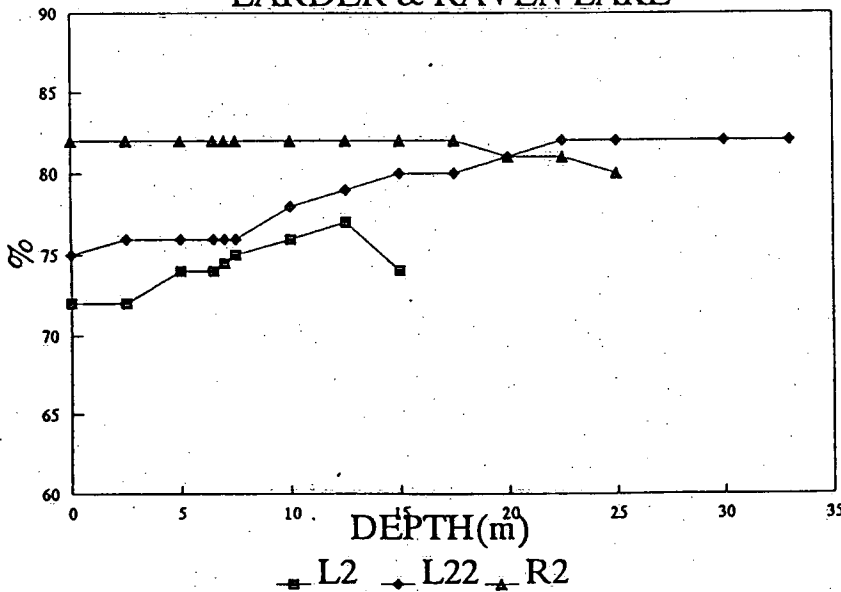
DEPTH	TEMP	LIGHT TRANS
0	19.8	72
2.5	19.5	72
5	19.4	74
6.5	19.3	74
7	19.1	74.5
7.5	18	75
10	10	76
12.5	8.2	77
15	7.8	74

### STATION L22

DEPTH	TEMP	LIGHT TRANS
0	18.5	75
2.5	18.4	76
5	18.3	76
6.5	18.3	76
7	18.3	76
7.5	18.2	76
10	10	78
12.5	8.1	79
15	7.5	80
17.5	7	80
20	6.7	81
22.5	6.3	82
25	6	82
30	5.4	82
33	5	82

# LIGHT TRANSMISSION

## LARDER & RAVEN LAKE

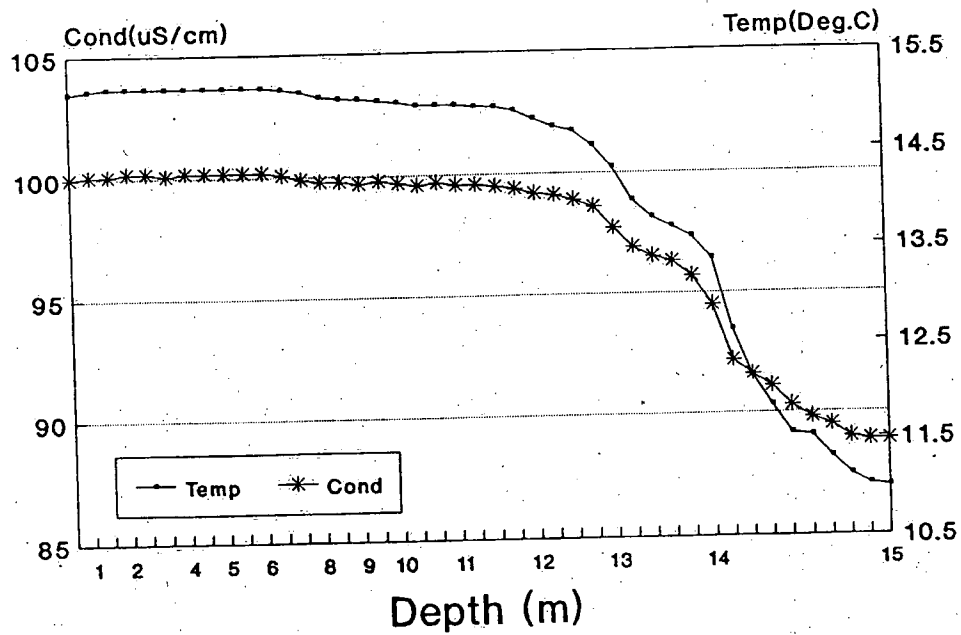


### STATION R2

DEPTH	TEMP	LIGHT TRANS
0	18.5	82
2.5	18.5	82
5	18.4	82
6.5	18.3	82
7	17	82
7.5	15	82
10	7.5	82
12.5	6.4	82
15	6	82
17.5	5.5	82
20	5.4	81
22.5	5.3	81
25	5.1	80

Figure 5. Temperature and light transmission in Larder Lake and Raven Lake

## LARDER LAKE (Stn #03)



## LARDER LAKE (Stn #03)

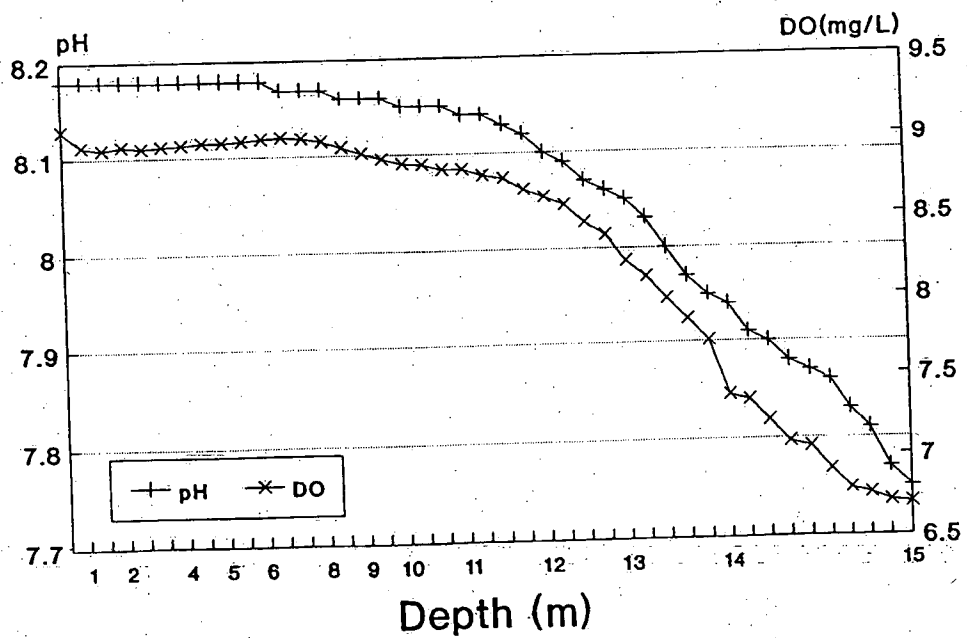
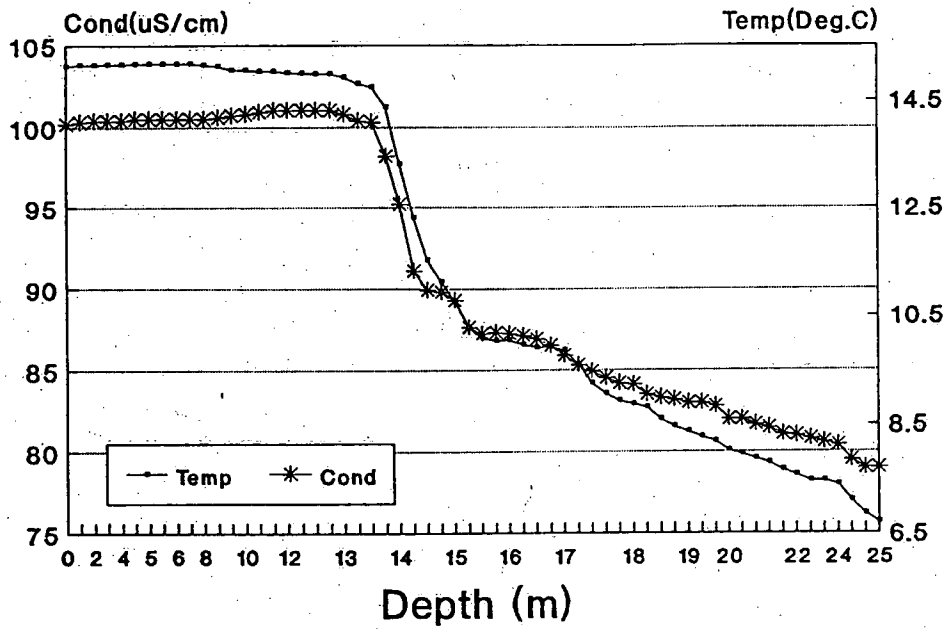


Figure 6. Hydrolab profile of conductivity, temperature, pH and dissolved oxygen in Larder Lake station 3

## LARDER LAKE (Stn #08)



## LARDER LAKE (Stn #08)

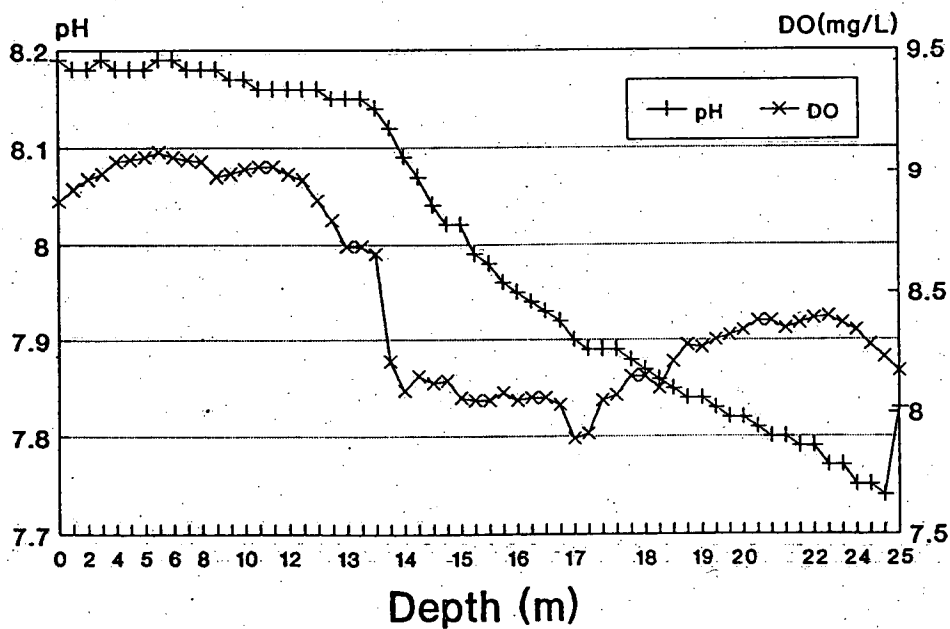
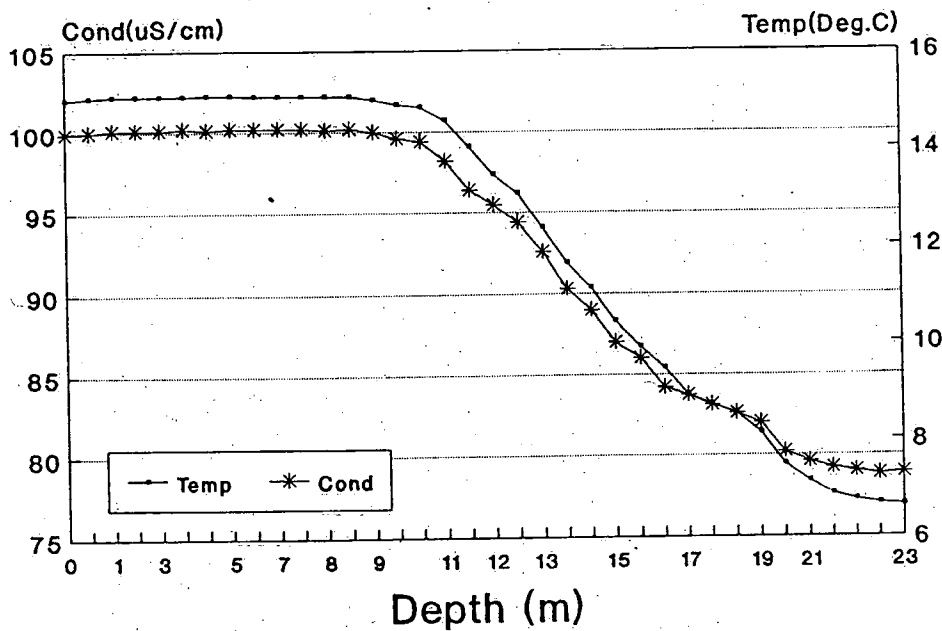


Figure 7. Hydrograph profile of conductivity, temperature, pH and dissolved oxygen in Larder Lake station 8



## LARDER LAKE (Stn #13)



## LARDER LAKE (Stn #13)

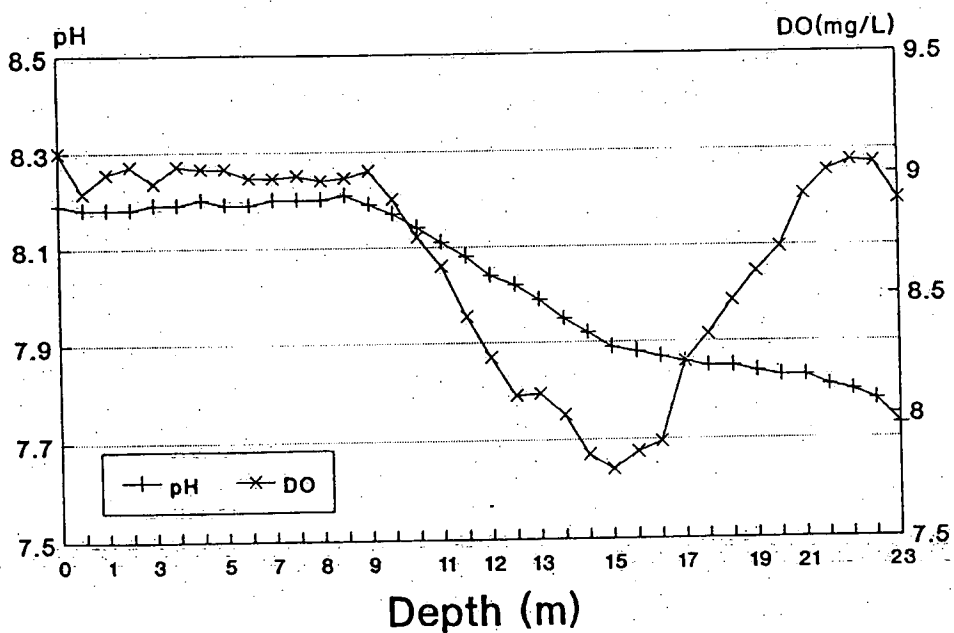
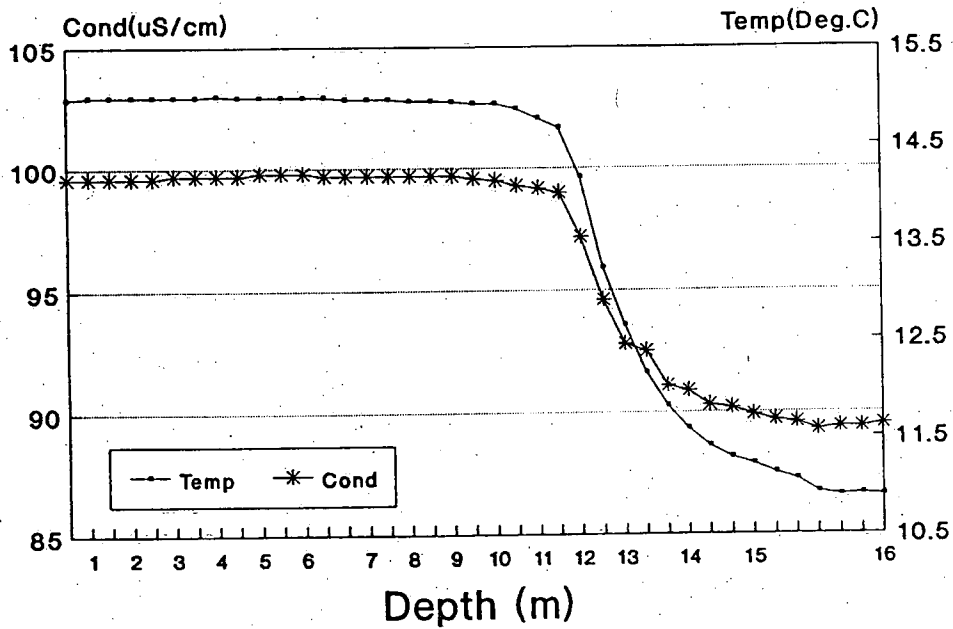


Figure 8. Hydrolab profile of conductivity, temperature, pH and dissolved oxygen in Larder Lake station 13

## LARDER LAKE (Stn #16)



## LARDER LAKE (Stn #16)

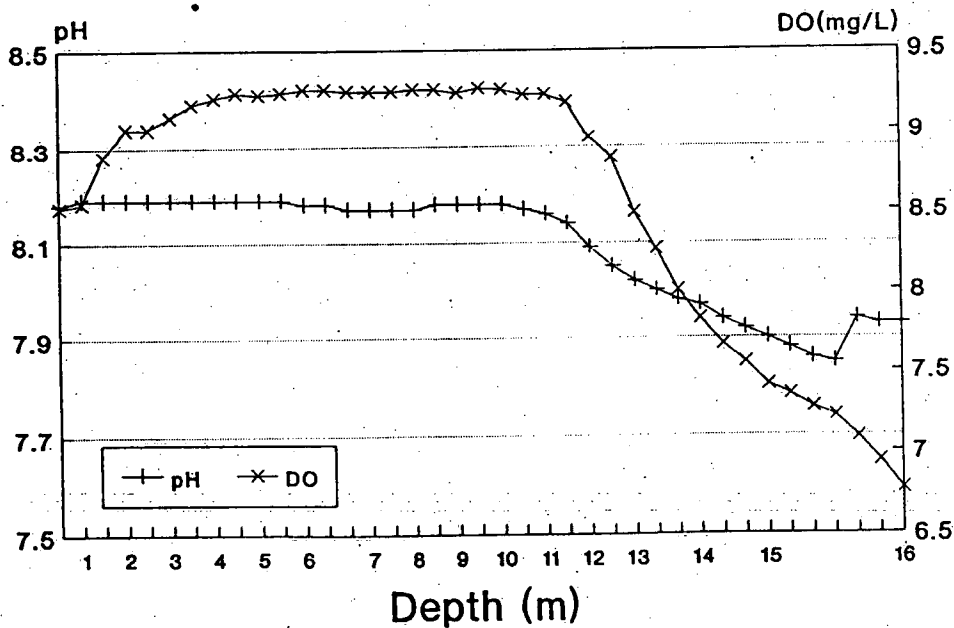
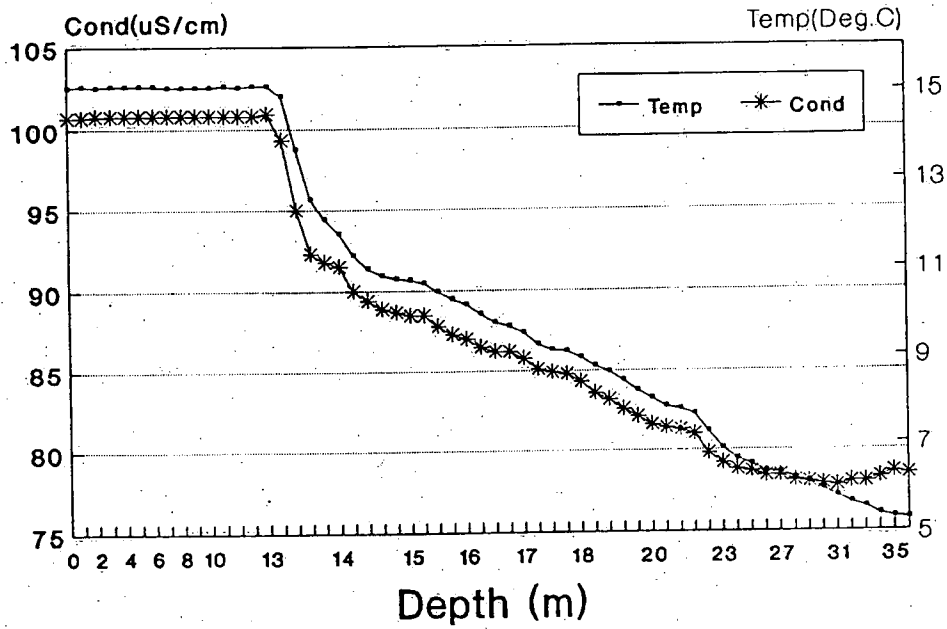


Figure 9. Hydrolab profile of conductivity, temperature, pH and dissolved oxygen

## LARDER LAKE (Stn #21)



## LARDER LAKE (Stn #21)

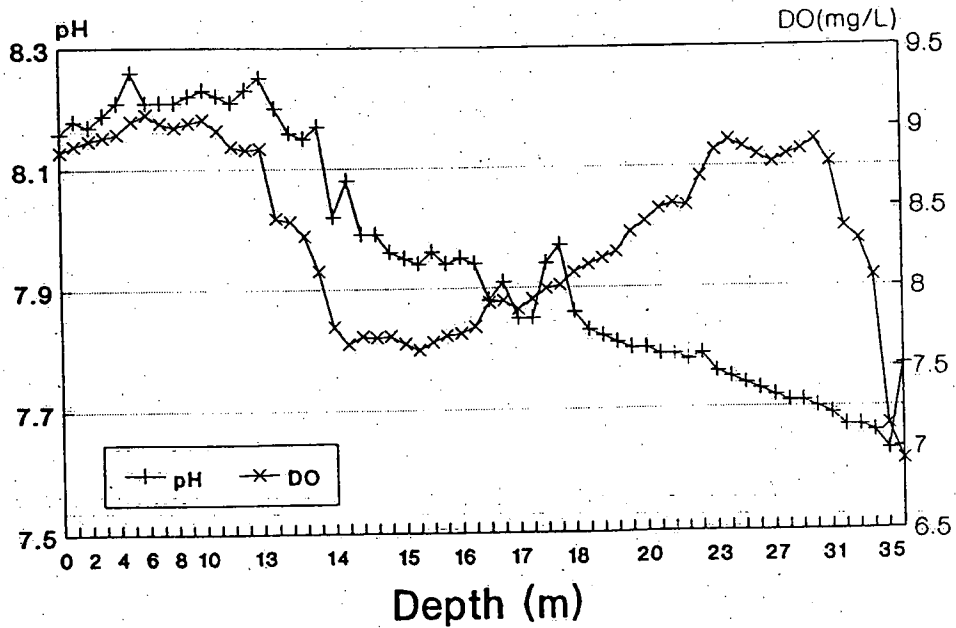
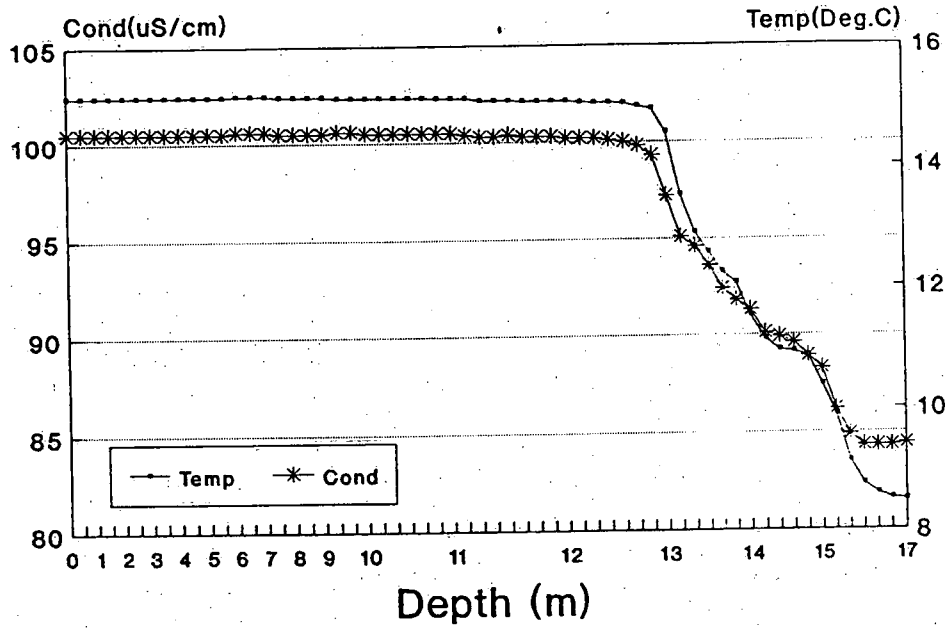


Figure 10. Hydrolab profile of conductivity, temperature, pH and dissolved oxygen

## LARDER LAKE (Stn #30)



## LARDER LAKE (Stn #30)

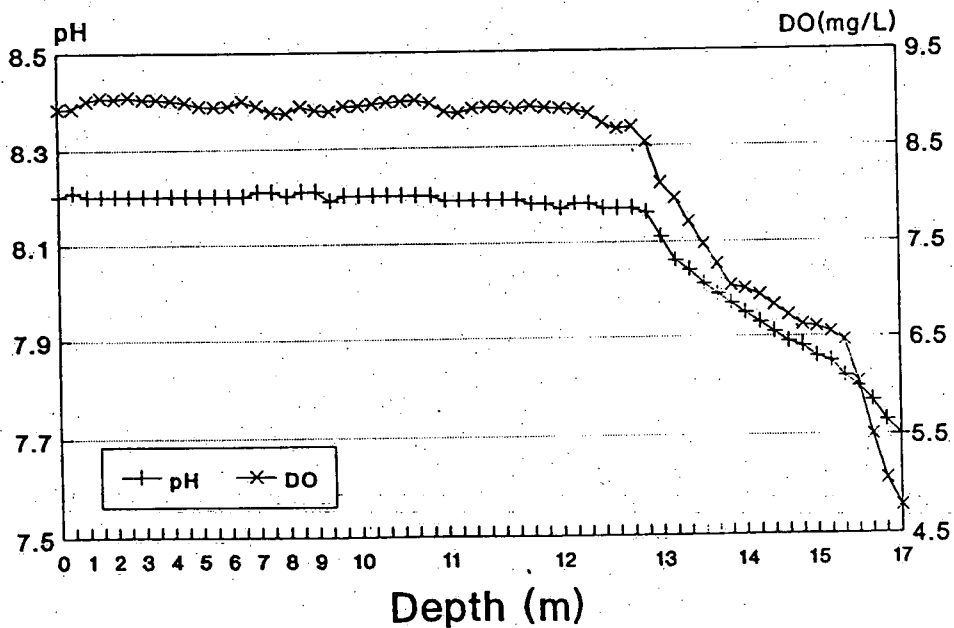
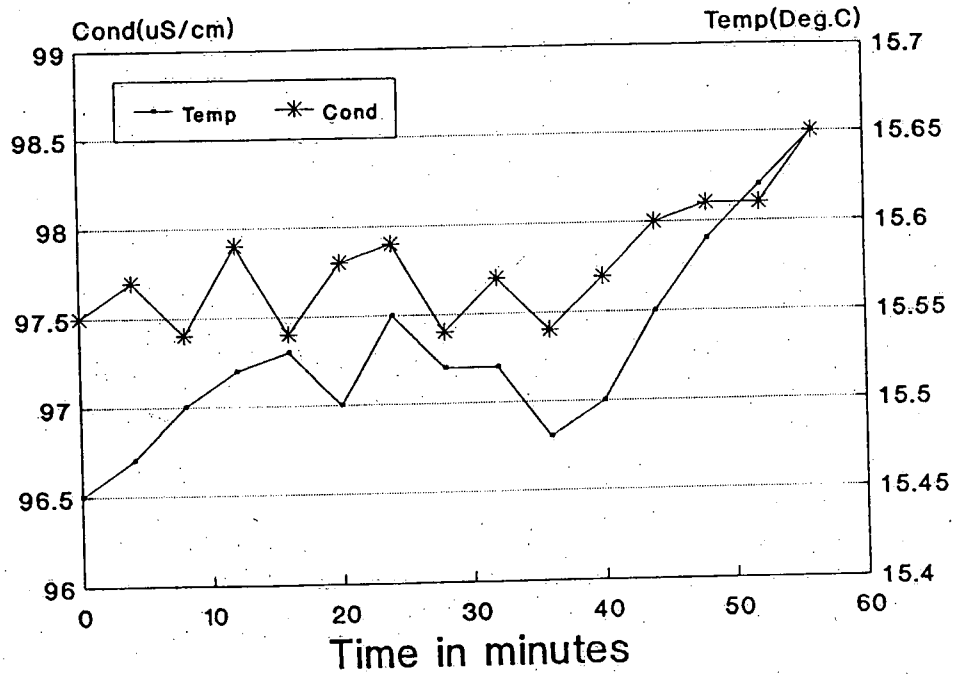
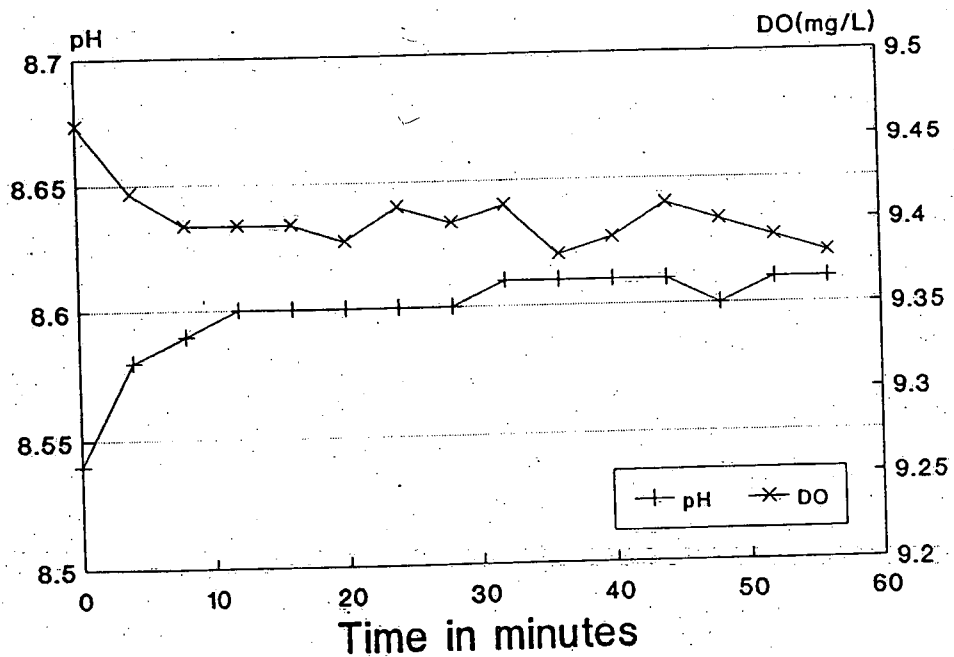


Figure 11. Hydrolab profile of conductivity, temperature, pH and dissolved oxygen

# LARDER RIVER



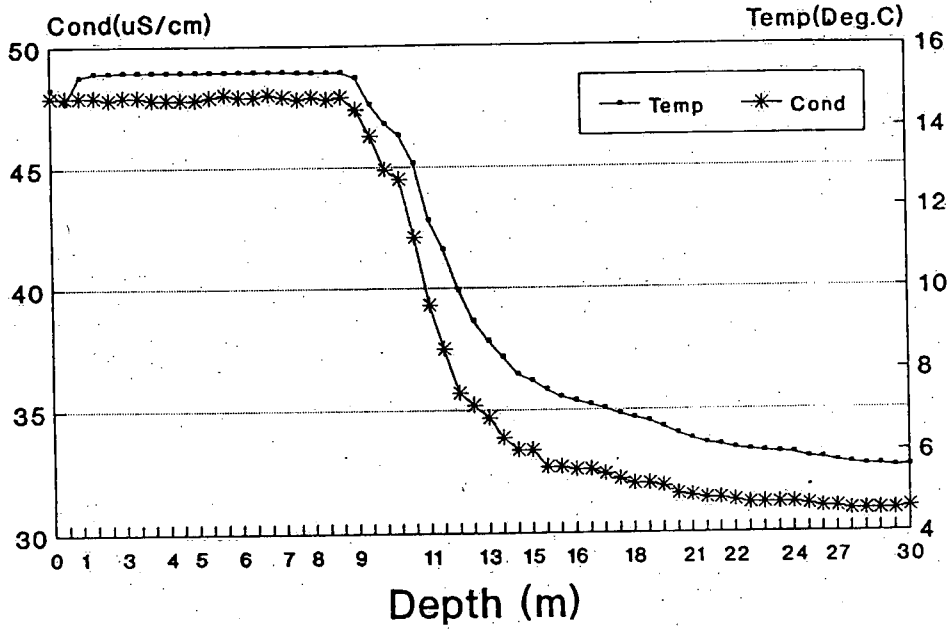
# LARDER RIVER



Larder River monitored at entrance to Raven Lake, over an one hour period

Figure 12. Hydrolab profile of conductivity, temperature, pH and dissolved oxygen

## RAVEN LAKE (Stn #01)



## RAVEN LAKE (Stn #01)

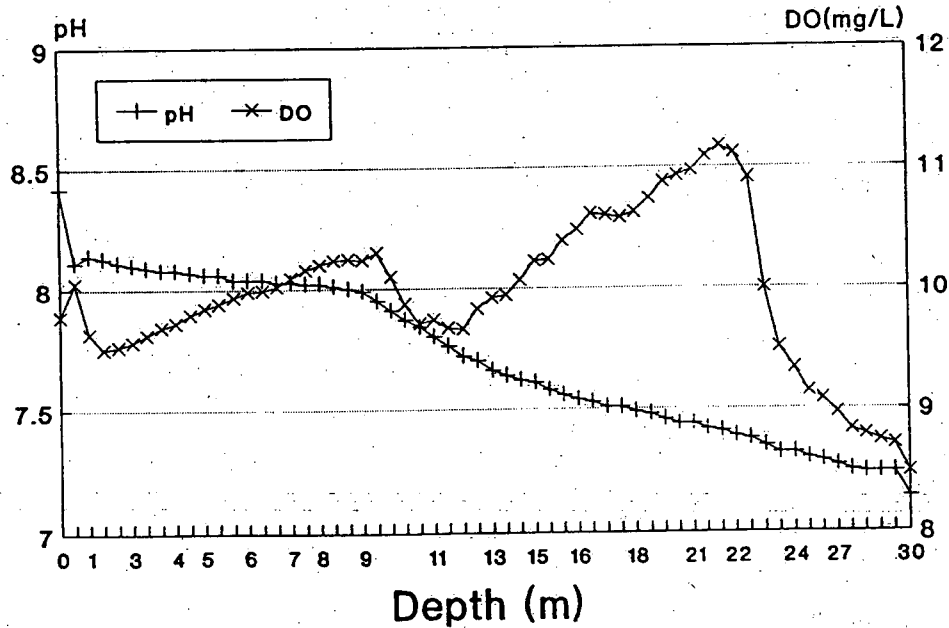
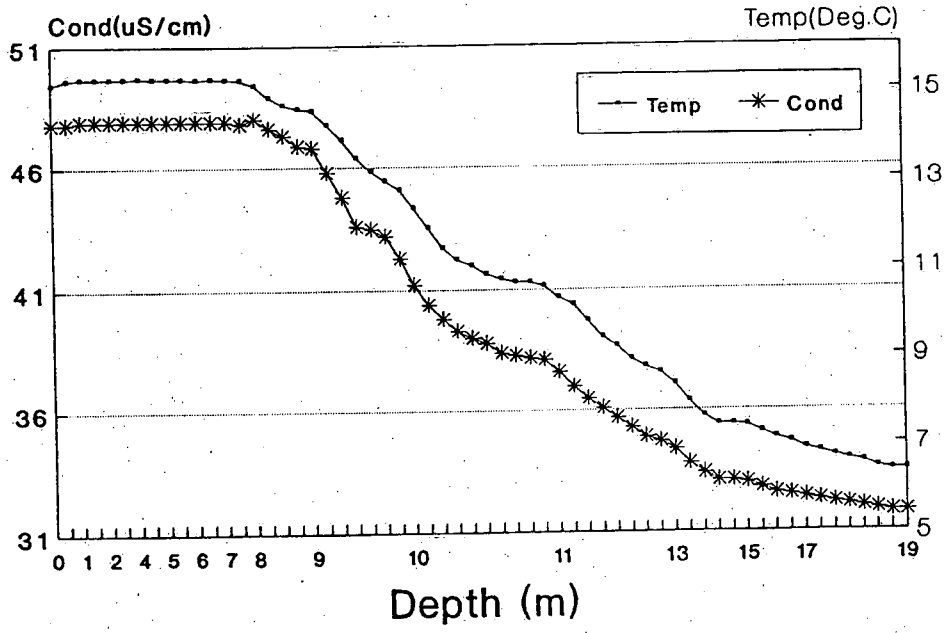


Figure 13. Hydrolab profile of conductivity, temperature, pH and dissolved oxygen

## RAVEN LAKE (Stn #02)



## RAVEN LAKE (Stn #02)

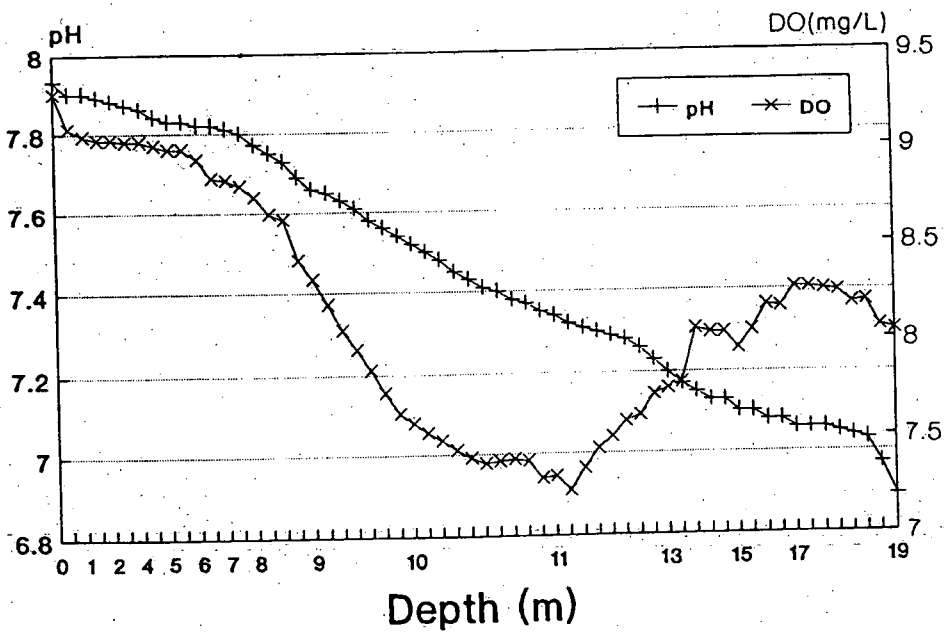
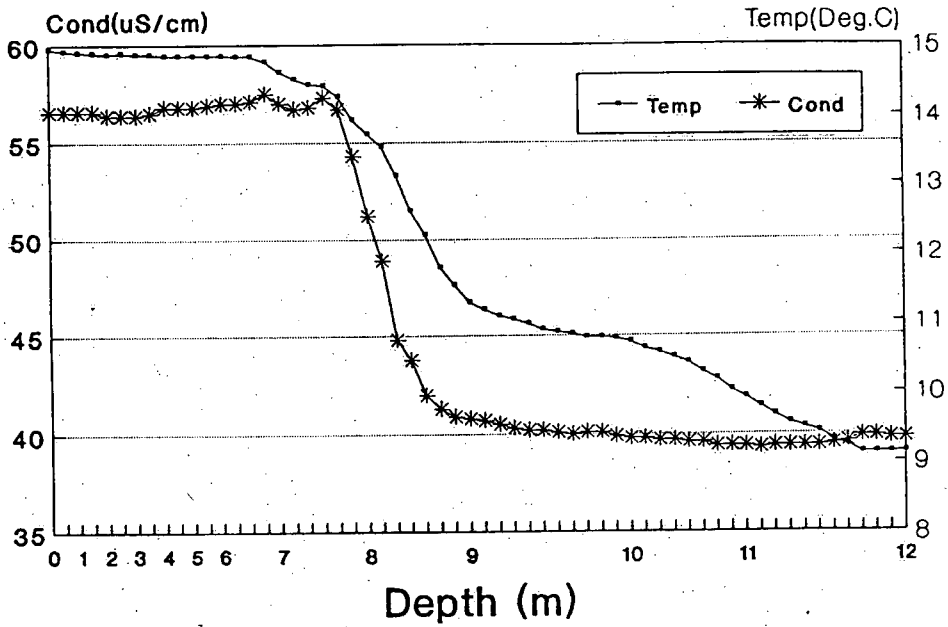


Figure 14. Hydrolab profile of conductivity, temperature, pH and dissolved oxygen in Raven Lake station 2

## RAVEN LAKE (Stn #03)



## RAVEN LAKE (Stn #03)

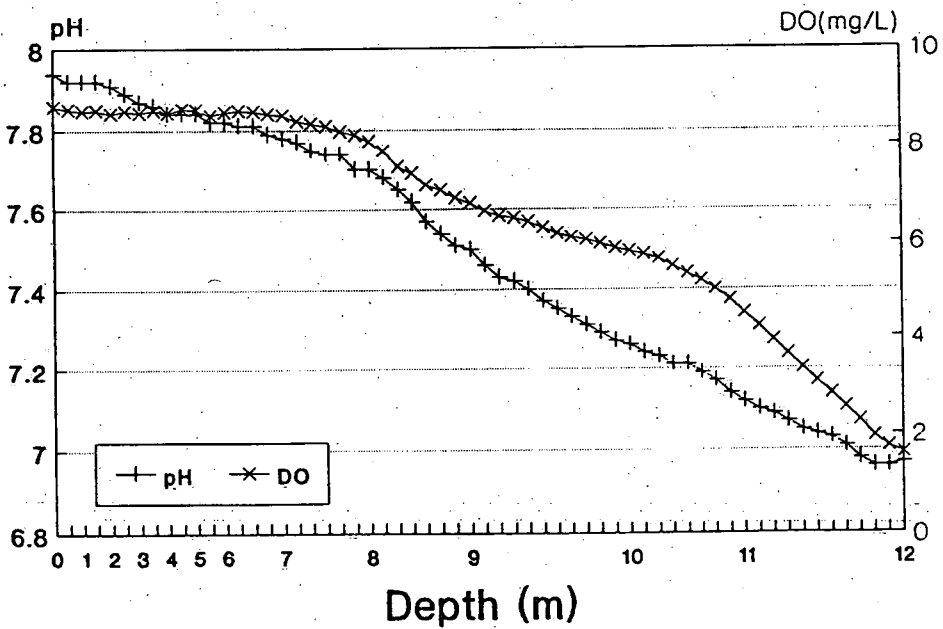
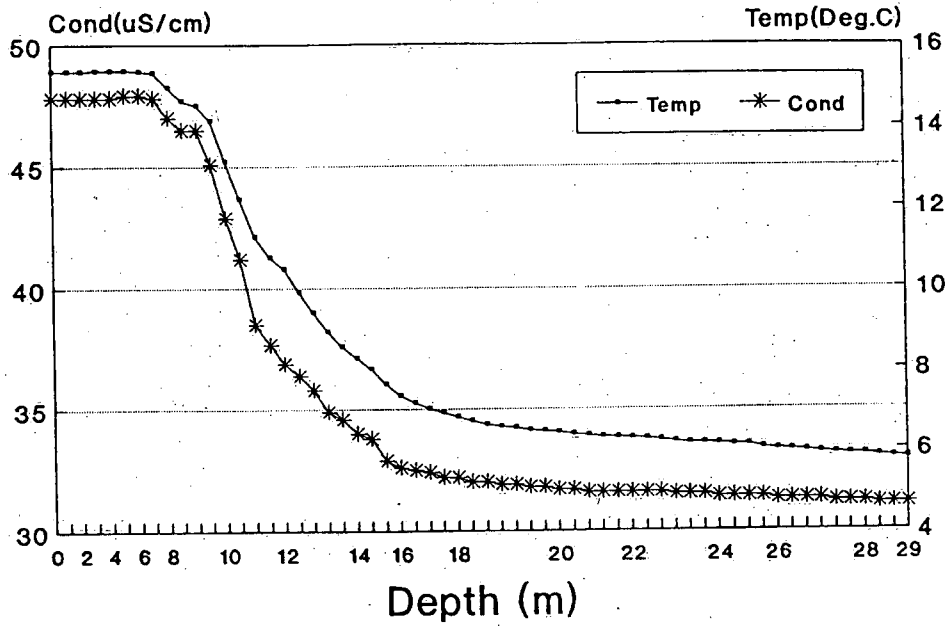


Figure 15. Hydrolab profile of conductivity, temperature, pH and dissolved oxygen



## RAVEN LAKE (Stn #04)



## RAVEN LAKE (Stn #04)

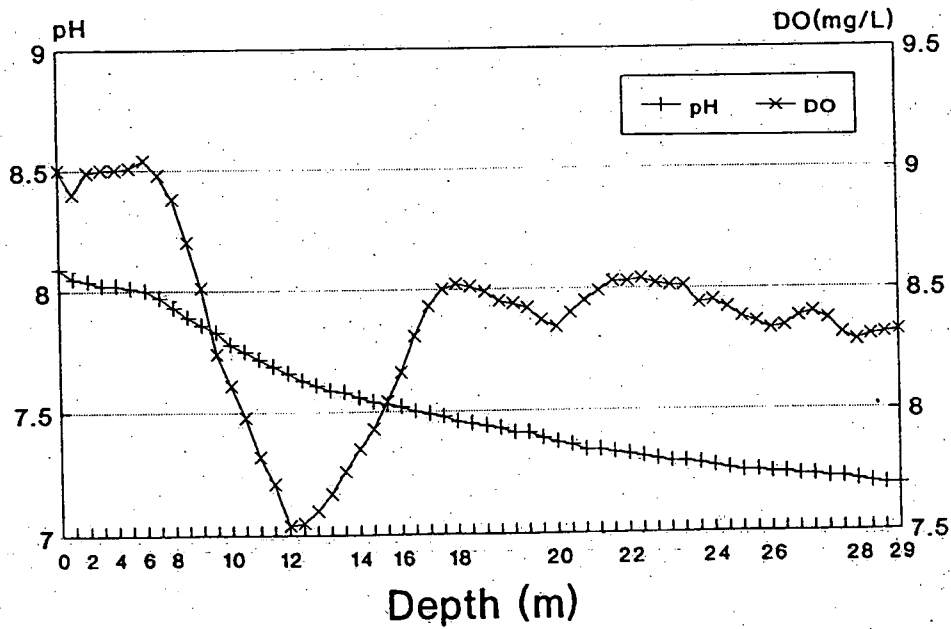
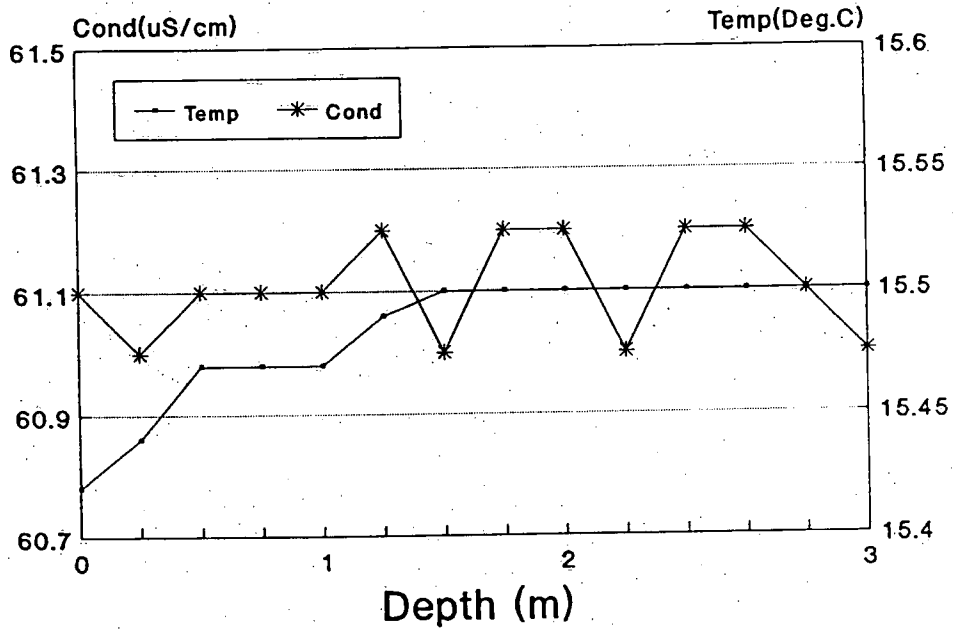


Figure 16. Hydrolab profile of conductivity, temperature, pH and dissolved oxygen in Raven Lake station 4

## BARBER LAKE (Stn #01)



## BARBER LAKE (Stn #01)

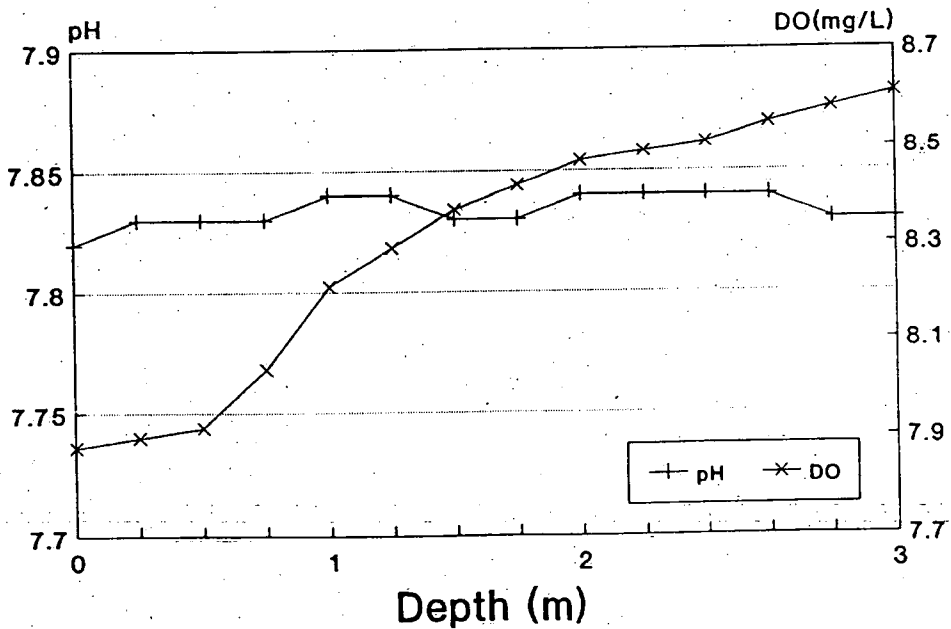


Figure 17. Hydrolab profile of conductivity, temperature, pH and dissolved oxygen

# Phosphorus - Chlorophyll Relationship (Precambrian Shield Lakes)

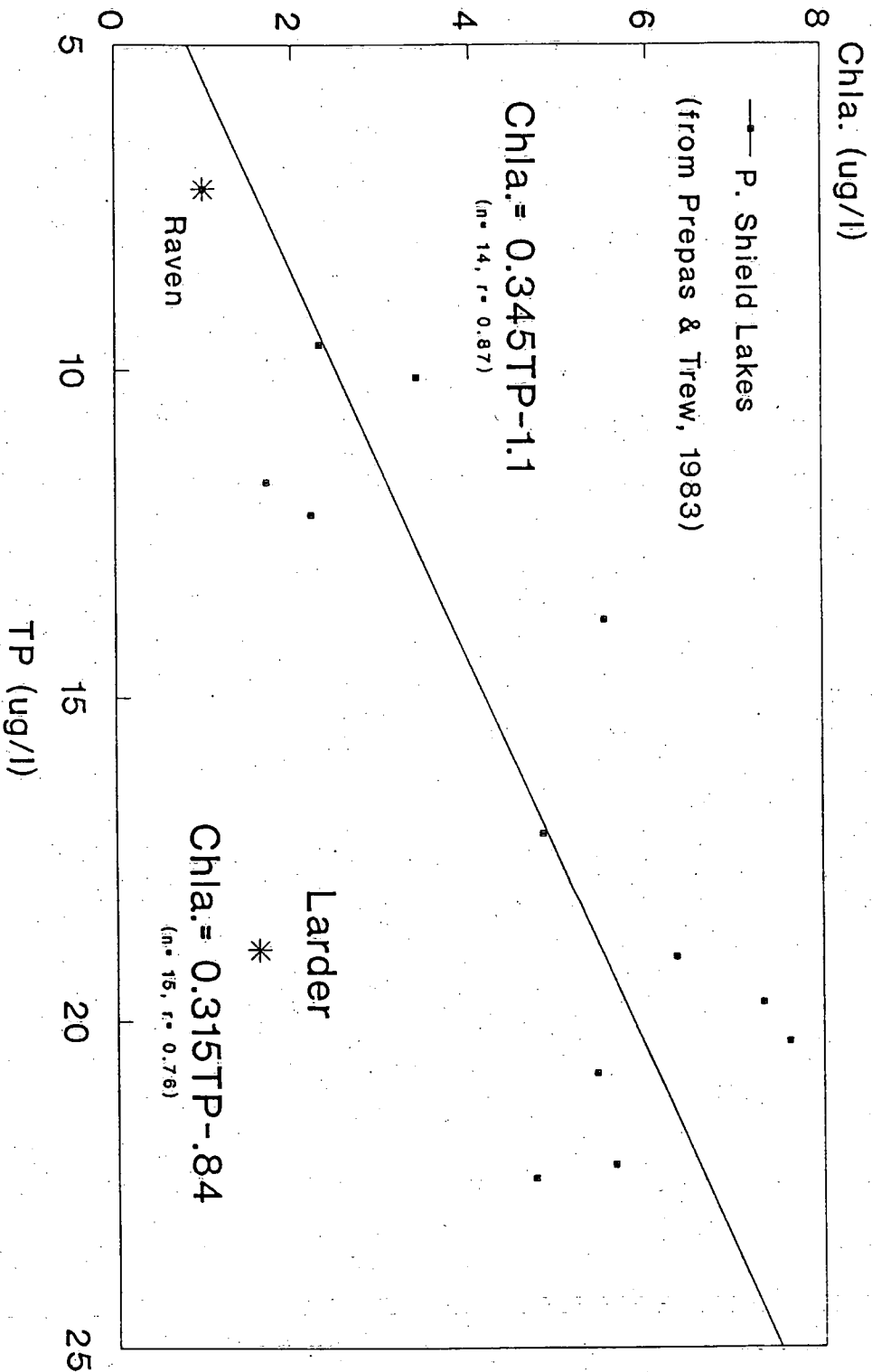


Figure 18. Relationship between total phosphorus and uncorrected Chlorophyll a in Precambrian Shield Lakes, Larder Lake and Raven Lake

# Phosphorus - Chlorophyll Relationship (Central Ontario Lakes)

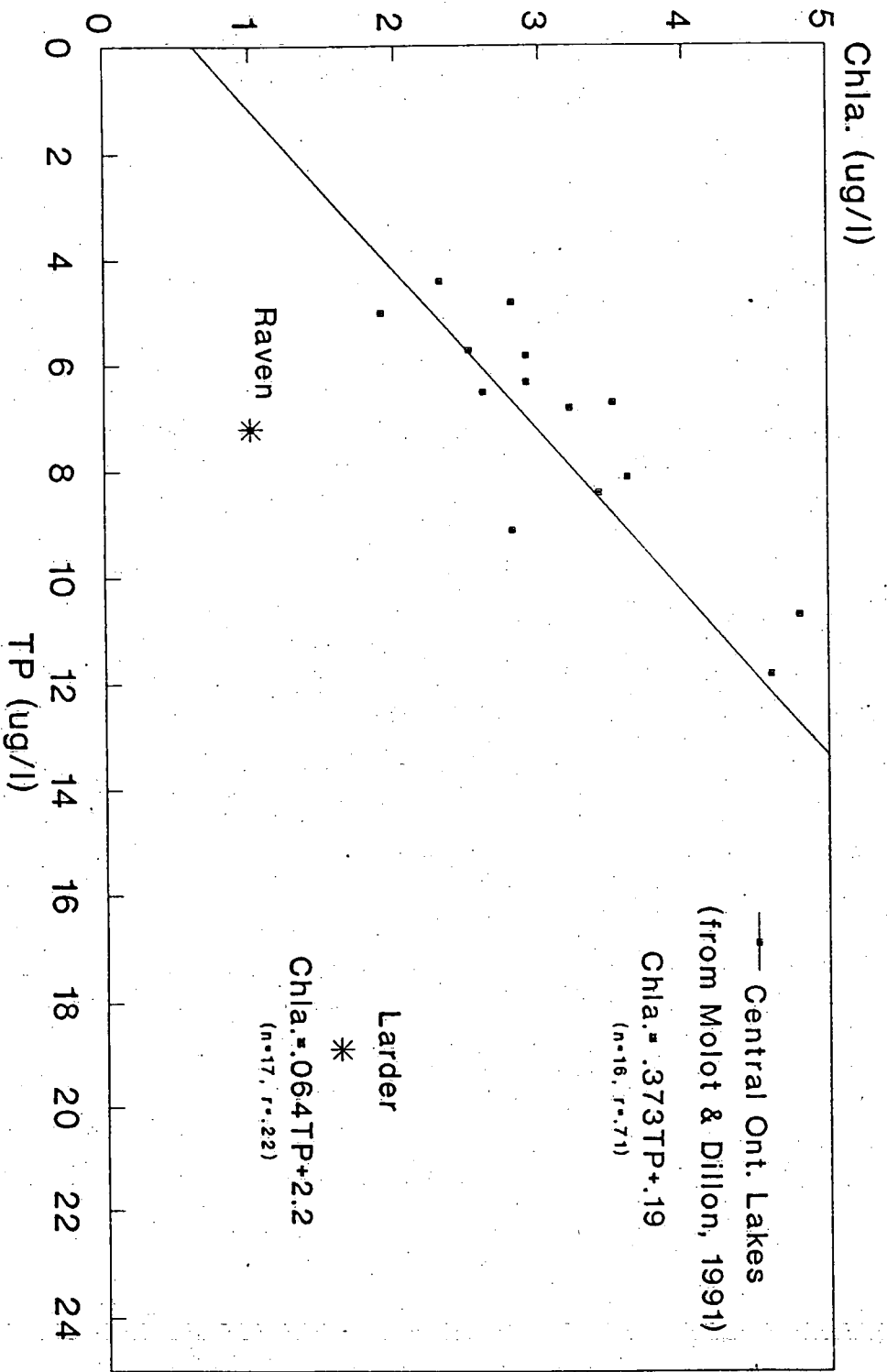


Figure 19. Relationship between total phosphorus and uncorrected Chlorophyll<sub>a</sub> in Central Ontario Lakes, Larder Lake and Raven Lake

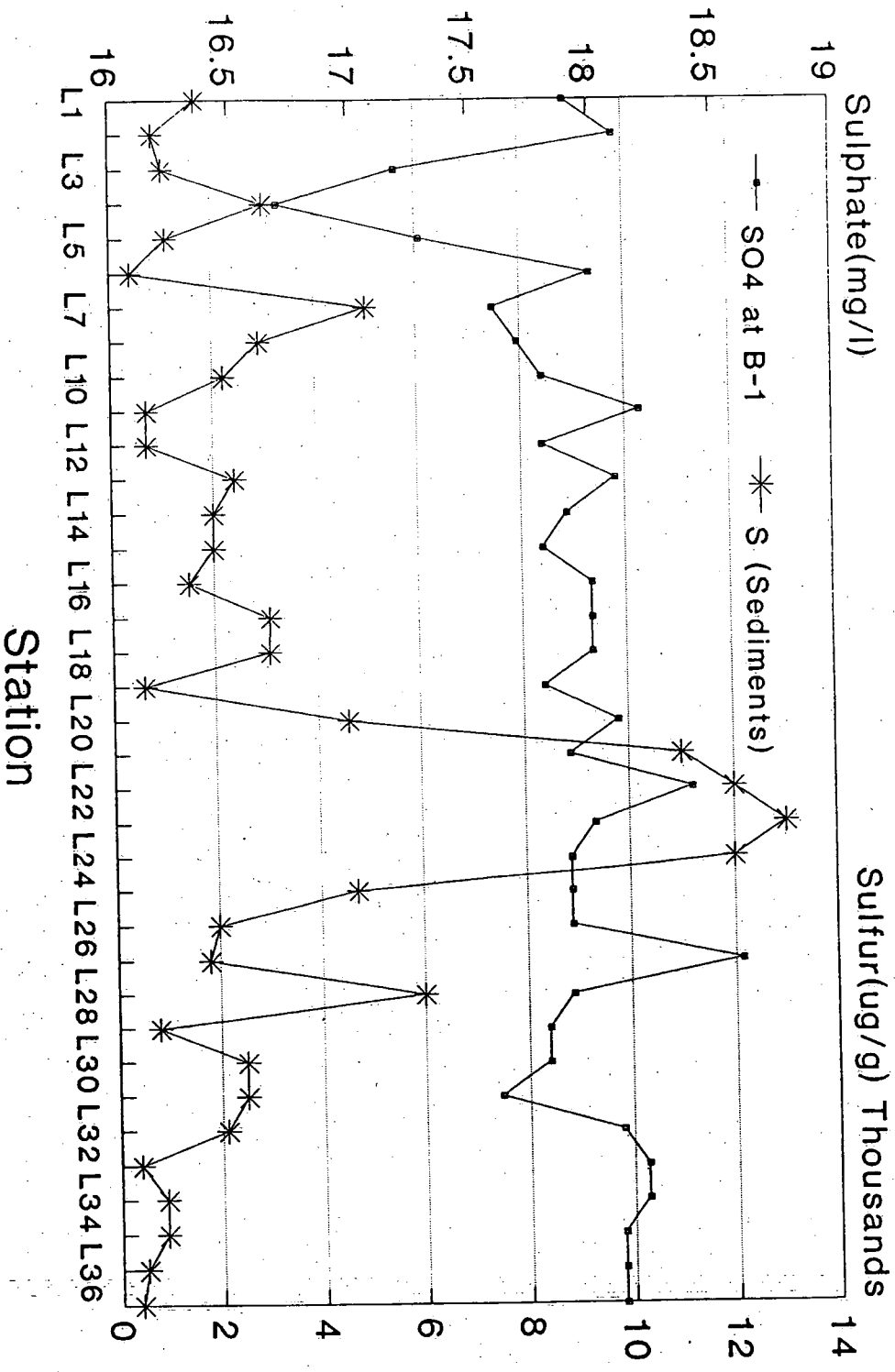
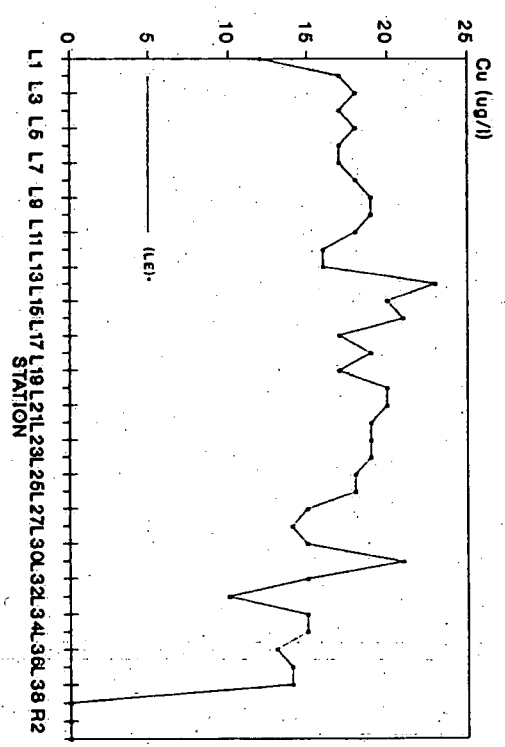
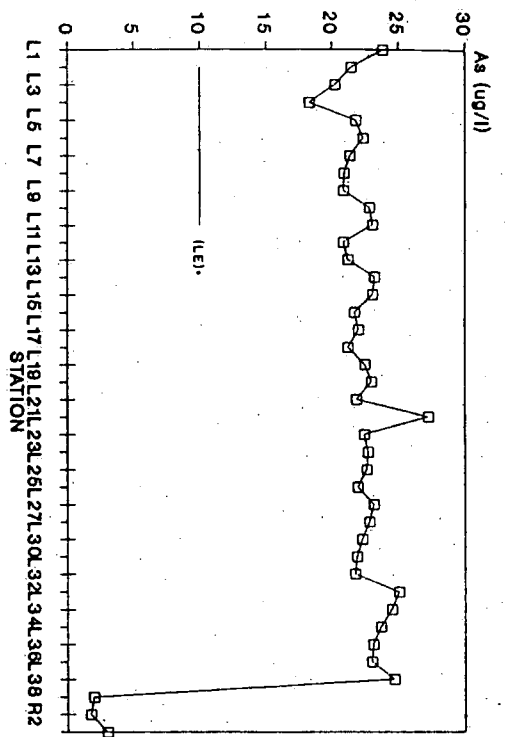


Figure 20. Concentration of sulphate and sulfur in Larder Lake water and sediments



**CONCENTRATION OF DISSOLVED AS, CU, NI AND ZN IN LARDER (L) AND RAVEN (R) LAKES**

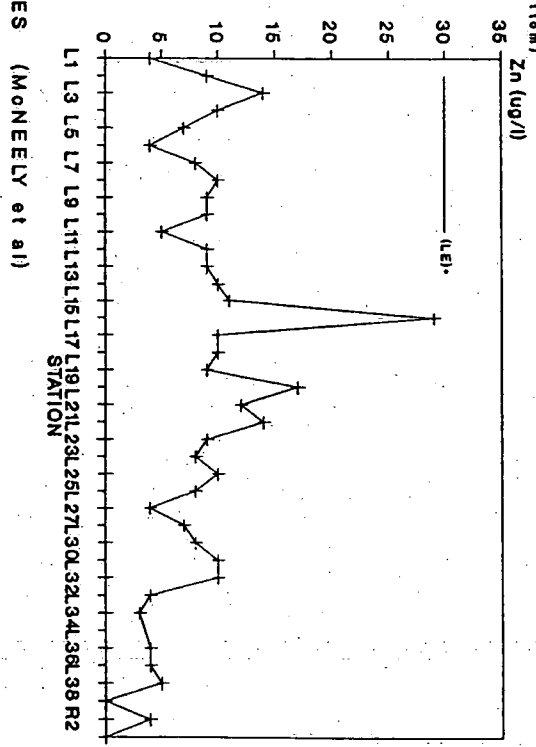
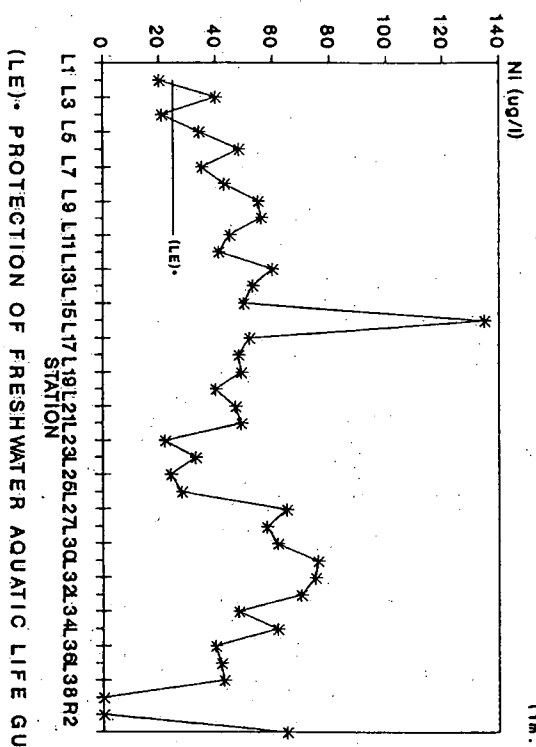


Figure 21. Concentration of dissolved As, Cu, Ni and Zn in Larder Lake (L) and Raven Lake (R)

(LE) = PROTECTION OF FRESHWATER AQUATIC LIFE GUIDELINES (McNEELY et al)

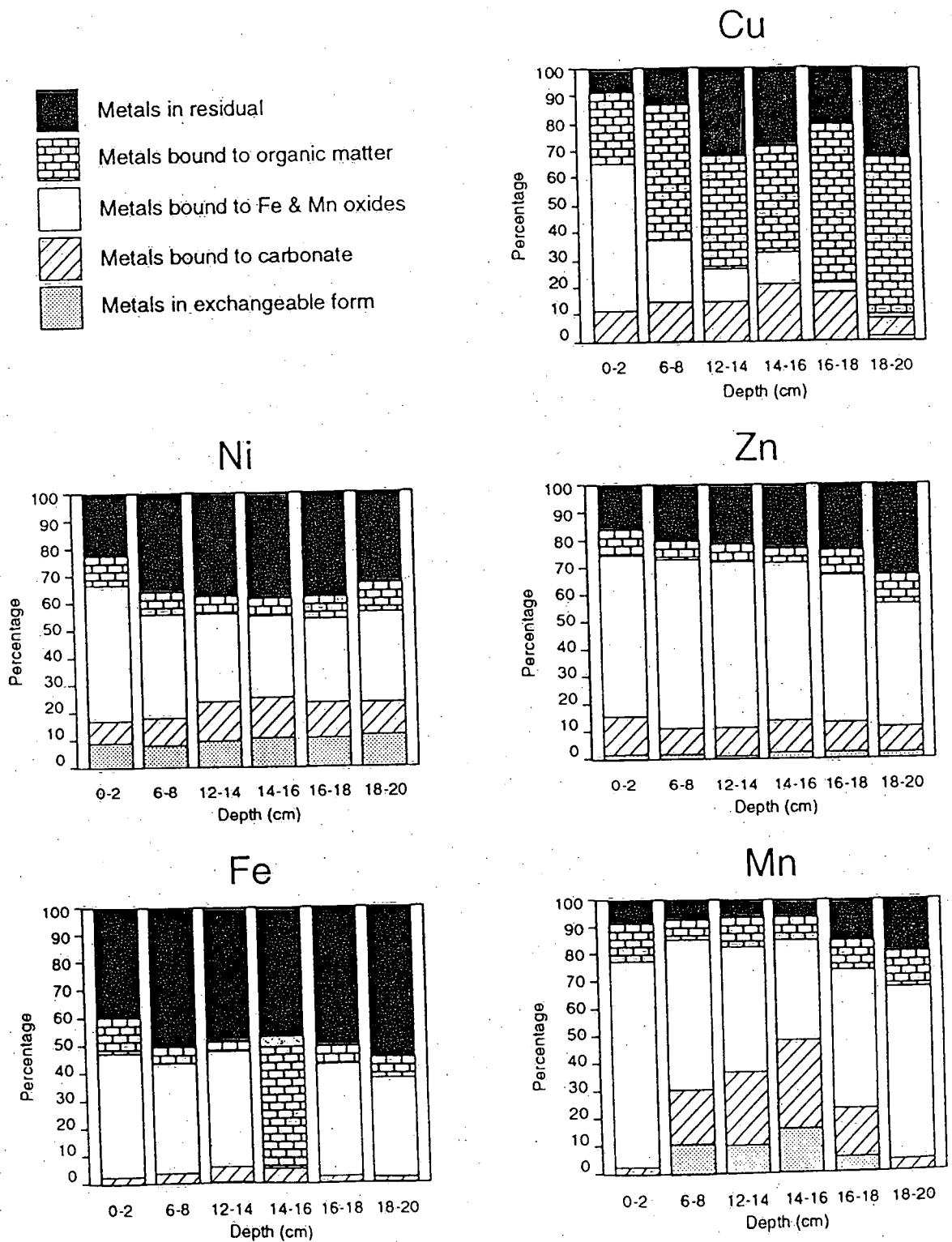
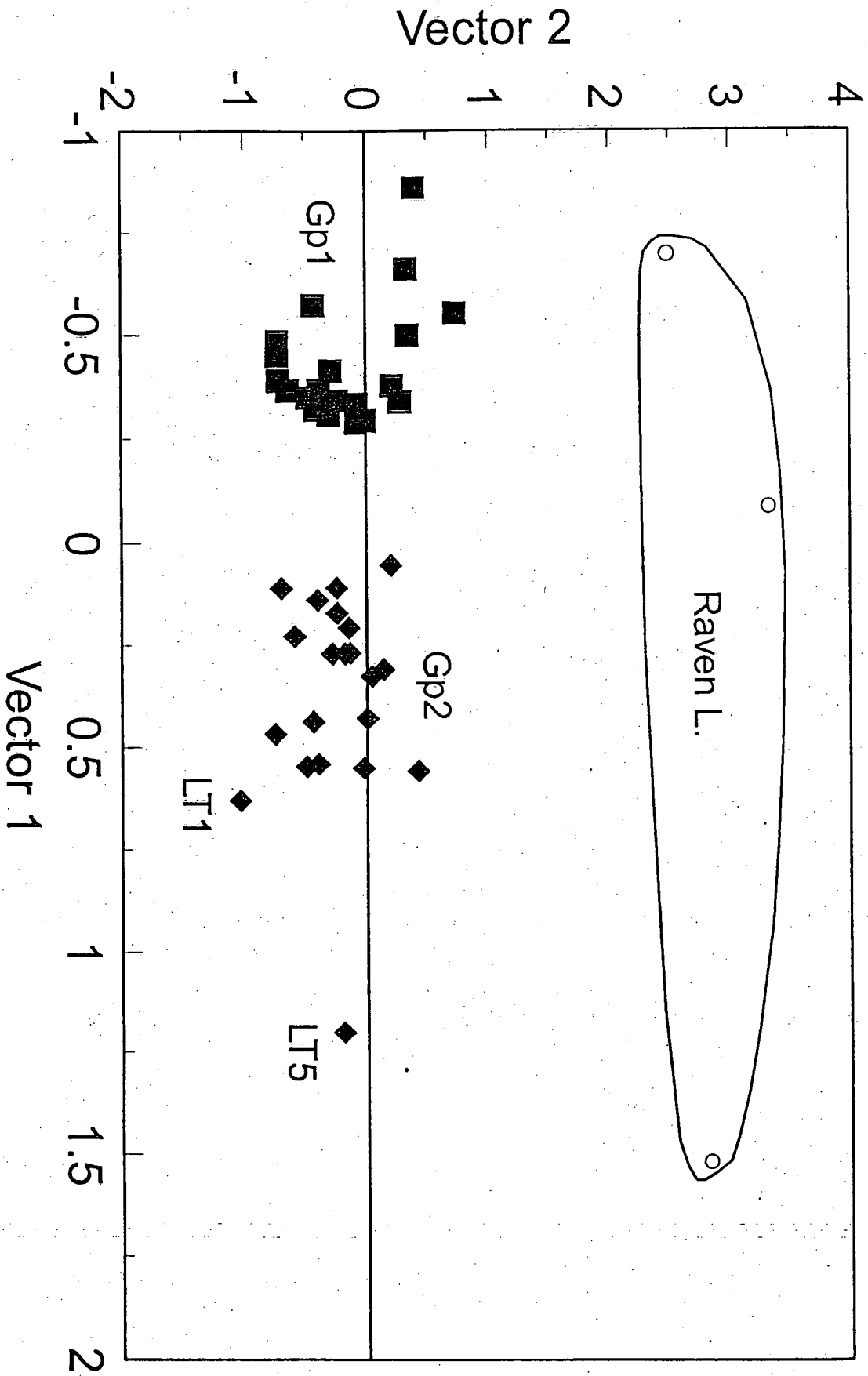


Figure 22. Metal speciation in sediment fractions

Figure 23. Larder Lake and Raven Lake surface water chemistry





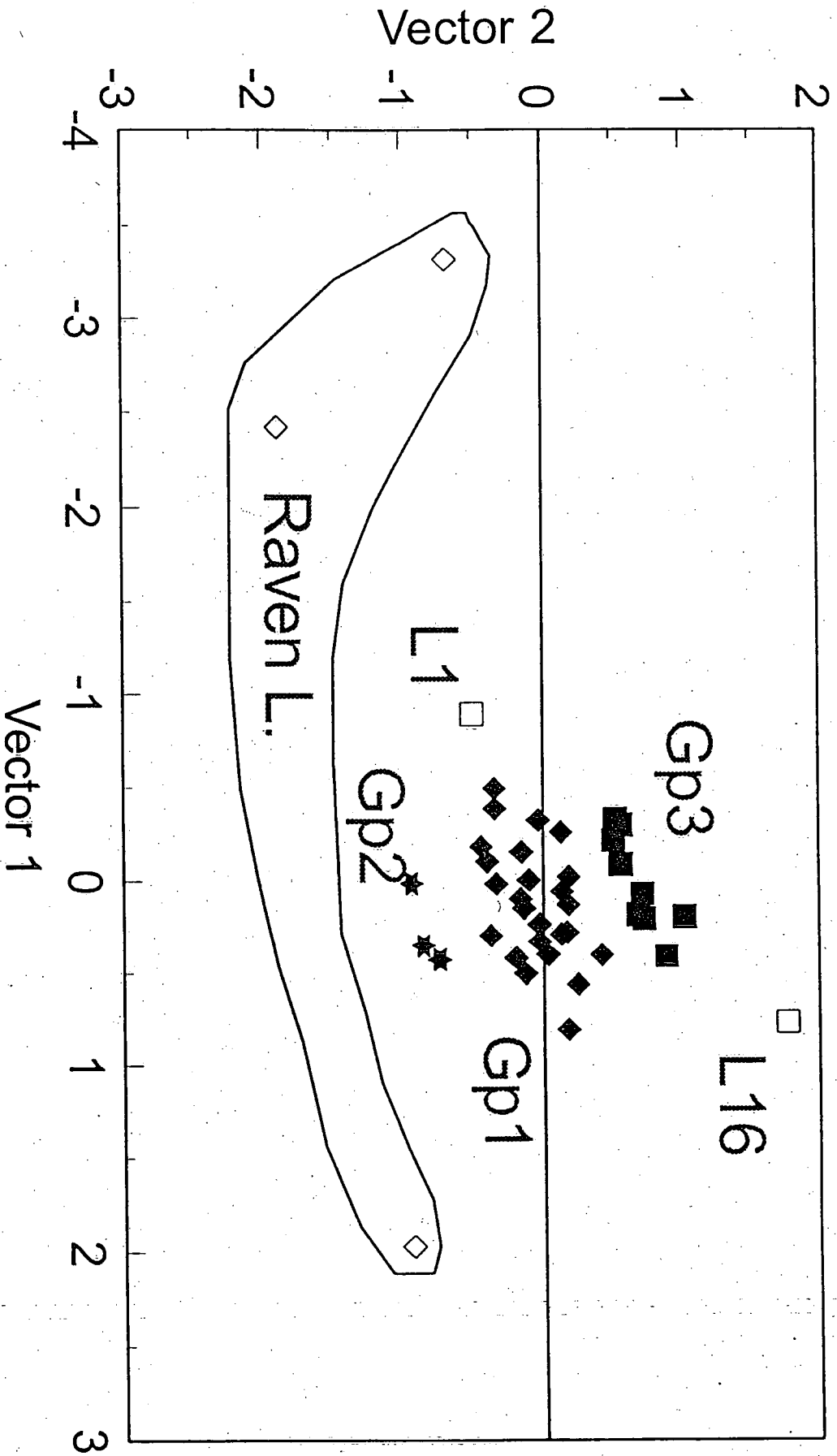
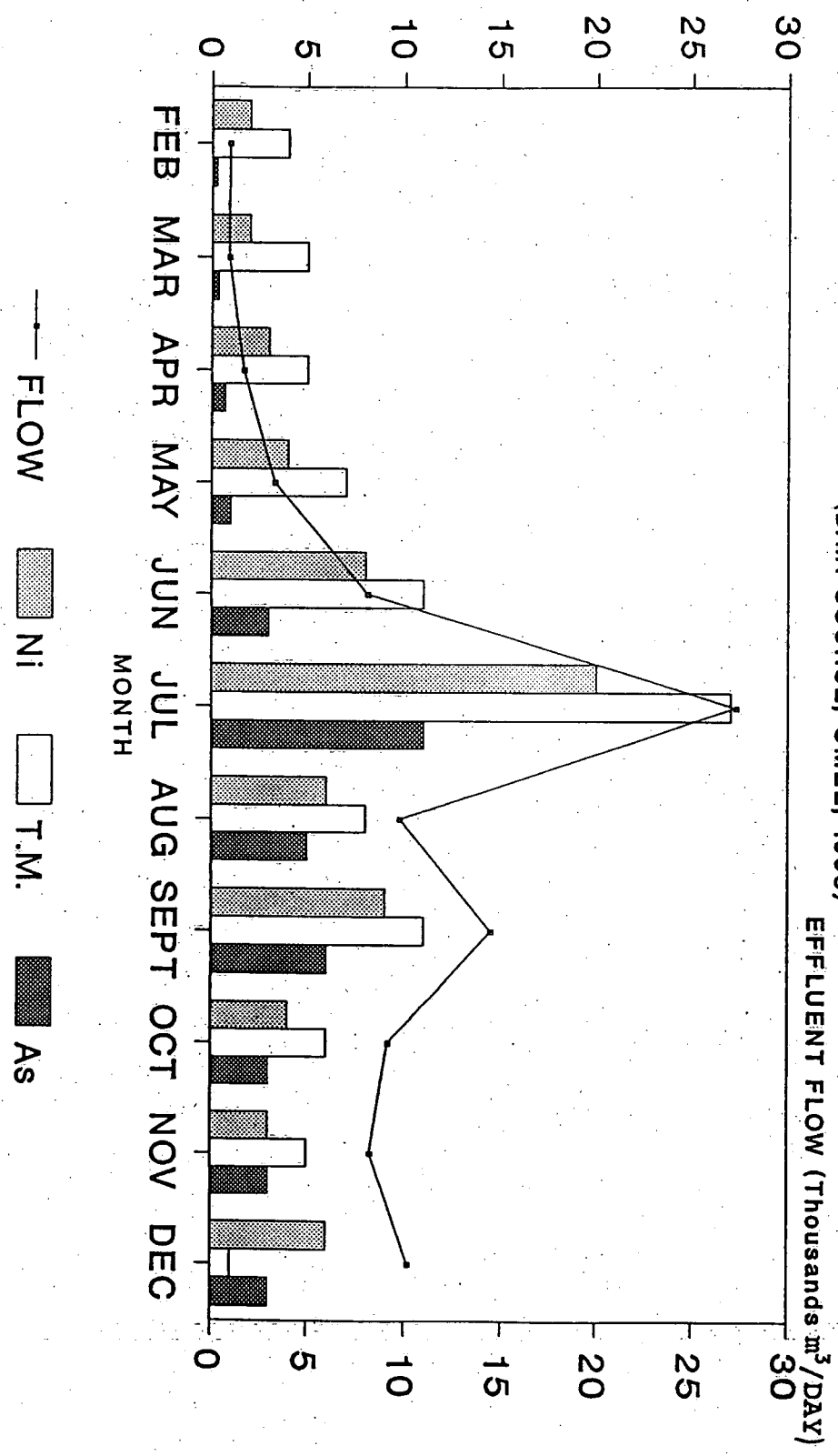


Figure 24. Larder Lake and Raven Lake bottom water chemistry

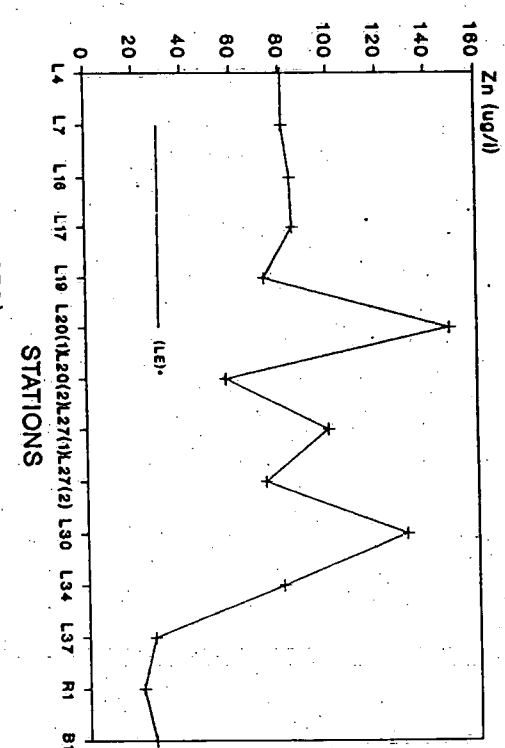
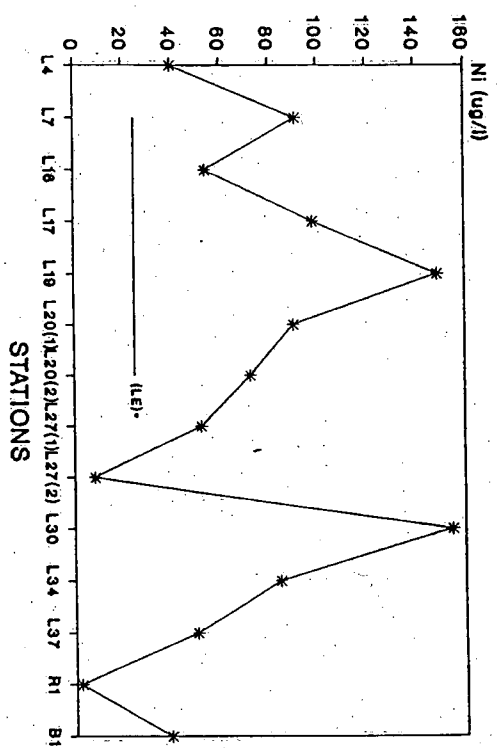
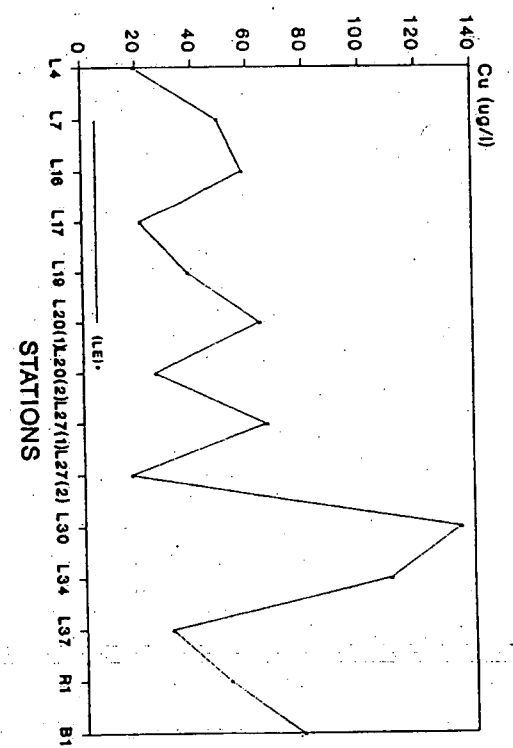
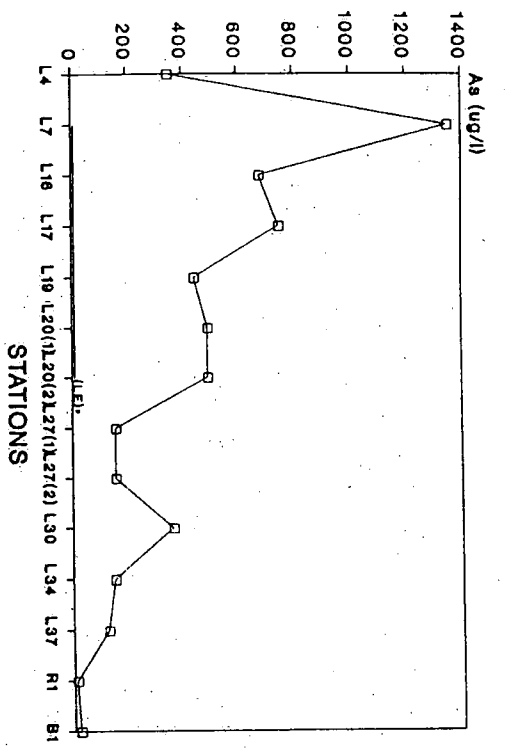
# TAILINGS POND OUTLET EFFLUENT 1992

(DATA SOURCE, OMEE, 1993)



TOTAL METALS (T.M.) IS THE SUM OF Cu, Ni, Pb & Zn (Kg/DAY).  
EFFLUENT FLOW RATE FOR FEBRUARY TO MAY, ARE 1991 FIGURES (m³/DAY)

Figure 25. Tailings Pond Outlet effluent 1992



(LEI) • PROTECTION OF FRESHWATER AQUATIC LIFE GUIDELINES (McNEELY et al, 1979)

Figure 26. Concentration of As, Cu, Ni and Zn in sediment pore water in Larder Lake (L), Raven Lake (R) and Barber Lake (B)

Figure 27. Larder Lake - major elements - 4 groups

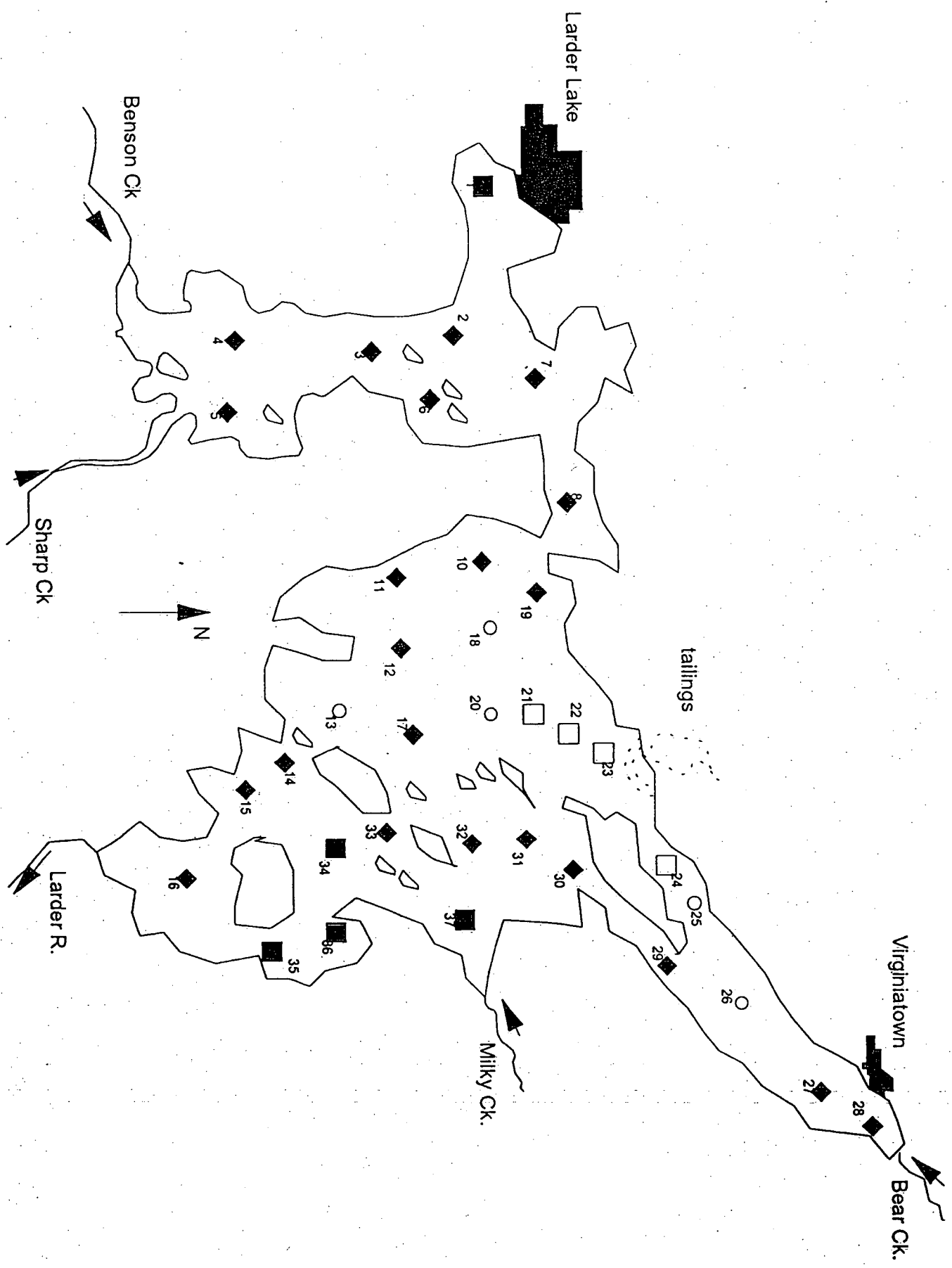
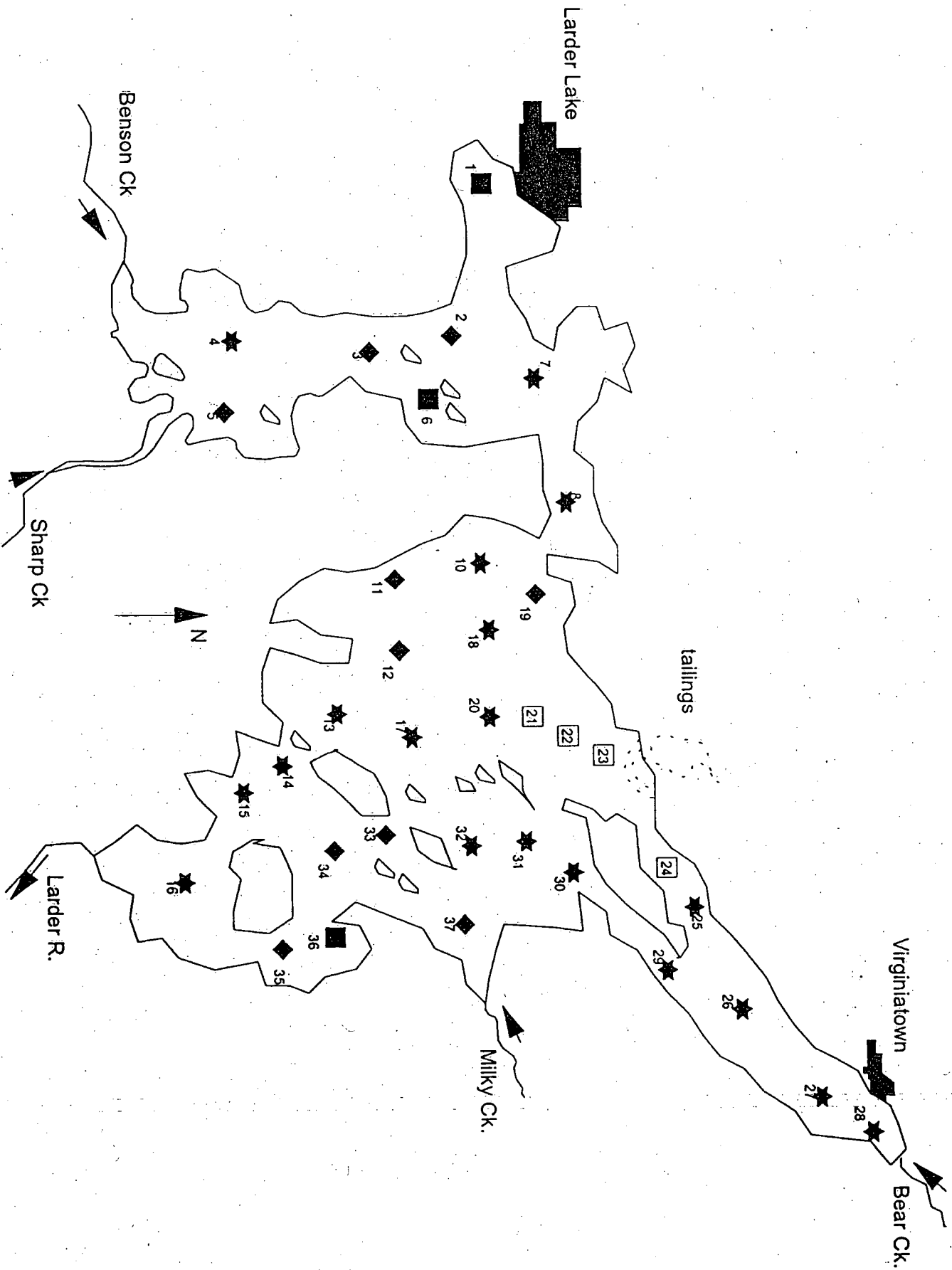


Figure 28. Larder Lake - trace elements - 4 groups



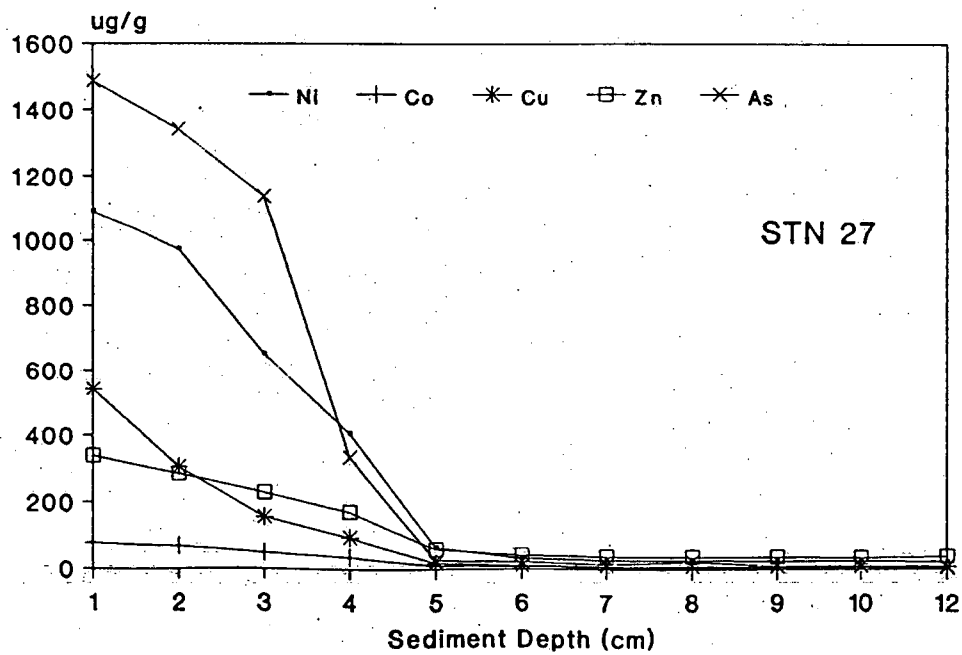
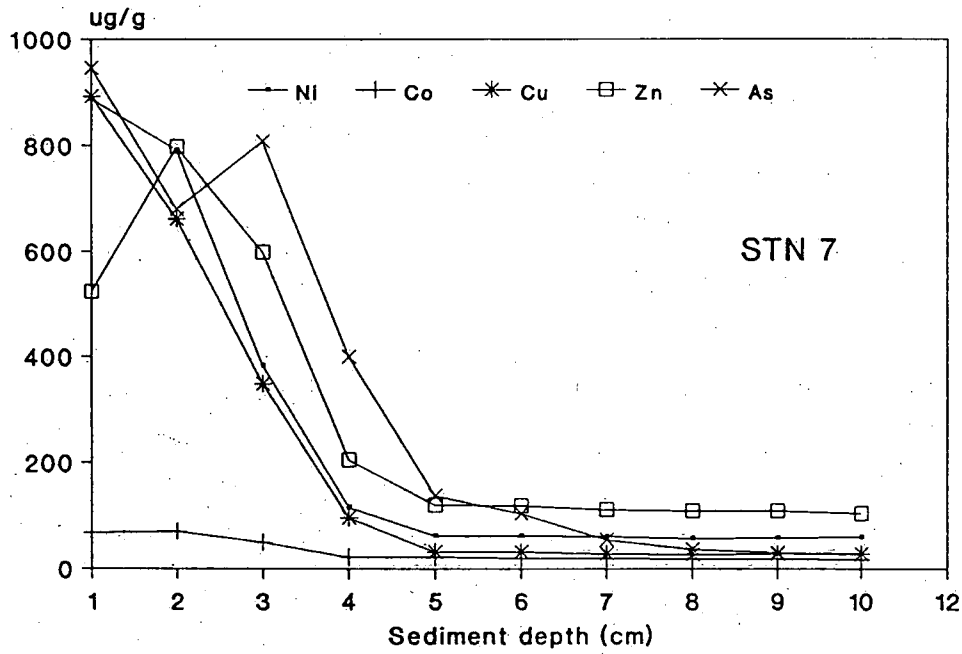
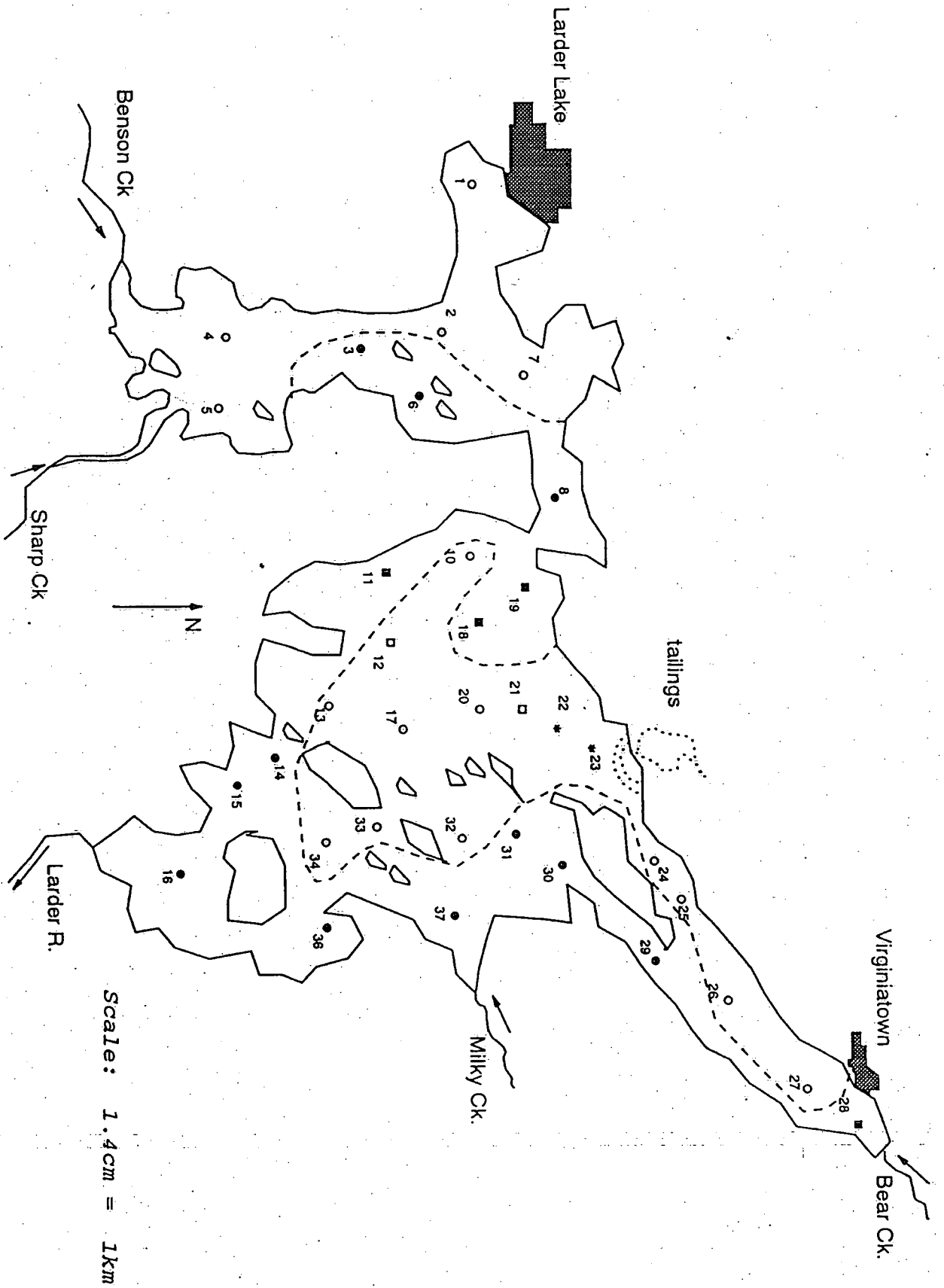


Figure 29. Concentration profiles of Ni, Co, Cu, Zn, and As in sediment from stations 7 and 27 in Larder Lake

Figure 30. Benthic community distribution in Larder Lake



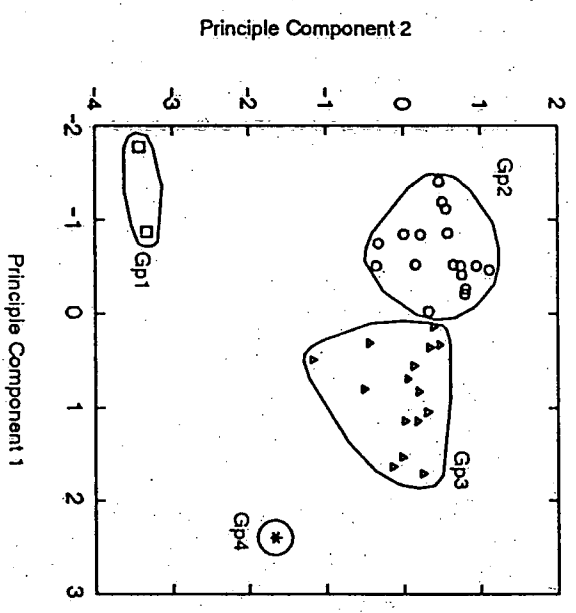
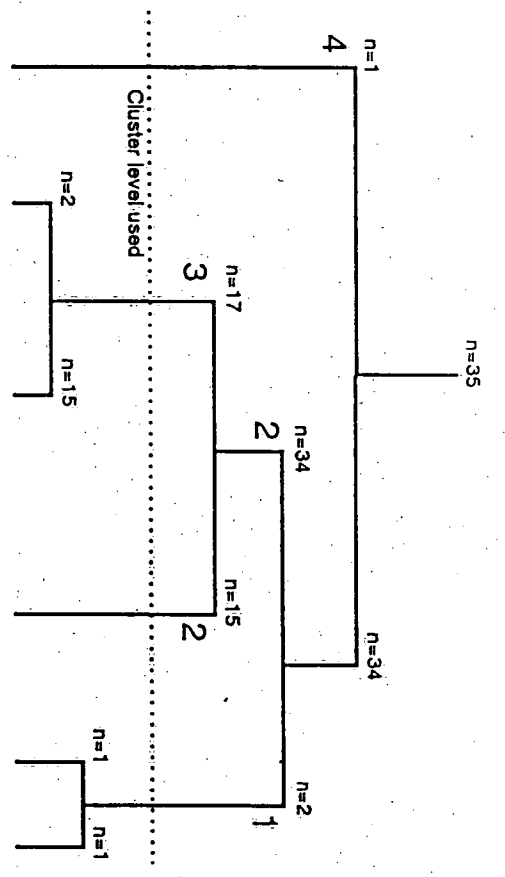
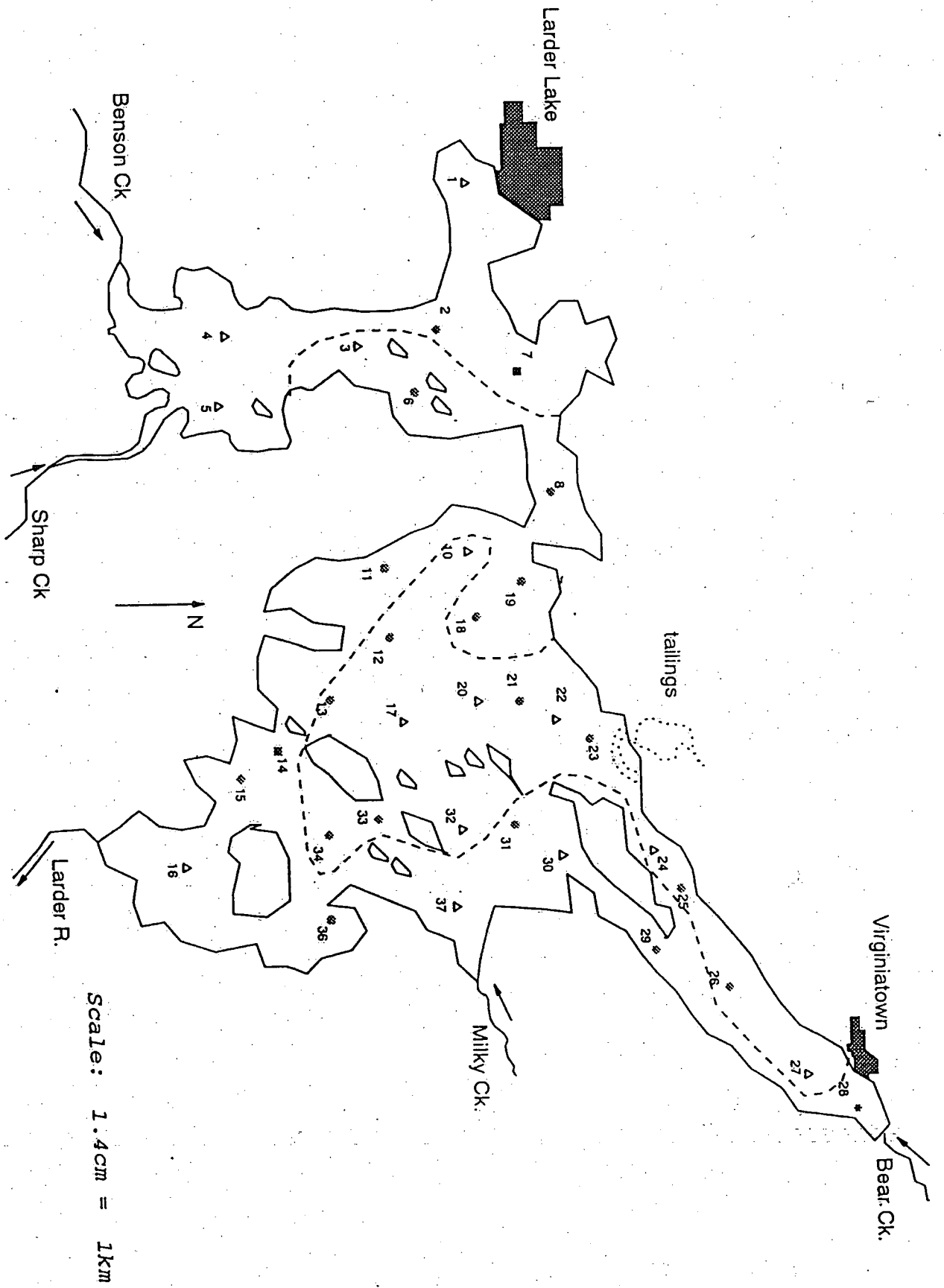
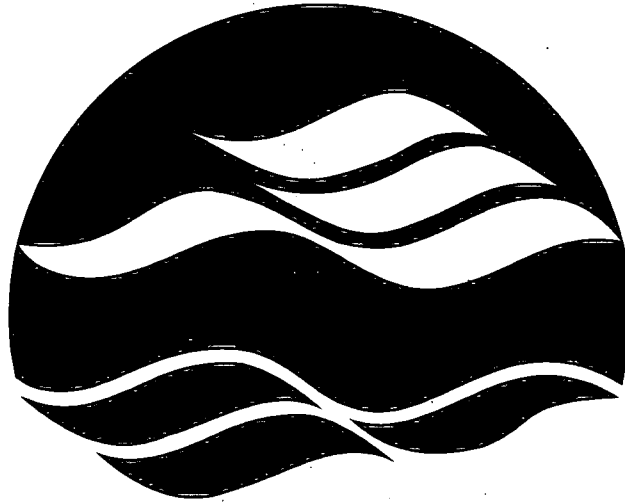


Figure 31. Dendrogram and Principle Component Ordination of Larder Lake benthic communities



Figure 32. Distribution of toxicity cluster analysis group





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