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GEOCHEMICAL ASSESSMENT OF SUBAQUEOUS TAILINGS DISPOSAL IN ANDERSON LAKE, MANITOBA
1993-1995 STUDY PROGRAM

MEND Project 2.11.3abc

This work was done on behalf of MEND and sponsored by
Hudson Bay Mining and Smelting Company Limited, National Water Research Institute
as well as Manitoba Energy and Mines and
the Canada Centre for Mineral and Energy Technology (CANMET) through
the Canada/Manitoba Mineral Development Agreement.

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FINAL REPORT

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August 1996

EXECUTIVE SUMMARY

Sulphide-rich zinc-, copper-, and lead-bearing tailings have been deposited via floating pipeline into shallow (< 8 m) Anderson Lake in north-central Manitoba since 1979. The lake water contains elevated levels of dissolved metals which are derived mainly from an acid-generating roadway along the north shore. Water-column sampling and sediment coring were carried out through the ice on Anderson Lake in April 1993. Two sites were occupied, one proximal to the tailings discharge (Station B, the "pure tailings" site) and the other about 2 km away (Station A, the "natural sediments" site). Interstitial waters were extracted from duplicate cores collected at each location. The water column was strongly stratified at both locations, exhibiting four layers at the natural sediments site (two of which were dysaerobic or anoxic), and two layers near the tailings outfall, the lower being dysaerobic. The unusual multiple layering probably reflects the influence of laterally variable advective processes. High concentrations of dissolved iron in shallow pore waters indicate that the sediments at both locations were anoxic at shallow subsurface depths. Concentrations of Zn, Cu, Pb and Cd were very low or undetectable in the pore waters. There was no evidence of release of Cu, Cd or Pb from the deposited tailings, although there was evidence of possible minor release of Zn from surface sediments in one of the tailings cores. Metals were removed from pore waters below the upper 10 cm at both sites, which is attributed to precipitation of authigenic sulphide phases.

In August, 1993, water column sampling, sediment coring and membrane dialysis array (peeper) deployments were performed at the same two sites occupied during the Winter Survey. An additional shallow-water tailings site was sampled for interstitial waters alone. During the Summer Survey the water column was well mixed, containing elevated concentrations of Zn, Cu and Pb. However, those same metals (and Cd) displayed precipitous decreases across the sediment-water interface at all sites indicating that the sediments of Anderson Lake (natural and tailings) were acting as a sink rather than a source for these metals. Metal precipitation in the interstitial waters was attributed to precipitation of authigenic sulphides. Arsenic appeared to respond to more complex seasonal cycling being released at depth and possibly precipitated within the surficial sediment. Dissolved As was likely released from reduction of oxides rather than oxidative release from tailings.

Two additional studies were carried out subsequent to the work described above. The first (Appendix G) involved observations of Anderson Lake water quality after discharge of tailings to the lake had ceased (June to October, 1995); lake thermal and meteorological data were used in support of the geochemical interpretation. The water quality in Anderson Lake was found to respond to meteorological events. Increases in precipitation were accompanied by increases in dissolved Zn and decreases in conductivity, suggesting that the degradation in water quality resulted from the introduction of residual acid salts associated with historic acid-rock drainage. The second study (Appendix H) involved an overview of the mine-related inputs to Anderson Lake which assessed the relationships between the various inputs and the observed historical changes in lake chemistry. The limited available evidence suggests that the primary controls on past metal and acidity enrichments stemmed from unbuffered underground mine discharges and acidic minesite drainages. The findings of these sister studies are consistent with those of the previous MEND assessments of Anderson Lake.

SOMMAIRE

Des résidus sulfurés contenant du zinc, du cuivre et du plomb ont été déposés au moyen d'un pipeline flottant dans les eaux peu profondes du lac Anderson (< 8 m) dans le centre-nord du Manitoba depuis 1979. Les eaux du lac contiennent de fortes concentrations de métaux dissous qui proviennent surtout d'une route acidogène bordant la rive nord. Des échantillons de la colonne d'eau et des carottes de sédiments ont été prélevés à travers la glace du lac Anderson en avril 1993. Deux sites ont été occupés, un situé près de la décharge à résidus (station B, site de «résidus purs») et l'autre situé à environ 2 km plus loin (station A, site de «sédiments naturels»). Des eaux interstitielles ont été extraites des carottes prélevées à chaque endroit. La colonne d'eau était fortement stratifiée aux deux endroits, présentant quatre couches au site des sédiments naturels (dont deux couches dysaérobies ou anoxiques) et deux couches près de la décharge à résidus, la couche inférieure étant dysaérobie. La stratification multiple anormale dénote probablement un effet d'advection latéral variable. Les fortes concentrations de fer dissous dans les eaux interstitielles peu profondes indiquent que les sédiments sont aux deux endroits anoxiques à faible profondeur. Les concentrations de Zn, de Cu, de Pb et de Cd étaient très faibles, voire indécelables, dans les eaux interstitielles. Il n'y avait aucun indice d'émanations de Cu, de Cd ou de Pb provenant des résidus déposés, même si de faibles émanations de Zn auraient été libérées par les sédiments de surface d'après l'examen d'une carotte de résidus. Des métaux ont été extraits des eaux interstitielles sous la marque des 10 premiers centimètres dans les deux sites; ils seraient attribuables à la précipitation de phases sulfurées authigènes.

En août 1993, des réseaux de points d'échantillonnage de la colonne d'eau, de carottage des sédiments et de dialyse sur membrane ont été mis en place aux deux mêmes sites qui avaient été occupés pendant le relevé d'hiver. Dans un autre site de résidus en eau peu profonde, seules les eaux interstitielles ont été échantillonnées. Pendant le relevé d'été, la colonne d'eau était bien brassée, et sa concentration de Zn, de Cu et de Pb était élevée. Toutefois, la teneur en ces mêmes métaux (et en Cd) présentait de fortes diminutions à travers l'interface sédiments-eau dans tous les sites, indiquant que les sédiments du lac Anderson (sédiments naturels et résidus) ont, pour ces métaux, agi comme un puits plutôt que comme une source. La précipitation de métaux dans les eaux interstitielles a été attribuée à la précipitation de sulfures authigènes. L'arsenic en profondeur a semblé décrire un cycle saisonnier d'émission plus complexe et a peut-être précipité dans les sédiments superficiels. De l'arsenic dissous a probablement été libéré par la réduction d'oxydes plutôt que par l'oxydation des résidus.

Les travaux décrits ci-dessus ont été suivis de deux études complémentaires. La première (Annexe G), a consisté dans des observations de la qualité des eaux du lac Anderson après que l'on eut cessé de déverser des résidus dans la lac (juin à octobre 1995); les données thermiques et météorologiques relatives au lac ont été utilisées à l'appui de l'interprétation des données géochimiques. On a déterminé que la qualité de l'eau du lac Anderson dépendait des phénomènes météréologiques. L'augmentation des précipitations était accompagnée d'une augmentation de Zn dissous et d'une diminution de la conductivité, ce qui porte à croire que la dégradation de la qualité de l'eau résultait de l'introduction de sels acides résiduels associée au drainage cumulatif des roches acides. La deuxième étude (Annexe H) comprend un aperçu des déversements d'origine minière dans le lac Anderson et présente une évaluation des rapports entre les déversements et les changements chronologiques de la chimie du lac qui ont été observées. L'évidence disponible est limitée, mais elle permet de croire que les facteurs principaux qui ont contribué dans le passé à l'apport de métaux et à l'acidité du lac étaient les eaux de la mine souterraine qui étaient évacuées directement dans le lac ainsi que le drainage acide du site minier. Les résultats de ces deux études similaires corroborent les évaluations précédentes de l'eau du lac Anderson réalisées par NEDEM.

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PREAMBLE

Introduction

Finding an environmentally sound, yet cost effective, mode for disposal of sulphide-containing mine waste has been a challenge facing both the mining industry and government for many decades. Given the critical role played by oxygen in the process of acid generation, thoughts towards abatement of this problem have focused around elimination of oxygen as a reactant. Consequently, arguments for subaqueous disposal arose naturally from the premise that acid generation from sulphides could be suppressed when submerged underwater where oxygen concentrations are greatly diminished relative to the atmosphere. In other words, lowering the concentration of one of the principal reaction ingredients (oxygen) would lower the oxidation reaction rate, hence the rate of generation of acid and dissolved metals. This premise was based on the well understood chemical characteristics of natural water bodies and sediments.

While founded on sound theoretical principals, the efficacy of subaqueous disposal prior to the 1980's was largely unproven and supported by only a few, limited scientific studies. In order to address the paucity of relevant data, a suite of projects created through the BCARD Task Force and MEND were designed, and involved fieldwork in a series of lakes where mine tailings had been deposited (Anderson and Mandy Lakes, Manitoba; Buttle and Benson Lakes, British Columbia). The program utilized a variety of state-of-the-art sampling, analytical and interpretive techniques designed to measure directly the reactivity and short and long-term chemical stability of subaqueous mine tailings deposits. Further, the questions to be answered by the project temporarily avoided the many and complex biological components, and focused on the geochemical environment. It was determined that once subaqueous tailings reactivity had been adequately assessed, and the geochemical processes delineated, the biological issues could be approached in a better-defined context and on a project-specific basis.

The results of the work supported the hypothesis: sulphide-rich mine tailings, when stored in the subaqueous environment, were largely chemically unreactive. In the few instances where release of dissolved metals were observed, natural secondary chemical processes within the sediments inhibited their release to the water column.

The following overview is intended to provide a summary of the MEND Project reports and a general description of the geochemical systems which contribute to the effectiveness of subaqueous disposal.

Background Chemistry

The instability or reactivity of metal sulphides arise from their mode of formation. Sulphides are formed in reducing environments (in the absence of oxygen). Consequently, they are unstable and susceptible to chemical reaction in the oxygen-rich environment of the earth's surface. Accordingly, the most stable environment in which to store sulphide-rich mine tailings is one devoid of oxygen - one that mimics their environment of genesis.

Subaqueous systems are an effective first approximation of a stable environment for sulphides not because they are devoid of oxygen (indeed, subaqueous environments most often have measurable concentrations of dissolved oxygen), but rather because they contain low oxygen levels even in their most saturated state. The maximum concentration of dissolved oxygen found in natural waters is approximately 25,000 times lower than that fonnd in the atmosphere. Because the rate of sulphide oxidation is in part dependent on the concentration of oxygen, it is readily apparent that the generation of acid and dissolved metals will be dramatically minimized underwater. Further, once the small inventory of dissolved oxygen in the water is consumed, it is typically replaced very slowly by processes of molecular diffusion and small-scale turbulence; the transfer of oxygen in water is nearly 10,000 times slower than similar transfers in air. Consequently, storage under permanent water cover is perhaps the single most effective measure that may be taken to inhibit acid generation from sulphidic mine tailings.

Sediments recreate an environment stable to sulphide minerals even more effectively than a water cover, in part because of the low concentrations of dissolved oxygen but also because of a natural tendency for sediments to become chemically reducing. To understand why the sedimentary environment is an appropriate site for the storage of sulphidic mine tailings, it is first necessary to outline some of the natural chemical processes found in that environment.

Natural sediments typically contain a spectrum of components ranging from eroded rocks and soils of local origin to unique substances formed within the deposits. However, of all the components found in natural sediments, the remains of plants and animals (organic matter) is perhaps the most important as they are considered to be the fuel for almost all chemical reactions that occur after deposition. This is because organic matter (like sulphides) is unstable in the presence of oxygen; it has a natural tendency to decompose into its constituent elements (mostly simple molecules containing the elements carbon, nitrogen, phosphorus, sulphur and hydrogen). In other words, organic matter consumes or reacts with the oxidant oxygen to form carbon dioxide and a suite of simple, biological by-products. This reaction is accelerated by a host of bacterial species which catalyse the reaction to derive energy for their own needs. Because the concentration of oxygen in natural waters is initially low, it is often rapidly depleted within the surface layers of sediments. When oxygen is no longer available to react with the organic matter, secondary oxidants are utilized in its place by the bacterial community. They are in order of preference: nitrate, Mn-oxide, Fe-oxide, sulphate and carbon dioxide; once one secondary oxidant is consumed (*i.e.,* nitrate) the next most favoured is consumed (*i.e.,* Mn-oxide) until all are exhausted. Of particular importance is the consumption of sulphate, since the by-product of the reaction between sulphate and organic matter (in the absence of more favourable oxidants) is hydrogen sulphide, a natural analogue to metal sulphide minerals. Thus, the natural tendency in sediments is toward the creation of an environment in which sulphides form naturally, and sulphide-rich mine tailings are at their most stable in just such settings.

Methods of Examination

There are two principal ways in which to assess whether or not sulphidic mine tailings are reacting or releasing acid and metals to the subaqueous environment. The first is direct microscopic or petrographic observation of the submerged tailings particles. Thus far, in all cases where subaqueous sulphide tailings have been studied, no signs of oxidation have been observed. However, a far more sensitive, effective and elegant approach is to look for direct effects of sulphide oxidation such as a drop in pH, an increase in sulphate or the most direct indicator of all, an increase in dissolved metals. Since dissolved metals are the parameters of environmental concern and because they exist at very low concentrations naturally, measuring their distribution within sediment porewaters (the water surrounding the deposited sediment or tailings particles) yields a very sensitive indication of tailings reactivity as well as potential environmental impact.

The distribution of dissolved metals in porewaters has been determined by two proven approaches. Within the MEND projects, sampling of porewaters was accomplished utilizing the techniques of sediment coring and dialysis array (peeper). Sampling porewaters by core involves the collection of sediment with a specialized, light-weight, gravity corer. The porewaters are separated from the sediment solids by placing sequential slices of sediment into a centrifuge; the resulting fluid fraction is filtered and analysed for dissolved metals. Peepers sample porewaters much more passively. Peepers consist of an array of depressions or wells in a plexiglas plate. The wells are filled with ultra-pure water and covered with a filtration membrane. The peeper is inserted vertically into the sediments and allowed to equilibrate within the sediments for 10 to 14 days. During that period, dissolved metals move across the membrane into the sample wells while the solids are excluded. After 10 to 14 days, the water within the sample wells is chemically indistinguishable from that of the porewaters; the sample waters are removed from the wells and analysed for dissolved metals.

In order to avoid oxidizing the samples by allowing them to contact the atmosphere, all sample handling of both cores and peepers after collection is carried out in nitrogen-filled, plastic glove bags. Once the porewaters have been filtered (again, under nitrogen), they are "preserved" for subsequent analysis by the addition of a small amount of ultra-pure acid.

Chemical Manifestations of Dissolved Metals in Porewaters

Upon their formation, sediment porewaters are no more than lake water trapped between sediment particles; in the absence of chemical reactions, the composition of porewaters would be identical to the overlying lake water. If tailings are reactive and release dissolved metals to the environment, the most sensitive manifestation will be locally elevated concentrations of dissolved metals within shallow porewaters (*e.g.*, Figure 1(a)). Conversely, precipitation or consumption of dissolved metals is characterised by concentrations that decrease with depth (*e.g.*, Figure 1(b)).

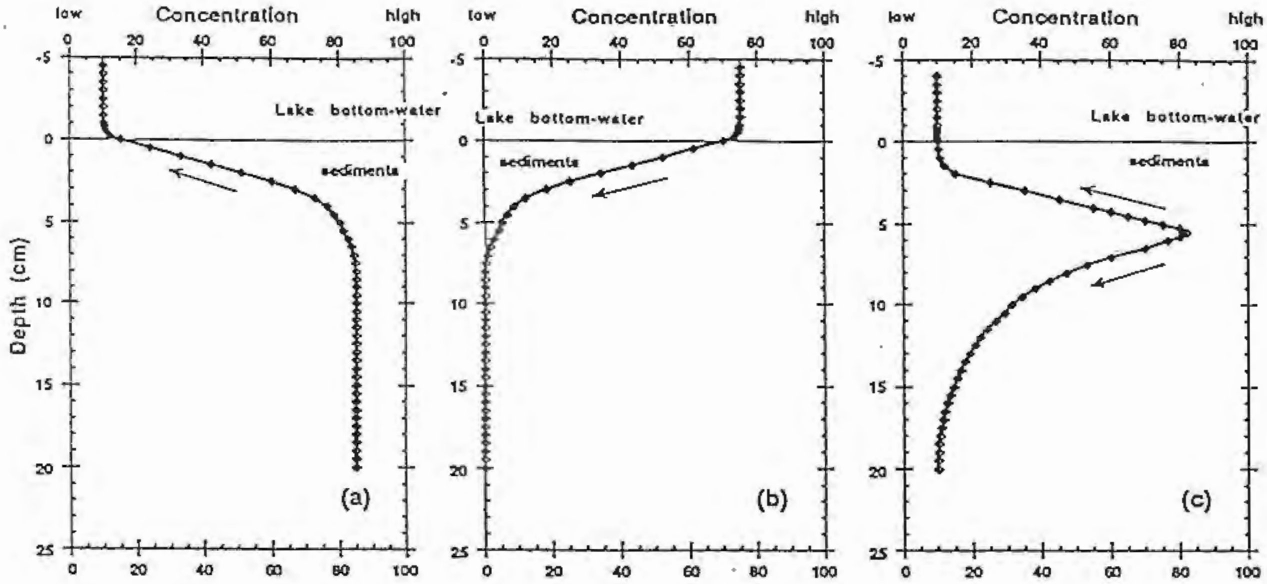

Figure 1 Three hypothetical concentration profiles for dissolved metals in the porewaters of tailings or natural sediments: (a) release of metal to pore solution. The arrow shows the gradient in concentration (from high to low) and the consequent direction of migration of dissolved metal ions; (b) consumption of dissolved metal by the deposits (*e.g.* via chemical precipitation). In this case, dissolved metals are diffusing into the lake floor; (c) subsurface release of metal to pore solution, with migration along the concentration gradients away from the zone of release, as shown by the arrows. Consumption below the peak concentration is indicated (*e.g.* via precipitation of a metal sulphide phase) as well as above the maximum which can occur when iron and/or manganese oxide particles present in the near-surface sediments adsorb upwardly migrating metal ions.

Release or consumption of dissolved metals results in the formation of adjacent zones of differing concentrations. The difference in dissolved metal concentration between a high and a low define a concentration *gradient* and results in net migration of dissolved metals from the zone of high concentration to the zone of low concentration. In sediments, this process occurs through the random motion associated with all dissolved molecules and is termed molecular diffusion. The amount of dissolved metals that migrates down a concentration gradient (from high to low concentration) is termed the flux and is proportional to the steepness of the gradient. In other words, a greater flux (*i.e.*, a greater transport of dissolved metals) occurs where a very high concentration is immediately adjacent to a very low concentration.

If a concentration gradient extends across the sediment-water interface, metals can be said to be diffusing out of or into the sediments (to or from lake water) depending on the direction of the gradient. Lower concentrations of dissolved metals in porewater relative to the overlying lake water indicates a flux of metals into the sediments from lake water (Figure 1(b)). Conversely, higher concentrations in porewaters than lake water infers a flux in the opposite direction (Figure 1(a)).

In the majority of the MEND project work undertaken thus far, metals have been observed to diffuse into the sediments from the overlying lake water. This has occurred in part because some of the lakes contained elevated concentrations of dissolved metals, but more importantly because of the natural tendency for sediments to create the environment stable to sulphides as discussed above. When sulphate is utilised as a oxidant in the decomposition of organic matter within the sediments, a natural by-product is hydrogen sulphide. Hydrogen sulphide is highly reactive with most dissolved metals (such as Cd, Cu, Hg, As, Mo, Ni, Fe, Pb, Zn and others) resulting in rapid precipitation of those metals as insoluble, solid metal sulphides. Because sulphate reduction (sulphide formation) typically occurs at shallow depths within sediments, there is a commensurate zone of localized metal consumption with the establishment of a dissolved metal concentration gradient from lake water into the sediments. The result is a flux or transport of dissolved metals into the surface sediments from the overlying lake water with the tailings acting as a sink for dissolved metals rather than a source. The concentration profile characteristic of such a case is shown in Figure 1(b).

In some instances, dissolved metals have been observed to be released from sediment solids to the porewaters. At first glance, this might suggest that the tailings are releasing dissolved metals to the overlying lake water, particularly if the concentration gradient extends to the sediment-water interface. However, there are several complicating factors that must be considered when such profiles are observed. First, several metals (such as Cd, Cu, and Zn) are released to near-surface porewaters naturally as they are often associated with organic matter - they are not tailings-derived. As the organic material decomposes or oxidizes, those associated metals are released in dissolved form and may indeed migrate back into the overlying lake water. This most commonly occurs in sediments where oxygen has not been sufficiently depleted (or more specifically, where sulphide precipitation is absent). Such release is a natural phenomenon and accounts for much of the natural cycling of certain trace metals in many natural environments. The second factor is that even though there may be some release of metals from tailings to porewaters in certain cases, a process referred to as *oxide blocking* or *oxide scavenging* can intercept much of the upward flux of those metals before the dissolved species cross the sediment-water interface into the lake water.

Such scavenging involves oxides of iron and manganese, two of the secondary oxidants discussed above. Where dissolved oxygen is present, Fe and Mn oxides exist as solids whose surfaces strongly adsorb many trace metals. When they are utilized in subsurface sediments as secondary oxidants in the absence of oxygen, they revert to dissolved Fe and Mn creating concentration gradients. As dissolved Fe and Mn diffuse upward toward the sediment-water interface, they eventually encounter dissolved oxygen and revert back to their original solid, oxide form. Iron and manganese oxides are both efficient in adsorbing a broad range of dissolved metal ions. Thus, their continuons formation in the near-surface sediments results in the establishment of an effective "blocking mechanism" that inhibits dissolved metals from entering the water column.

One final barrier to *all* metal release from tailings within lake sediments is time. The burial of tailings by natural sediments or more recently deposited tailings occurs progressively with time and has a profound effect on the ability of even the most reactive substances to affect lake water quality. As the dominant transport mechanism of dissolved metals in sediments is diffusion, and because mass transport by diffusion is effective only over short distances (*i.e.,* a few centimetres), accumulation of a relatively thin layer of sediments over an abandoned tailings deposit is sufficient to isolate tailings chemically from the water column. In this regard, subaqueous tailings disposal from a tailings reactivity stand-point is at worst a relatively short-term issue even though this "worst" condition has not as yet been observed. Nonetheless, once deposition has ceased and tailings have been buried by a few centimetres of natural sediment, they can for all intents and purposes be considered to be chemically secure for the foreseeable future.

Conclusions

This MEND project work to date has involved the study of tailings in natural lakes; little attention has been paid to the comparatively abiotic system of the man-made tailings ponds. This and future research will be directed toward such systems; however, several generalizations can be drawn from the MEND data which apply equally to both tailings ponds and natural lakes.

Firstly, the diminished concentration of oxygen dissolved in water is the single-most effective inhibitor to tailings oxidation; low concentrations of oxygen translate into low oxidation reaction rates. The presence of a permanent water cover not only minimizes the maximum concentration of oxygen to which the tailings may be exposed, but it also inhibits the rate at which that oxygen may be resupplied.

Secondly, even though tailings ponds are typically deplete in organic carbon, they still present conditions suitable to long-term storage of sulphide-rich material. Sulphide-bearing tailings themselves act as an analogue for natural sediments in that they progressively lower the concentration of oxidants, thus enhancing the potential for long-term stability.

Finally, time itself is an effective component in allowing the establishment of a physical barrier which prevents the release of metals to the overlying lake waters. The accumulation of a veneer of natural sediments (a few centimetres thick) effectively isolates the tailings. Subaqueous disposal is at worst a relative short-term risk that decreases with time to yield a stable, passive but effectively final control system.

GÉOCHIMIE : APERÇU

Introduction

Trouver un moyen tant respectueux de l'environnement qu'économique pour éliminer les déchets miniers sulfurés a été pendant des décennies un défi qu'ont tenté de relever l'industrie minière et le gouvernement. Vu le rôle critique que joue l'oxygène dans la production d'acide, les efforts pour résoudre le problème ont été axés sur l'élimination de l'oxygène comme agent de réaction. Par conséquent, la solution de la déposition subaquatique a découlé naturellement du principe selon lequel la production d'acide à partir de sulfures pourrait être éliminée par submersion dans l'eau où les concentrations d'oxygène sont beaucoup plus faibles que dans l'atmosphère. En d'autres termes, abaisser la concentration d'un des principaux agents de réaction (l'oxygène) permettrait de diminuer la vitesse d'oxydation, donc la vitesse de production d'acide et de métaux dissous. Ce principe s'appuyait sur les caractéristiques chimiques bien connues des plans d'eau naturels et des sédiments.

Quoique fondée sur des principes théoriques valables, la déposition subaquatique s'est avérée avant les années 1980 d'une efficacité très douteuse, n'étant recommandée que par quelques études scientifiques limitées. Faute de données pertinentes, une série de projets ont été mis sur pied dans le cadre du groupe de travail sur le drainage minier acide de la Colombie-Britannique (BCARD) et du programme NEDEM et ont comporté des travaux de terrain sur une série de lacs dans lesquels des résidus miniers avaient été déversés (lacs Anderson et Mandy au Manitoba; lacs Buttle et Benson en Colombie-Britannique). Le programme a fait intervenir diverses techniques d'échantillonnage, d'analyse et d'interprétation de pointe permettant de mesurer directement la réactivité et la stabilité chimique à court et long termes des dépôts submergés de résidus miniers. En outre, des questions auxquelles devaient permettre de répondre le projet, les auteurs ont écarté temporairement celles portant sur les nombreux aspects biologiques complexes pour se concentrer sur le milieu géochimique. Il a été résolu qu'une fois la réactivité des résidus submergés bien évaluée, et les phénomènes géochimiques cernés, les questions biologiques pourraient être abordées dans un contexte mieux défini et sur une base de projets particuliers.

Les résultats des travaux ont confirmé l'hypothèse selon laquelle les résidus miniers sulfurés sont très peu réactifs chimiquement lorsqu'ils sont submergés. Les rares fois que des métaux dissous ont été libérés, des phénomènes chimiques secondaires au sein des sédiments ont retardé leur libération dans la colonne d'eau.

L'aperçu qui suit vise à résumer les rapports NEDEM et à décrire dans l'ensemble les systèmes géochimiques qui contribuent à l'efficacité de la déposition subaquatique.

Contexte chimique

L'instabilité ou la réactivité des sulfures métalliques tient à leur mode de formation. Les sulfures se forment dans des milieux réducteurs (en l'absence d'oxygène). Par conséquent, ils sont instables et peuvent réagir chimiquement dans un milieu riche en oxygène telle la surface de la terre. Ainsi, le milieu le plus stable où stocker des résidus miniers sulfurés est un milieu exempt d'oxygène, qui se rapproche du milieu de leur genèse.

Les systèmes submergés offrent en première approximation les conditions de stabilité recherchées pour les sulfures, non pas parce qu'ils sont exempts d'oxygène (en fait, ils renferment le plus souvent des quantités mesurables d'oxygène dissous), mais plutôt parce qu'ils contiennent de faibles concentrations d'oxygène, même à l'état saturé. La concentration maximale d'oxygène dissous dans les eaux naturelles est environ 25 000 fois inférieure à la teneur de l'atmosphère. Comme la vitesse d'oxydation des sulfures dépend en partie de la concentration d'oxygène, il ressort que la production d'acide et de métaux dissous sera minimale sous l'eau. En outre, une fois que le peu d'oxygène dissous dans l'eau est consumé, il est en général remplacé très lentement par diffusion moléculaire et par turbulence à petite échelle; le passage de l'oxygène dans l'eau se fait près de 10 000 fois plus lentement que dans l'air. Par conséquent, le stockage sous une couverture aqueuse permanente est peut-être le seul moyen vraiment efficace pour empêcher les résidus miniers sulfurés de produire de l'acide.

Les sédiments constituent pour les minéraux sulfurés un milieu encore plus stable qu'une couverture aqueuse, en partie à cause de leur faible concentration d'oxygène dissous, mais aussi à cause de leur tendance naturelle à devenir chimiquement réducteurs. Pour comprendre pourquoi les sédiments constituent un milieu propice au stockage des résidus miniers sulfurés, il faut d'abord décrire certains phénomènes chimiques qui se produisent dans ce milieu.

Les sédiments naturels contiennent en général une gamme d'éléments allant de roches et de sols érodés d'origine locale à des substances uniques qui se sont formées dans les dépôts. Toutefois, de tous les éléments contenus dans les sédiments naturels, les vestiges de plantes et d'animaux (matière organique) sont peut-être les plus importants car ils sont considérés comme le combustible de presque toutes les réactions chimiques qui se produisent après leur dépôt. Il en est ainsi parce que la matière organique (comme les sulfures) est instable en présence d'oxygène; elle tend naturellement à se décomposer en ses éléments constituants (essentiellement des molécules simples contenant du carbone, de l'azote, du phosphore, du soufre et de l'hydrogène). En d'autres termes, la matière organique se consume ou réagit en présence d'oxygène, et se transforme en dioxyde de carbone et en une série de sous-produits biologiques simples. Cette réaction est accélérée par la présence d'une panoplie d'espèces bactériennes qui catalysent la réaction pour en tirer de l'énergie pour leurs propres besoins. Comme la concentration d'oxygène dans les eaux naturelles est faible au départ, il arrive souvent qu'elle diminue rapidement à rien dans les couches superficielles de sédiments. Lorsqu'il n'y a plus d'oxygène pouvant réagir avec la matière organique, les bactéries jettent leur dévolu sur les oxydants secondaires : les nitrates d'abord, puis les oxydes de Mn et de Fe, les sulfates et le dioxyde de carbone; lorsqu'un oxydant secondaire est épuisé (p. ex. les nitrates), les bactéries se ruent sur le suivant (l'oxyde de Mn) jusqu'à ce qu'elles les aient tous consumés. La consommation des sulfates est très importante parce que le sous-produit de la réaction entre un sulfate et la matière organique (en l'absence d'oxydants plus attrayants) est le sulfure d'hydrogène, analogue aux minéraux métalliques sulfurés. Ainsi, les sédiments tendent naturellement à créer des conditions dans lesquelles les sulfures se forment naturellement et les résidus sulfurés des mines sont les plus stables dans de telles conditions.

Méthodes d'examen

Il existe deux principales méthodes pour évaluer si des résidus sulfurés réagissent ou libèrent de l'acide et des métaux en milieu submergé. La première est l'observation microscopique ou pétrographique directe des particules de résidus submergés. Jusqu'à ce jour, chaque fois qu'on a étudié des résidus sulfurés submergés, aucun indice d'oxydation n'a été relevé. Il existe toutefois une méthode bien plus sensible, efficace et élégante, qui consiste à rechercher les effets directs de l'oxydation des sulfures comme une chute du pH, une augmentation de la concentration de sulfate ou l'indicateur le plus direct, une augmentation de la concentration des métaux dissous. Comme les métaux dissous sont les paramètres qui nous intéressent sur le plan environnemental et que leur concentration est naturellement très faible, leur répartition dans les eaux interstitielles des sédiments (eau entourant les particules de sédiments ou les résidus déposés) donne des indications très détaillées sur la réactivité des résidus et leurs effets possibles sur l'environnement.

La répartition des métaux dissous dans les eaux interstitielles a été établie par deux méthodes. Dans les projets NEDEM, les eaux interstitielles ont été échantillonnées par les techniques du carottage des sédiments et de l'échantillonnage par dialyse. Le carottage des eaux interstitielles consiste à prélever des sédiments au moyen d'un appareil léger de carottage par gravité. Les eaux interstitielles sont séparées des matières sédimentaires par centrifugation de tranches séquentielles de sédiments; la fraction liquide résultante est filtrée et soumise à l'analyse des métaux dissous. Le plateau de dialyse permet d'échantillonner beaucoup plus passivement les eaux interstitielles. Il s'agit d'un plateau de plexiglas portant un réseau de dépressions ou de puits. Les puits sont remplis d'eau très pure et recouverts d'une membrane filtrante. Le plateau est plongé verticalement dans les sédiments pendant 10 à 14 jours jusqu'à ce l'équilibre avec les sédiments soit atteint. Pendant cette période, la membrane laisse passer les métaux dissous dans les puits tout en bloquant les matières solides. Au bout de 10 à 14 jours, l'eau dans les puits d'échantillonnage est identique aux eaux interstitielles; l'eau d'échantillonnage est retirée des puits et soumise au dosage des métaux dissous.

Pour ne pas que les échantillons s'oxydent en entrant en contact avec l'atmosphère, toutes les opérations de manipulation des carottes et des plateaux de dialyse après le prélèvement se font dans des sacs à gants en plastique remplis d'azote. Une fois les eaux interstitielles filtrées (toujours sous azote), elles sont «conservées» pour analyse ultérieure par l'addition d'une petite quantité d'acide très pur.

Manifestations chimiques des métaux dissous dans les eaux interstitielles

Quand elles se forment, les eaux interstitielles des sédiments ne sont que de l'eau du lac piégée entre les particules de sédiment; en l'absence de réactions chimiques, la composition des eaux interstitielles serait identique à celle des eaux lacustres sus-jacentes. Si les résidus sont réactifs et libèrent des métaux dissous dans l'environnement, la manifestation la plus critique de ces derniers est la présence par endroits de concentrations élevées de métaux dissous dans les eaux interstitielles à faible profondeur (voir figure 1 a)). Par contre, la précipitation ou la consommation de métaux dissous est caractérisée par des concentrations qui diminuent en fonction de la profondeur (voir figure 1 b)).

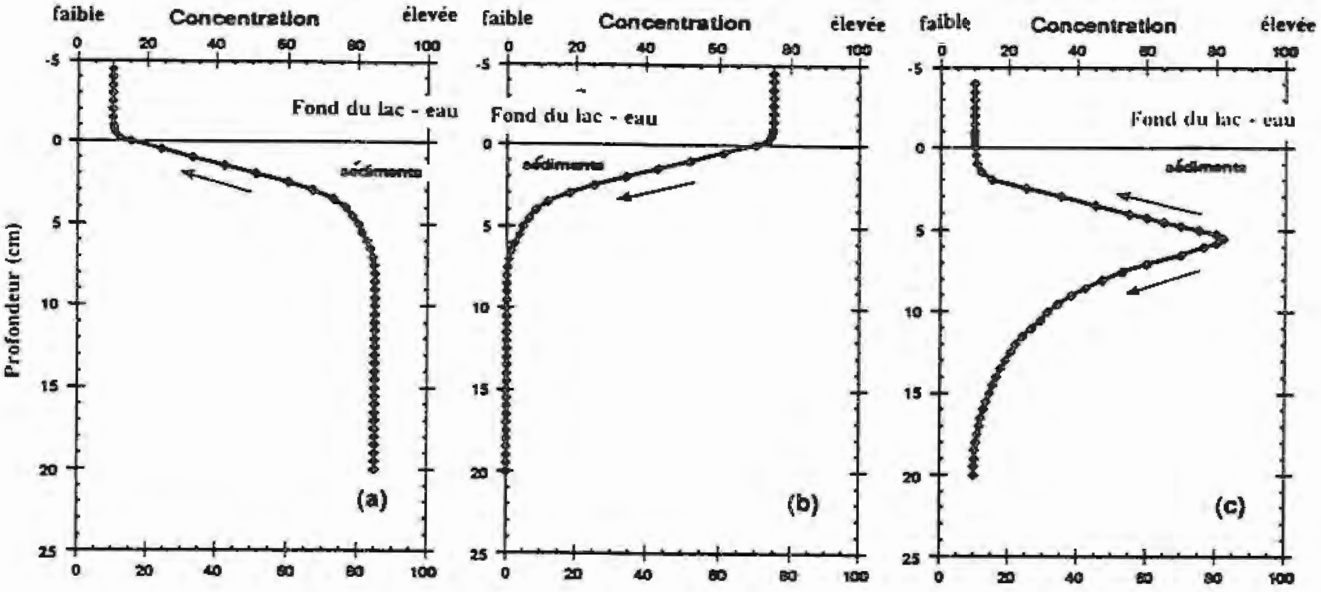

Figure 1

Trois profils théoriques de concentration des métaux dissous dans les eaux interstitielles des résidus ou des sédiments naturels : a) libération de métal dans la solution interstitielle. La flèche indique le gradient de concentration (d'élevée à faible) et donc la direction de migration des ions de métal dissous; b) consommation de métal dissous par les dépôts (p. ex. par précipitation chimique). Dans ce cas, les métaux dissous diffusent dans le fond du lac; c) libération de métal de sub-surface dans la solution interstitielle, avec migration le long des gradients de concentration en s'éloignant de la zone de libération, comme l'indiquent les flèches. La consommation est indiquée au-dessous de la concentration maximale (p. ex. par précipitation d'une phase de sulfure de métal) ainsi qu'au-dessus du maximum, ce qui peut arriver lorsque les particules d'oxyde de fer et/ou de manganèse présentes dans les sédiments près de la surface absorbent les ions métalliques migrant vers le haut.

La libération ou la consommation de métaux dissous entraîne la formation de zones adjacentes de concentrations différentes. L'écart entre une concentration élevée et une concentration faible de métaux dissous définit un *gradient* de concentration et produit une migration nette de métaux dissous de la zone de concentration élevée vers la zone de concentration faible. Dans les sédiments, ce phénomène se produit au hasard du mouvement de toutes les molécules dissoutes et s'appelle la diffusion moléculaire. La quantité de métaux dissous qui migrent le long d'un gradient de concentration (vers une concentration plus faible) s'appelle le flux et est proportionnelle à la grandeur du gradient. En d'autres termes, le flux est plus grand (plus de métaux dissous sont transportés) lorsqu'une zone de très forte concentration jouxte une zone de très faible concentration.

Si un gradient de concentration traverse l'interface sédiments-eau, on peut dire que les métaux diffusent à l'extérieur ou à l'intérieur des sédiments (depuis ou vers l'eau du lac) selon la direction du gradient. Si la concentration de métaux dissous dans les eaux interstitielles est plus faible que dans l'eau du lac sus-jacente, le flux de métaux se déplace des sédiments vers l'eau du lac (figure 1 b)). Par contre, si la concentration est plus élevée dans les eaux interstitielles que dans l'eau du lac, le flux se déplace dans le sens opposé (figure 1 a)).

Dans la majorité des projets NEDEM menés jusqu'à ce jour, on a observé que les métaux diffusent de l'eau du lac sus-jacente vers les sédiments. Cela s'est produit en partie parce que certains lacs contenaient des concentrations élevées de métaux dissous, mais surtout parce que les sédiments ont naturellement tendance à créer un milieu stable pour les sulfures comme il a été dit plus haut. Lorsque du sulfate agit comme oxydant dans la décomposition de la matière organique des sédiments, il en résulte un sous-produit naturel, le sulfure d'hydrogène. Ce dernier réagit promptement avec la plupart des métaux dissous (Cd, Cu, Hg, As, Mo, Ni, Fe, Pb, Zn, etc.), faisant précipiter rapidement ces derniers sous forme de sulfures solides insolubles. Comme la réduction du sulfate (en sulfure) se produit en général à faible profondeur dans les sédiments, il s'établit une zone finie de consommation localisée de métaux en présence d'un gradient de concentration des métaux dissous qui va de l'eau du lac vers les sédiments. Il en résulte un flux ou un transport de métaux dissous vers les sédiments de surface à partir de l'eau du lac sus-jacente, et les résidus agissent comme un puits plutôt que comme une source de métaux dissous. La figure 1 b) indique un profil de concentration type dans un tel cas.

Il est parfois arrivé que des métaux dissous ont été libérés par des matières sédimentaires dans les eaux interstitielles. À première vue, on pourrait croire que les résidus libèrent des métaux dissous dans l'eau du lac sus-jacente, surtout si le gradient de concentration traverse l'interface sédiments-eau. Il faut toutefois tenir compte de plusieurs facteurs qui compliquent les choses lorsque de tels profils sont observés. Premièrement, plusieurs métaux (p. ex. Cd, Cu et Zn) sont libérés naturellement dans les eaux interstitielles près de la surface, car ils sont souvent associés à la matière organique et ne proviennent pas des résidus. Lorsque la matière organique se décompose ou s'oxyde, les métaux en question sont libérés sous forme dissoute et peuvent en fait retourner dans l'eau du lac sus-jacente. Cela se produit surtout dans les sédiments quand l'épuisement de l'oxygène est incomplet (ou plus particulièrement en l'absence de précipitation de sulfure). Il est naturel que des métaux soient ainsi libérés : cela explique en grande partie le cycle de certains métaux à l'état de traces dans de nombreux milieux naturels. Deuxièmement, même s'il y a parfois libération de métaux des résidus vers les eaux interstitielles, un phénomène appelé *blocage par les oxydes* ou *piégeage par les oxydes* peut diminuer en grande partie le flux vers le haut de ces métaux avant que les espèces dissoutes franchissent l'interface sédiments-eau et passent dans l'eau du lac.

Un tel piégeage fait intervenir des oxydes de fer et de manganèse, deux des oxydants secondaires susmentionnés. En présence d'oxygène dissous, les oxydes de Fe et de Mn sont à l'état de solides dont les surfaces adsorbent solidement les métaux à l'état de traces. Lorsqu'ils sont mis à contribution dans les sédiments sous la surface comme oxydants secondaires en l'absence d'oxygène, ils se retransforment en Fe et Mn dissous, établissant des gradients de concentration. Lorsque le Fe et le Mn diffusent vers l'interface sédiments-eau, ils entrent tôt ou tard en contact avec de l'oxygène dissous et reprennent leur forme originale d'oxydes solides. Les oxydes de fer et de manganèse adsorbent efficacement une vaste gamme d'ions métalliques dissous. La production constante de ces oxydes dans les sédiments près de la surface constitue donc un «mécanisme de blocage» efficace qui empêche les métaux dissous d'entrer dans la colonne d'eau.

Le temps est une dernière barrière contre *toute* libération de métaux par les résidus se trouvant dans des sédiments lacustres. L'enfouissement de résidus sous des sédiments naturels ou une couche plus récente de résidus se fait progressivement dans le temps et a un effet déterminant sur la capacité des substances réactives, même les plus réactives, d'altérer la qualité des eaux du lac. Comme la diffusion est le principal mécanisme de transport des métaux dissous dans les sédiments et que le transport massif par diffusion n'est efficace que sur de courtes distances (quelques centimètres), il suffit qu'une couche relativement mince de sédiments s'accumule sur les résidus abandonnés pour isoler chimiquement ces derniers de la colonne d'eau. À cet égard, la déposition subaquatique des résidus, sur le plan de la réactivité de ces derniers, est au pire une question à relativement court terme même si aucun «pire» cas de la sorte n'a encore été observé. Néanmoins, une fois la déposition terminée et les résidus submergés et enfouis sous quelques centimètres de sédiments naturels, ils peuvent à toutes fins être considérés comme chimiquement sûrs dans un avenir prévisible.

Conclusions

Le projet NEDEM a consisté jusqu'à ce jour à étudier le comportement des résidus dans des lacs naturels; on s'est peu penché sur les conditions relativement abiotiques des parcs à résidus

Premièrement, la concentration réduite d'oxygène dissous dans l'eau est le principal inhibiteur d'oxydation des résidus; plus la concentration d'oxygène est faible, plus la vitesse d'oxydation est faible. Non seulement la présence d'une couverture d'eau permanente réduit au minimum la concentration maximale d'oxygène auquel les résidus pourraient être exposés, mais elle diminue aussi la vitesse de renouvellement de cet oxygène.

Deuxièmement, même si les parcs à résidus sont général exempts de carbone organique, ils offrent encore des conditions propices au stockage à long terme des matières riches en sulfures. Les résidus sulfurés eux-mêmes se comportent comme des sédiments naturels en ce qu'ils abaissent progressivement la concentration d'oxydants, favorisant ainsi leur stabilité à long terme.

Enfin, le temps est en soi un moyen efficace pour que s'établisse une barrière physique qui empêche que des métaux soient libérés dans les eaux lacustres sus-jacentes. L'accumulation d'une couche de sédiments naturels (quelques centimètres) permet d'isoler efficacement les résidus. La déposition subaquatique présente au pire un risque à relativement court terme qui diminue dans le temps jusqu'à ce s'établisse une barrière finale stable, passive, mais efficace.

1.0 INTRODUCTION

Well established diagenetic cycles of many trace elements and organic matter, in concert with a growing body of data, indicate that the limited presence of oxygen found in subaqueous settings inhibits tailings oxidation and the concomitant generation of acidity and dissolution of trace metals. Thus, present-day considerations for long-term disposal of sulphide-rich mine tailings are increasingly focusing on subaqueous storage in marine and lacustrine settings over the more conventional terrestrial impoundments. This evolution has occurred not for short-term economical benefits (for which it has transpired historically) but rather because research suggests that such a mode of deposition results in greater long-term chemical stability of potentially reactive sulphide tailings (Pedersen *et al.* 1993; Rescan 1991).

The probability that subaqueous deposition will prove to be an environmentally acceptable technology has inspired the completion of a series of geochemical surveys related to subaqueous tailings deposits. Collectively, these surveys were designed to broaden the geochemical database as well as help dispel misconceptions regarding subaqueous disposal replacing speculation with scientific fact.

Although the ultimate goal of such research is to facilitate accurate predictions of long-term stability of lacustrine tailings deposits, it is first necessary to acquire a high degree of understanding of the chemical behaviour of these materials in various environmental settings. Thus, the initial MEND (the Mine Environment Neutral Drainage program) surveys focused on the collection of data from actively accumulating, as well as abandoned, subaqueous tailings deposits in an attempt to monitor both short and long-term chemical stability of such material under differing depositional regimes.

Following the initial suite of surveys (which included Anderson Lake, Mandy Lake, Buttle Lake and Benson Lake), the reports were sent for critical peer review by a respected, credible scientific authority. The Rawson Academy of Science was given the mandate to scrutinize the work, and to suggest what aspects might be addressed in future work to further strengthen the research program.

While the Rawson Academy review deemed the work of high calibre, several possible improvements to the program were suggested.

1. Additional confidence from an analytical perspective should be fostered through a more rigorous quality assurance/quality control (QA/QC) protocol; it was suggested that 20% of the project resources focus on QA/QC.
2. While many different depositional regimes were studied in the previous work, little attention was focused on reproducibility. Small scale variability should be addressed by collecting samples from immediately adjacent sites.
3. Although cores had been collected at various times of the year, seasonal effects had not been addressed specifically; a more rigorous seasonal sampling regime was suggested.
4. Most of the previous work had been performed in the deepest, most stable areas of the lakes. The less stable shallows, where tailings may be reworked and re-exposed over longer (decade) time scales had been overlooked. Sampling of such deposits was recommended.
5. While the geochemistry had been addressed very well, little to no attention had been afforded the biological aspects. More extensive biological surveys were recommended.

Based on the recommendations of the Rawson review, MEND Project 2.11 was founded. The MEND Project 2.11 Planning Committee decided to focus on long-term geochemical studies in Anderson Lake, Manitoba and Buttle Lake, British Columbia. Geochemical surveys were designed not only to address the issues outlined by the Rawson Academy review, but also to enhance the utility of the available data while maintaining scientific credibility. Thus, MEND Project 2.11 not only attempted to firm the foundation of data on which informed decisions could be made but it also strived to bridge the gap between a passive understanding of relict deposit reactivity and the more proactive approach of predicting the chemical behaviour of future deposits.

This report focuses on the two geochemical surveys performed in Anderson Lake, Manitoba, during April and July of 1993; it targets the specific issues raised by the Rawson Academy and others, with one notable exception. It is recognized that biological aspects of such work are critical to a comprehensive picture; indeed, biological implications are the ultimate reason for which this work was performed. However, given the complexity of biological systems in concert with the many unknowns that remain in the geochemistry, the biological components of this work were postponed to future surveys where they could be based on a firm geochemical foundation.

1.1 Scope of Work

The two surveys performed in Anderson Lake were identical in most respects. Both surveys involved sampling of the water column with a custom-designed *in situ* water column sampler as well as sampling of the sediments and associated porewaters by core extrusion and centrifugation. However, the deployment of membrane dialysis arrays (peepers) was added to the scope of the Summer Survey to better address trace metal fluxes across the sediment-water interface. Additionally, the National Water Research Institute (NWRI) collaborated on the Summer Survey deploying independently prepared peepers to enhance the field QA/QC component. Details of the individual surveys are discussed in Section 2.2.

2.0 STUDY AREA AND METHODS

2.1 Study Area

Anderson Lake, a small (0.5 km wide by 6.3 km long), shallow (average depth 2.1 m) Precambrian Shield lake, is located in northwest Manitoba near the township of Snow Lake (Figure 2-1). Anderson Lake is mesotrophic to eutrophic and hosts natural sediments rich in organic matter (20 to 30% organic carbon by weight). However, the lake has historically supported few fish and is not used recreationally; local perception is that Anderson Lake is "dead."

2.1.1 Historical Overview

Prior to 1979, Anderson Lake was used solely as a source of water for the adjacent Anderson mine. Since that time, it has served as a depository to mine tailings produced by the Snow Lake mill operated by Hudson Bay Mining and Smelting Co. Ltd. Over the years, the mill (rated at 3,450 mtpd) has served seven local mines, processing a Cu-Pb-Zn ore, and producing tailings rich in sulphide and silicate gangue minerals (mostly quartz and feldspar with minor amounts of hornblende, epidote, chlorite and carbonates; Rescan 1990). The sulphide portions consist mostly of pyrite with accessory pyrrhotite; framboidal pyrite also occurs in trace amounts but is associated with organic matter in the lake (Rescan 1991).

Between 1979 and 1990, approximately 8 million tonnes of tailings were deposited into the lake via surface discharge through a floating, movable, Sclair pipe 30 cm in diameter. The pipe location has moved frequently to avoid excessive accumulation of tailings in any one area but generally discharge has occurred to deeper waters in winter and shallower waters in summer.

Anderson Lake itself has been described as land-locked, receiving minimal input from runoff (some of which is derived from the mine area), swamp drainage and precipitation. Of particular importance is drainage from the northern shore of the lake where tailings were used to build an access road in the late 1970s. Drainage from the road is acidic, and has a visible negative impact on adjacent vegetation. It also significantly influences lake water quality. For example, drainage samples collected by mine personnel on July 8, 1993 from the Pumphouse and Backfill

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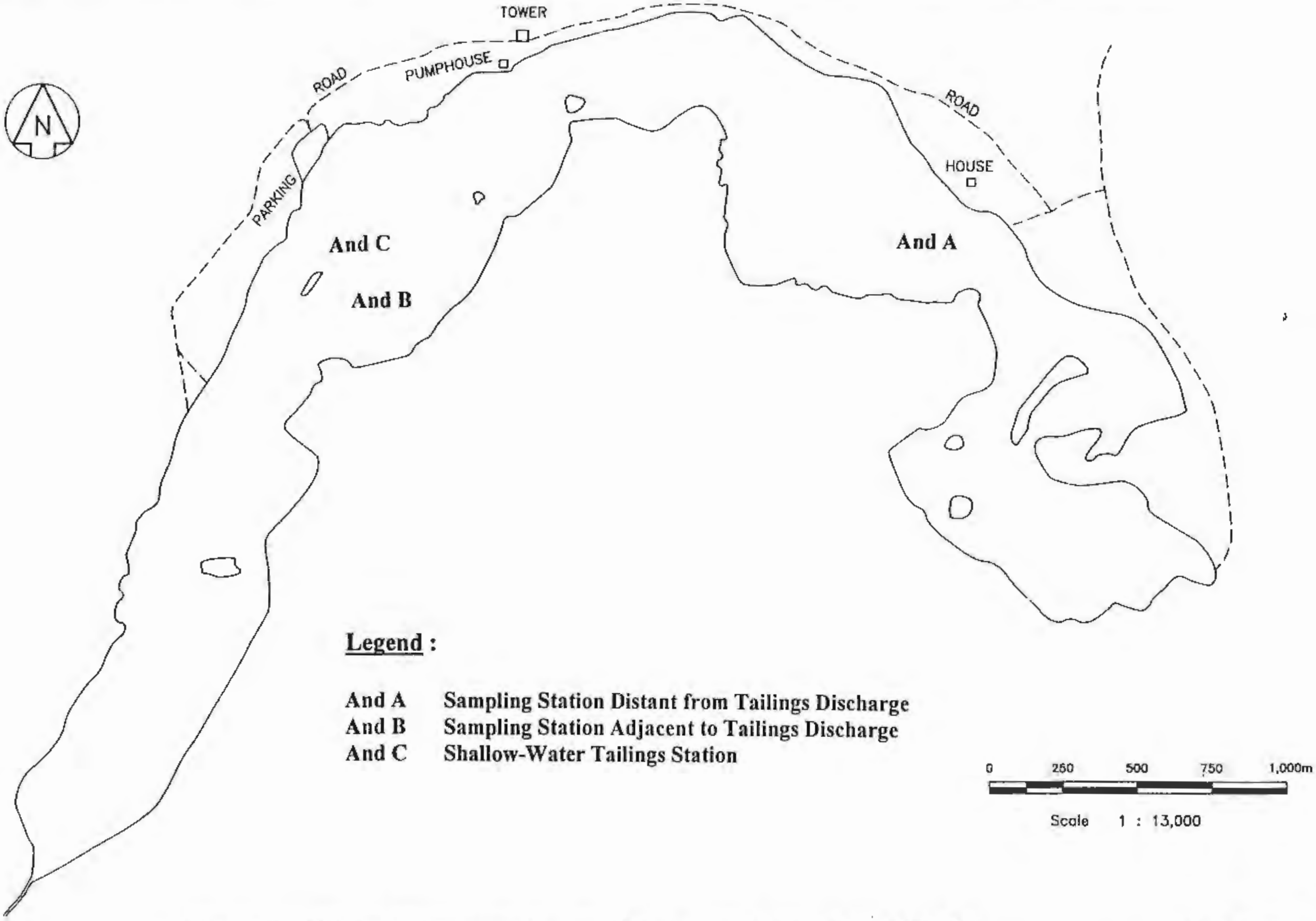

Figure 2-1 Winter and Summer Survey Stations - Anderson Lake, Manitoba

Rescan

Fig 2-1

culverts near the north shore of the lake contained 18 to 20 mg/L Zn, 4-6 mg/L Cu and had a pH of 3. Drainage from the adjacent unused mine area registered Zn concentrations up to 96 mg/L, Cu contents up to 30 mg/L and pH levels as low as 2.7. Prior to closure in 1988, Anderson mine shaft waters were directed to the lake; one set of typical samples collected in 1984 had a pH of ~3 and contained up to 23 mg/L Zn and 1,140 mg/L SO_4^{2-}.

The tailings do not contribute high levels of dissolved metals to Anderson Lake in the discharge, although they are a sulphate source; for example, a sample of the tailings slurry collected from the outflow as it exited the mill in April, 1993 contained 1,190 mg/L SO_4^{2-}, but only 0.007 mg/L dissolved Zn and 0.015 mg/L Cu. The tailings leaving the mill are typically highly alkaline, as the circuits are run at pH > 10. However, the discharge into the lake from the floating pipeline consists of the tailings slurry plus acidic, metal-rich waters pumped from two other mines. The mixed discharge to the lake therefore may act as a direct source of dissolved metals, in addition to the culverted drainage along the north shore. The dissolved metal content in the discharge will depend largely on the degree to which the metals in the added acidic waters are precipitated as hydroxides when the solutions are neutralized by the alkaline tailings.

To combat the low pH that occasionally develops in the lake, the mine has added 50% NaOH solution periodically to the central area of the basin since 1986. The caustic is added by pouring the solution from 45 gallon drums set on the end of the moving pontoon barge when the lake is ice free. About 22,000 litres of caustic were added in this way during the period July 1993 to March 1994. Of this total, about 13,000 litres were added during between August 10 and 15, 1993, just after the summer survey had been completed.

One other aspect of Anderson Lake chemistry warrants mention. An HBM&S memorandum dated May 25, 1982, in which the dissolved oxygen content of the lake water during the period of ice cover is discussed, notes that a slight to very strong H_2S smell was observed in water near the Anderson Dam discharge from late January until ice-out in mid-May, 1982. These observations strongly suggest that anoxia prevailed in the water column during that period.

2.1.2 Station Locations

Two stations were occupied through the course of the study on Anderson Lake; one proximal to tailings discharge (Station B) and one at a distal site dominated by natural sediments (Station A). A third station was sampled during the summer survey for sediment geochemistry at a shallow-water site where tailings were within one m of the lake surface (Station C) (Figure 2-1). No water column work was performed at this very shallow site.

2.2 Methods

A number of field sampling methods were employed to collect uncompromised samples from Anderson Lake sediments and water-column; they are outlined below.

2.2.1 Water column sampling

Three sampling modes were utilized to gather information about the water-column of Anderson Lake. Discrete, high-resolution samples were collected by peristaltic pump and *in situ* sampler; diurnal temperature and dissolved oxygen were measured by remote profiling; and seasonal temperature evolution was monitored by sediment and water-column thermistor arrays.

Water-Column Sampler

The *in situ* water column sampler consisted of a clear, segmented acrylic pipe (10 inch diameter) long enough to extend to the water surface (~3 m in length; Plate 2-1). At the base of the sample was an acrylic plate and spike designed to rest on the sediment-water interface, facilitating a stable deployment of the sampler (Plate 2-2). Above the base plate, holes were drilled at 5 cm intervals immediately above the proposed interface, decreasing in resolution to 50 cm near the top the sampler. Through each hole, a polyethylene quick-fit connector was affixed. On the inside, acid-washed low density polyethylene (LDPE) tubing was attached and threaded through the pipe to the open end at the top. To the sampling port on the outside of the pipe was attached an acid-washed polypropylene pipette-tip (~8 cm long) with ~25 laterally positioned holes designed to act as an "infuser" (Plate 2-2). Its purpose was to minimize the vertical zone of influence on the water column during sample collection.

Plate 2-1: ***In situ*** **water column sampler utilized in the Anderson Lake Surveys.**

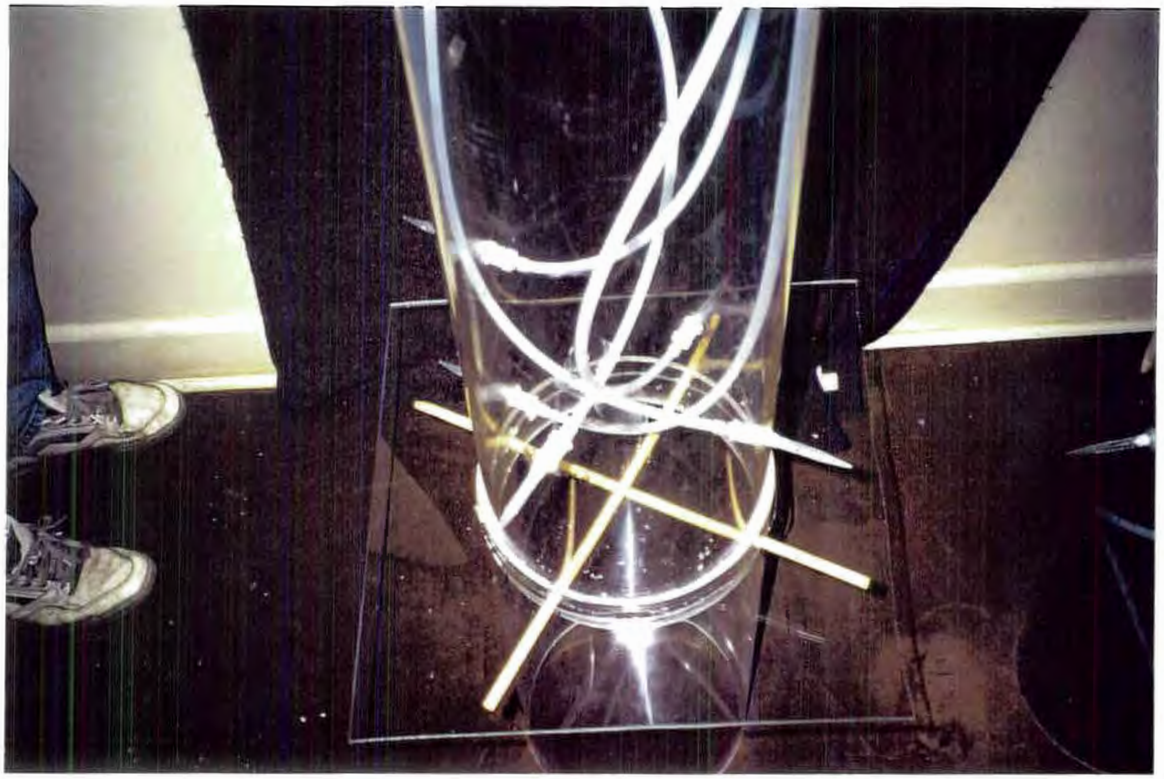

Plate 2-2: ***In situ*** **water column sampler base plate and sample ports.**

Deployment of the sampler during the winter survey took place through a hole in the ice. A 30 to 60 cm diameter hole was augered into the ice, through which the assembled water-column sampler was lowered. The sampler was constructed such that when deployed, the top was within a few centimetres of the lake surface. As the ice was 60 to 90 cm thick, such a deployment facilitated sampler stability as the sampler was anchored at the bottom by a spike and at the top by a "collar" of ice. Summer deployment was modified to account for the absence of stability provided by the ice. Stability was increased by enlargement of the stabilizing spike at the base of the sampler in addition to the use of three guyed lines running from the top of the sampler to 10 kg weights on the lake floor. Sampler installation was aided by scuba divers and a pontoon boat (Plate 2-1). During both surveys, the sampler was allowed to sit undisturbed for 24 to 48 hours prior to sampling to allow the water column to return to its original state.

Samples were collected by attaching the tubes of a multi-channel peristaltic pump (powered by portable generator) to the free sample lines at the top of the water-column sampler. Lake water was pumped directly into a nitrogen-filled glove bag where sub-samples were apportioned to various sample bottles. During the winter survey, the glove-bag was situated on a table on the ice immediately adjacent to the sampling hole. During the Summer Survey, sampling was accomplished from a pontoon boat moored adjacent to the sampler, using three separate anchors to ensure lateral stability (Plates 2-3 and 2-4). In both sampling regimes, lake water was pumped for a duration sufficient to flush the lines prior to sub-sample collection.

Sub-samples of unfiltered water column were collected for total metals, dissolved salts and total organic carbon (TOC), and stored in acid-washed polyethylene bottles except for TOC which was stored in 60 mL glass ampoules. Filtered water samples (< 0.45μm) were apportioned to four fractions:

1. dissolved metals - preserved acidified (pH 2.0) with ultra-pure HNO_3;
2. nutrients (NO_3^-, PO_4^{3-} as well as SO_4^{2-}) and pH, preserved frozen;
3. dissolved organic carbon (DOC) preserved refrigerated in glass bottles; and
4. $\sum H_2S$ - preserved with Zn-acetate.

Plate 2-3: Water column sampling during the Anderson Lake Winter Survey.

Plate 2-4: Water column sampling during the Anderson Lake Summer Survey.

Water-Column Profiling

Temperature measurements of the water column were deemed impossible to collect using samples pumped through the *in situ* water column sampler; the passage of lake water through the sampler tubing was expected to alter its temperature. Additionally, the shallow nature of Anderson Lake precluded the use of a relatively large CTD. As a result dissolved oxygen (DO) and temperature profiles were measured at each station on each survey with a YSI Model 58 dissolved oxygen meter and probe.

Profiles were collected by lowering the probe to an appropriate depth and allowing the electrode and thermistor to equilibrate before recording the readings and moving on to the next depth. Profiles were performed commensurate with water column sampling in order to temporally match the data. During the Winter Survey, this was accomplished by profiling through a hole in the ice ~5 m from the *in situ* water column sampler. During the Summer Survey, profiling occurred from the opposite end of the pontoon boat with respect to the water column sampler; as in the Winter Survey, Summer Survey profiling was performed ~5 m away to minimally influence the water column in the immediate vicinity of the sampler. Temperature and DO profiles were also collected through the night in the Summer Survey alone in order to monitor any diurnal fluctuations in temperature or oxygen. In all cases, the oxygen electrode was calibrated in the field while the temperature probe was calibrated in the lab with an accurate mercury thermometer; temperature measurements were always within ± 0.1°C.

Thermistor Strings

Preliminary data from the Winter Survey indicated that Anderson Lake did not respond to annual heating and cooling in the traditional "limnological" sense. It was suspected (based on isothermal temperature profiles) that Anderson Lake was salt-stratified and that lake turn-over was driven by wind-induced mixing after ice-out rather than from a break-down of thermal stratification. This issue, in addition to concerns of the Rawson Academy that the shallow-water tailings could (through cooling of the water column), induce thermal advection of the interstitial waters, gave rise to the use of thermistor arrays. Two strings of thermistors were deployed (one set of eight deployed vertically through the water column; another set of eight across the sediment-water interface) at Station B to monitor the temperature evolution of the water column and sediments of Anderson Lake.

The water column array was maintained by surface float and anchor. Thermistors were attached to acrylic plates which were in turn secured to the mooring hydrowire (Plate 2-5). Thermistor leads ran down the cable to a data logger laying on the mooring weight on the lake floor. The thermistors of the sediment array were supported by insertion into laterally-drilled holes in a PVC rod ~30 cm in length (Plate 2-6). The rod and thermistors were inserted by diver into the tailings until the sediment-water interface eclipsed the portion of the rod yielding the best distribution of thermistors across the interface.

High-temporal resolution data (sampling every 2 hours) from both arrays were collected from mid August to mid October of 1993 at which point the data was down-loaded, batteries changes and water-column array shortened in preparation for lake freeze-up. The data loggers were then configured for a lower sampling resolution (every 8 hours) in order to collect data throughout the under-ice conditions (mid October to mid April). Only the pre-winter data is available for this report.

2.2.2 Coring (Winter and Summer Surveys)

Coring took place in both the Winter and Summer Surveys of Anderson Lake; however, the exact method of core collection differed between the surveys.

During the Winter Survey, cores were collected through an augered hole in the ice by lowering a catcher and cutter-free, light-weight gravity corer (Pedersen *et al.* 1985) suspended from a metre-block and tripod (Plate 2-7). The corer was lowered slowly by hand, its progress was observed and controlled through the hole in the ice such that a high-quality core with an undisturbed interface was retrieved. Cores were carried by hand to the lab where processing began immediately. This technique proved highly successful.

During the Summer Survey, high-quality cores were collected by diver. An open-ended butyrate core barrel was slowly inserted into the sediments of Anderson Lake by a diver inverted above the lake floor. Once the desired degree of penetration had been acquired, the top of the core barrel was sealed by core-cap

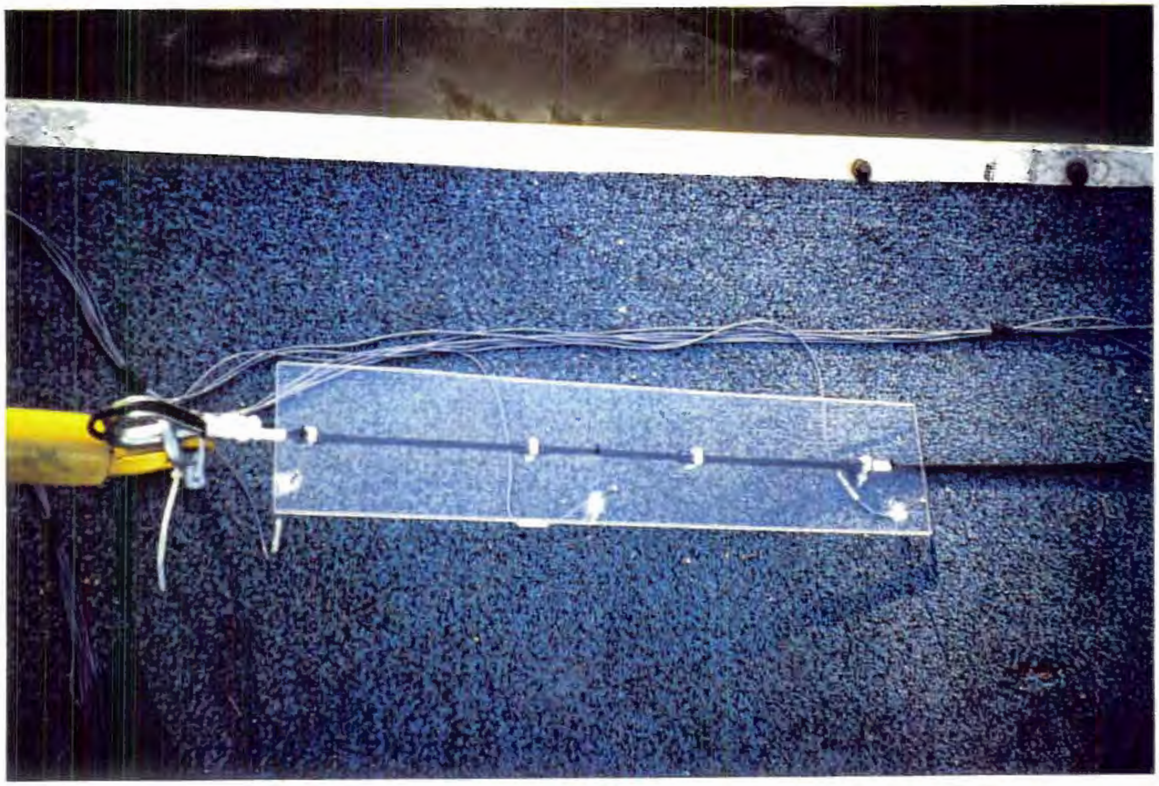

Plate 2-5: Acrylic plate with thermisters from water column thermister array.

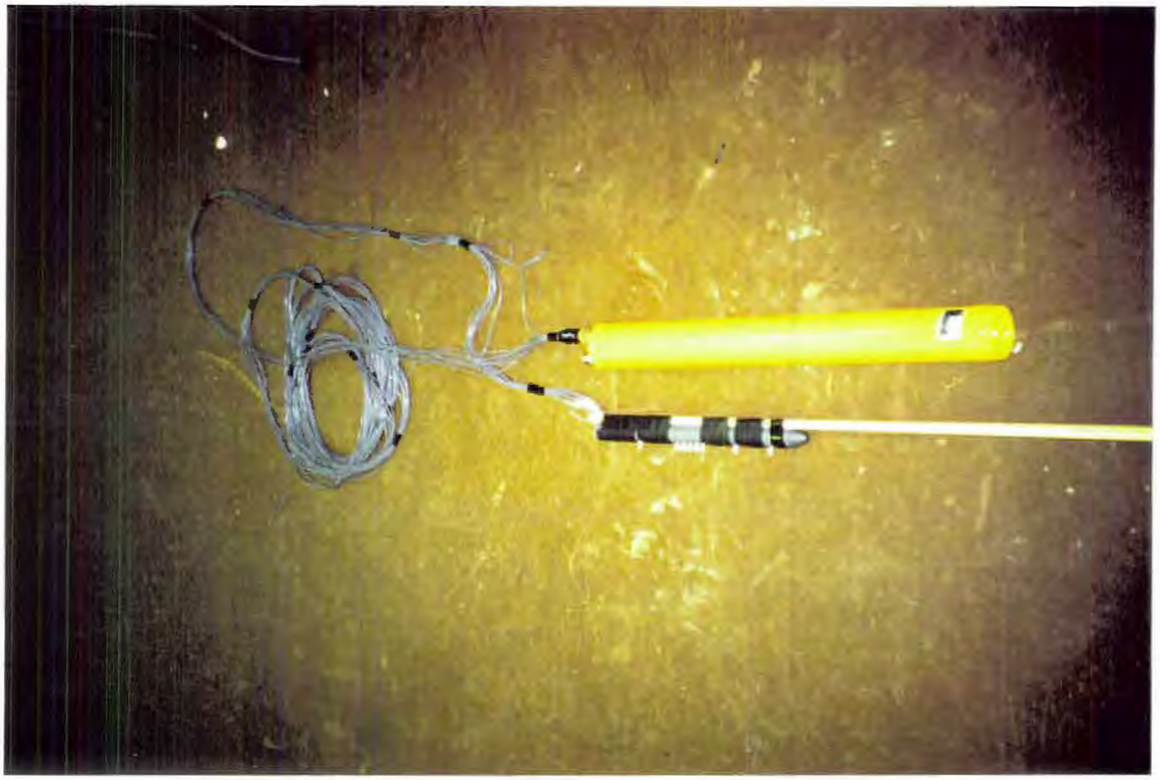

Plate 2-6: Sediment thermister array and datalogger.

Plate 2-7: Pedersen corer, and tripod prior to coring at Station A.

and tape. Core barrel and core were then slowly removed from the lake floor at which point the bottom of the barrel was sealed. The core was then carefully brought to the awaiting boat and returned immediately to the lab for processing. As in the Winter Survey, this technique proved highly successful in collecting high-quality, undisturbed cores (Plates 2-8 and 2-9).

Once in the lab, all cores were processed identically. Cores were first logged and then firmly attached to the underside of an extrusion table. The extrusion table, fitted with a nitrogen-filled glove-bag, had a hole in the centre through which the core was extruded. This allowed cores to be sectioned under clean conditions but more importantly, under an inert atmosphere thereby reducing the possibility of sample oxidation. This was of critical importance, particularly when sampling sections from the anoxic or reducing sediments of Anderson Lake.

The core was extruded into the glove-bag by inserting an o-ring-fitted PVC puck into the base of the core barrel and slowly pushing it up through the barrel with a scissor jack and sectioned PVC rod. Layers of the core were sliced sequentially using acid-washed, plastic utensils and placed into acid-washed, 250 mL HDPE centrifuge tubes (Plate 2-10). The sediment-filled centrifuge tubes were spun at ~1,200 gravities for 20 minutes at which point they were transferred to a second nitrogen-filled glove bag for decantation of the interstitial waters and filtration (Plate 2-11).

The supernatant water from the centrifuged sample was decanted into an acid-washed 30 mL polypropylene syringe barrel fitted with an acid-washed Syrfil 0.45 μm mixed cellulose acetate disposable filter. An acid-washed polyethylene piston fitted with a silicon o-ring was utilized to express the interstitial solution through the filter and into an acid-washed HDPE sample bottle. Sub-samples were collected for metabolites (NO_3^-, PO_4^{3-} as well as SO_4^{2-}; preserved frozen) and ΣH_2S (preserved by addition of Zn-acetate). The remaining filtrate was passed through a 0.1 μm Millipore polysulphone disposable filter and acidified to pH 2 with Seastar ultra-pure nitric acid for metal analyses.

2.2.3 Peepers

Peepers (dialysis membrane arrays) were deployed during the Anderson Lake Summer Survey in order to better address trace metal fluxes across the sediment-

Plate 2-8: A high-quality core collected at Station B during the Anderson Lake Winter Survey.

Plate 2-9: A high-quality core collected at Station C during the Anderson Lake Summer Survey.

Plate 2-10: Commencement of core sectioning in N_2- filled glove bag of the extrusion table.

Plate 2-11: Porewater filtration in secondary N_2- filled glove bag.

water interface. As part of the QA/QC component of the study, peepers were deployed by both Rescan and NWRI (National Water Research Institute) to assess more accurately the variability of the metal fluxes both from small scale inhomogeneities and methodological differences.

Peeper Preparation

Peeper methodologies differed primarily during assembly and sampling. Rescan peepers were assembled for deployment in a laminar flow hood (class 100 conditions) at UBC, prior to shipment to Manitoba. Peepers were first washed with a mild detergent and rinsed with copious amounts of DDW. All peeper components were then soaked in dilute ultrapure HNO_3 followed by several 24 hour soaks in DDW to remove any residual contaminants and acid. Preparation involved immersion of the clean peeper body in a plexiglass tank of de-oxygenated, distilled, deionized water (DDDW), where bubbles were first dislodged. Two peeper membrane configurations were utilized. In one configuration, a 0.2 µm polycarbonate membrane filter, overlain by a 0.45 µm polysulfone filter covered all wells simultaneously. The acrylic face plate, sided with a 70 µm pore size polyethylene frit, attached with several nylon screws held the filters in place and acted as a coarse filtering screen (Figure 2-2). The other configuration was identical except only the 0.2 µm polycarbonate membrane filter was used. The assembled peepers were stored in sealed acrylic boxes containing DDDW bubbled with nitrogen until deployment by diver insertion.

Carignan *et al.* (1994) have recently shown that plexiglass, from which the Rescan peepers were manufactured, absorbs (in air) 1.6 % vol/vol of O_2, which is lost slowly (half-time 5.7 d) once the material is exposed to an anoxic environment. The presence of such traces of oxygen could introduce an artifact by reacting with Fe^{2+} which diffuses into the peeper cells after deployment, precipitating $Fe(OH)_3$ *in situ*. Some portion of this particulate iron would later dissolve once samples were collected and acidified, leading to an overestimation of the true dissolved iron content. This phenomenon was originally described by Carignan (1984), who observed an orange discolouration on peepers deployed in anoxic lacustrine sediments in eastern Canada. However, there was no evidence for such an artifact in the Rescan peepers deployed for the Anderson Lake Summer Survey: no orange-yellow discolouration was observed on either the membranes or in the peeper cells below a few centimetres below the sediment-water interface. This

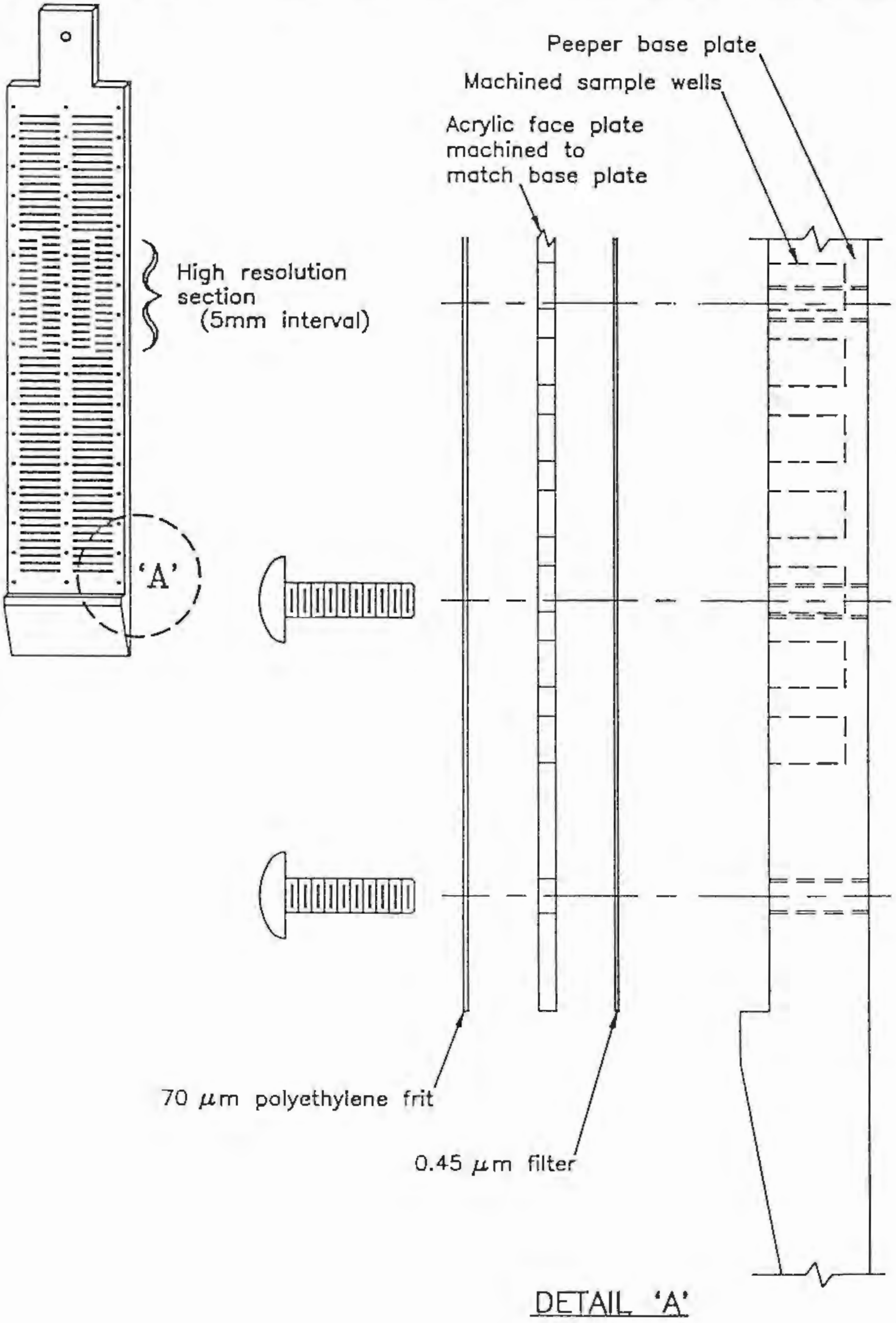

Figure 2-2 Schematic Diagram of a Membrane Dialysis Sampler (Peeper).

Rescan

suggests that the preparation procedure used in the study was appropriate. Presumably, the preparation of the Rescan peepers in deoxygenated water and their subsequent storage in nitrogen-saturated water in plexiglass sleeves for a minimum of one week prior to deployment was sufficient to reduce the absorbed O_2 content of the plexiglass to an insignificant level.

NWRI peeper preparation differed slightly from that of Rescan. Peepers were first acid-washed by soaking in 1 M HNO_3 followed by several rinses with DDW. NWRI peepers were assembled in the field lab by submergence in a clean plastic tank of DDW that was constantly deaerated with bubbled nitrogen. All adhering bubbles were first dislodged from the peeper body after which a 0.45 μm Gelman filter (also debubbled) overlain the submerged wells (Plate 2-12). An acrylic face-plate, secured with nylon or stainless steel screws, held the filter membrane in place. NWRI peepers were stored in DDDW-filled bubbling chambers until installation by diver.

Peeper Deployment

Three tandem and one single peepers were deployed at each of Stations A and B: two tandem by Rescan as station replicates, the additional tandem and single peeper by NWRI. The NWRI tandem peeper was utilized as an independently-processed control while the single was used for back-up and archival purposes. Two additional tandem peepers were deployed at Station C, a shallow-water (~1 m deep) tailings station, to assess the potential influence of different hydrographic/ geochemical conditions (specifically DO concentration) on tailings reactivity.

Peepers were pushed vertically into the sediment by divers; the tailings were soft enough to allow the divers to insert the peepers unaided by additional weight. However, the natural sediments at Station A were so uncohesive that they were deemed incapable of supporting a peeper vertically for the required deployment interval. As a result, 1 m dowels were affixed to the anterior edges of the peeper body, extending ~60 cm below the bottom of the peeper. This configuration served to anchor the peeper into the firmer, more consolidated sediments at depth. Each peeper was then attached to a central anchor via a slack line, the anchor was marked by buoy. Peepers were left deployed for 14 days.

Plate 2-12: NWRI peeper assembly in field lab.

Peeper Retrieval and Subsampling

Peepers were retrieved approximately two weeks after their initial deployment and within 24 hours of diver-collected cores. Divers initially assessed the condition of the peeper orientation and position within the sediments and then transferred the slack-line to a separate buoy (water column visibility prohibited photographs). Once all peepers were attached to separate buoys, retrieval commenced from the pontoon boat. Peepers were removed from the sediment by pulling the appropriate slack-line from the boat. The Rescan peepers were brought to just below the lake surface, agitated to remove adhering particulate matter, transferred to the boat and immediately inserted in their nitrogen-flushed storage boxes for transport to the field-lab where they were placed in a N_2-filled glove-bag (Plates 2-13 and 2-14). Processing involved careful removal of nylon screws, frit and face-plate, followed by removal of the 0.45 µm prefilter (where it was used). Two small holes were carefully made in the 0.2 µm polycarbonate filter through which samples was withdrawn using an Eppendorf pipette and acid-washed pipette tips (Plate 2-14).

NWRI processing involved retrieval of the peepers from the sediments in an identical manner to the methods used by Rescan. Following agitation in the lake, to remove adhering sediment particles, NWRI peeper sub-sampling was accomplished immediately on board the pontoon boat by rapidly withdrawing interstitial water with disposable syringes (Plate 2-15). The entire sampling of a tandem peeper occurred within the five to ten minutes, and as a result, there was insufficient time for sample oxidation to occur. The samples were transferred directly to pre-acidified acid-washed polyethylene vials.

2.2.4 Analytical Methods

The analytical work performed on the samples acquired from Anderson Lake is briefly addressed below. For a rigorous description, the reader is referred to the appropriate Appendices compiled by Analytical Services Laboratories and the University of British Columbia (Appendices A through E).

Samples were collected for water column, sediments and interstitial waters for both Anderson Lake surveys. Analyses were performed exclusively by Analytical Services Laboratories (ASL) and the University of British Columbia geochemistry group. Analyses were divided between the two labs according to sample type and

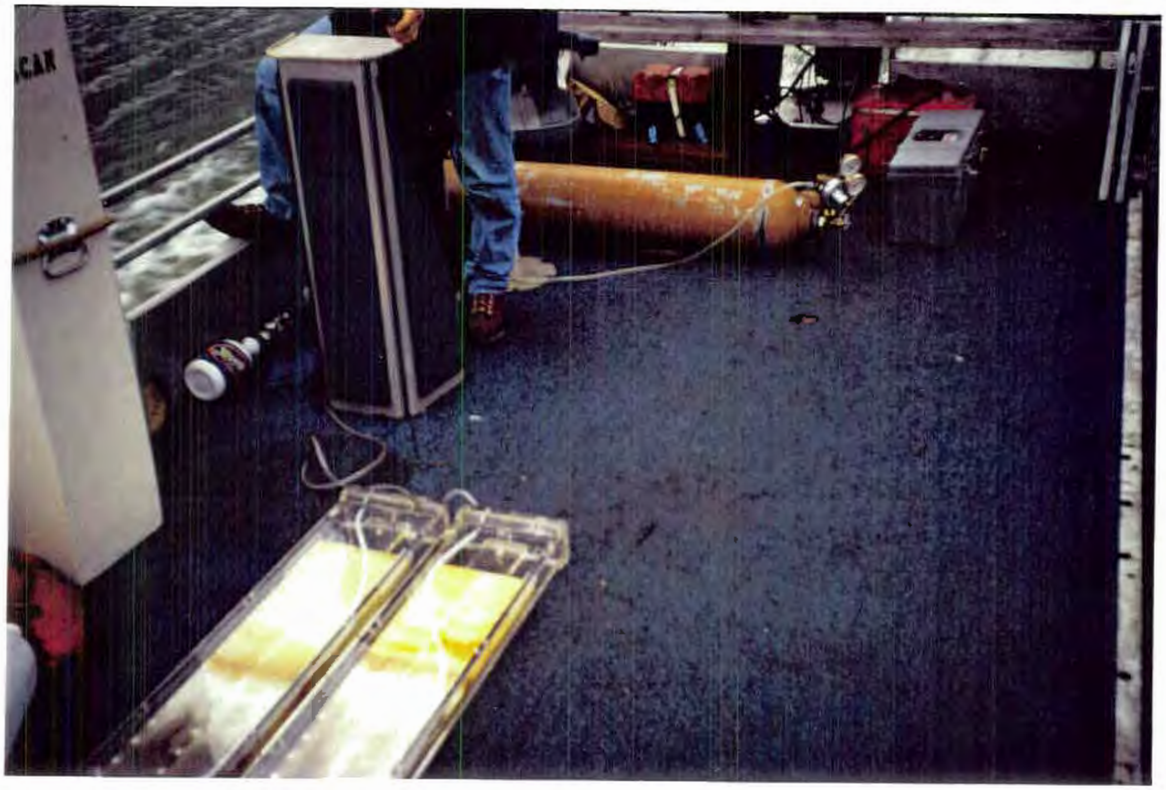

Plate 2-13: Rescan peepers in their N_2- flushed bubbling chambers awaiting transport to the lab.

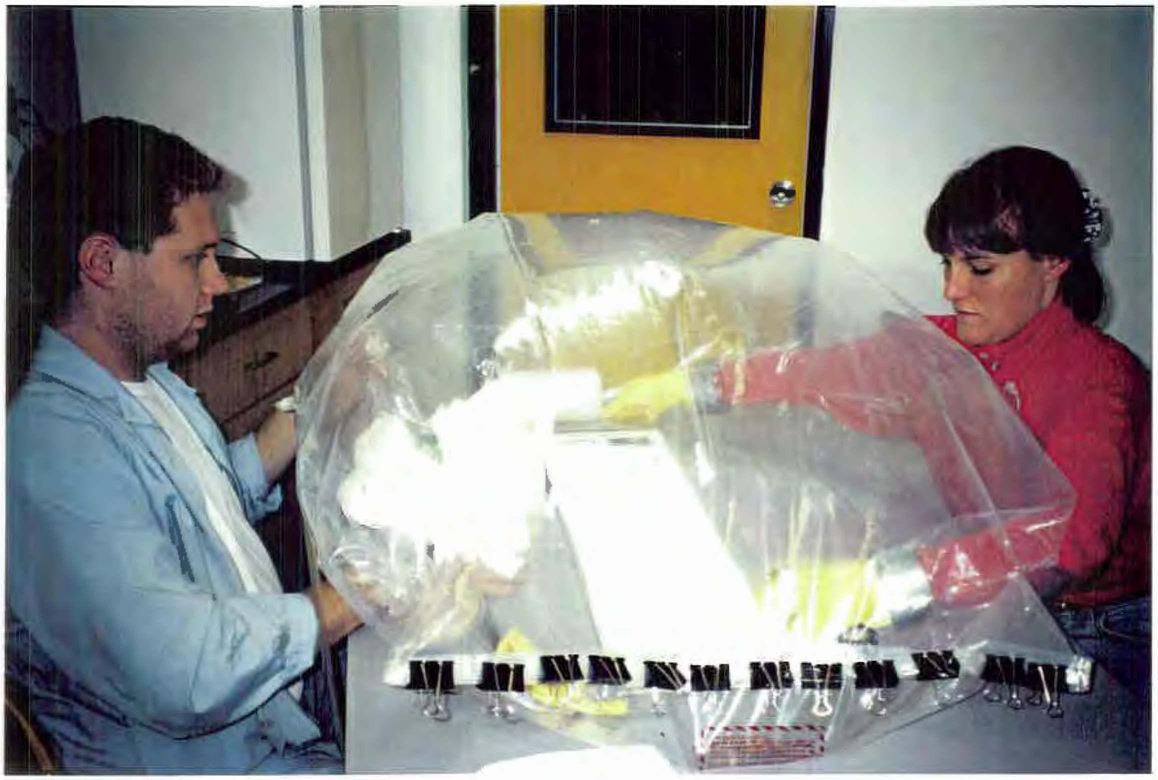

Plate 2-14: Subsampling of Rescan peeper in a N_2- filled glove bag.

Plate 2-15: NWRI peeper subsampling on station.

analyte, and, blind interlab calibrations were routinely performed as part of the QA/QC protocol (Appendix A).

All water column parameters were measured by ASL including total dissolved metals, total and dissolved organic carbon, and physical parameters (*i.e.* salinity, nutrients, pH, *etc.*). The sediment solids were also analysed by ASL with the exception of carbonate carbon, total carbon, nitrogen and sulphur, which were analysed by UBC. The sediment interstitial water parameters were all measured by UBC with the exception of Hg and As which were analysed by ASL.

3.0 RESULTS

3.1 Winter Survey

Water column, sediment and interstitial water samples were collected from two stations on Anderson Lake during April, 1993. The results of that survey are presented below.

3.1.1 Water Column

Water column profiles of dissolved oxygen and temperature at Station A (natural site) are shown in Figure 3-1. Both the temperature and oxygen data at Station A indicate a three-layer stratification below the ice in April 1993. Relatively high oxygen contents (up to 4.6 mg/L) were limited to a cold water layer 20 cm thick immediately under the ice. The oxygen concentration decreased sharply between 60 and 80 cm depth, where the temperature increased from < 1° to > 6°C. A mid-depth warm layer between 90 and 250 cm deep had a near-zero oxygen content. Up to ~1.5 mg/L O_2 occurred in a deeper 1 m thick aerobic zone, which was slightly cooler than water in the mid-depth layer and extended to the sediment-water interface.

Less complex temperature and dissolved oxygen profiles characterize the water column near the tailings outfall at Station B (Figure 3-1). Oxygenated water was confined to a thin horizon immediately below the base of the ice and to the water in the 50 cm deep hole through the ice, which must have been aerated (at both sites) when the holes were cut.

The different techniques used to collect the temperature/oxygen data and the water samples make it difficult to compare both sets of information precisely on a common vertical axis. There are three reasons for this. First, the temperature/oxygen data and water column samples were collected through different holes in the ice. Because the depth of the T/O_2 probe was measured relative to the free water surface in the hole, while the depth of the water samples was determined relative to the lake floor (the base of the sampler), the depth scales for each set of data have different references. Second, the lake floor is uneven, particularly where tailings have been deposited; during the summer survey, for

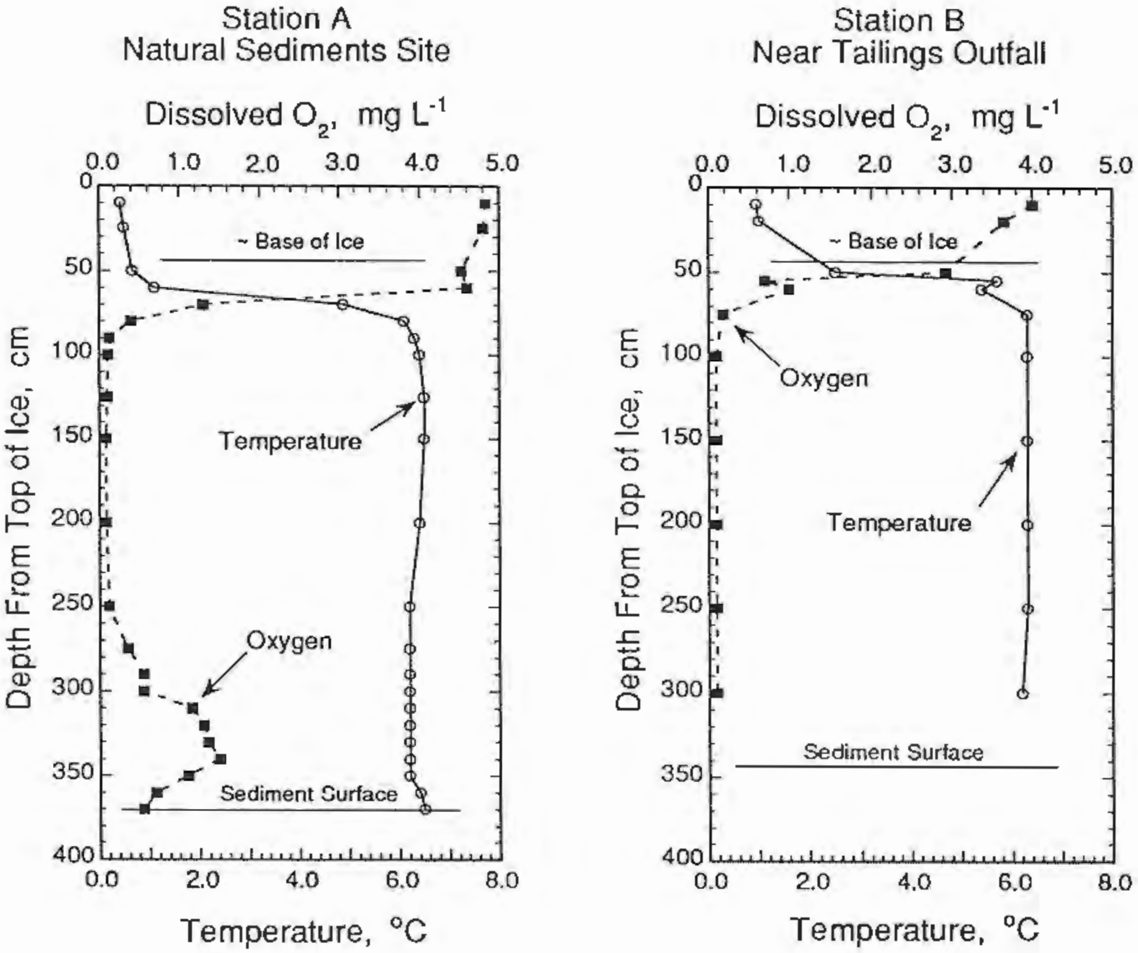

Figure 3-1: Oxygen and temperature profiles in the water column at Stations A and B in Anderson Lake in April 1993, during the week in which the cores were collected. The depth scale is relative to the ice surface, not to the bottom.

example, divers observed relief of about 1 m within a 10 m radius of the sampling site near the tailings outfall. Third, the plexiglass water-column sampler settled into the unconsolidated muds on the bottom at both sites, to the point where the lowermost sampling port was buried at Station B and the lower three ports were buried at Station A. Samples that were subsequently drawn from the buried ports were muddy, and presumably represent a mixture of pore and near-bottom water. The analytical results from some of these samples (A1, 2 and 3, and B1, 2 and 3; Appendix B) have not been included in the graphs, and are not discussed further; however, with the exception of the lowest port, the buried ports at Station A provided data consistent with the porewater data. Thus, caution must be used in any attempt to compare precisely the oxygen and temperature profiles with the vertical distributions derived from the water column samples.

Major ion distributions at Station A vary little throughout the water column, and at a coarse level, show no distinct relationship to the stratification indicated by the temperature and oxygen data. Samples collected near the (uncertainly-located) sediment-water interface show the most pronounced variation. In the interstitial waters as measured by the water column sampler, relative to the overlying waters, sulphate and calcium contents are slightly depleted, nitrate is greatly depleted, and ammonium, nitrogen and alkalinity are enriched (Figures 3-2 and 3-3). The declines in the major ion concentrations are matched by slight decreases in conductivity and hardness (Appendix B). The apparent higher temperature near the bottom is accompanied by a slight increase in conductivity immediately above the sediment-water interface.

Major ion and conductivity distributions at Station B show little variation in the upper three-quarters of the water column, but a marked increase in sulphate, calcium, and ammonium occurs in the lowermost 20 cm (Figures 3-2 and 3-3). At both sites, the pH increases significantly with depth from relatively low values (~4) in the upper 2 m to ~5.5 to 7 in the bottom waters (Figure 3-4).

In general, variations in the concentrations of dissolved metals parallel the stratification at both sites. Dissolved iron contents, for example are low (< 0.08 mg/L) in the oxic waters between 300 and 370 cm depth at Station A, but relatively high (up to ~9.5 mg/L) in the underlying "porewaters" (Figure 3-5). The oxygen-depleted waters at Station B hosted dissolved Fe contents of ~2 mg/L between 50 and 250 cm depth; below this horizon, the concentrations increase

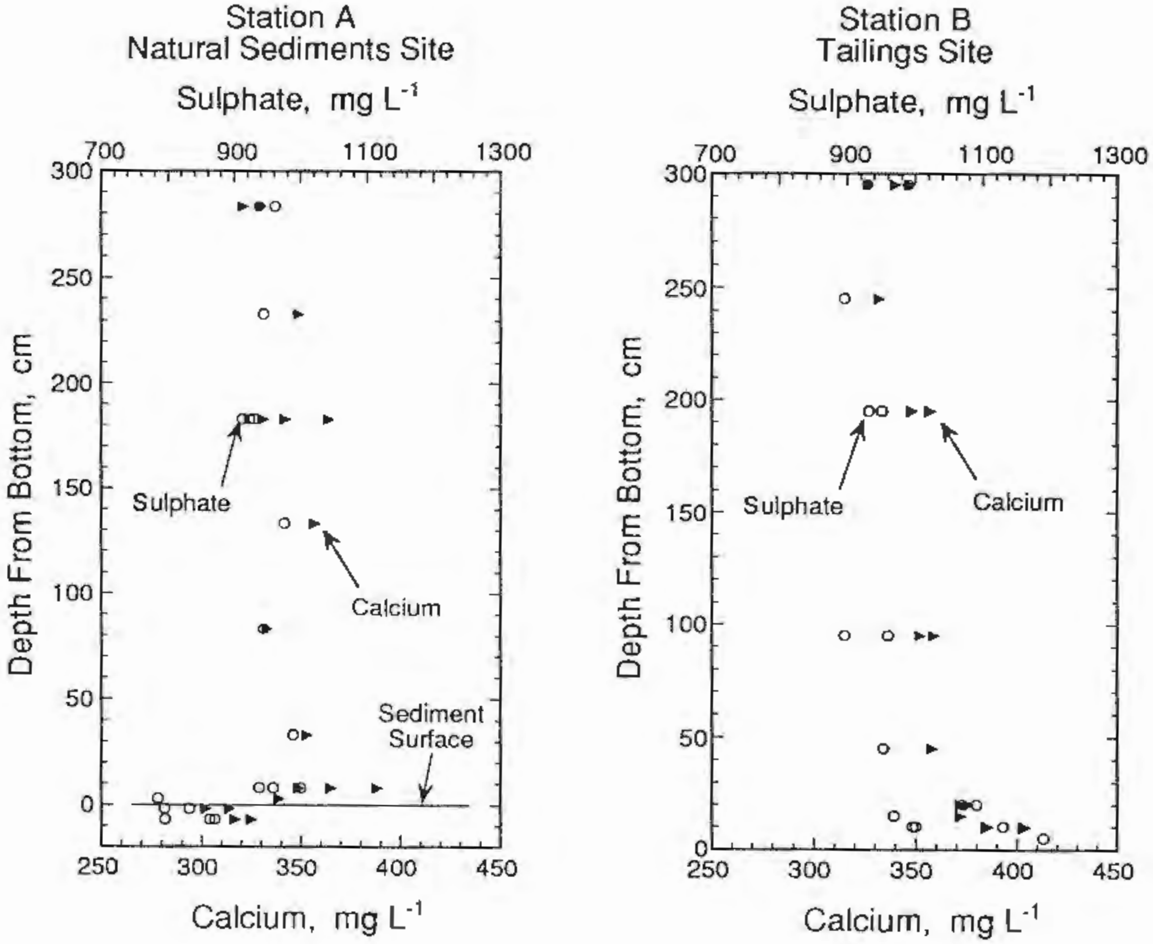

Figure 3-2: **Dissolved sulphate and calcium distributions in the water column at Stations A and B in Anderson Lake in April 1993. The depth scale is relative to the bottom, not to the ice surface.**

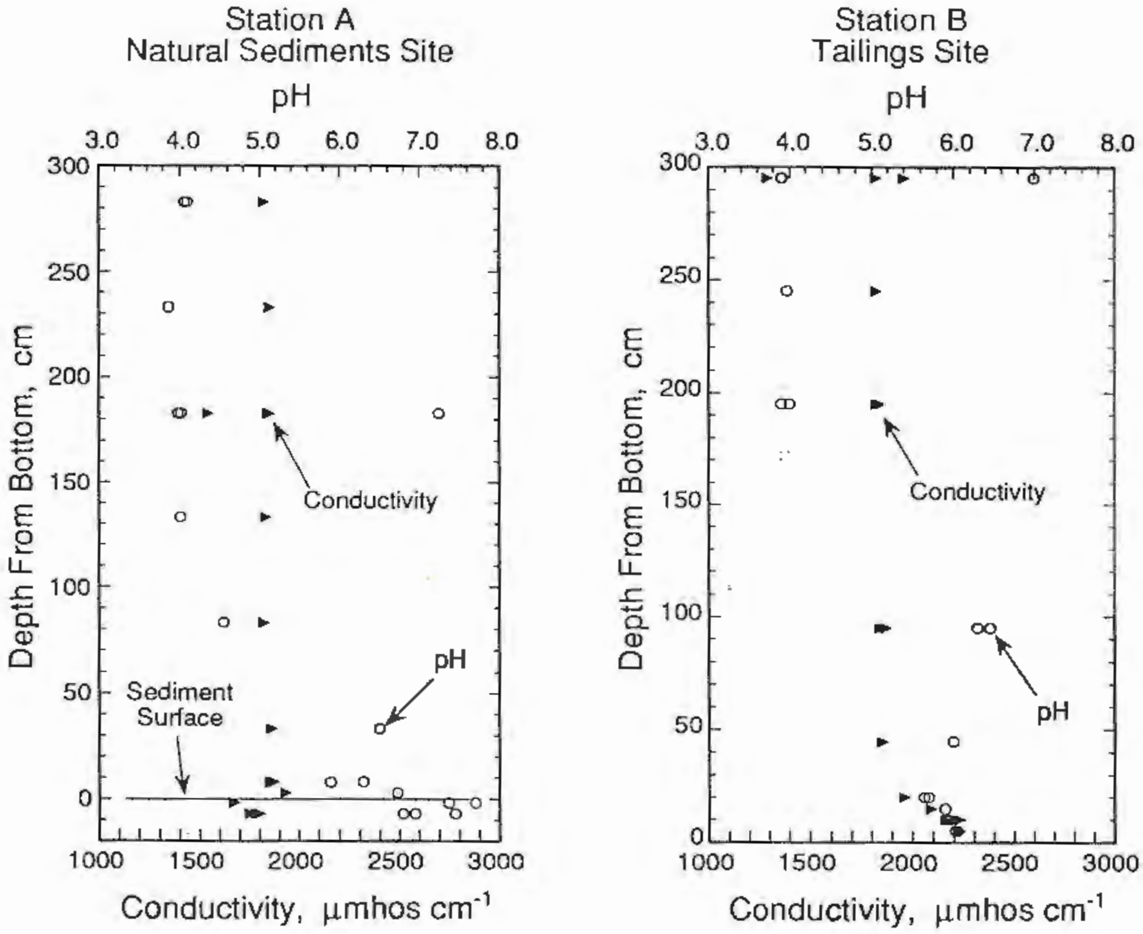

Figure 3-4: **Conductivity and pH distributions in the water column at Stations A and B in Anderson Lake in April 1993. The depth scale is relative to the bottom, not to the ice surface.**

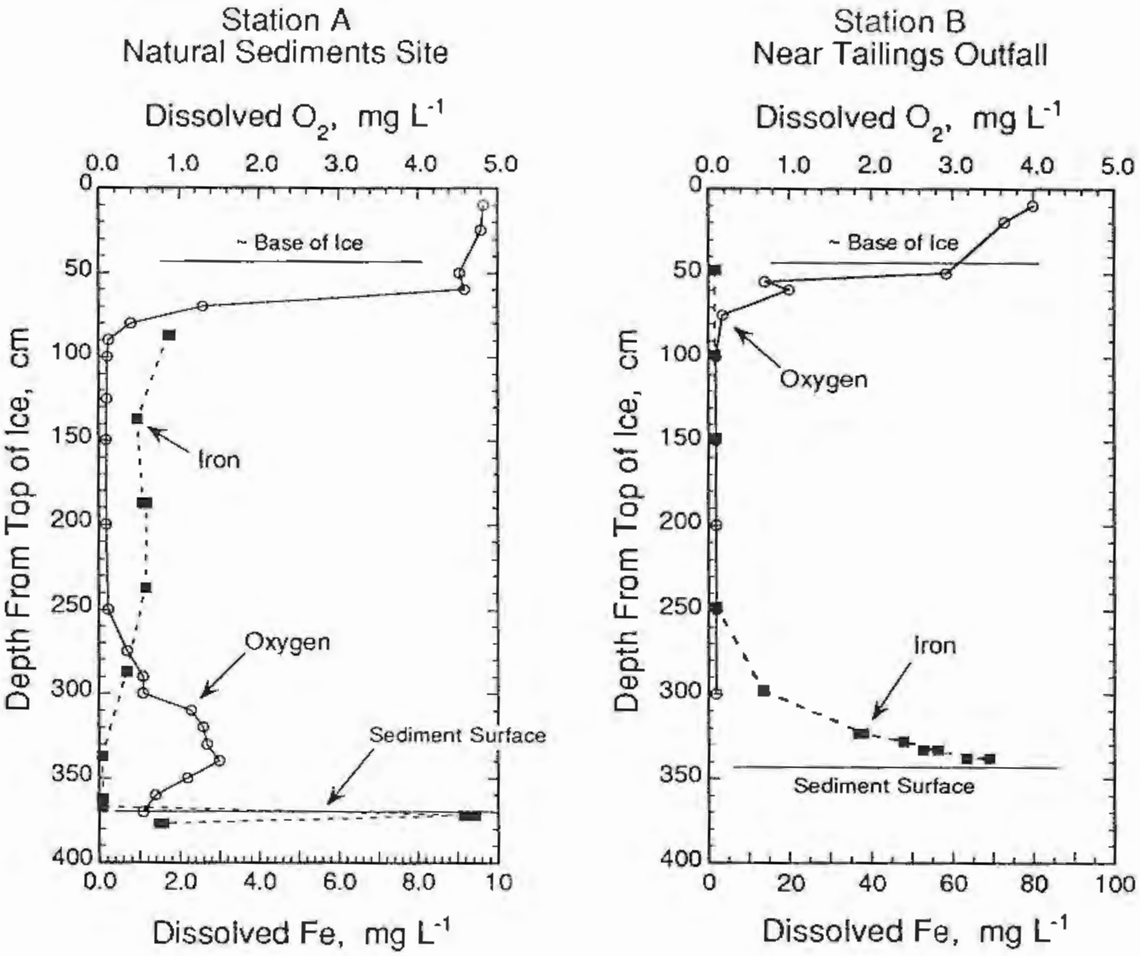

Figure 3-5: Dissolved oxygen and iron distributions in the water column at Stations A and B in Anderson Lake in April 1993. The depth scale is relative to the ice surface, not to the bottom, and may be slightly in error for the iron profile as samples for dissolved iron measurements were collected with the water column sampler. The depth of the sampler ports was determined relative to the bottom, not to the ice surface.

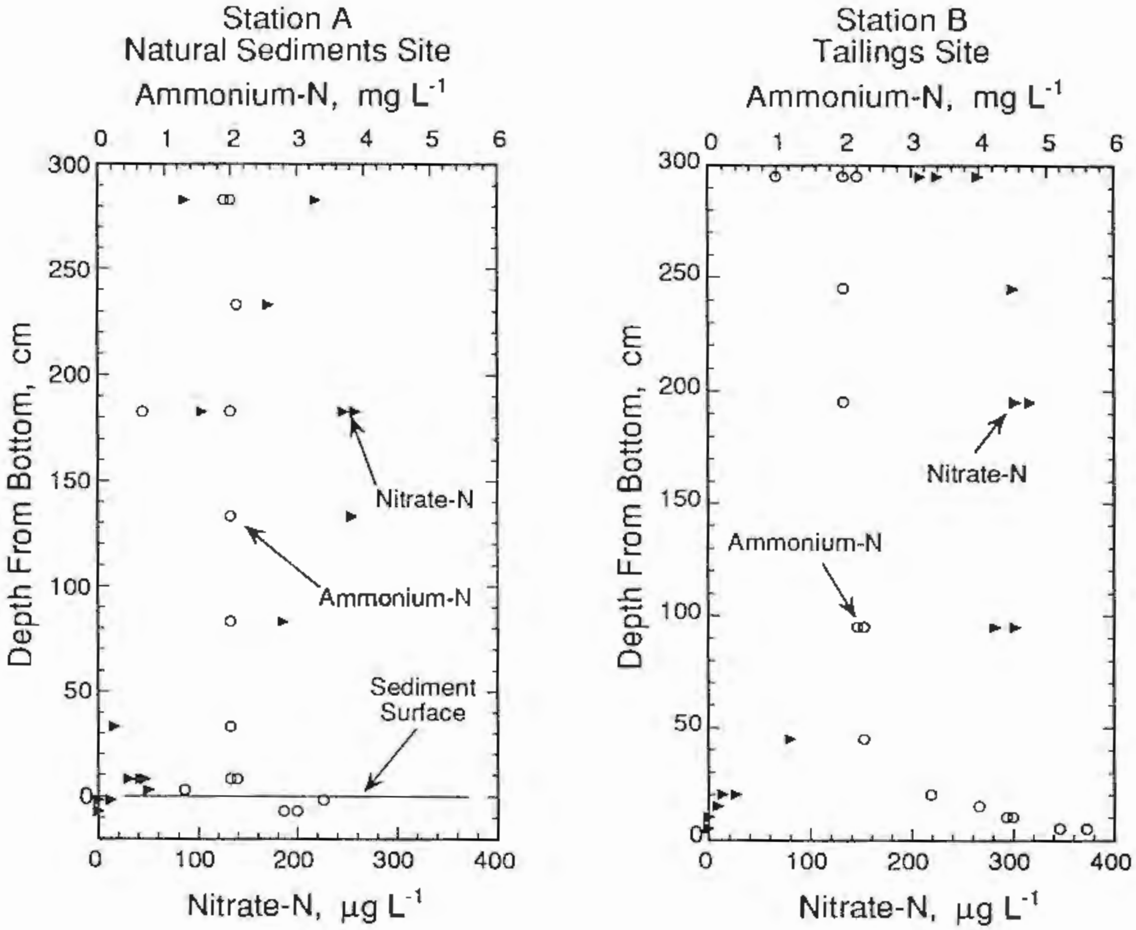

Figure 3-3: Dissolved ammonium and nitrate distributions in the water column at stations A and B in Anderson Lake in April 1993. The depth scale is relative to the bottom, not to the ice surface.

steadily and markedly toward the bottom, reaching ~70 mg/L in the deepest sample.

The distribution of dissolved zinc in the water columns at both sites is opposite to that of Fe; high Zn values of up to ~400 µg/L occur where Fe contents are low, and diminish sharply in the Fe-rich intervals (Figure 3-6). The contrast between the two elements is particularly pronounced in the lower 20 cm at Station A where abrupt changes in both the Fe and Zn contents occur across the sediment-water interface.

Dissolved arsenic distributions in the water column are very similar to those of iron at both sites, although the absolute As concentrations near the tailings outfall (0.3 to 0.6 µg/L) are only about one-third of those at the natural sediments site (Figure 3-7). Dissolved manganese closely follows the distribution of iron at both sites (Figure 3-8); concentrations range from 200 to 400 µg/L throughout the water columns at both locations with the exception of the lowermost 20 cm where levels reach a maxima of ~330 µg/L at Station A and 800 µg/L at Station B.

Copper concentrations are low relative to zinc but show similar distributions. Dissolved Cu values in the near-bottom waters at both sites (Figure 3-8) are very low, and approach the analytical detection limit (0.5 µg/L). Cadmium and mercury contents were approximately at or below their respective detection limits (0.2 µg/L and 0.01 µg/L) in all samples.

3.1.2 Sediments

Duplicate cores for sediment and iuterstitial water analyses were collected through holes about 3 m apart with both taken approximately 5 m from the water column sampler at Station A. At Station B, the cores were taken about 12 m apart and ~10 m from the water column sampler. The lightweight gravity corer described by Pedersen *et al.* (1985) was used, and the quality of all four cores was excellent. Core logs are presented in Appendix C-1.

Cores A1 and A2 collected ~3 m apart at the natural sediments site were visually and compositionally very similar. Both cores were veneered by a 2 to 3 mm thick cap of rusty-brown noncohesive fine-grained sediment, which contained abundant organic fragments. Small copepods (Daphnia?) were abundant in the water

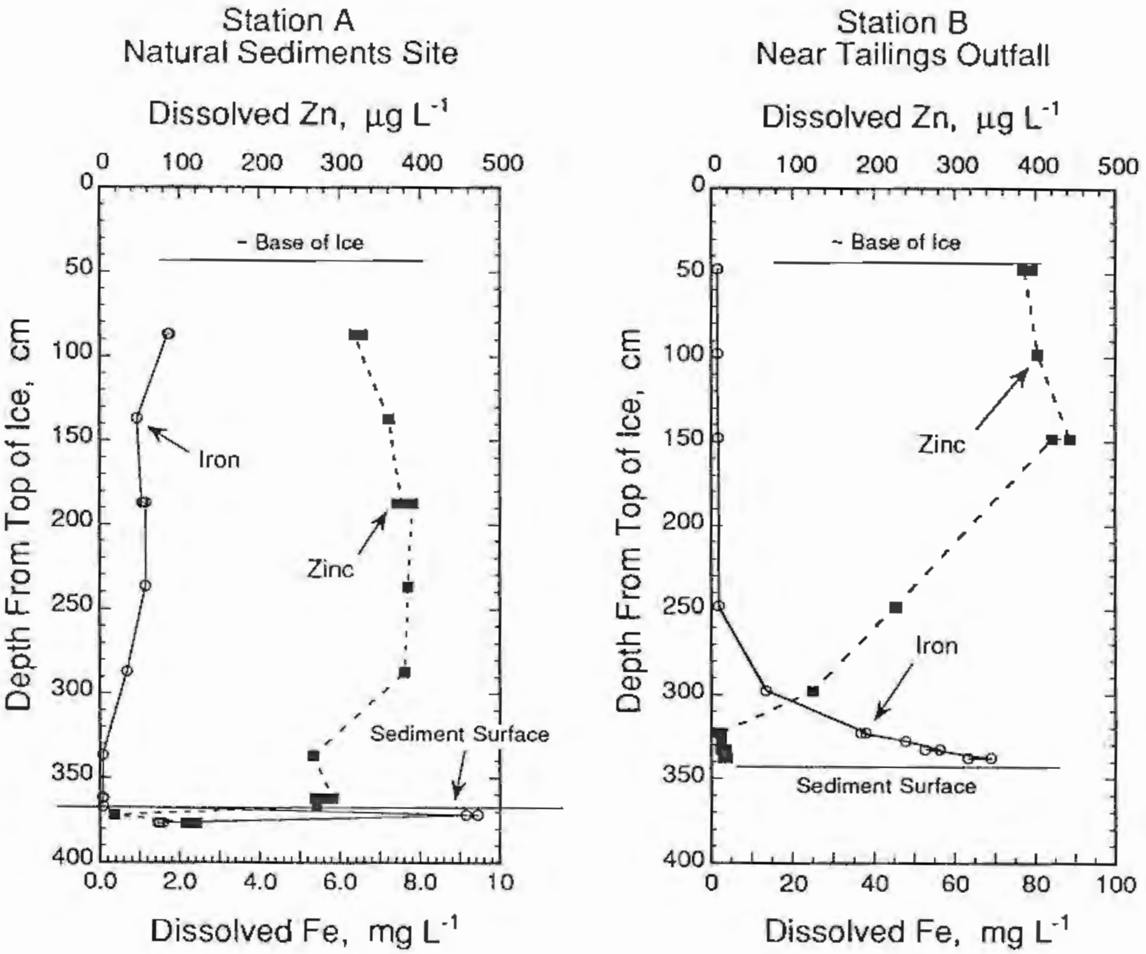

Figure 3-6: **Dissolved iron and zinc distributions in the water column at Stations A and B in Anderson Lake in April 1993. The depth scale is relative to the bottom, not to the ice surface.**

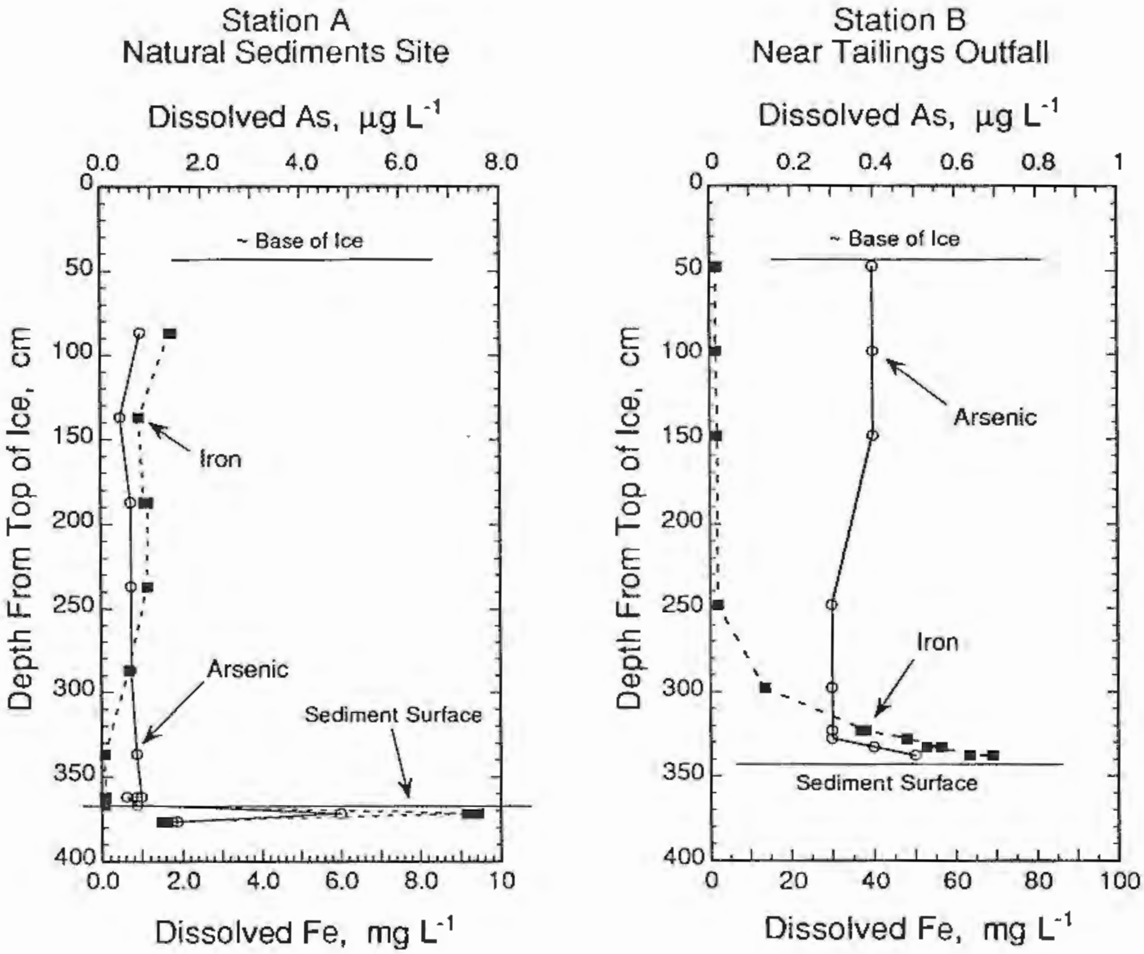

Figure 3-7: Dissolved iron and arsenic distributions in the water column at Stations A and B in Anderson Lake in April 1993. The depth scale is relative to the bottom, not to the ice surface.

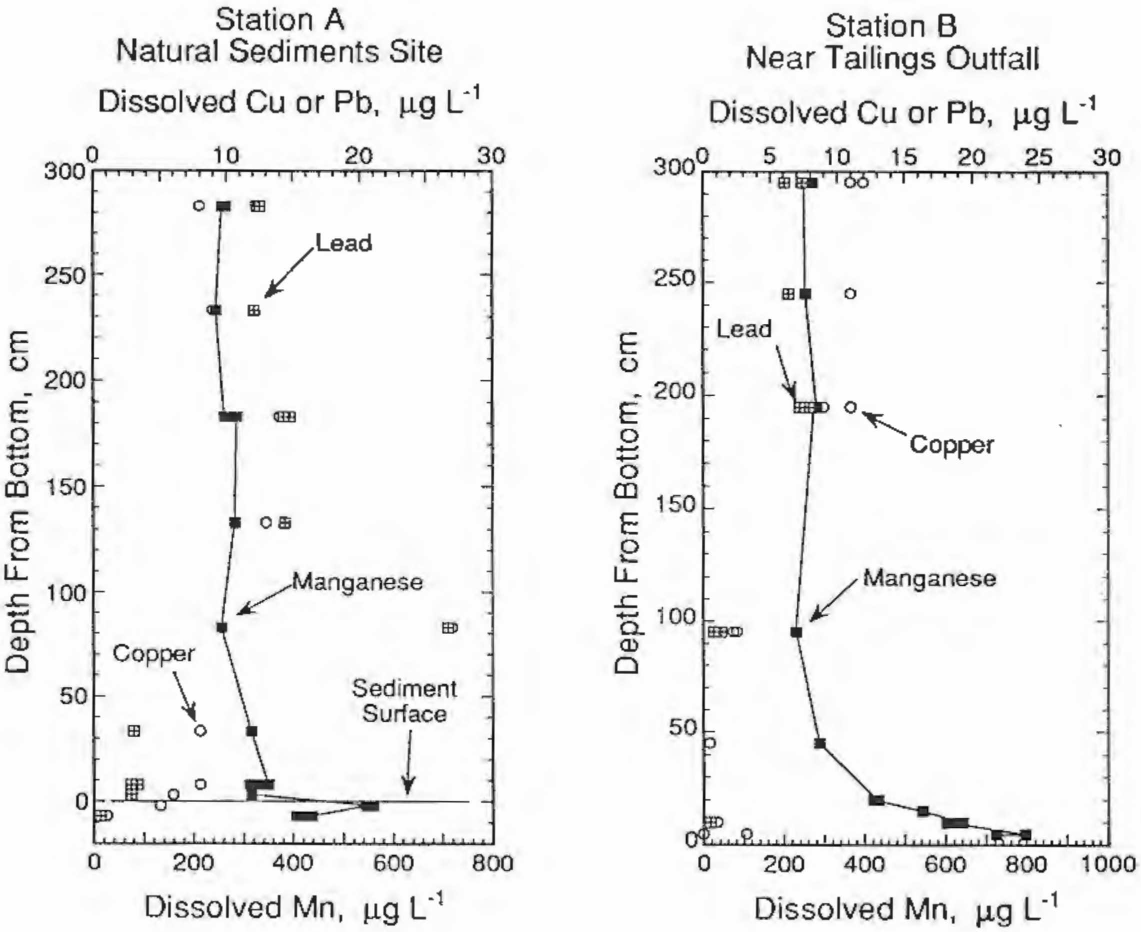

Figure 3-8: Dissolved copper, lead and manganese distributions in the water column at Stations A and B in Anderson Lake in April 1993. The depth scale is relative to the bottom, not to the ice surface.

immediately above the sediment-water interface and were observed burrowing into the rust-colored surface layer. The surface veneer was underlain by about 10 cm of charcoal-gray fine-grained gelatinous ooze, which graded into the brown, gelatinous, homogeneons, organic-rich ooze that characterized the lower 40 cm of both cores. Small, presumably methane bubbles developed below 30 cm depth in both cores shortly after collection. Both cores raised about 12 m apart at Station B consisted of undifferentiated fine-grained gray tailings which contained a very high proportion of glistening, very fresh-looking pyrite grains. The lake floor at this location was irregular with differences of more than 1 m depth between sites only 12 to 15 m apart. Observations made by divers during the August 1993 survey of the lake confirmed that the sediment surface near the tailings outfall is hummocky. Lobes of tailings appear to account for the observed differences in local relief.

Cores A1 and A2 consist of essentially tailings-free, organic-rich sediments below about 12 cm from the water-sediment interface, as shown by the organic carbon, Fe/Al, S, Zn, Cu, Pb, As, and Cd distributions (Figures 3-9 to 3-16). The upper stratum in both cores is composed of a mixture of tailings and natural sediments with metals concentrations reaching maxima between 1 and 2 cm depth. The marked compositional similarity of cores A1 and A2 is not matched by the pair of cores from Station B. Organic carbon, Fe/Al, S, Zn, Cu, Pb, As, and Cd distributions in cores B1 and B2 show differences (Figures 3-9 to 3-16) with depth, which apparently reflect significant local-scale lateral inhomogeneities in the tailings deposit in the lake. This inhomogeneity is not inconsistent with the variable composition of the ore feedstock, the hummocky terrain in the vicinity of the outfall, and the frequent changing of the location of the discharge point.

Petrologic examination of a set of polished sections prepared from sediment subsamples taken from core A1 indicate that the lithogenic fraction of the natural sediments is composed typically of silt-sized quartz grains with accessory feldspar, biotite, hornblende and rare carbonate (Appendix C-2). Framboidal pyrite occurs in all samples at this site, including the upper 0.5 cm of the deposits. The framboids are typically fine-silt-sized and occurred either free or incorporated within organic flocs (Plate 3-1). Crystalline sulphides, consisting mainly of pyrite, with some pyrrotite and some chalcopyrite, are also observed in the top 12 cm of

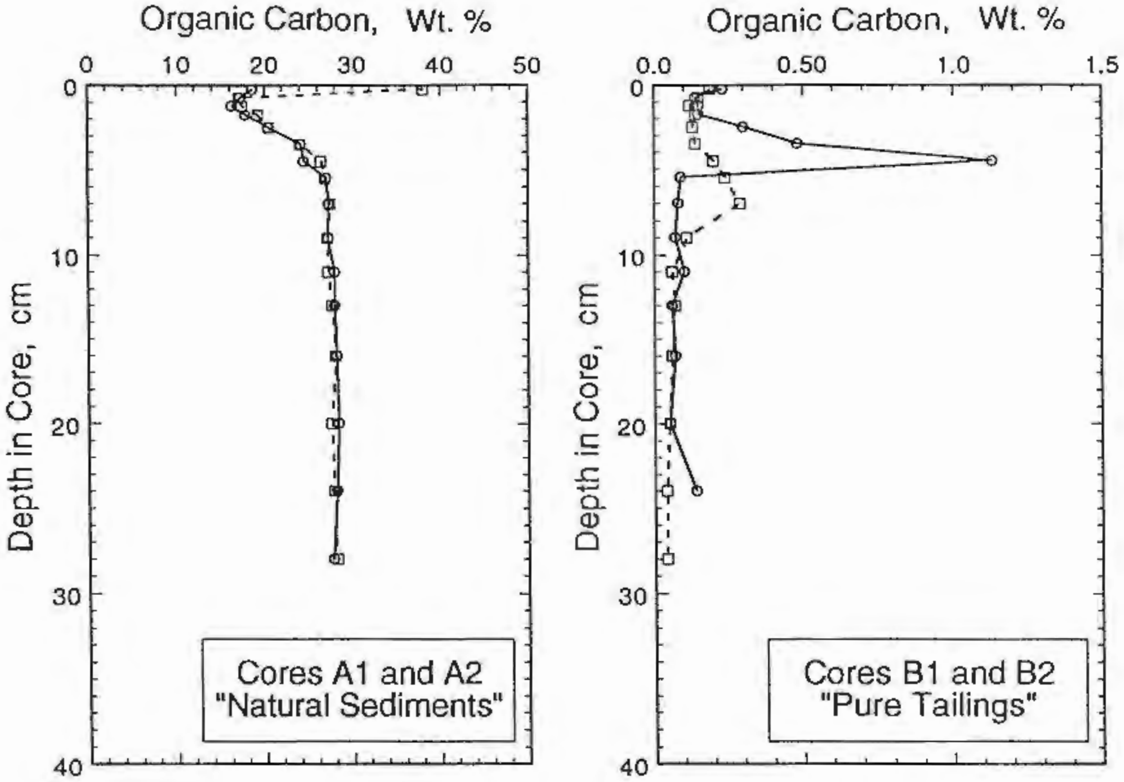

Figure 3-9: **Sedimentary organic carbon concentrations in duplicate cores from Stations A and B in Anderson Lake in April 1993. The open circles represent cores A1 and B1.**

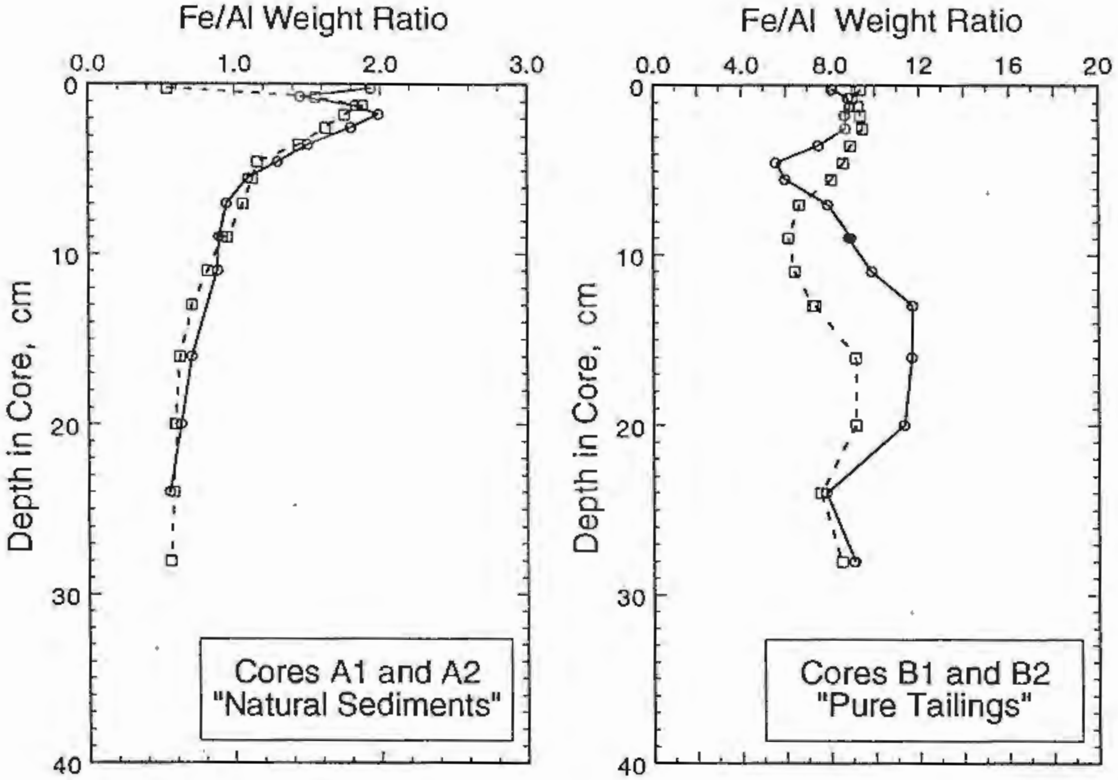

Figure 3-10: Sedimentary Fe/Al weight ratio profiles in duplicate cores from Stations A and B in Anderson Lake in April 1993. The open circles represent cores A1 and B1. The low value at the surface of Core A2 reflects an unusually low Fe concentration in this sample and may be an analytical artifact.

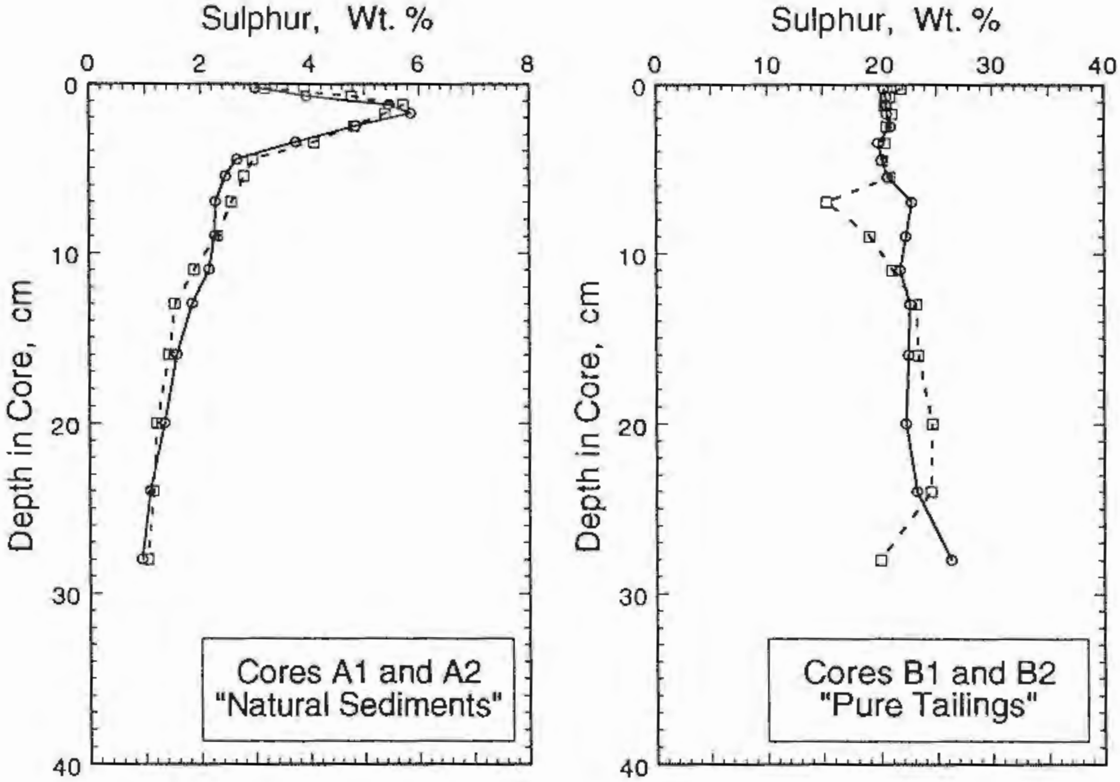

Figure 3-11: Sedimentary sulphur concentration profiles in duplicate cores from Stations A and B in Anderson Lake in April 1993. The open circles represent cores A1 and B1.

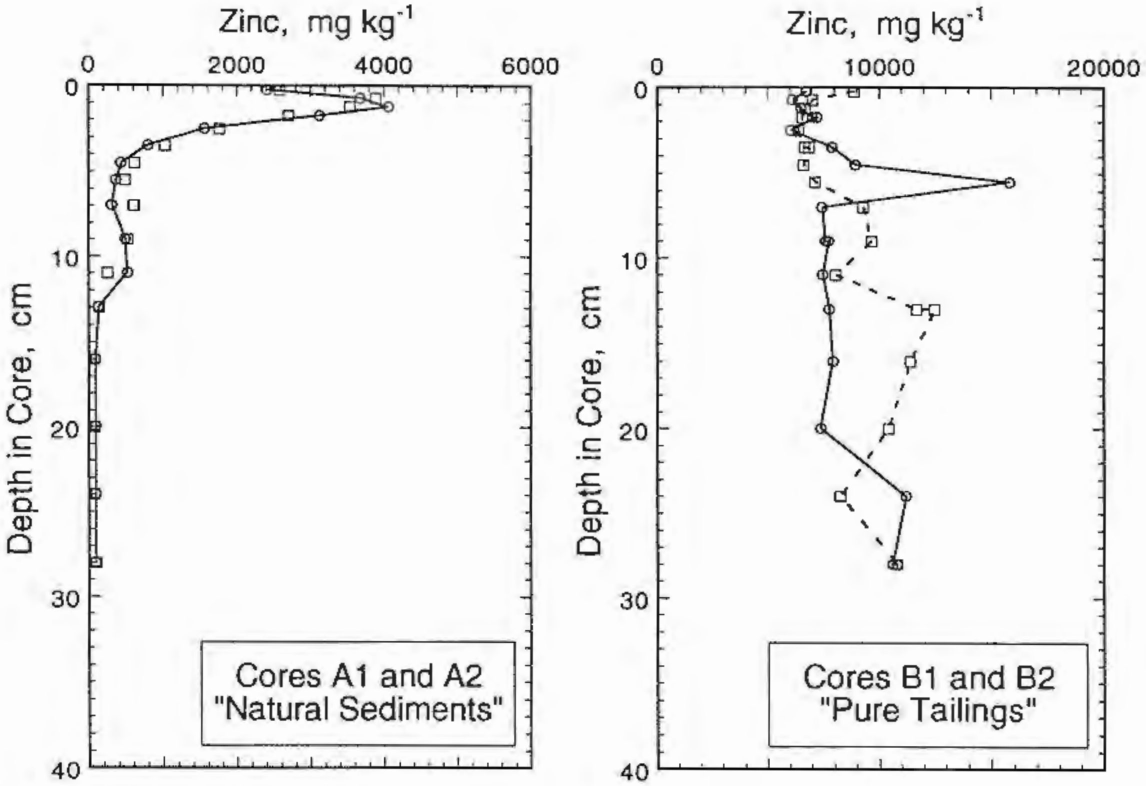

Figure 3-12: Sedimentary zinc concentration profiles in duplicate cores from Stations A and B in Anderson Lake in April 1993. The open circles represent cores A1 and B1.

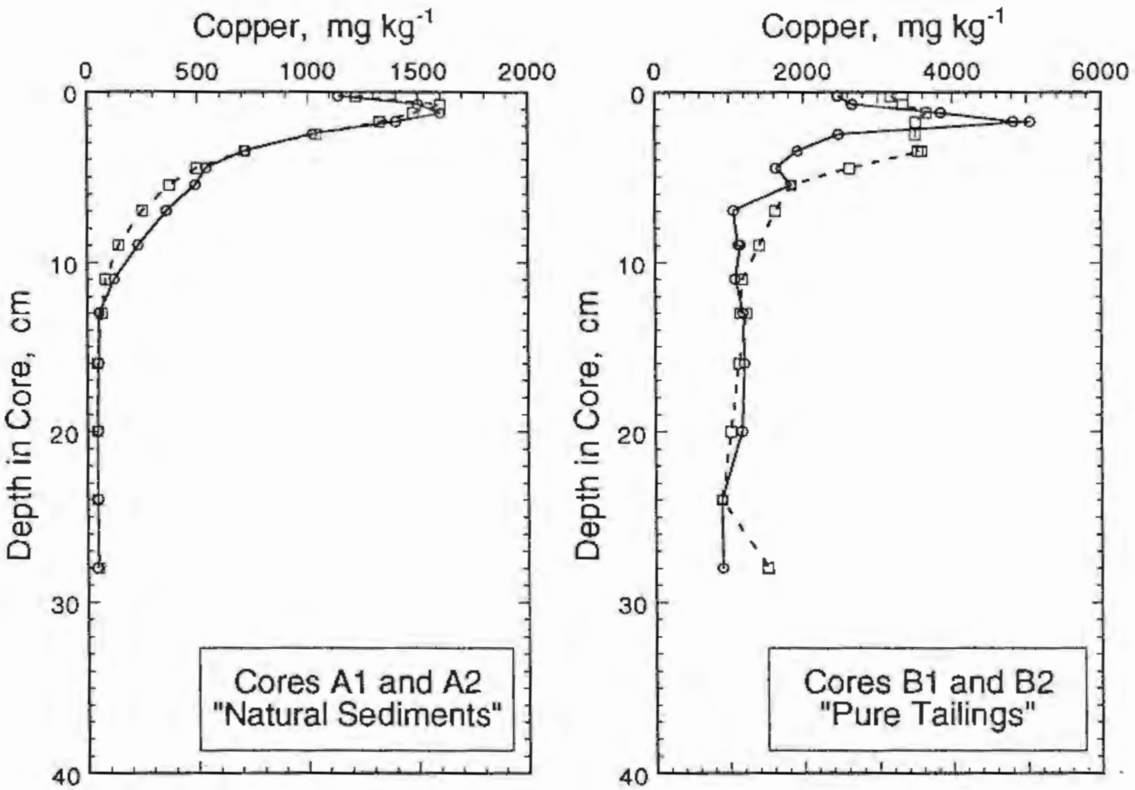

Figure 3-13: **Sedimentary copper concentration profiles in duplicate cores from Stations A and B in Anderson Lake in April 1993. The open circles represent cores A1 and B1.**

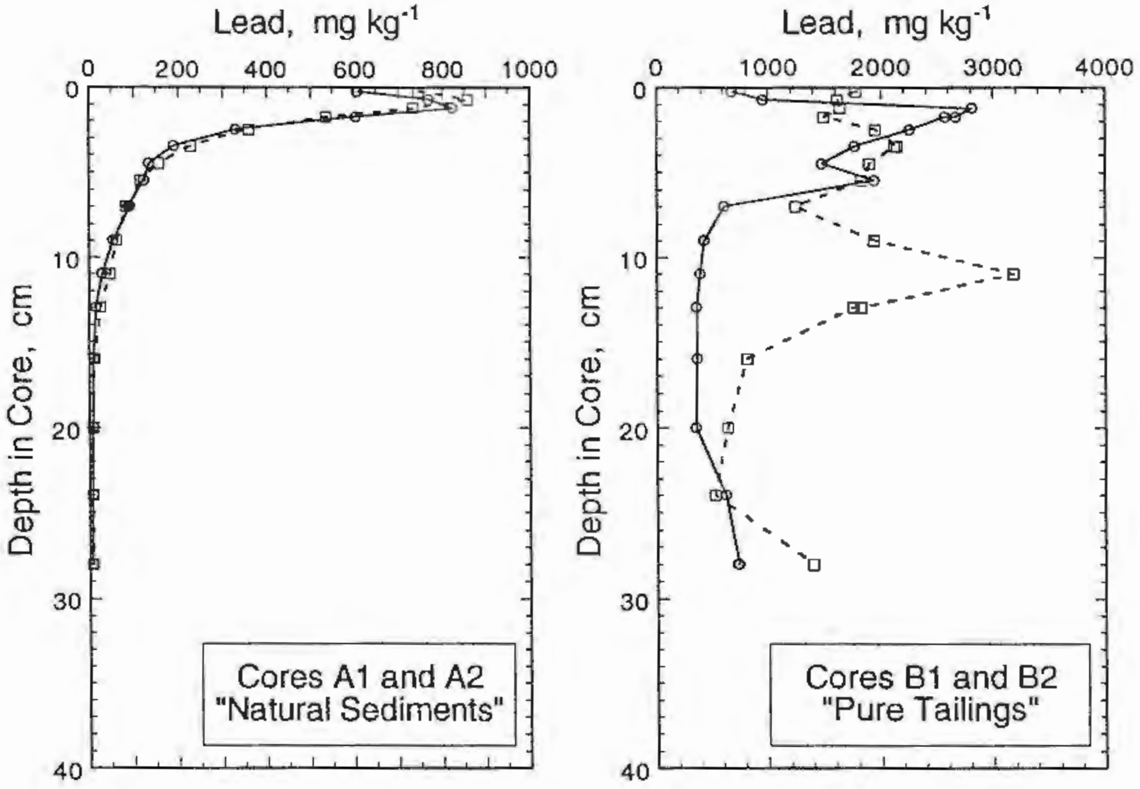

Figure 3-14: Sedimentary lead concentration profiles in duplicate cores from Stations A and B in Anderson Lake in April 1993. The open circles represent cores A1 and B1.

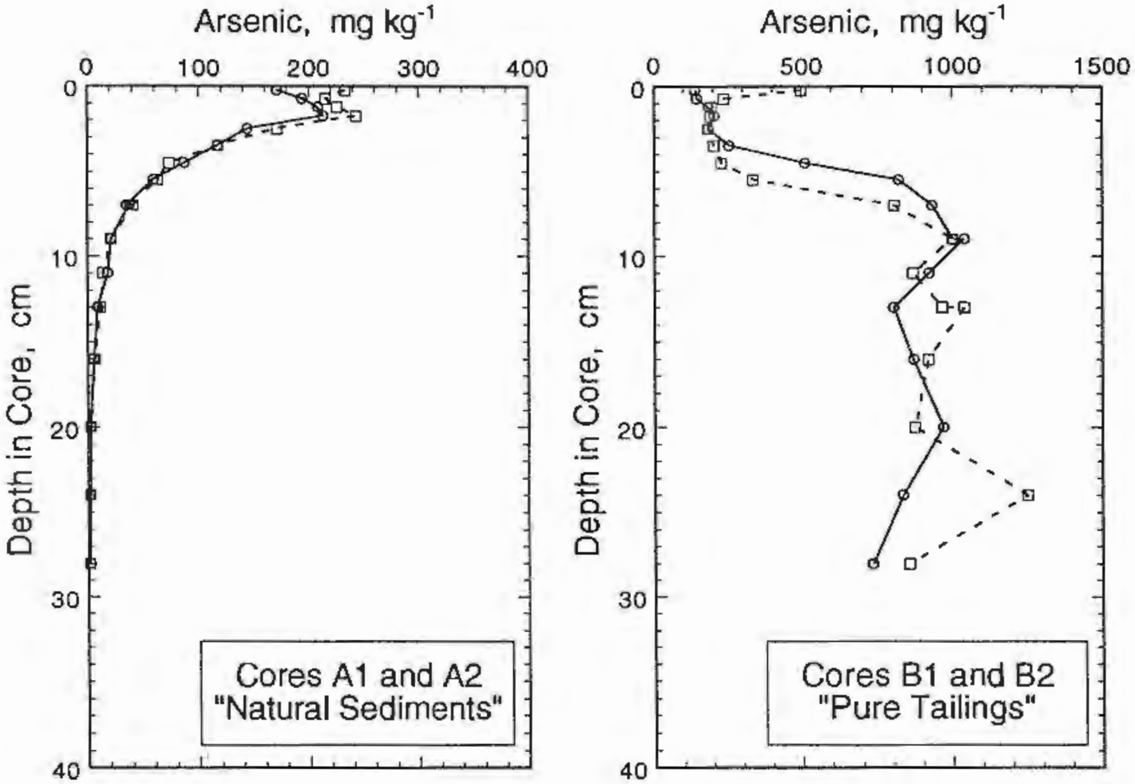

Figure 3-15: Sedimentary arsenic concentration profiles in duplicate cores from Stations A and B in Anderson Lake in April 1993. The open circles represent cores A1 and B1.

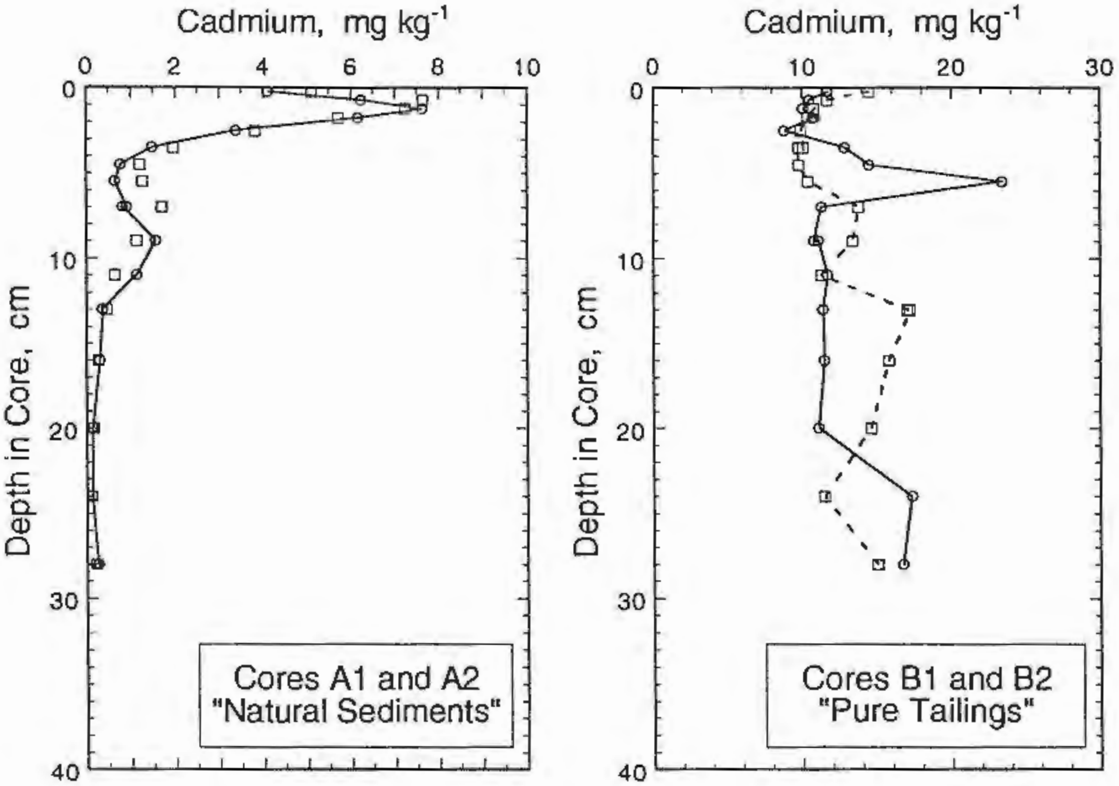

Figure 3-16: Sedimentary cadmium concentration profiles in duplicate cores from Stations A and B in Anderson Lake in April 1993. The open circles represent cores A1 and B1.

the cores, but not at greater depths. These silt-sized grains were all fresh, regardless of composition.

Examination of polished sections from subsamples of the tailings at Station B (Core B1) revealed a very high sulphide content with approximately equal proportions of pyrite and pyrrotite (Plate 3-2). The silicate fraction consisted predominantly of quartz and feldspars with accessory hornblende, chlorite and biotite. Considerable variation in texture of the tailings was observed with depth in the core, which presumably represent changes in feedstock, milling procedures, and hydraulic influences during deposition. A very high concentration of sphalerite (~3.5 %) was observed in the sample AL-9 (5 to 6 cm deep, Core B1); this is consistent with the very high zinc concentration of ~16 x 10^3 mg/kg measured in a split of the same sample. No authigenic framboids were observed in these deposits, and without exception the sulphide grains were consistently fresh. No visual evidence of leaching or oxidation was noted (Appendix C-2).

3.1.3 Interstitial Waters

All filtered porewater samples from all four cores were analyzed for a suite of dissolved metals, including Fe, Mn, Zn, Cu, Pb, Cd, As and Hg. Sulphate, nitrate, and total dissolved sulphide was measured in selected aliquots where volume permitted. Supernatant (core-top) water samples were also collected by syringe at a height about 30 cm above the sediment-water interface and were analyzed at UBC for a number of dissolved metals. The results from these samples disagreed with measurements made on the bottom waters collected with the water-column sampler. The compositions of the core-top waters were similar to values measured at mid-depth in the water column, not at the bottom. Examination of the data revealed that the difference is not due to any analytical difficulty, but instead reflects a design limitation of the corer. The upper portion of the sleeve valve of the corer has two large ports which allow upward-flowing water to escape during instrument descent. However, the flow is not free, in that the total cross-sectional area of the ports is less than that of the mouth of the plastic core barrel. Therefore there is some resistance to the flow of water through the barrel during lowering. This restricted flushing causes some water inside the barrel to be carried down with the corer, for probably not more than one or maybe two metres. Normally this would pose no problem, but in a shallow and highly stratified water column,

Plate 3-1: Polished section showing framboidal pyrite at the natural sediment site, Station A - Anderson Lake.

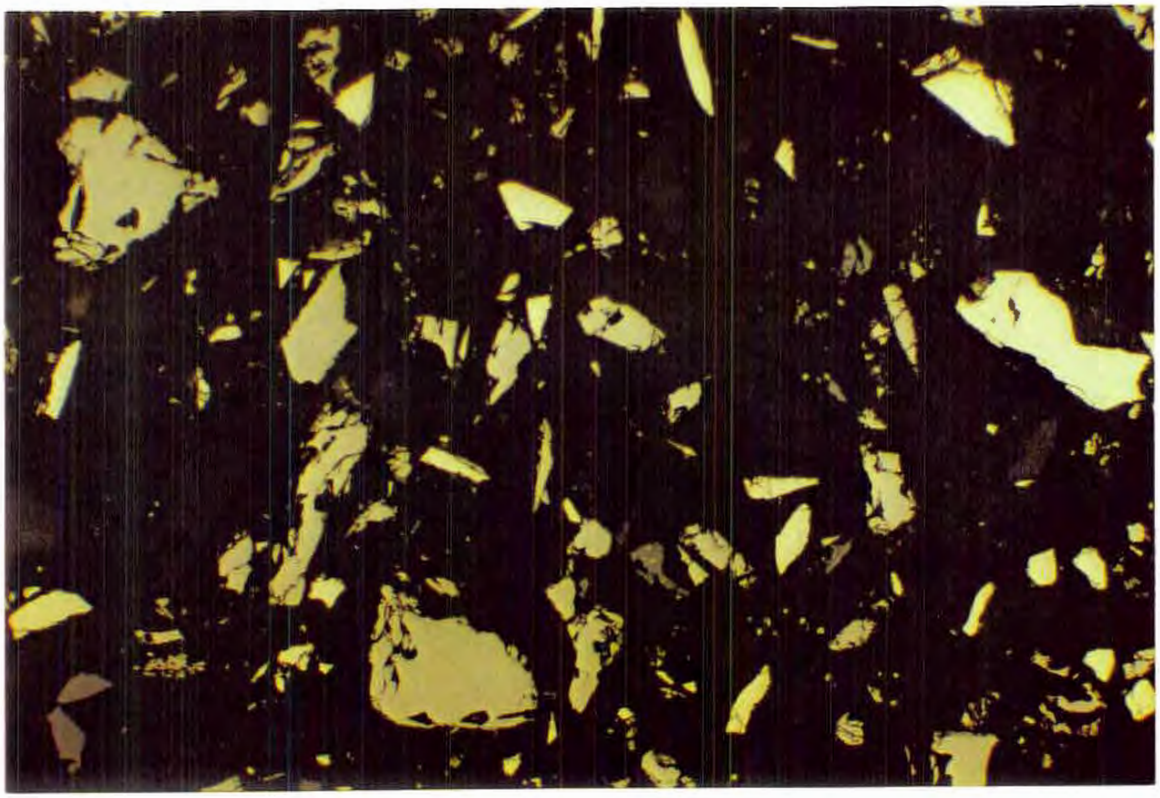

Plate 3-2: Polished section from tailings site showing abundant pyrite.

there is the potential for the supernatant water to consist of a mixture of waters from different layers. A second problem is that the ports in the corer sit 30 to 50 cm above the sediment-water interface. This distance is greater than the thickness of the compositionally distinct strata observed in the bottom waters at both sites during the winter survey. Consequently, the supernatant water samples collected in this study cannot be considered to consist entirely of near-bottom waters, and data from these samples will not be used. The composition of the sample collected with the water-column sampler immediately above the sediment-water interface at each site will instead be used in comparisons with shallow porewaters.

Dissolved Fe profiles are shown in Figure 3-17 along with concentrations measured in the lowermost sample (5 cm above the bottom) collected with the water column sampler. The "duplicate" profiles are similar in form at each site: high concentrations characterize the porewaters in the upper several centimetres, particularly in the Station B cores; below the upper 10 cm, concentrations fall to very low values. Dissolved Mn distributions are fundamentally different (Figure 3-18): there is no significant increase with depth in the upper 10 cm, and there is no depletion toward the base of the cores as is evident for iron. The poor duplication of the pore-water manganese distributions at Station B implies significant heterogeneity over short distances within the tailings deposit.

Dissolved Zn concentrations at the natural sediments site sharply decrease with depth in the upper 2 cm of the deposits (Figure 3-19), similar to the tailings in core B1, whereas in B2, a peak in concentration (~25 μg/L) occurs between 0.5 and 2 cm depth. Dissolved As distributions in the cores from Station A closely follow the porewater iron profiles (Figure 3-20), reaching maxima of 40 to 80 μg/L at shallow depths. Maximum arsenic concentrations in the tailings porewaters are much lower, reaching ~10 μg/L several centimetres below the surface in both cores (Figure 3-20). Dissolved As was undetectable (< 0.5 μg/L) between 0.75 and 2.5 cm depth in both cores B1 and B2, and the peak concentrations at greater depths appear to be slightly below those of iron. Dissolved Cu (Figure 3-21) is essentially undetectable (≤ 0.12 μg/L) in all porewaters extracted from the pure tailings cores (as well as in the overlying bottom water). In cores A1 and A2, maximum concentrations of 2.8 μg/L are observed in the upper 2 cm, with very low or undetectable values at greater depths. Neither lead nor cadmium are

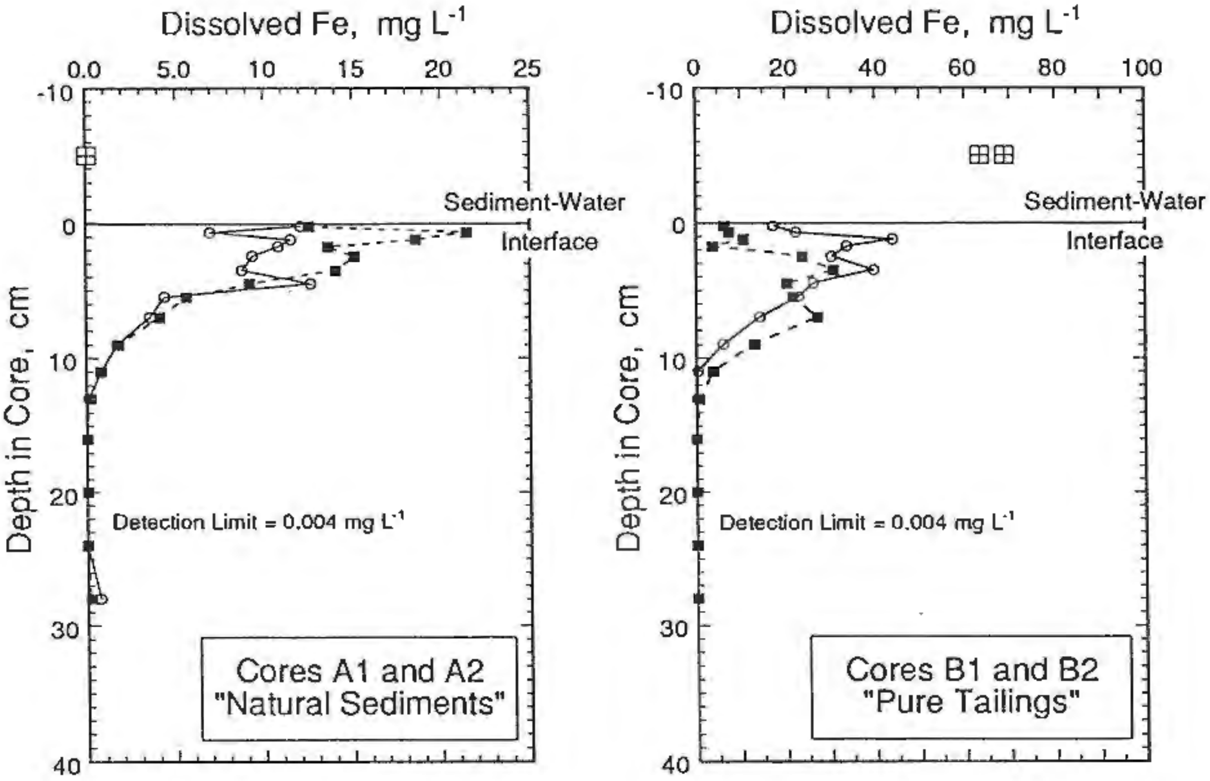

Figure 3-17: **Dissolved (<0.2 µm-filtered) iron concentration profiles in duplicate cores from Stations A and B in Anderson Lake in April 1993. The open circles represent cores A1 and B1, and the crossed squares above the interface represent the concentration in the lowermost sample(~5 cm above the bottom) collected with the water-column sampler.**

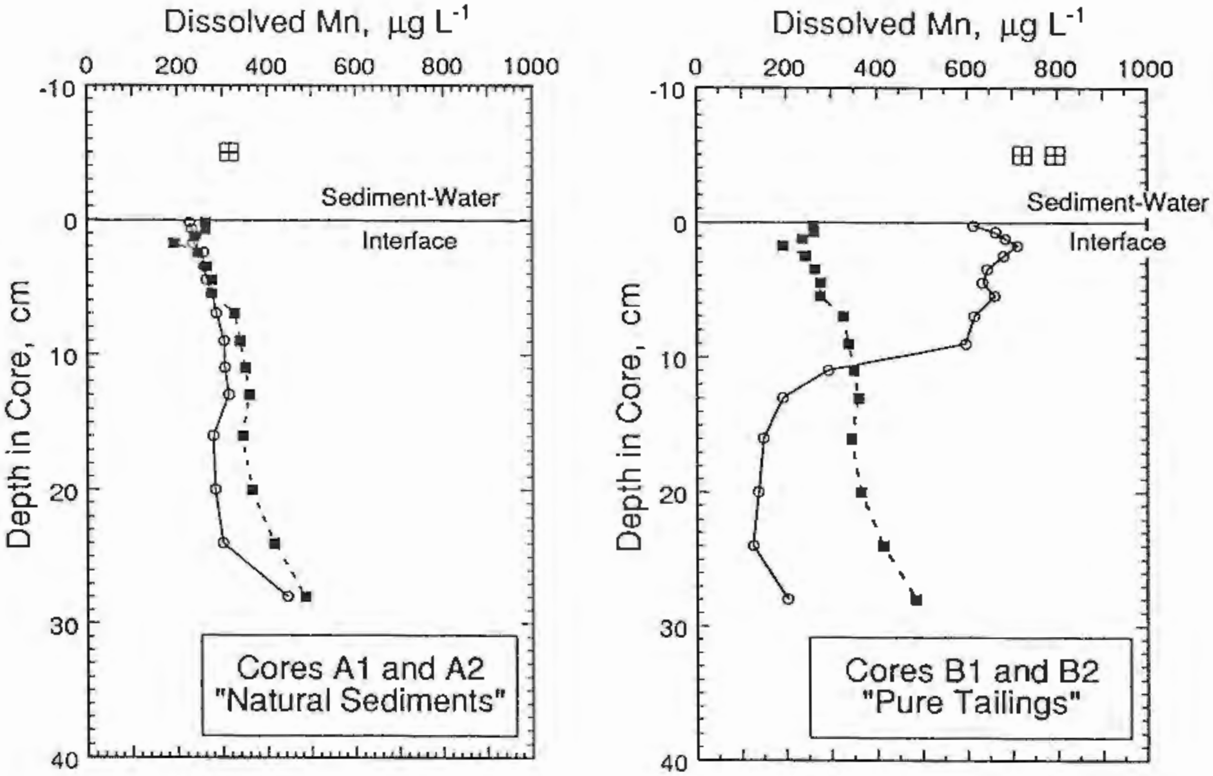

Figure 3-18: Dissolved (<0.2 µm-filtered) manganese concentration profiles in duplicate cores from Stations A and B in Anderson Lake in April 1993. The open circles represent cores A1 and B1, and the crossed squaresabove the interface represent the concentration in the lowermost sample (~5 cm above the bottom) collected with the water-column sampler.

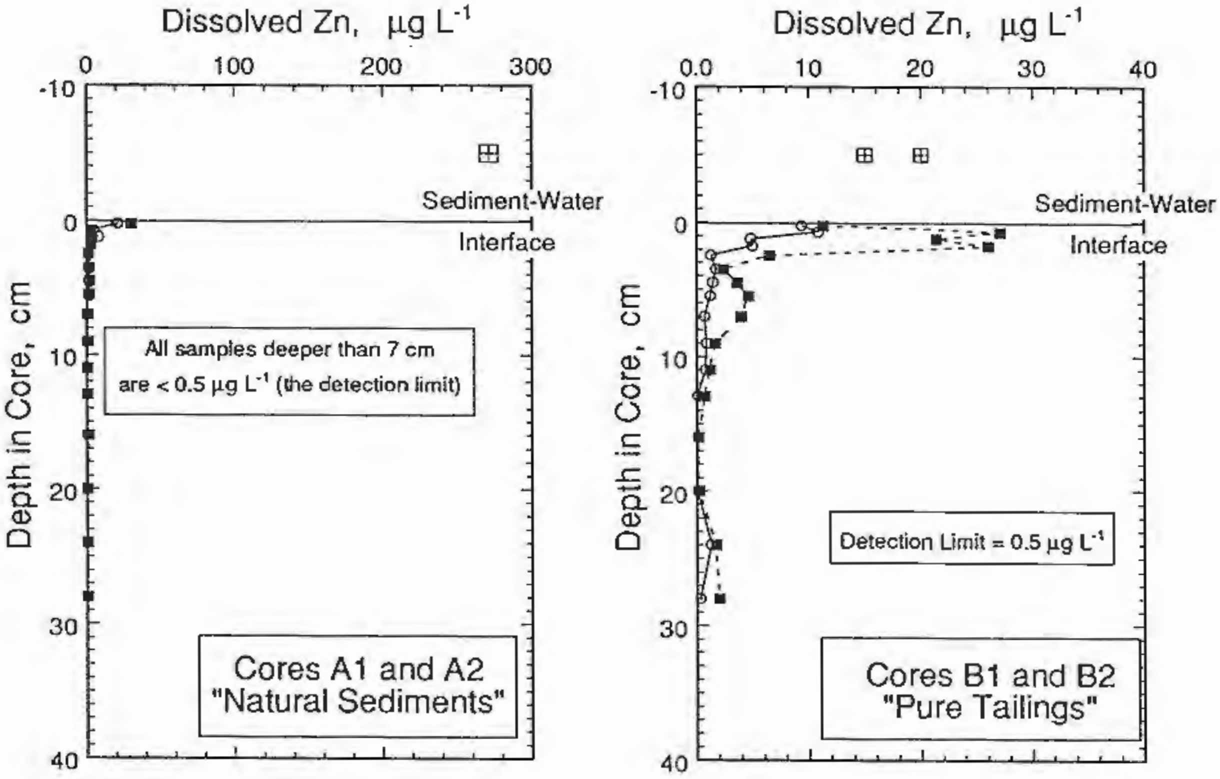

Figure 3-19: **Dissolved (<0.2 µm-filtered) zinc concentration profiles in duplicate cores from Stations A and B in Anderson Lake in April 1993. The open circles represent cores A1 and B1, and the crossed squares above the interface represent the concentration in the lowermost sample (~5 cm above the bottom) collected with the water-column sampler.**

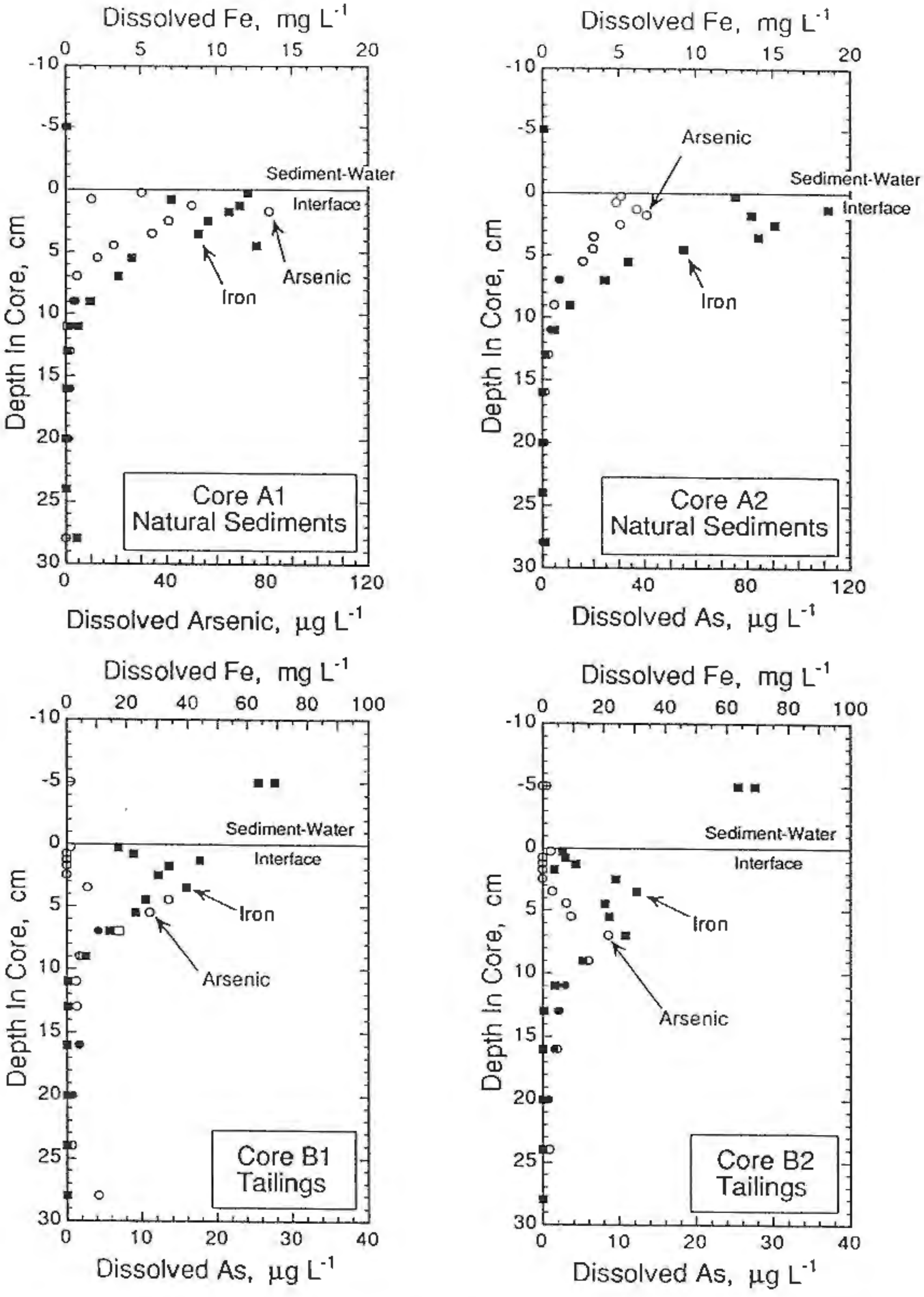

Figure 3-20: **Dissolved (<0.2 µm-filtered) arsenic and iron concentration profiles in duplicate cores from Stations A and B in Anderson Lake in April 1993. Open circles represent arsenic. Data points above the interface represent the concentrations of each element in the lowermost samples (~5 cm above the bottom) collected with the water-column sampler at each site.**

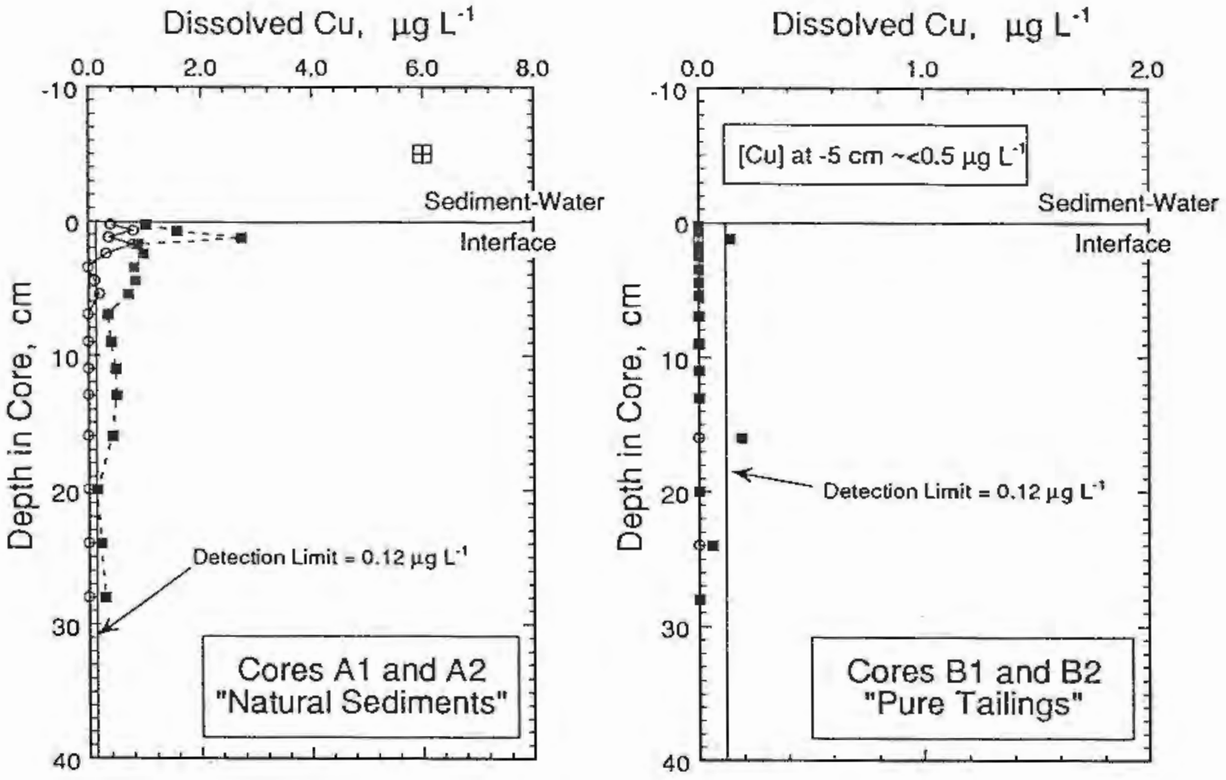

Figure 3-21: Dissolved (<0.2 μm-filtered) copper concentration profiles in duplicate cores from Stations A and B in Anderson Lake in April 1993. The open circles represent cores A1 and B1, and the crossed square above the interface at Site A represents the concentration in the lowermost sample (~5 cm above the bottom) collected with the water-column sampler. Copper was not detectable in the bottom water at Site B.

detectable in any of the porewater samples at either station (Figures 3-22 and 3-23, respectively), except in the 1.25 cm sample in Core A1 where the cadmium concentration is marginally above the detection limit. Lead and cadmium are primarily undetectable in the bottom waters at either site. Dissolved mercury concentrations in the tailings porewaters (Station B) are very low, being close to the detection limit of 0.1 µg/L and never exceeding 0.15 µg/L (Appendix E, Table E-3). Levels in porewaters in the natural sediments (Cores A1 and A2) are slightly higher on average, but never exceed 0.25 mg/L (Figure 3-24).

Sulphate distributions in porewaters from the two locations showed considerable contrast. In the natural sediments, SO_4^{2-} decreases with depth from values of ~900 mg/L at the surface to ~400 to 600 mg/L at the base of the cores (Figure 3-25). Concentrations increase with depth in the tailings, reaching maxima of ~2,000 mg/L in the lower 10 cm of the cores, which is about twice the level in the local bottom waters at the time of core collection. Dissolved sulphide was not detectable in porewaters from the tailings cores, in contrast to the measurable but low levels (up to ~800 µg/L as H_2S) recorded at the natural sediments site (Figure 3-25).

3.2 Summer Survey

Three locations were sampled in August, 1993 (Figure 2-1), one (Station B, the "Tailings" site) near the tailings outfall in nearly 4 m of water, a second (Station A, the "Natural Sediments" site) some 2 km to the southeast in a bay which has never received tailings directly, and the third (the "Shallow Tailings" site, Station C) in a very shallow area floored by tailings one hundred metres northwest of the Station B. The first two sites correspond to Stations B and A of the winter survey, respectively, and the third was occupied to test the specific question as to whether tailings submerged in very shallow water might be more prone to oxidation than elsewhere.

3.2.1 Water Column

Water column profiles of dissolved oxygen and temperature are shown in Figure 3-26. Both sets of data at both sites show that the water column was isothermal, warm (~19°C), well-mixed, and reasonably well oxygenated (~6 to 7 mg/L O_2) during the sampling period. Profiles collected at 0020 hours and 1300 hours on

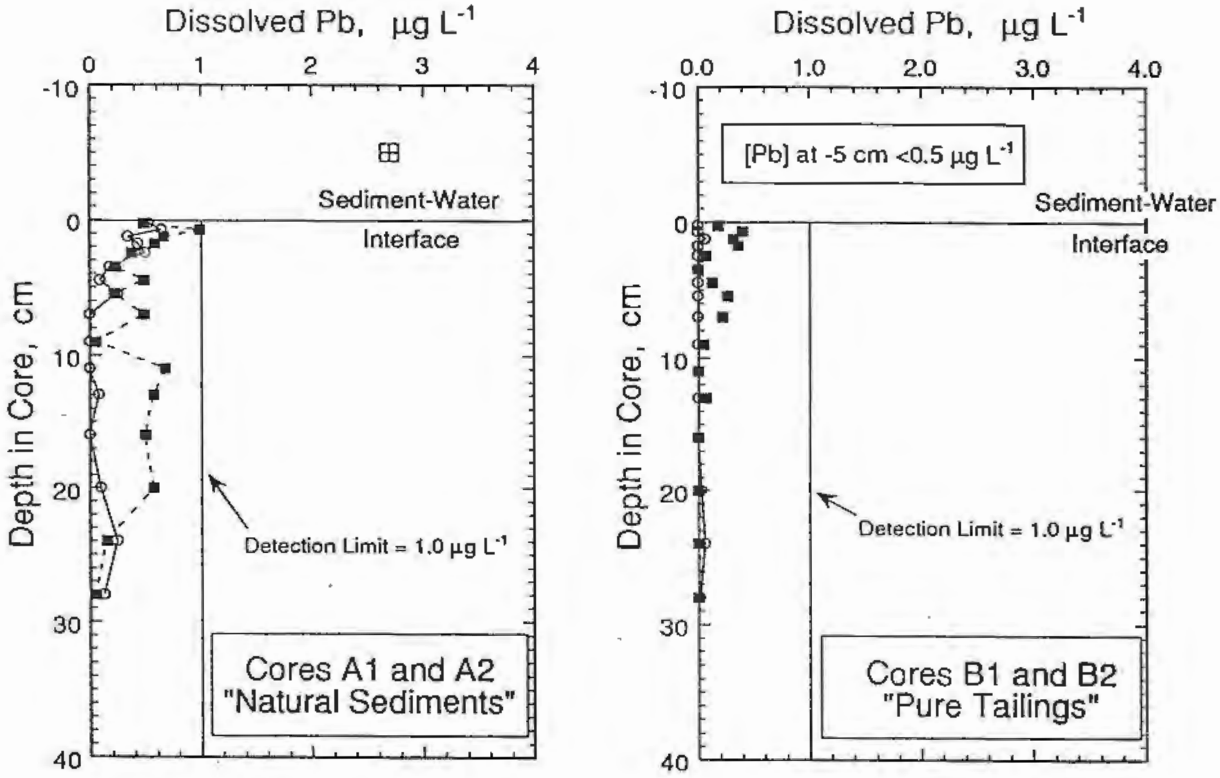

Figure 3-22: Dissolved (<0.2 mm-filtered) lead concentration profiles in duplicate cores from Stations A and B in Anderson Lake in April 1993. The open circles represent cores A1 and B1, and the crossed square above the interface at Site A represents the concentration in the lowermost sample (~5 cm above the bottom) collected with the water-column sampler. Lead was not detectable in the bottom water at Site B.

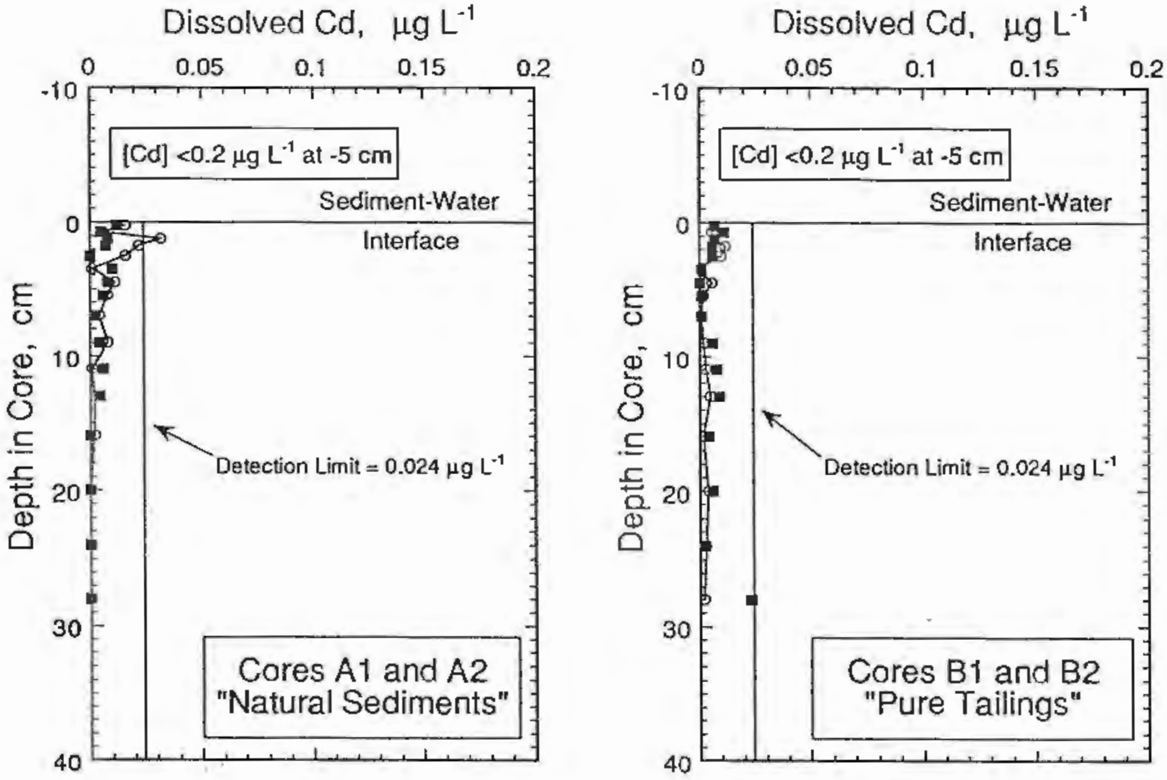

Figure 3-23: Dissolved (<0.2 mm-filtered) cadmium concentration profiles in duplicate cores from Stations A and B in Anderson Lake in April 1993. The open circles represent cores A1 and B1. Cadmium was not detectable in the bottom water at either site.

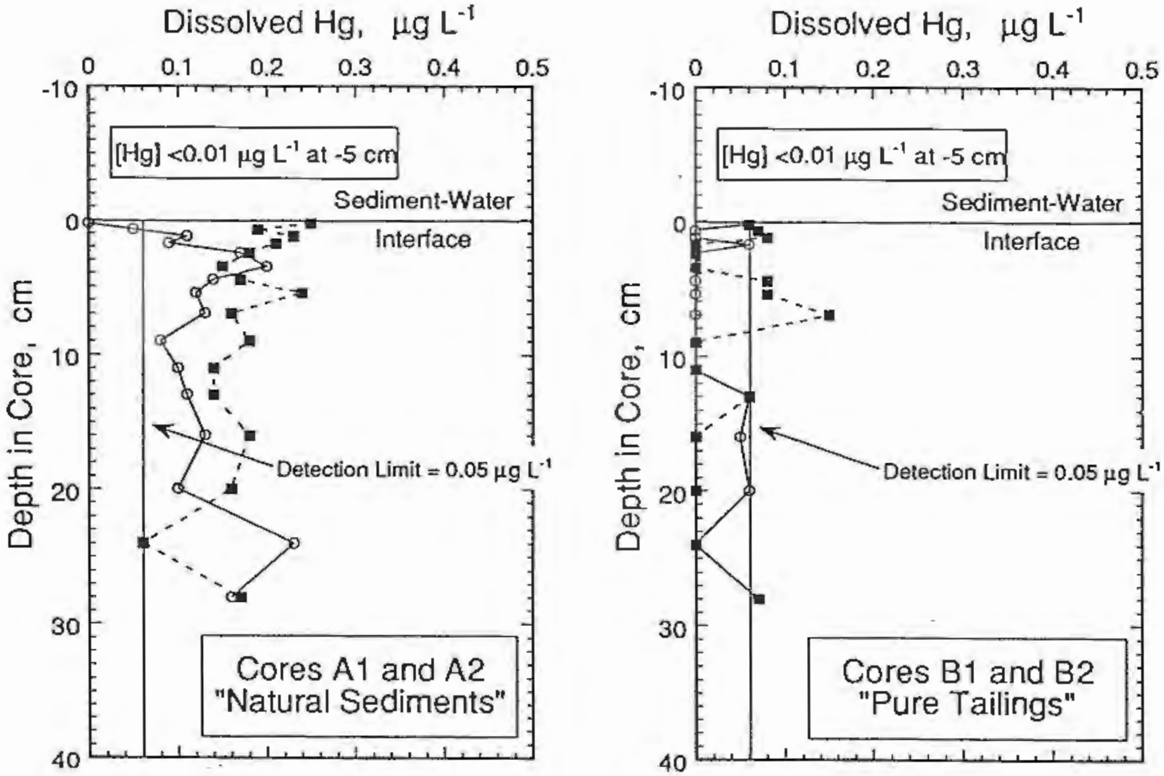

Figure 3-24: Dissolved (<0.2 mm-filtered) mercury concentration profiles in duplicate cores from Stations A and B in Anderson Lake in April 1993. The open circles represent cores A1 and B1. Mercury was not detectable in the bottom water at Site B.

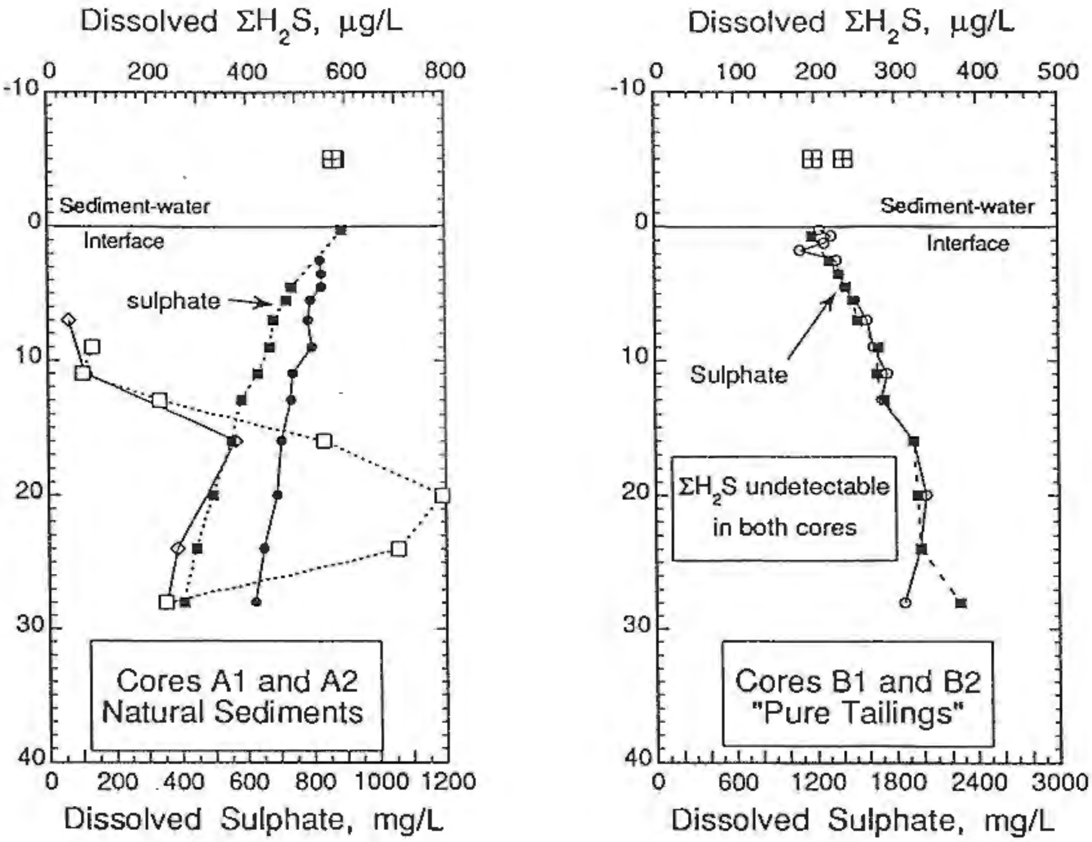

Figure 3-25: **Dissolved (<0.2 mm-filtered) hydrogen sulphide and sulphate concentration profiles in duplicate cores from Station A and sulphate profiles from Station B in Anderson Lake in April 1993. The open circles represent cores A1 and B1, and the crossed squares above the interface at both sites represent the sulphate concentration in the lowermost sample (~5 cm above the bottom) collected with the water-column sampler at each site. H_2S was not detectable in pore waters at Station B.**

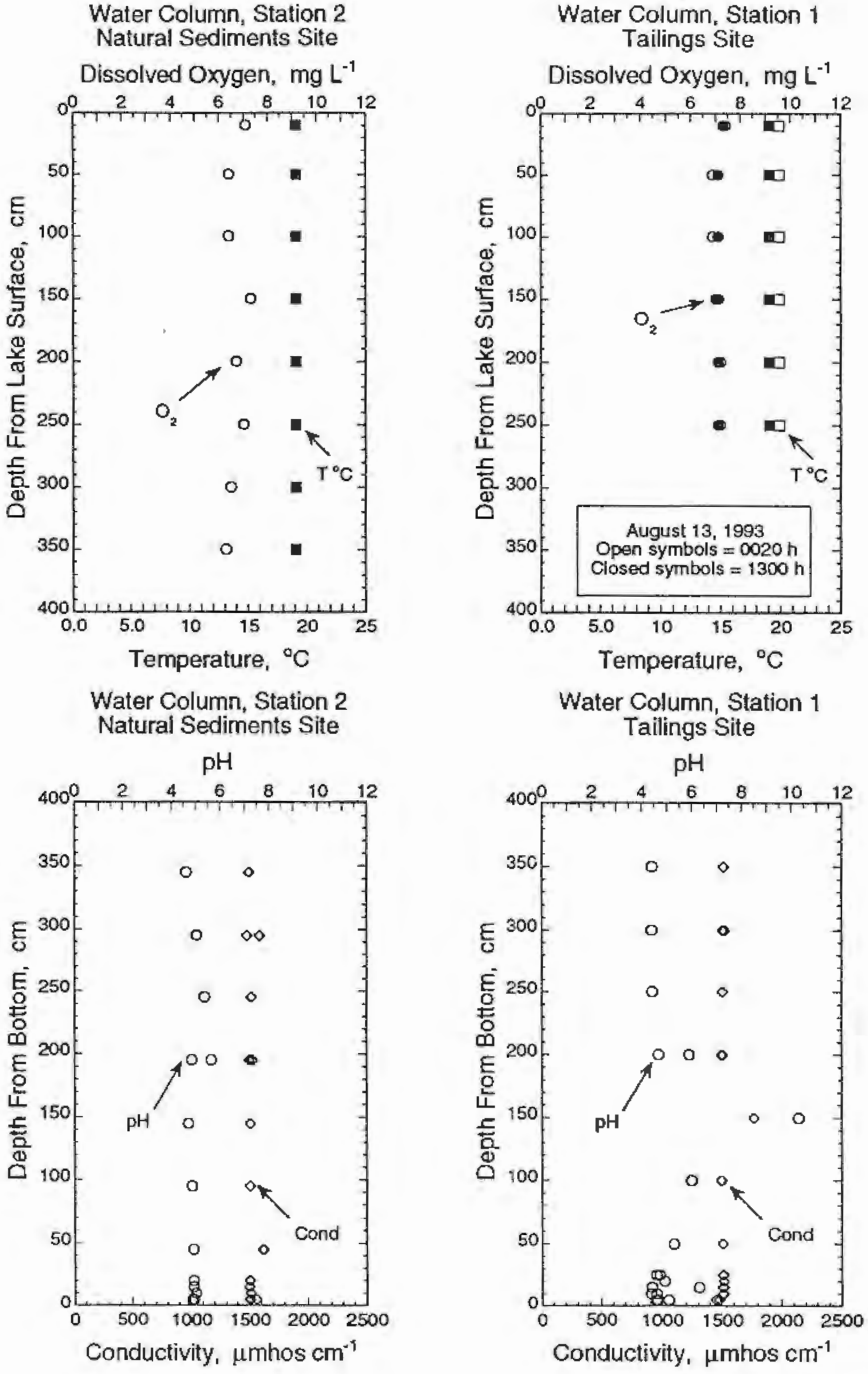

Figure 3-26: Oxygen, temperature, pH and conductivity distributions in the water column at Stations 1 and 2 in Anderson Lake in August 1993. The depth scale for the oxygen and temperature data is relative to the lake surface, while the pH and conductivity data are plotted relative to the bottom.

August 13 to check on the extent of diurnal variation showed that the temperature actually decreased abont ~0.6°C between the night and daytime measurements (Figure 3-26), due to the 13th being cooler than August 12 and very windy. Conductivity, pH, and selected major and minor ion distributions are presented in Figures 3-26 and 3-27. Few variations with depth are seen at either site. The waters were acidic, with the pH averaging ~5, and were rich in ammonium (~2 mg/L), sulphate (~800 mg/L), dissolved calcium (~300 mg/L), iron (~0.05 to 0.15 mg/L), zinc (~350 to 450 µg/L), copper (~20 to 30 µg/L), lead (~30 to 60 µg/L), and manganese (~250 to 300 µg/L). Differences in mean concentrations between sites were minor: slightly higher concentrations of dissolved metals and ammonium were observed at the tailings site, and slightly higher nitrate levels were measured at the natural sediments location. One sample from the tailings site collected 150 cm above the bottom had an unusual composition, with a pH > 10, a high conductivity (Figures 3-26) and an extremely high dissolved Fe content (~1 mg/L, not shown in Figure 3-28), relative to the other samples. Dissolved Fe will readily and almost instantly precipitate from solution at such an alkaline pH; hence, it is reasonable to conclude that there is something wrong with this sample, and it is excluded from further discussion.

Dissolved arsenic and cadmium concentrations are invariant with depth, being ≤ 1 µg/L and ~0.4 µg/L respectively (Appendix B). Mercury was not detectable (< 0.01 µg/L) in any samples.

3.2.2 Sediments

One core was collected by divers at each of the natural sediments and tailings sites by hand inserting butyrate barrels. Underwater visibility was poor at both locations, but was sufficient to reveal an uneven bottom at both locations. Relief at the hummocky tailings site was on the order of a metre over length scales of several metres. The quality of the 68 and 48 cm long cores was excellent, and interstitial waters were extracted under nitrogen from both. A third 16 cm long core was collected by diver from the turbid shallow tailings site (~1.5 m deep), where the coarse texture of the deposits made penetration difficult. The tailings at this site consisted of a highly porous lag deposit of pyrite-rich indurated clasts. The clasts ranged from < 1 mm to > 10 mm in size, and were composed entirely of

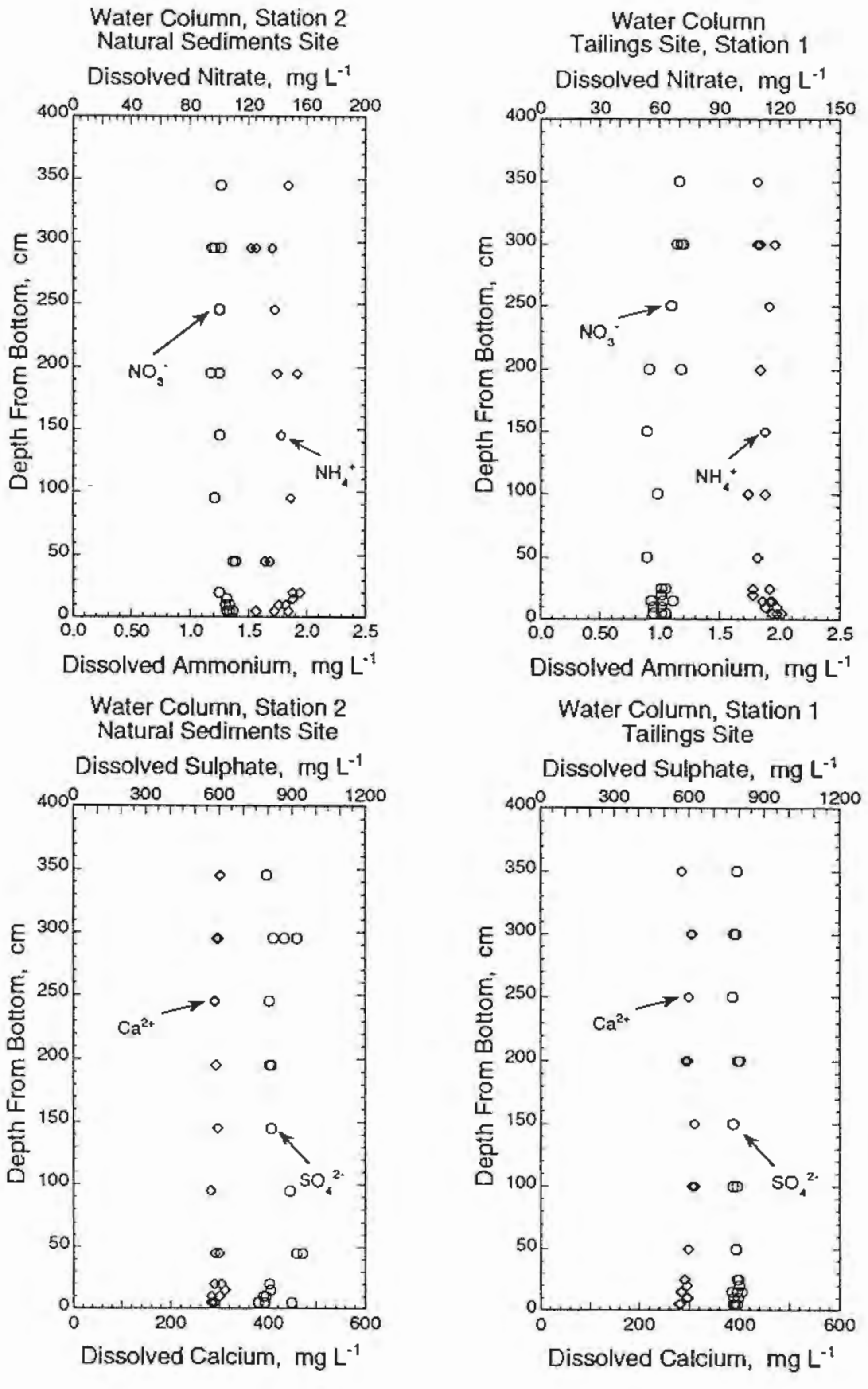

Figure 3-27: Dissolved ammonium, nitrate, sulphate and calcium distributions in the water column at Stations 1 and 2 in Anderson Lake in August 1993. The depth scale is relative to the bottom.

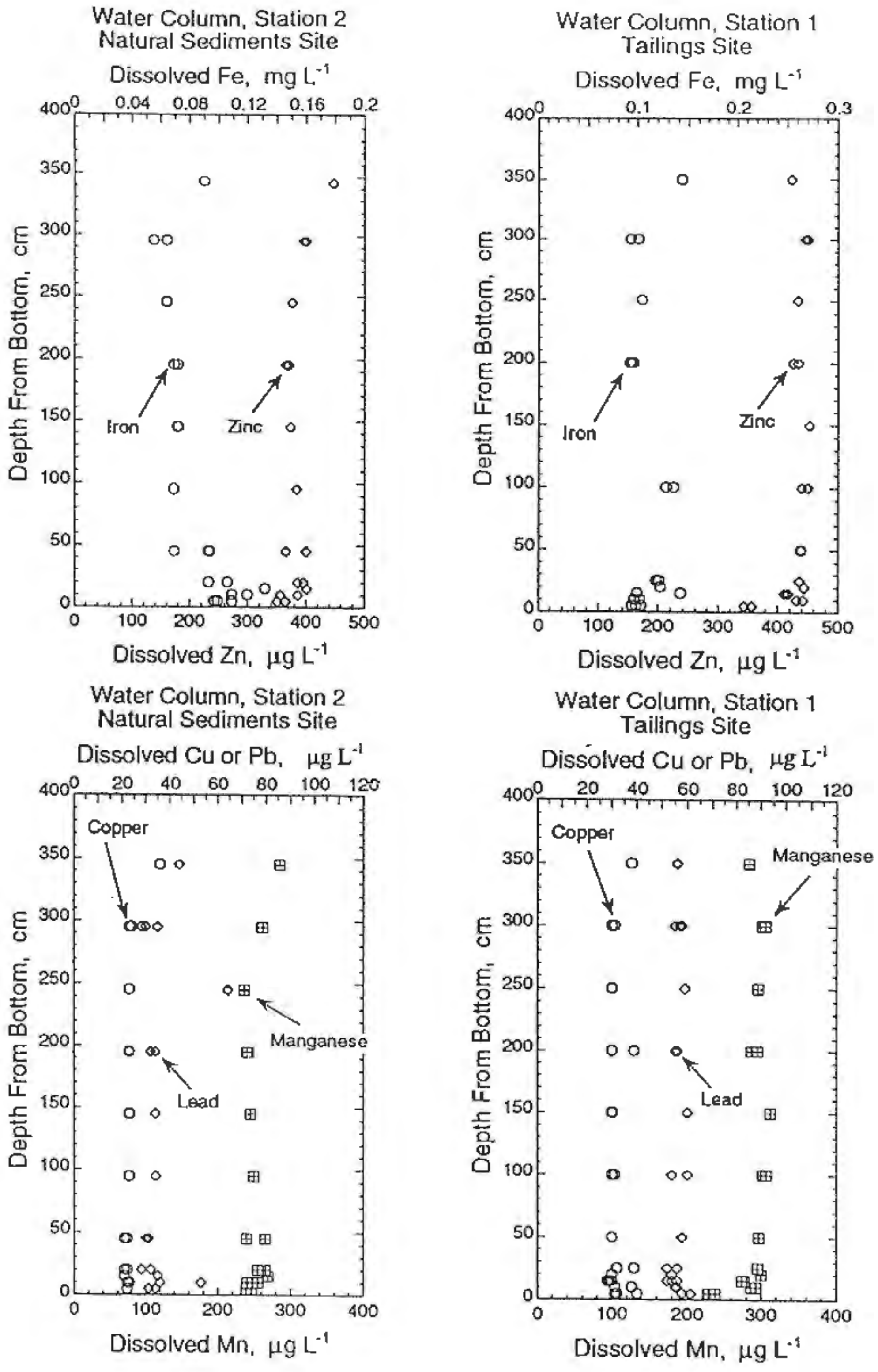

Figure 3-28: **Dissolved iron, zinc, copper, lead and manganese distributions in the water column at Stations 1 and 2 in Anderson Lake in August 1993. The depth scale is relative to the bottom.**

tailings grains. All pyrite particles, either discrete or within the clasts, appeared fresh and unaltered. Detailed core logs are presented in Appendix C-1.

Each of the cores was capped with a rust- to orange-coloured ferruginous veneer. At the natural sediments site this consisted of a 2 mm thick gelatinous rust-coloured layer, with abundant faecal casts and several protruding worm tubes on the upper surface. Burrows with oxidized haloes were observed down to 10 cm depth, suggesting active bioturbation in this interval. The surface veneer was underlain by about 10 cm of charcoal-gray fine-grained gelatinous ooze, which graded into a brown, gelatinous, homogeneous, organic-rich ooze that characterized the lower 40 cm of the core. A strong smell of H_2S was evident below ~12 cm depth during subsequent processing. At the tailings and shallow tailings sites, the ferruginous layer was 2 to 3 mm thick and had a gelatinous, filamentous character evocative of a bacterial mat. The mat was easily lifted off the core-tops with a spatula. More than half of the mat was removed from the top of the tailings-site core in this way, and reserved frozen as a discrete sample. The sample has been examined by Dr. Bill Mohn at the UBC Department of Microbiology and consists of filamentous algae in a matrix of rust to brown coloured flocculent material, presumably iron oxyhydroxides. Dr. Mohn suggests that the algae may be cyanobacteria. No algal mat was evident on the tops of the cores collected from this area during the winter survey. A second important difference between the winter and the summer survey cores is that the duplicate cores collected from this site during the winter consisted of pure tailings, while those recovered in the summer contained a mixture of both tailings and natural sediments. The upper 22 cm of the core was composed of a lobate admixture of tailings and natural deposits, with the latter dominating between 10 and ~15 cm depth and tailings comprising most of the 16 to 22 cm interval. Below 22 cm the deposits consisted almost entirely of natural, organic-rich ooze.

The natural sediment core consists of essentially tailings-free, organic-rich sediments below about 12 cm deep, as shown by the C_{org}, N, S, Zn, Cu, Pb, Cd, Mn and As distributions (Figures 3-29 to 3-31). The upper layer in both cores is composed of a mixture of tailings and natural sediments with metals concentrations being highest in the top centimetre. Very similar vertical distributions were seen in the duplicate cores raised from the same station in the winter survey. Pyrite is the dominant host for sulphur in the core, and is a major

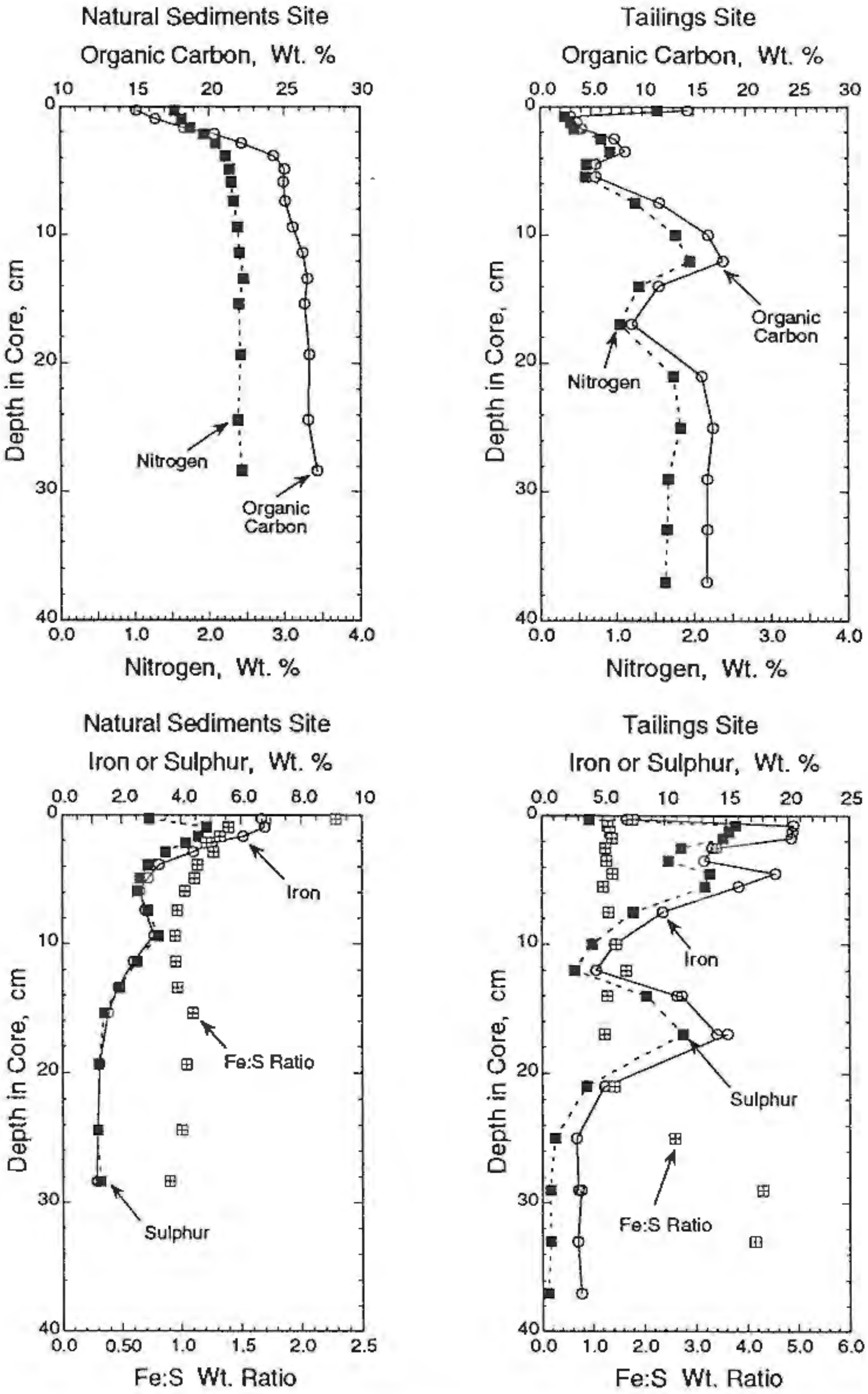

Figure 3-29: Organic carbon, nitrogen, iron, sulphur and Fe:S wt. ratio distributions in sediment cores collected during the summer survey at the natural sediments and tailings sites.

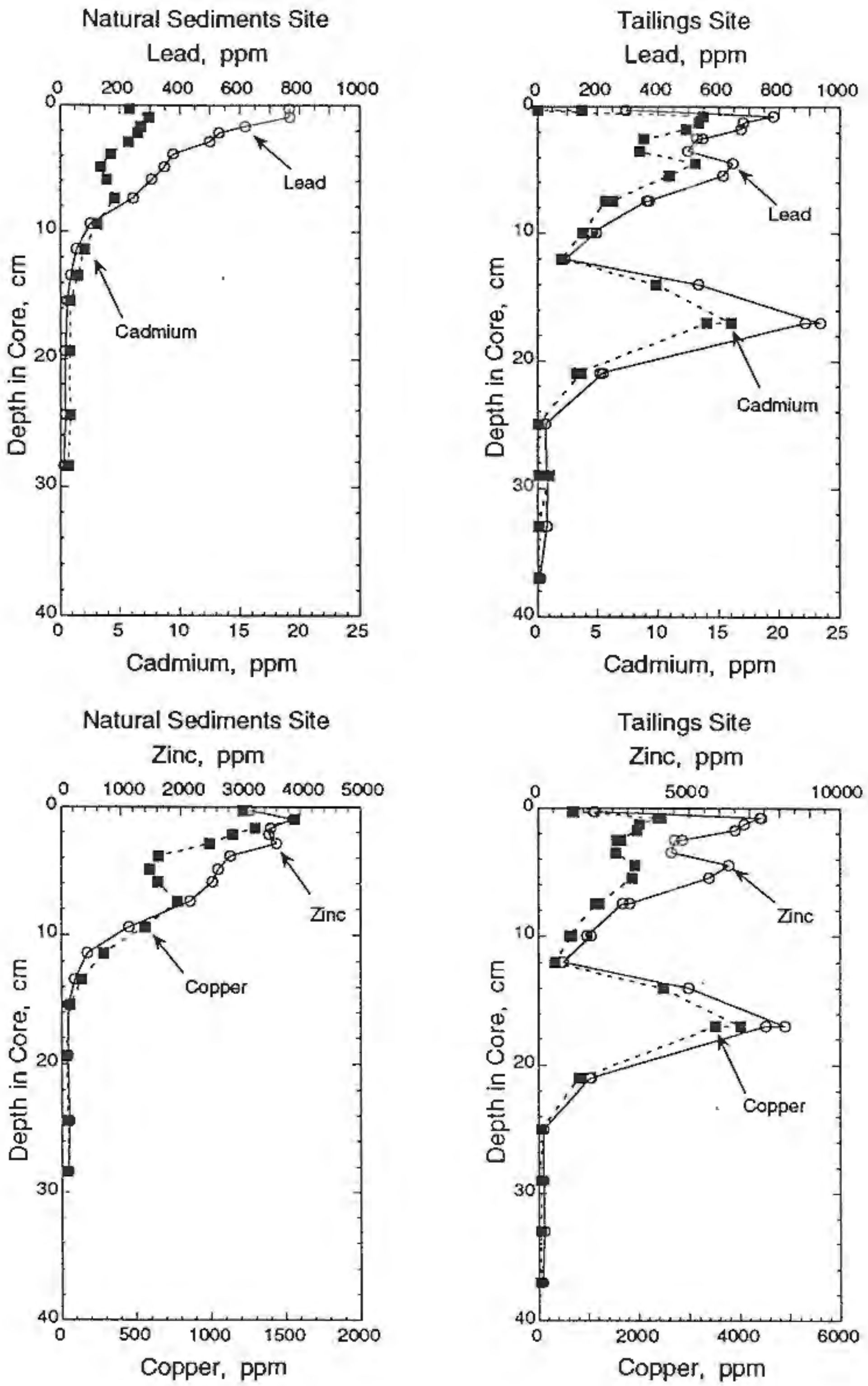

Figure 3-30: Lead, cadmium, zinc and copper distributions in sediment cores collected during the summer survey at the natural sediments and tailings sites.

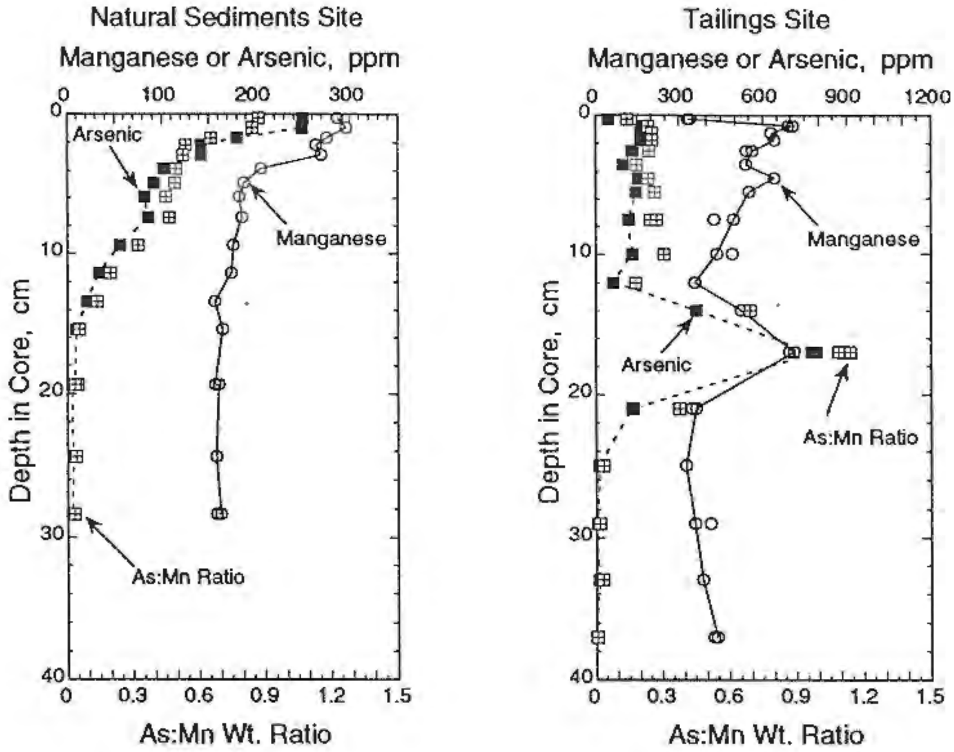

Figure 3-31: **Manganese, arsenic and As:Mn wt. ratio distributions in sediment cores collected during the summer survey at the natural sediments and tailings sites.**

host for iron. The high Fe:S weight ratio at the surface of the core is twice that seen in deeper samples (Figure 3-29), which reflects the high iron oxyhyroxide component in the surface veneer. The Fe:S ratio would probably have been much higher at the surface had not more than half of the algal mat been removed for independent analysis. The similarity seen in the winter and summer survey cores collected at the natural sediment station is not matched at the tailings site. Organic carbon, Fe, S, Zn, Cu, Pb, Cd, As, and Mn distributions in the summer survey core (Figures 3-29 to 3-31) reflect the vertically varying admixture of tailings and natural sediments in the core described in the core log. Tailings are abundant in the core in the upper 6 cm and in the 16 to 22 cm depth interval, whereas organic matter is abundant in the top 5 mm, in the interval between 8 and 15 cm, and below 20 cm. The pair of winter survey cores collected from the same location (within 30 metres of each other) both consisted of pure tailings of somewhat variable composition, but natural sediments were not a significant component. These contrasts indicate that there can be marked variations in the extent of deposition of the tailings over short distances even relatively near the discharge point.

3.2.3 Interstitial Waters

Porewater samples from the two cores from the natural sediments and the tailings sites, and dialysis-array ("peeper") samples from sets of peepers emplaced at all three sampling locations were analyzed for ΣH_2S and a suite of dissolved metals, including Fe, Mn, Zn, Cu, Pb, Cd, As and Hg. Supernatant (core-top) water samples were also collected by syringe at a height about 30 cm above the sediment-water interface and were analyzed for a number of dissolved metals.

3.2.3.1 Shallow Tailings Site

Dissolved Fe and As profiles from two Rescan peepers emplaced ~3 to 4 m apart are shown in Figure 3-32. The "duplicate" profiles show significant differences both in form and absolute concentrations which may reflect short-scale lateral inhomogeneity at this site. Extremely high dissolved iron concentrations occur at shallow subsurface depths at both locations, reaching ~90 and ~120 mg/L within 2 cm of the interface in two of the peeper cell banks; a maximum of ~80 mg/L occurs in the right cell bank of peeper 11. The offset between the two profiles in

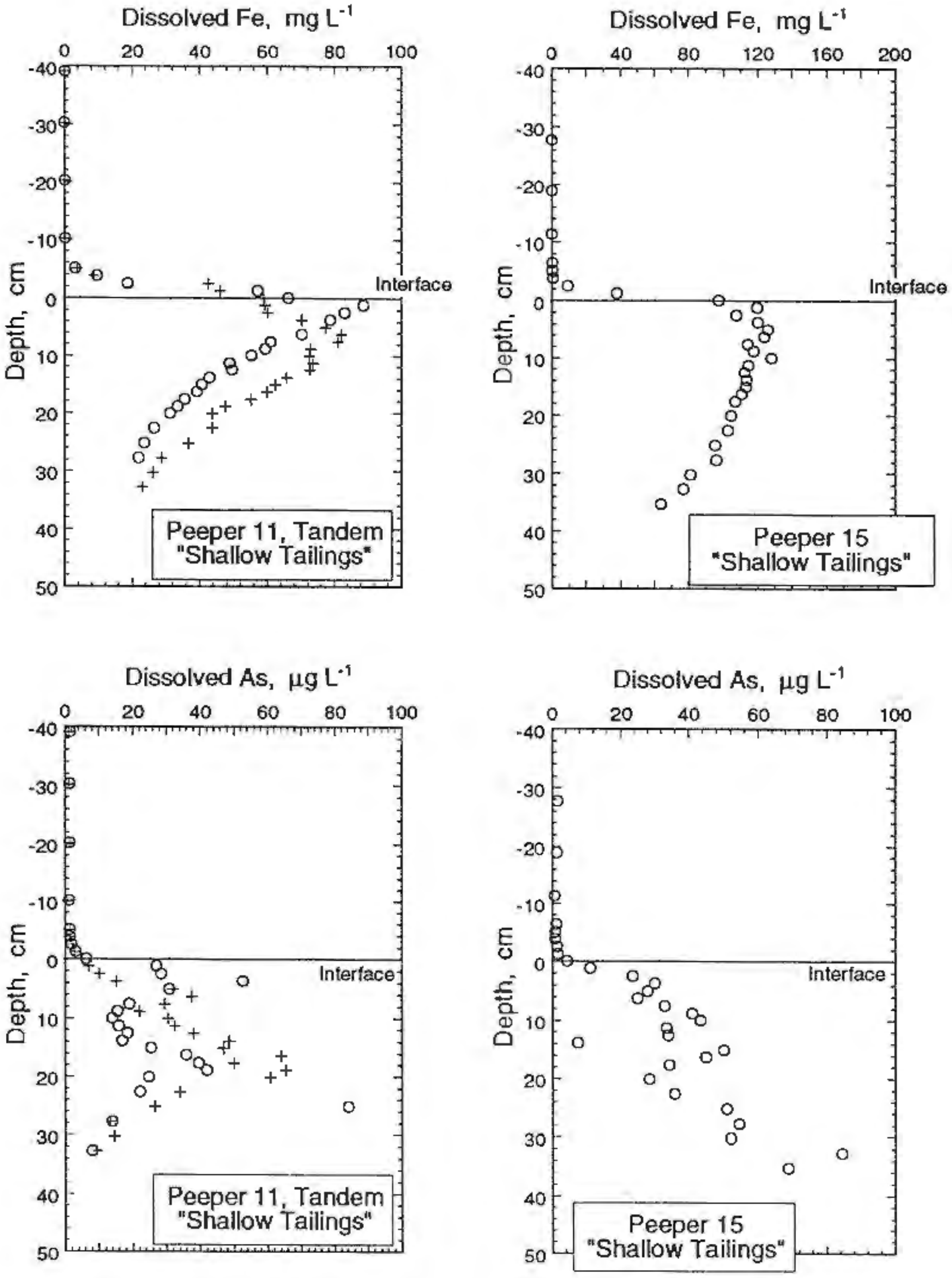

Figure 3-32: Dissolved iron and arsenic distributions in tandem peeper porewaters at the shallow tailings site in August 1993. Open circles indicate samples from the left cell bank.

peeper 11 may reflect uneven topography at the site which could produce uneven immersion across the face of the peeper (the centre lines of the two banks of cells in each tandem Rescan peeper are about 12 cm apart). Below the near-surface maxima, concentrations decrease smoothly with depth, more sharply in peeper 11 than in 15. Arsenic concentrations in the porewaters increase with depth, all three profiles showing double maxima of up to ~90 µg/L (Figure 3-32). Manganese increases smoothly with depth in all three peeper banks, reaching deep maxima of ~2,000 µg/L at ~22 cm depth in peeper 11 and 1,500 µg/L at the base of peeper 15 (Figure 3-33). The profiles are similar in form to those for arsenic at this location.

Dissolved Zn, Cu, Pb, and Cd concentrations at the shallow tailings site are high in all samples more than several centimetres above the sediment-water interface. The levels match the average concentrations measured in water column at the tailings station several hundred metres to the southeast. The concentrations of the four metals decrease sharply with depth as the sediment-water interface is crossed (Figures 3-34 and 3-35). The location of the interface was estimated upon peeper recovery to the nearest peeper cell (nearest 1.3 cm) based on staining and the location of adhering sediments on the frit. However, the mean location of the interface at a high-energy location such as the shallow tailings site could vary somewhat depending on the extent of resuspension, erosion and redeposition. Conditions during retrieval of the peepers at this site were windy. Thus, the steep declines seen in the metals concentrations just above the marked interface could be an artifact, and reflect recent exposure of shallowly-buried cells shortly before recovery. It is more probable that the profound concentration decreases occur in the upper few centimetres of the sediments rather than in the well-mixed water column.

Dissolved sulphide and dissolved mercury concentrations were below detection limit (< ~17 µg/L, and < 0.1 µg/L, respectively) in all of the samples analyzed from both peepers at this site.

3.2.3.2 Tailings Site

Interstitial water samples were collected at the tailings site from two tandem Rescan peepers (Nos. 12 and 13), one tandem NWRI peeper, and a single core, yielding seven profiles in all for most metals.

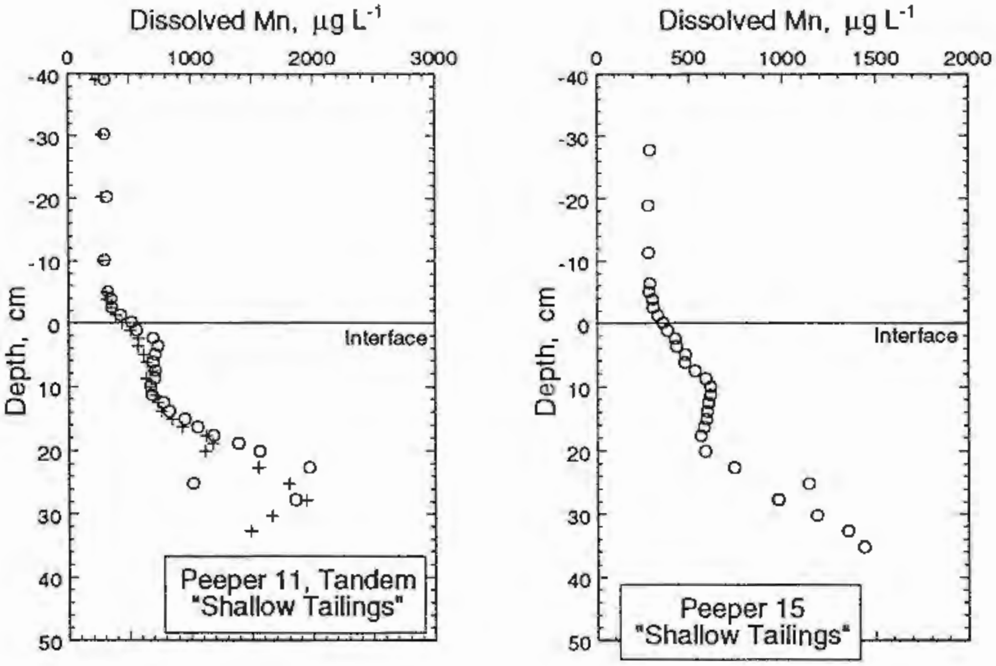

Figure 3-33: Dissolved manganese distributions in peeper porewaters at the shallow tailings site in August 1993. Open circles indicate samples from the left cell bank.

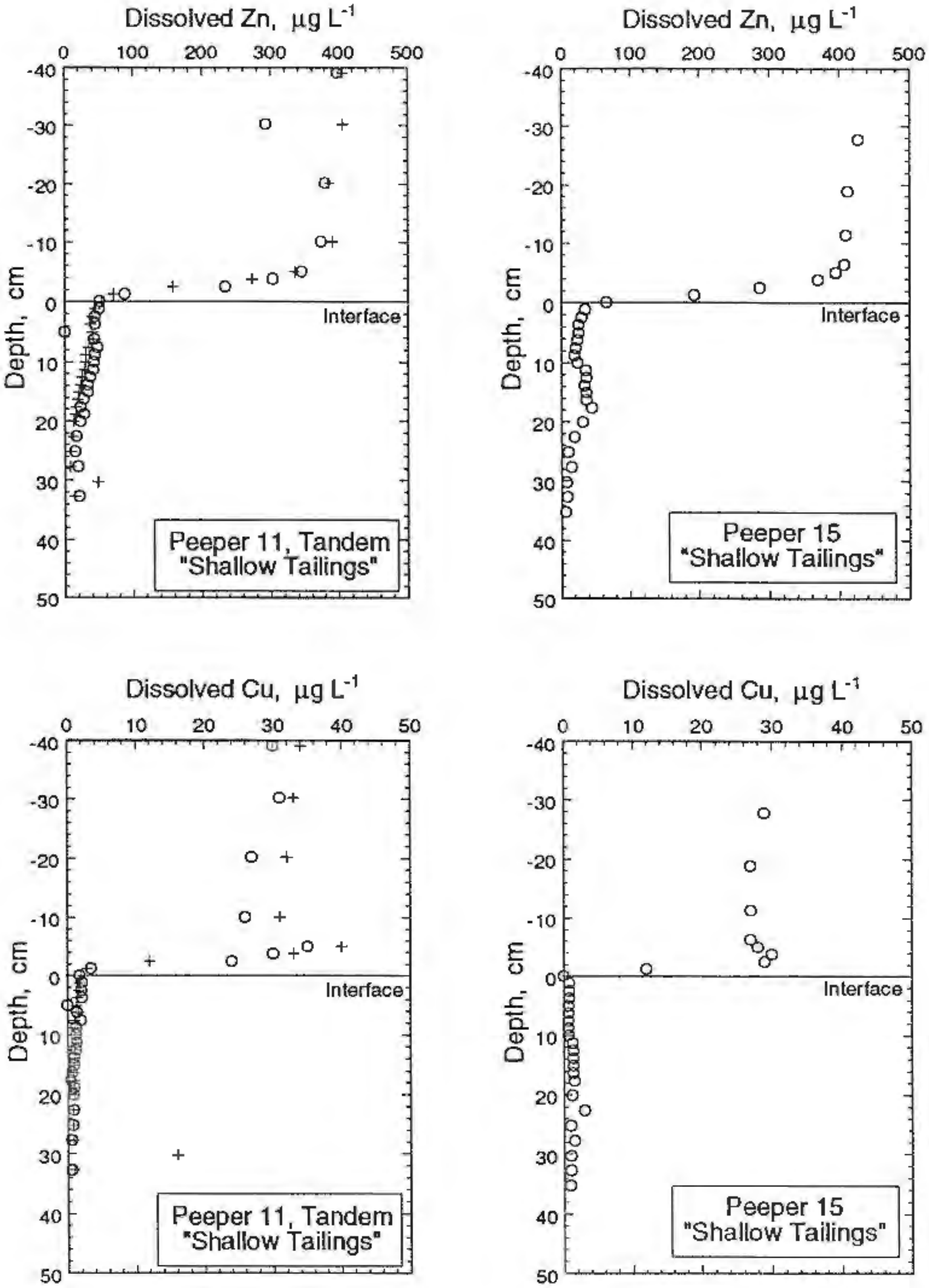

Figure 3-34: Dissolved zinc and copper distributions in peeper porewaters at the shallow tailings site in August 1993. Open circles indicate samples from the left cell bank.

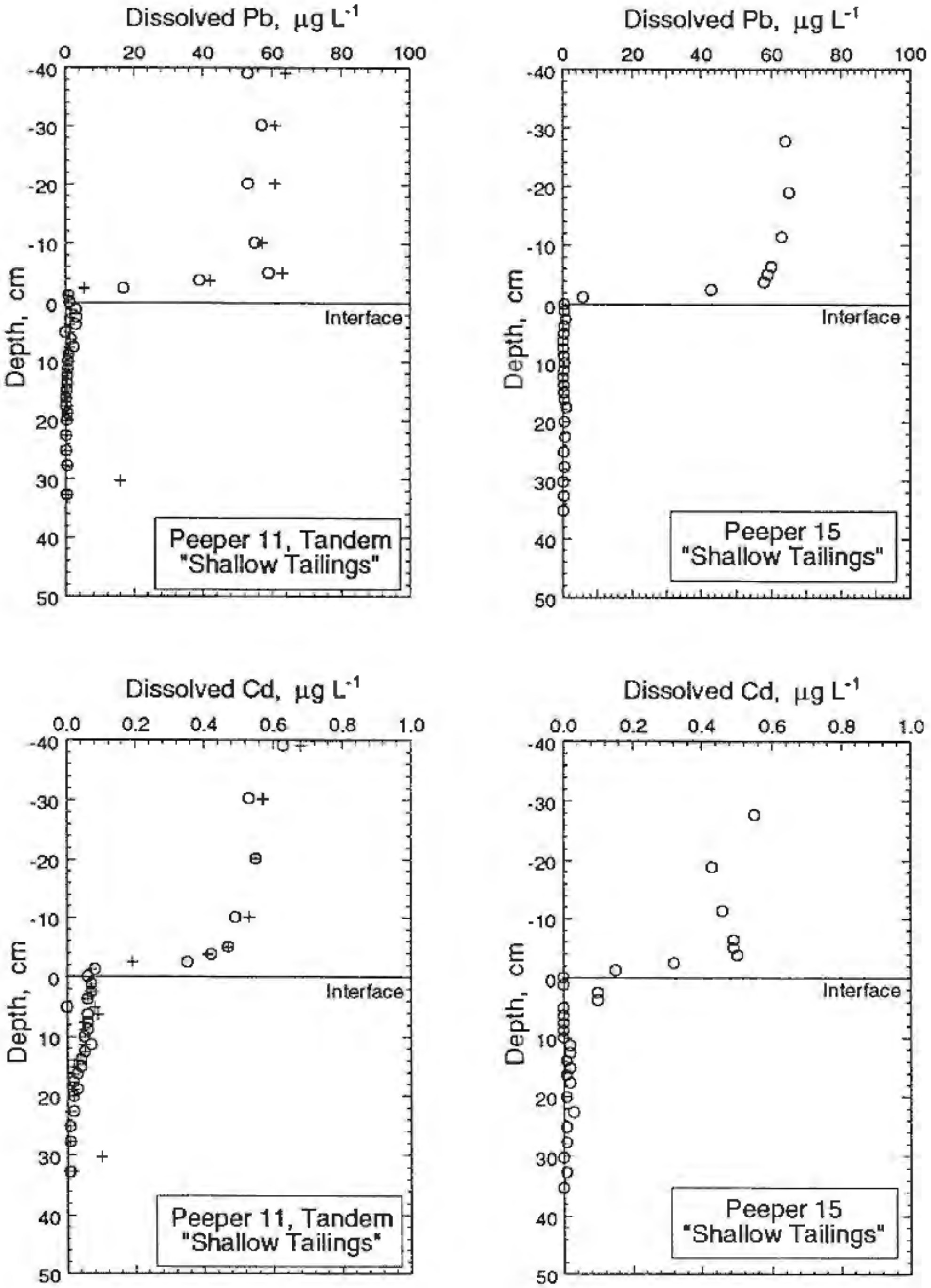

Figure 3-35: Dissolved lead and cadmium distributions in peeper porewaters at the shallow tailings site in August 1993. Open circles indicate samples from the left cell bank.

The profiles are similar in general, but some important differences exist, particularly for iron. Dissolved Fe concentrations increase sharply immediately below the interface in all cases (Figure 3-36). Shallow maxima of ~4 mg/L and ~35 mg/L are seen in the top 2 cm respectively in the core and the NWRI profiles, but not in the distributions in Rescan peepers 12 and 13, where maxima are less well defined and are on the order of 15 mg/L. Relatively high levels are seen at depth, toward the base of the core (~4 mg/L) and in the lower half of the NWRI peeper where one sample from one cell bank contained ~26 mg/L. The three pairs of profiles from the tandem peepers show significant differences between each pair; concentrations at the same depth vary in some instances by a factor of three (Figure 3-36). Some of the differences among the three peepers can potentially be attributed to lateral heterogeneity in the tailings deposits, but this explanation is unsatisfactory in explaining the contrasts between the pairs of profiles from individual peepers. It also cannot account for the marked difference in the form of the peeper profiles and those obtained from extraction of porewaters from the several cores from the area collected in summer 1990 and in winter and summer 1993. The core profiles have invariably shown a near-surface maximum and a sharp depletion in dissolved Fe at depth. Similar disagreements among the peepers are seen at the natural sediments site (see below). A more plausible explanation for the disparities among the various dissolved Fe profiles is that the peepers suffer from a design flaw, as postulated below in the discussion section.

Like iron, dissolved Mn profiles at the tailings site show a sharp increase immediately at or below the sediment-water interface, and variable concentrations at depth (Figure 3-37). Maximum concentrations are in each case on the order of 800 μg/L, much lower than the highest observed levels of dissolved Fe. The core profile and the tandem NWRI profiles indicate two Mn maxima, one at a shallow depth (≤ 6 cm) and the other below 30 cm, while the Rescan peeper profiles (peepers 12 and 13) differ significantly. A near-surface maximum of ~800 μg/L is seen in one profile from peeper 12 but not the other, whereas no shallow maximum is defined by the data in peeper 13 (Figure 3-37).

The marked difference in the dissolved As distributions in the core and the two Rescan peepers is puzzling (Figure 3-38). The smooth core profile shows a clear maximum in dissolved As of ~200 μg/L at 16 cm depth whereas the concentrations measured in the peeper samples are all ~ < 1.5 μg/L, very close to the detection

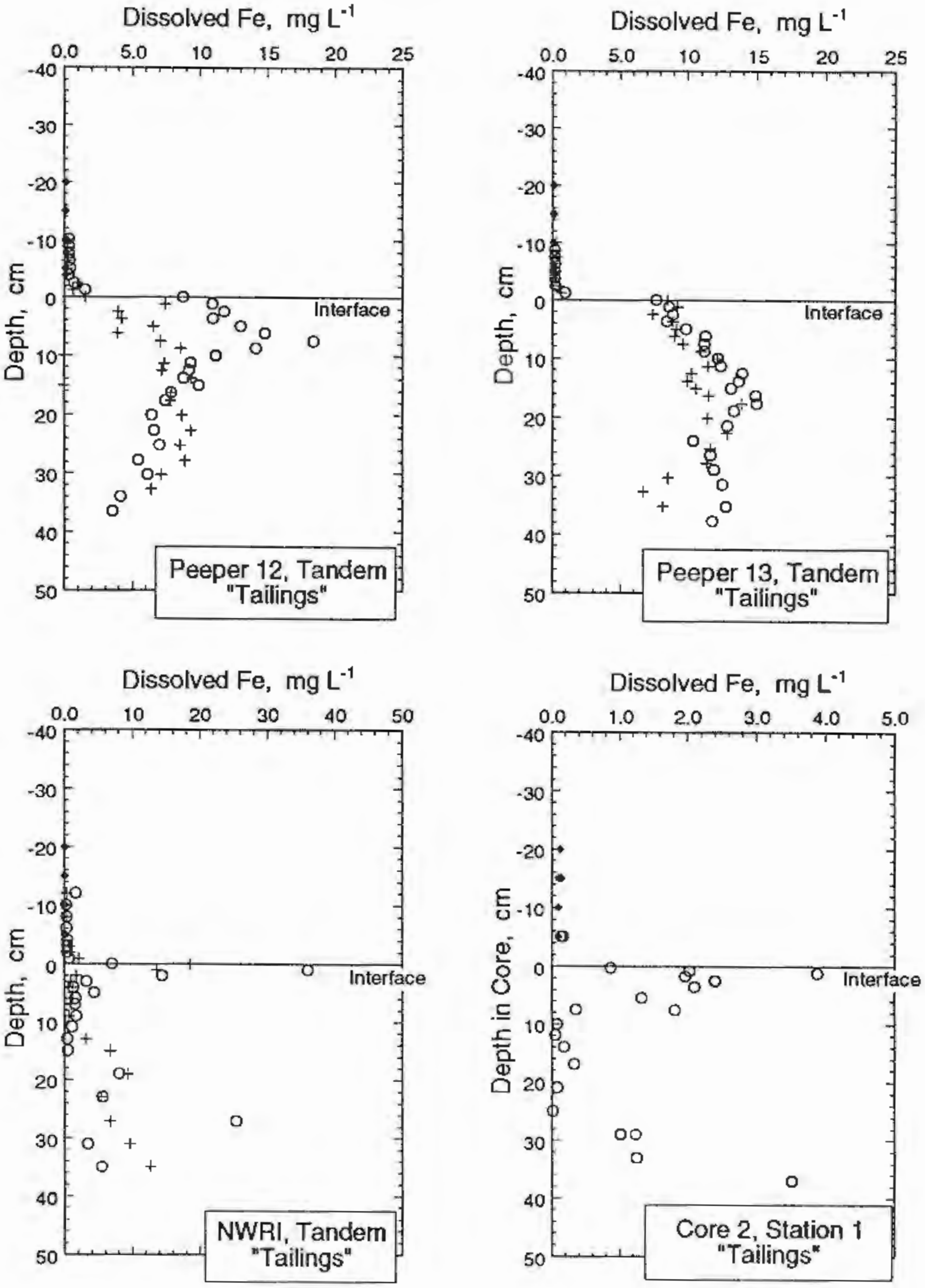

Figure 3-36: Dissolved iron distributions in tandem peeper and core porewaters at the tailings site in August 1993. Open circles on the peeper plots indicate samples from the left cell bank. Solid triangles indicate samples collected with the water column sampler.

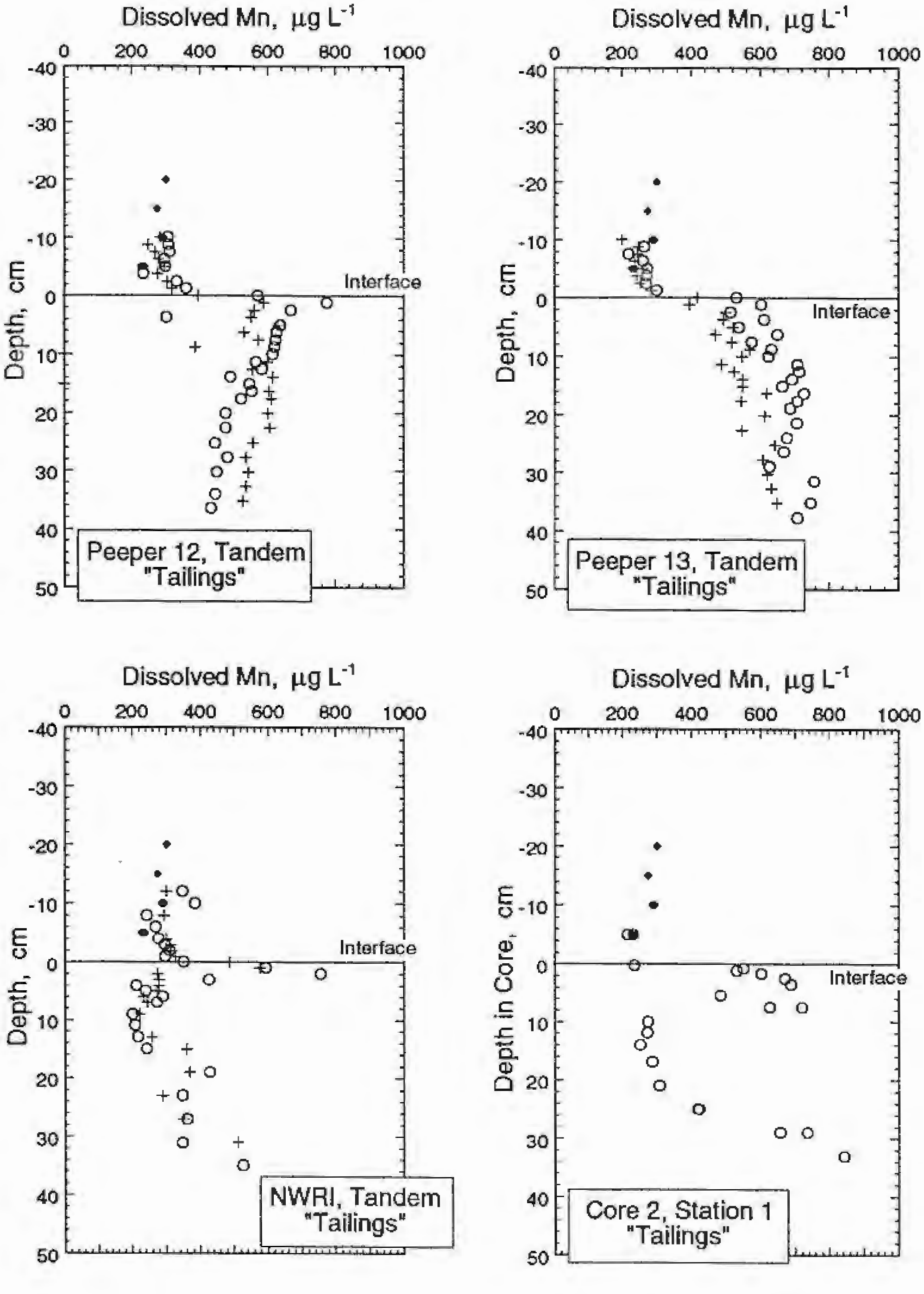

Figure 3-37: Dissolved manganese distributions in tandem peeper and core porewaters at the tailings site in August 1993. Open circles on the peeper plots indicate samples from the left cell bank. Solid triangles indicate samples collected with the water column sampler.

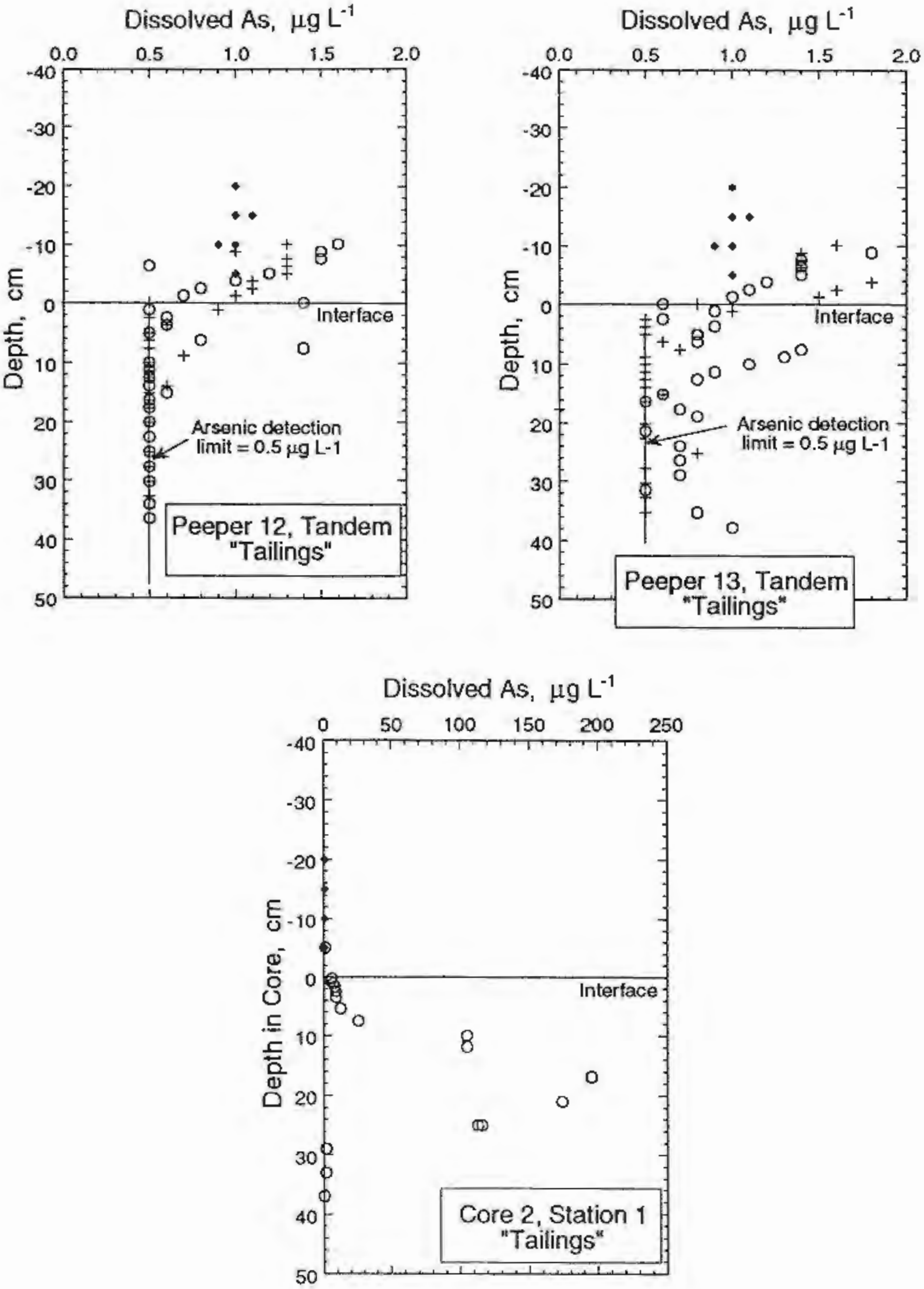

Figure 3-38: Dissolved arsenic distributions in tandem peeper and core porewaters at the tailings site in August 1993. Open circles on the peeper plots indicate samples from the left cell bank. Solid triangles indicate samples collected with the water column sampler.

limit. This group of peeper samples was run as one batch at ASL, on a different day from the core samples, and an analytical difficulty was initially suspected.

However, the data were carefully reviewed by ASL, and a number of samples were rerun and confirmed the existing dissolved As results from peepers 12 and 13. Additionally, a select set of the NWRI archive samples from the same site were analysed and the results were again all near the detection limit. Thus, the marked contrast between the group of five peeper profiles for arsenic and the single core pore water profile appears to be real.

Dissolved Zn, Cu, Pb and Cd distributions are shown in Figures 3-39 to 3-42. Without exception, the profiles show very steep downward declines in the concentrations of these four metals at or immediately below the sediment-water interface. The profiles from the core agree well with those from the peepers, with the exception that the average concentrations at depth are lowest in the core samples. Concentrations measured in the supernatant (core-top) water and in the peeper samples above the interface agree reasonably well with levels observed in the near-bottom samples collected with the water-column sampler, with the possible exception of cadmium. Aliquots collected with the sampler exhibit somewhat lower concentrations than those seen in the peeper cells (Figure 3-42).

Dissolved sulphide was not detected in any of the samples analyzed at this location. Elevated sulphate concentrations were observed in the sediments of Station B relative to the overlying water column (Table 3-1). Subsequent to this observation, measurements of dissolved Ca were made on a select suite of peeper samples from Station B to confirm whether gypsum dissolution could account for the elevated sulphate. Calcium is seen to increase concurrently with sulphate, across the sediment water interface suggesting that this premise is true (Table 3-1).

3.2.3.3 Natural Sediments Site

Dissolved metals distributions measured in three tandem peepers and a single core at the natural sediments site (Station A) fall into two groups. Results from the core and the NWRI peeper agree reasonably well for most metals (the exception being Fe) and are consistent with distributions observed in the winter survey and in the

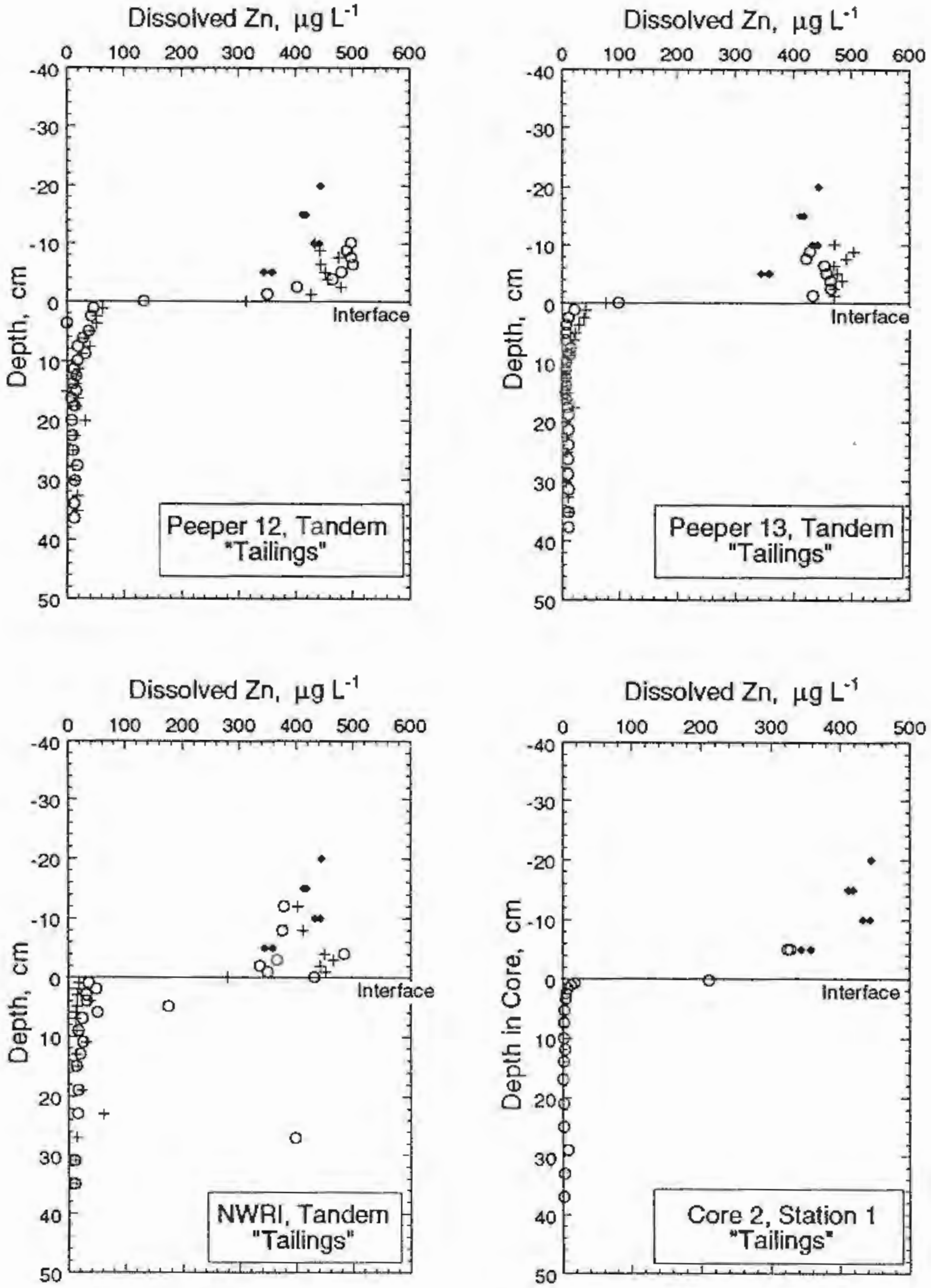

Figure 3-39: Dissolved zinc distributions in tandem peeper and core porewaters at the tailings site in August 1993. Open circles on the peeper plots indicate samples from the left cell bank. Solid triangles indicate samples collected with the water column sampler.

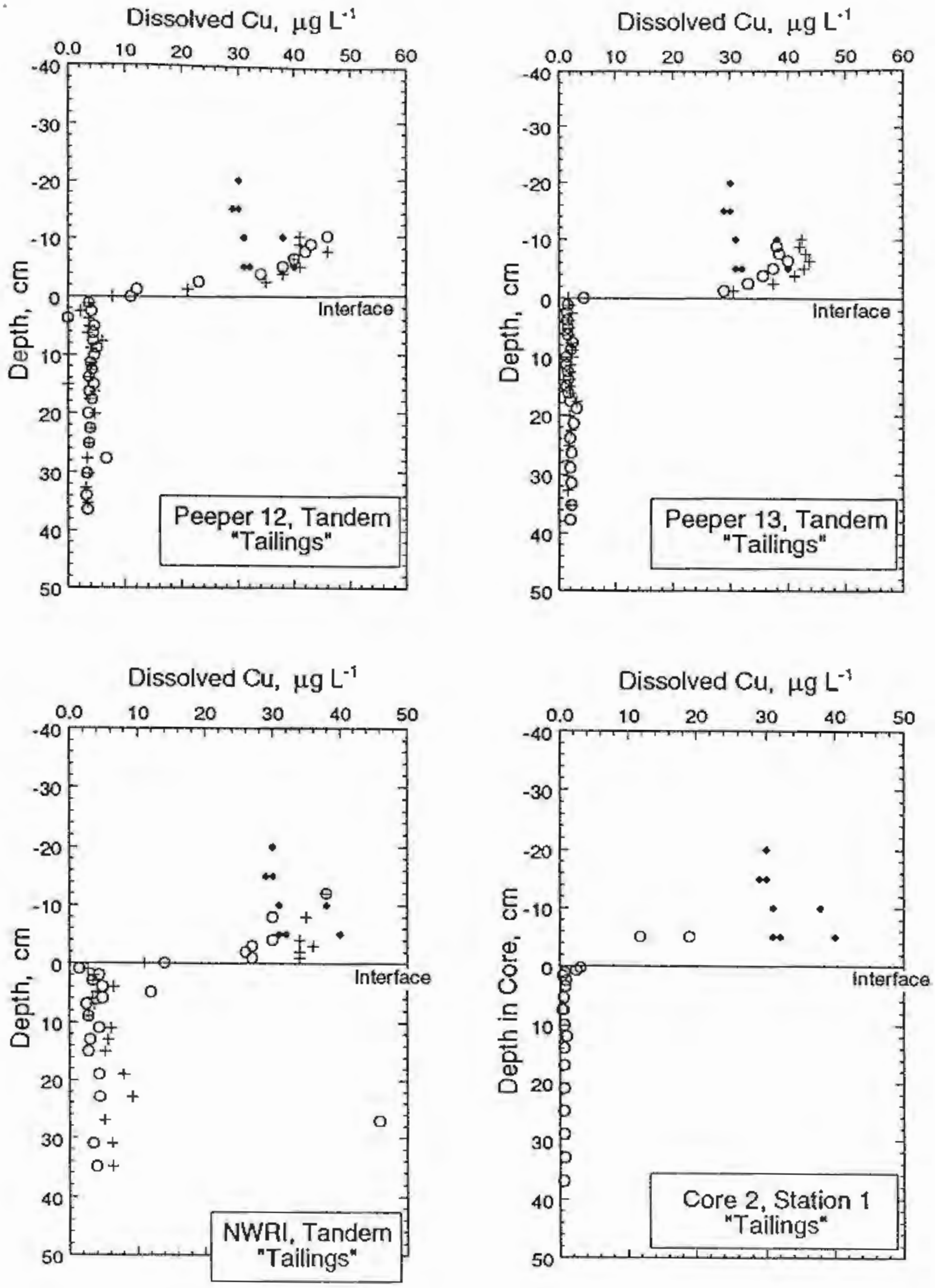

Figure 3-40: Dissolved copper distributions in tandem peeper and core porewaters at the tailings site in August 1993. Open circles on the peeper plots indicate samples from the left cell bank. Solid triangles indicate samples collected with the water column sampler.

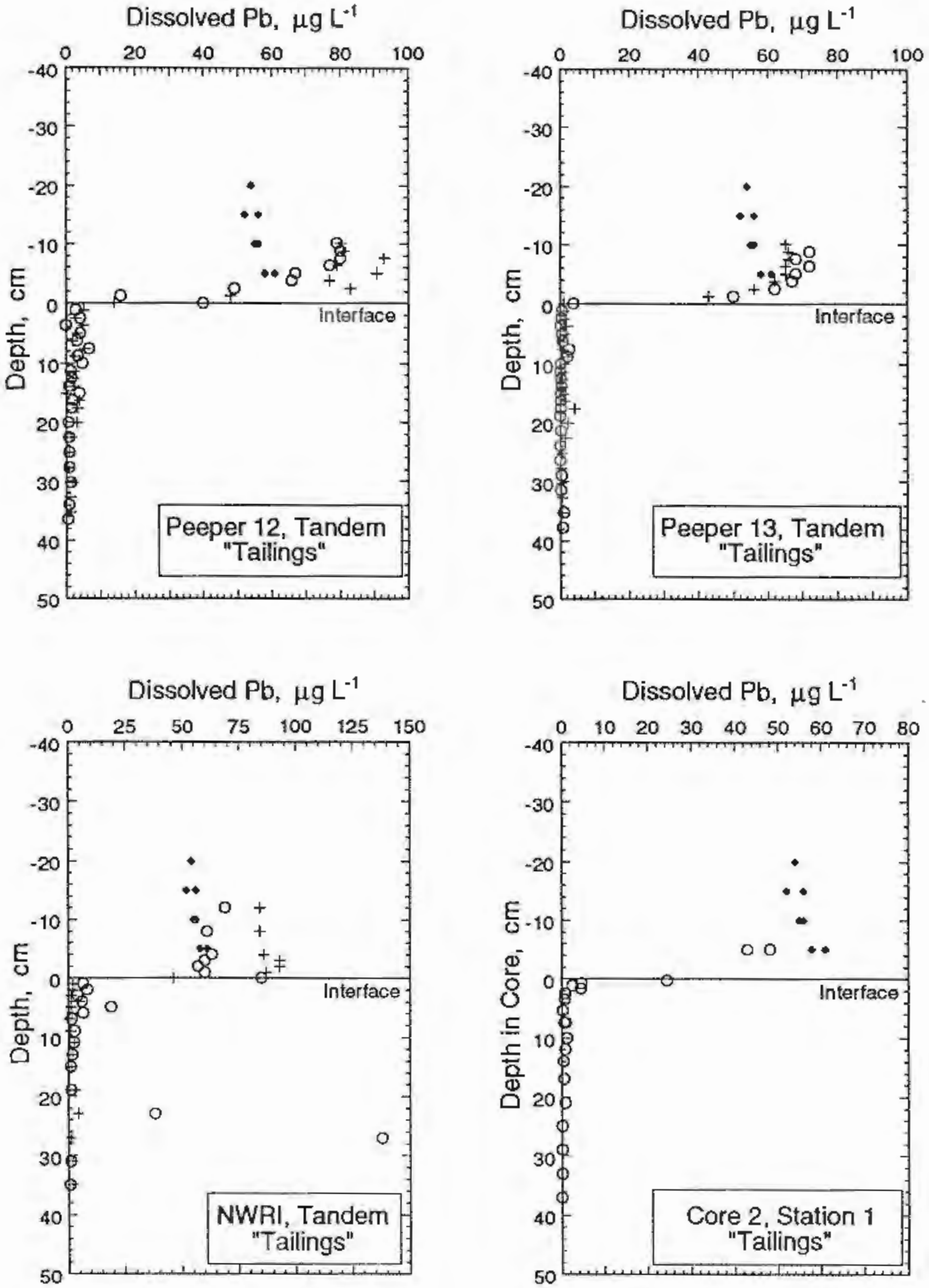

Figure 3-41: Dissolved lead distributions in tandem peeper and core porewaters at the tailings site in August 1993. Open circles on the peeper plots indicate samples from the left cell bank. Solid triangles indicate samples collected with the water column sampler.

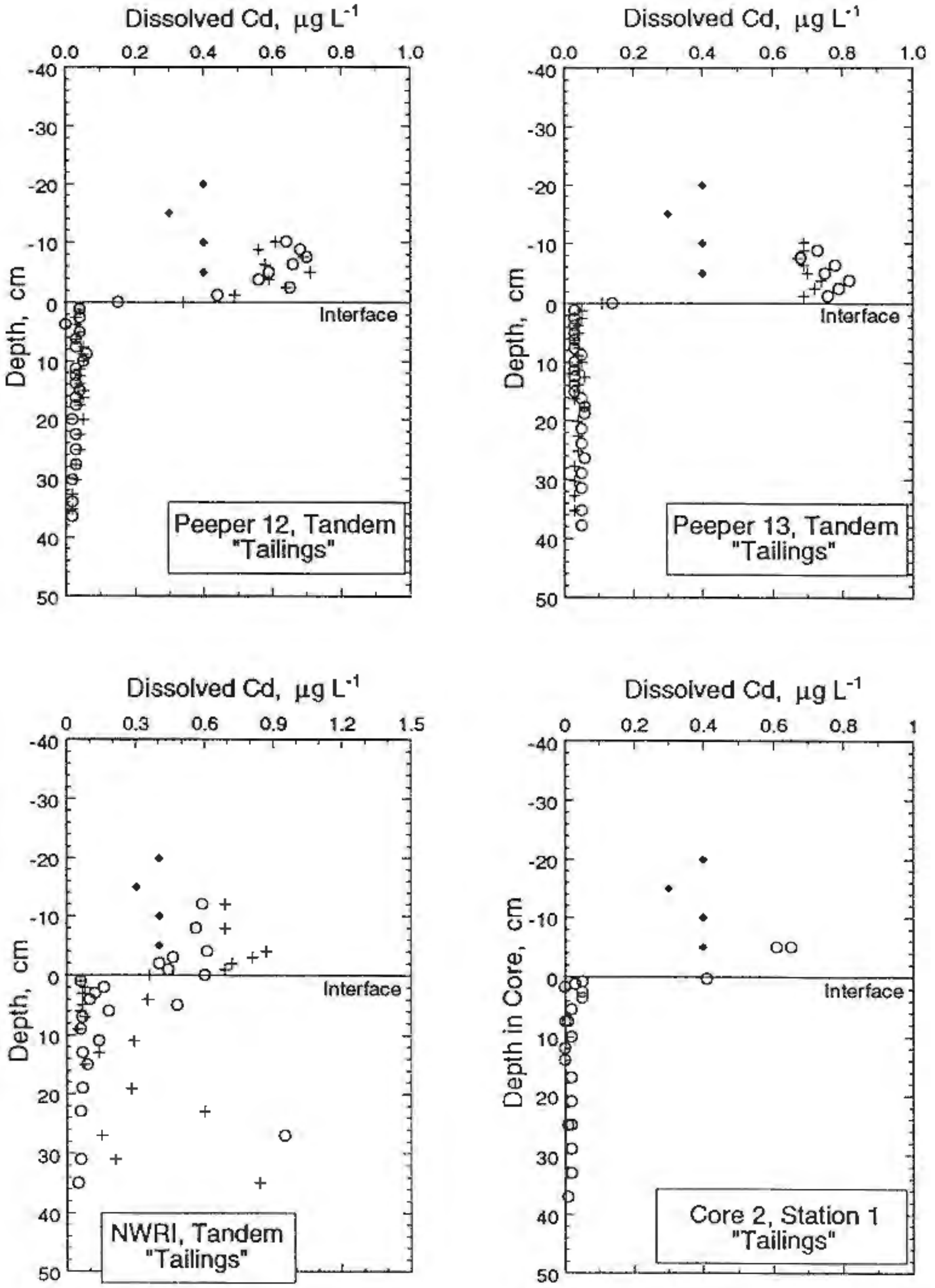

Figure 3-42: Dissolved cadmium distributions in tandem peeper and core porewaters at the tailings site in August 1993. Open circles on the peeper plots indicate samples from the left cell bank. Solid triangles indicate samples collected with the water column sampler.

Table 3-1

Dissolved Sulphate and Calcium from Rescan Tailings Peeper #13 (Station B)

Depth (cm)	Ca (mg/L)	SO_4 (mg/L)
-10.08	331	798
-8.82	321	796
-7.56	321	775
-5.04	339	783
3.78	676	1,850
5.04	653	1,802
6.3	636	1,817
12.6	677	1,703
16.38	685	1,803
25.2	688	1,768

* Depths are relative to the sediment-water interface, positive with depth into the sediments.

1990 project, but the Rescan peepers yield markedly different profiles which have not been seen in previous work.

The core profile for dissolved Fe at the "natural" site exhibits a sharp maximum (~13 mg/L) just below the interface and a smooth decrease with depth to very low values below 6 cm (Figure 3-43). Both profiles from the NWRI peeper show a sharp increase in iron content immediately below the interface, but the pair differs at slightly greater depths. The right-hand cell bank shows a steep decline in dissolved Fe between 3 and 20 cm depth, but a similar decline in the left bank is displaced 6 to 8 cm downward. The maximum concentrations in this peeper are the highest seen at this site, reaching almost 40 mg/L in the upper 10 cm, three-fold higher than seen in the core profile. Much lower concentrations are observed in the profiles from peeper 14 (Figure 3-43). The left cell bank from this peeper yielded a profile similar in form (but not abundance) to the core profile, with a sharp maximum occurring in the top centimetre. In contrast, a weak maximum is seen in the right cell bank just above the interface, while below the interface

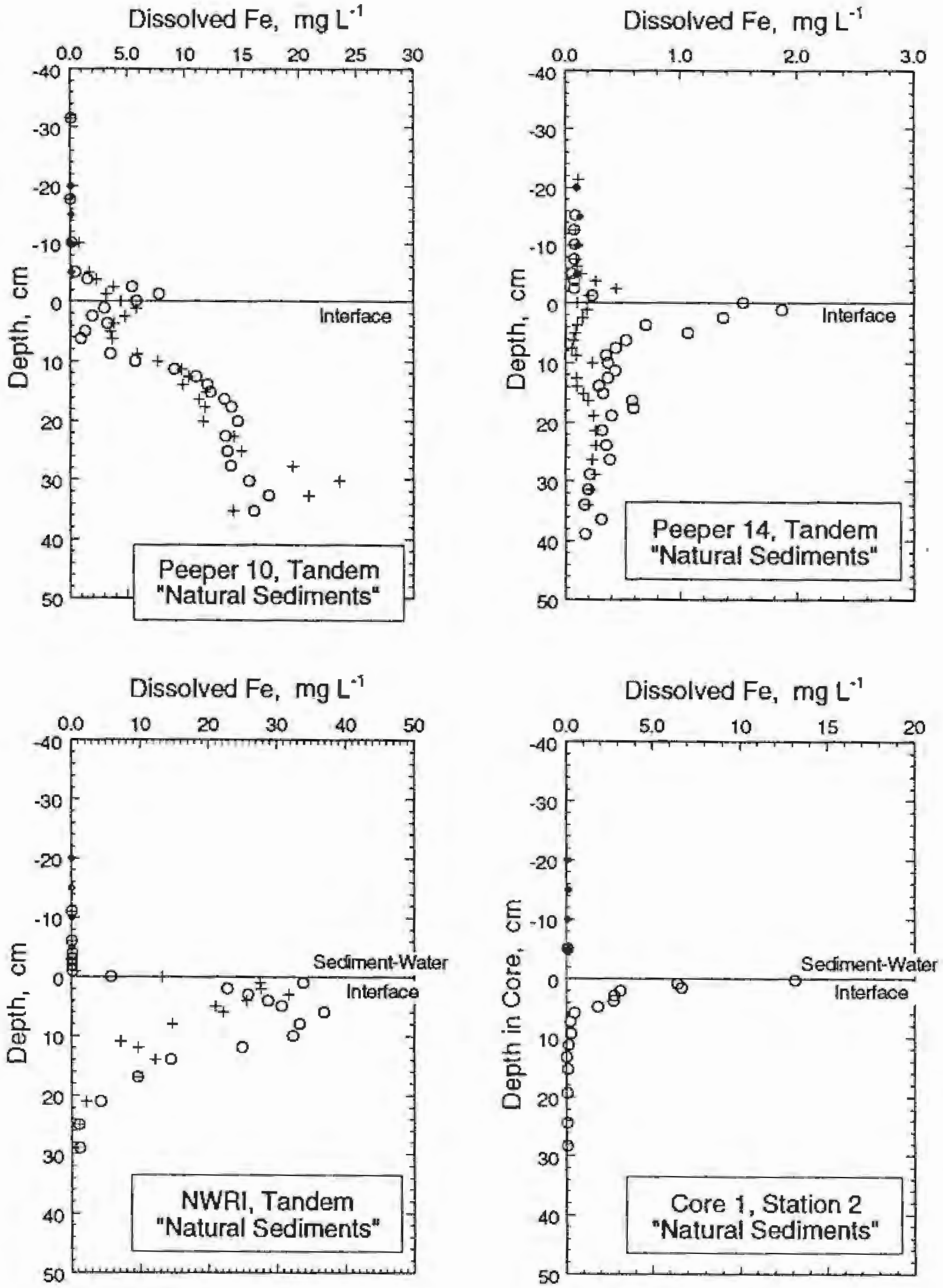

Figure 3-43: Dissolved iron distributions in tandem peeper and core porewaters at the natural sediments site in August 1993. Open circles on the peeper plots indicate samples from the left cell bank. Solid triangles indicate samples collected with the water column sampler.

concentrations vary smoothly between 0.05 and 0.2 mg/L. Much higher concentrations characterize both profiles in peeper 10 where the concentration increases unevenly with depth, reaching > 20 mg/L in the right cell bank near the bottom of the profile.

All dissolved manganese profiles at this site are similar (Figure 3-44) in general form. Concentrations range between 150 and 500 µg/L and show slight increases with depth. On average, concentrations in the core samples are one-third lower than those seen in the peeper profiles.

Arsenic distributions follow those of dissolved iron (compare Figures 3-43 and 3-45). Levels reach ~60 µg/L in the shallow subsurface peak in the core profile, only ~3 µg/L in the shallow maximum in the left cell back of peeper 14, and ~16 to 25 µg/L at depth in the profiles from peeper 10. Arsenic was not measured in the NWRI samples.

Dissolved Zn, Cu, Pb and Cd distributions at this site conform, to a limited degree, with the pattern established by the iron distributions (Figures 3-46 to 3-49). The sharp decreases with depth immediately below the interface that have been seen repeatedly in previous studies are illustrated by the profiles in the core and the NWRI peeper. However, the other peepers show different profiles. In peeper 14, the zinc content remains high, and similar to that in the overlying water, to a depth of ~20 cm in both profiles before decreasing sharply to very low concentrations below ~26 cm depth. A generally similar pattern is seen in this peeper for the other three metals. In peeper 10, a relatively steep decrease in concentration below the interface is seen for all four metals in the right-hand cell bank, but a slight maximum is observed at ~5 cm depth in the left bank. The concentrations of all four metals in this shallow maximum are very similar to those in the overlying bottom water. Below the maximum, a sharp decline in metal content occurs, and the Zn, Cu, Pb and Cd concentrations below ~9 cm are very low.

Dissolved sulphide was detected in the core and at depth in the left cell bank of peeper 14 (Figure 3-50). The appearance of H_2S in the core porewaters at 8 cm depth matches observations based on odour during core extrusion. Sulphide was undetectable (< ~17 mg/L) above 8 cm depth in the core.

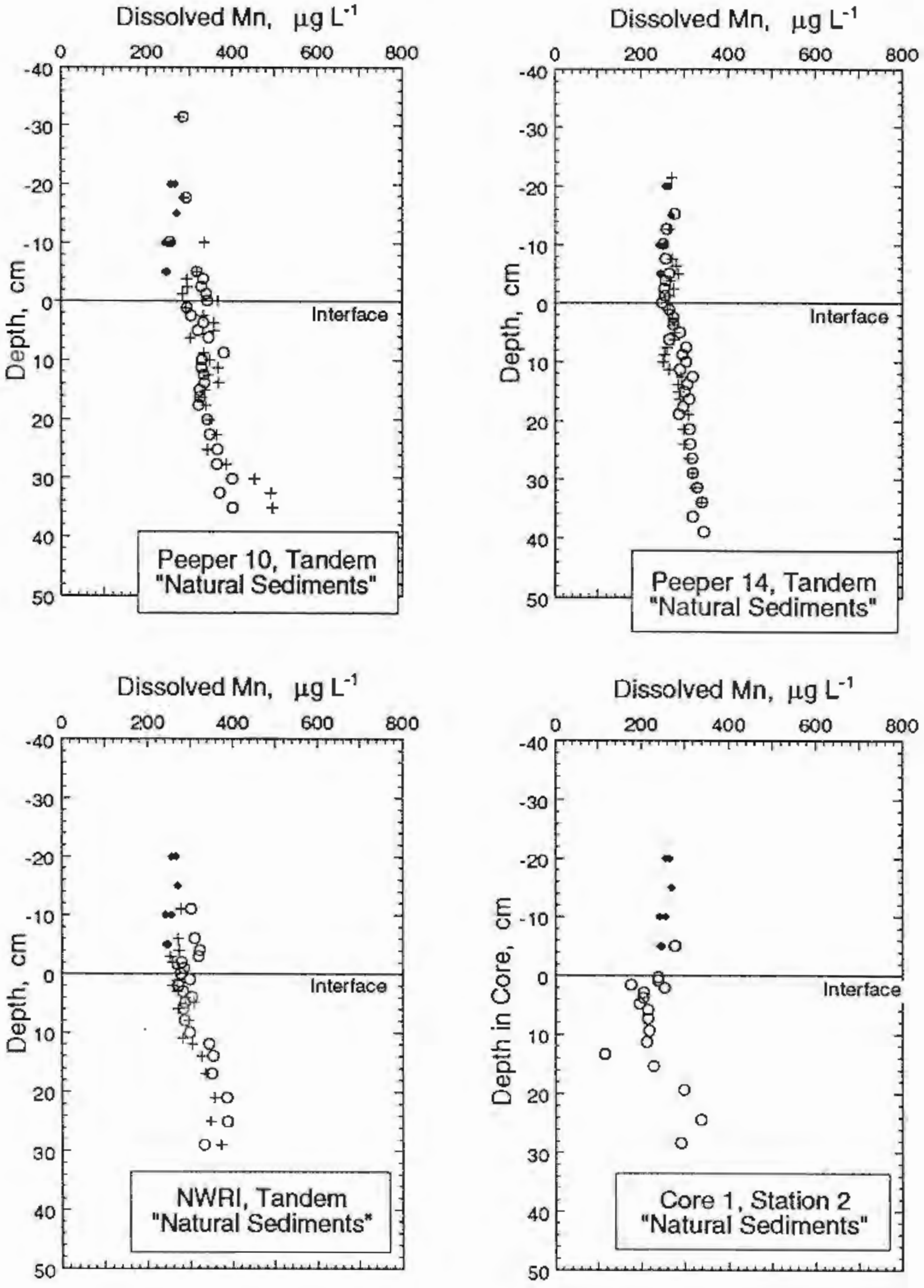

Figure 3-44: Dissolved manganese distributions in tandem peeper and core porewaters at the natural sediments site in August 1993. Open circles on the peeper plots indicate samples from the left cell bank. Solid triangles indicate samples collected with the water column sampler.

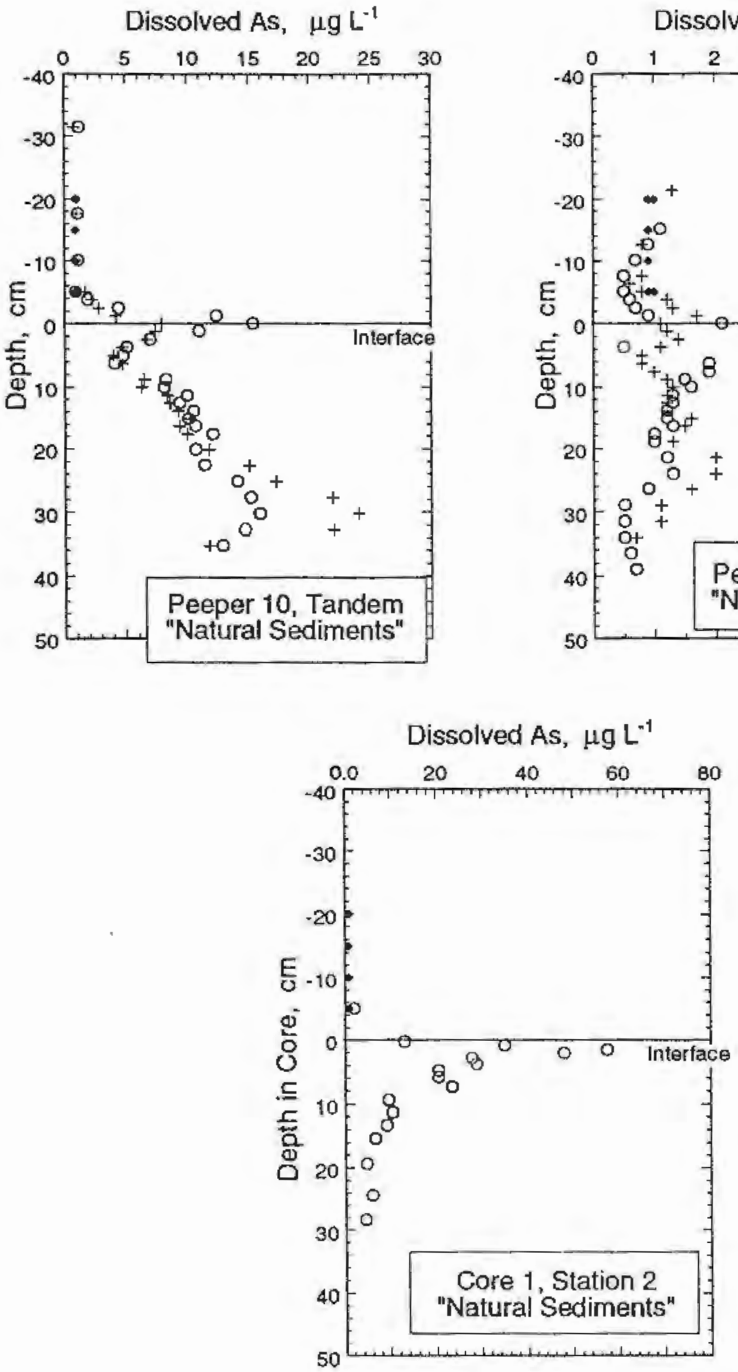

Figure 3-45: Dissolved arsenic distributions in tandem peeper and core porewaters at the natural sediments site in August 1993. Open circles on the peeper plots indicate samples from the left cell bank. Solid triangles indicate samples collected with the water column sampler.

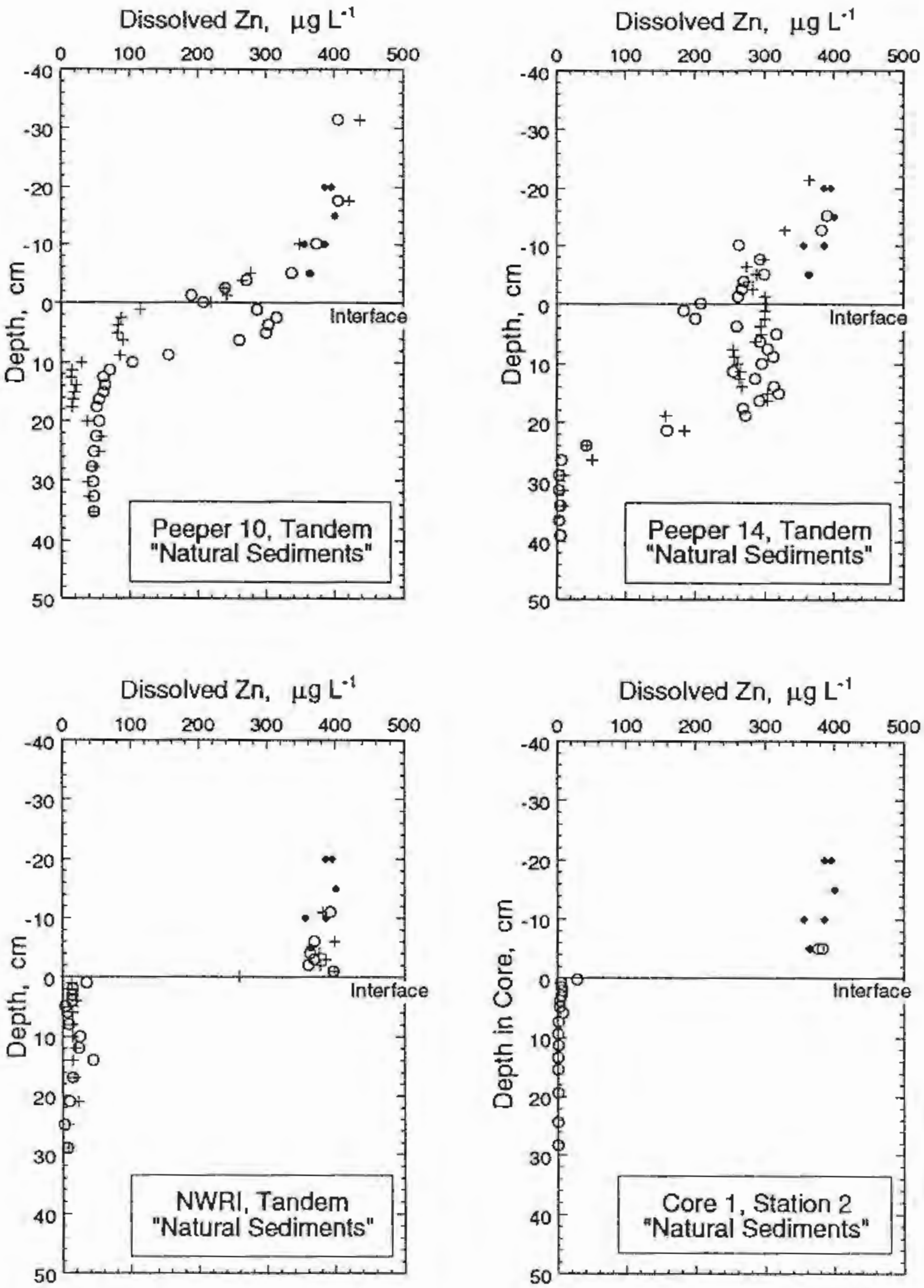

Figure 3-46: Dissolved zinc distributions in tandem peeper and core porewaters at the natural sediments site in August 1993. Open circles on the peeper plots indicate samples from the left cell bank. Solid triangles indicate samples collected with the water column sampler.

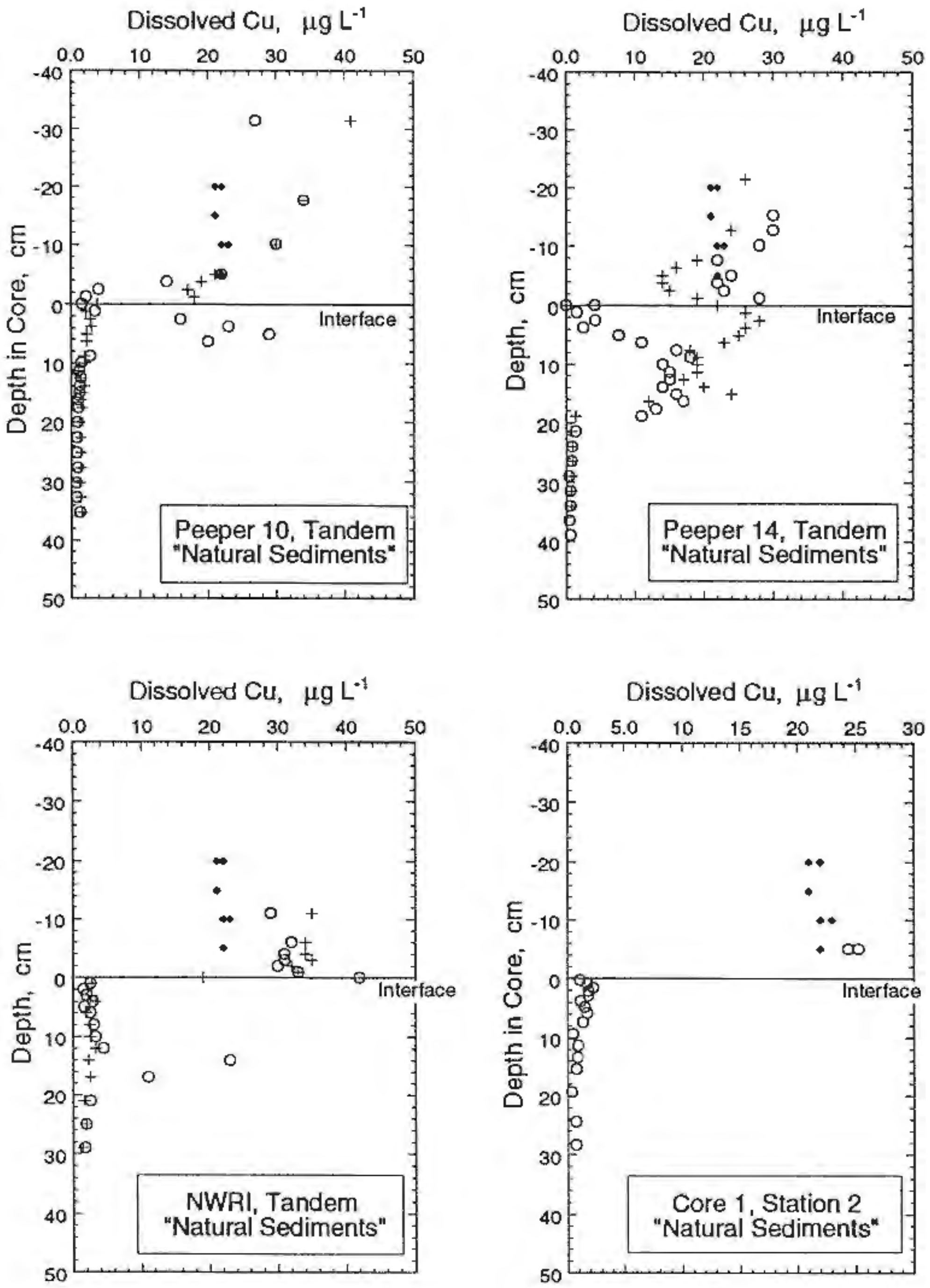

Figure 3-47: Dissolved copper distributions in tandem peeper and core porewaters at the natural sediments site in August 1993. Open circles on the peeper plots indicate samples from the left cell bank. Solid triangles indicate samples collected with the water column sampler.

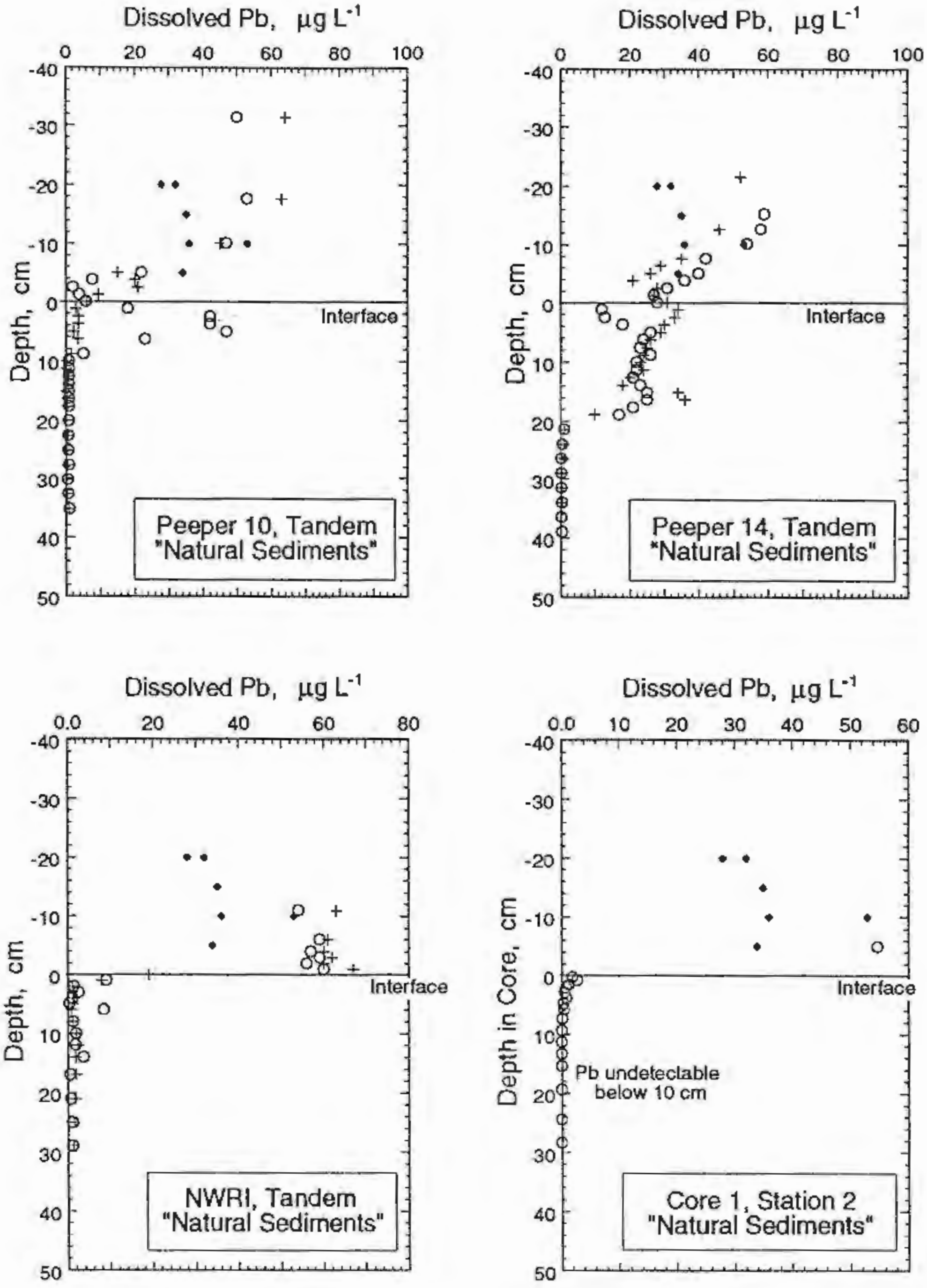

Figure 3-48: **Dissolved lead distributions in tandem peeper and core porewaters at the natural sediments site in August 1993. Open circles on the peeper plots indicate samples from the left cell bank. Solid triangles indicate samples collected with the water column sampler.**

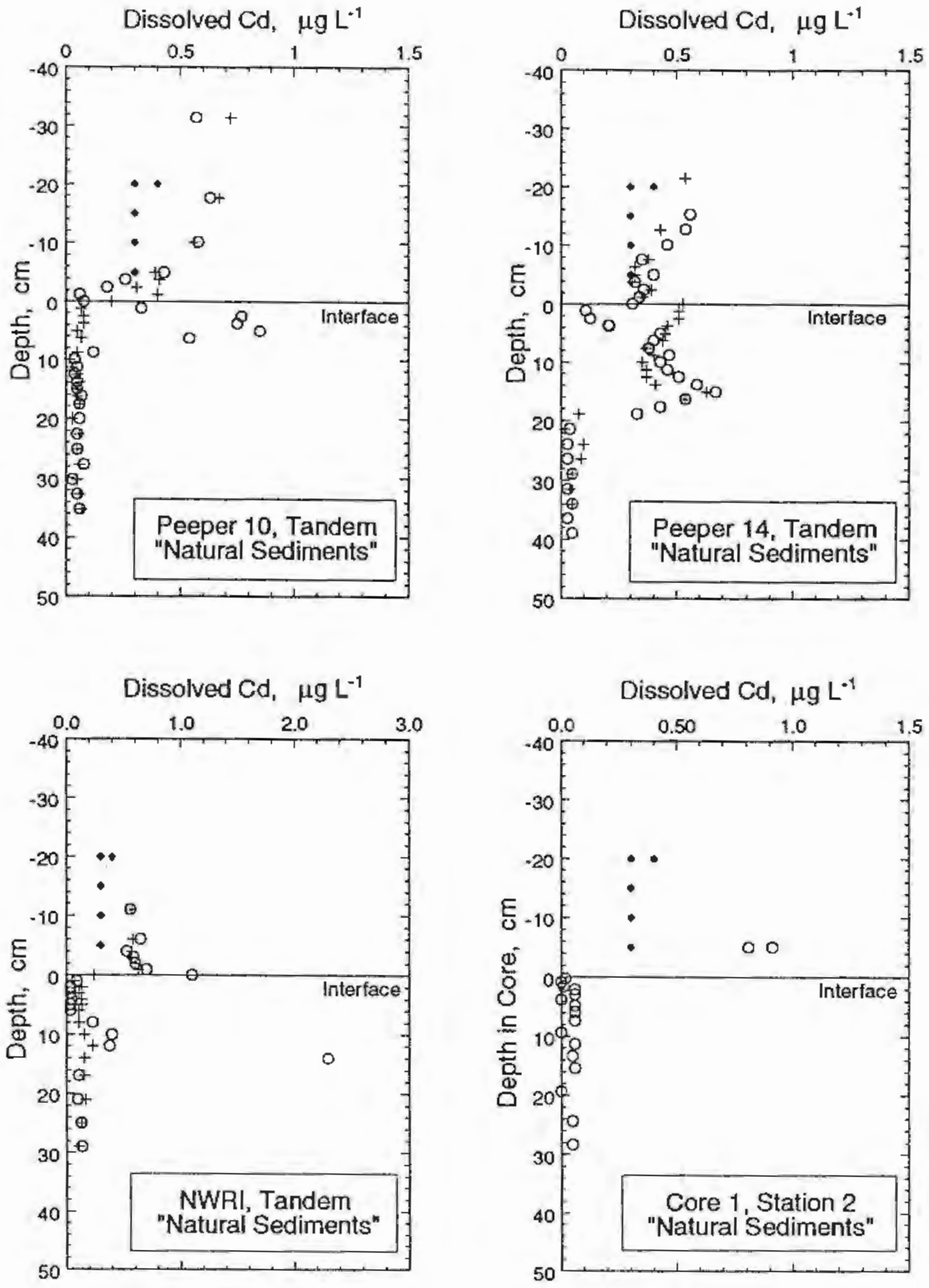

Figure 3-49: **Dissolved cadmium distributions in tandem peeper and core porewaters at the natural sediments site in August 1993. Open circles on the peeper plots indicate samples from the left cell bank. Solid triangles indicate samples collected with the water column sampler.**

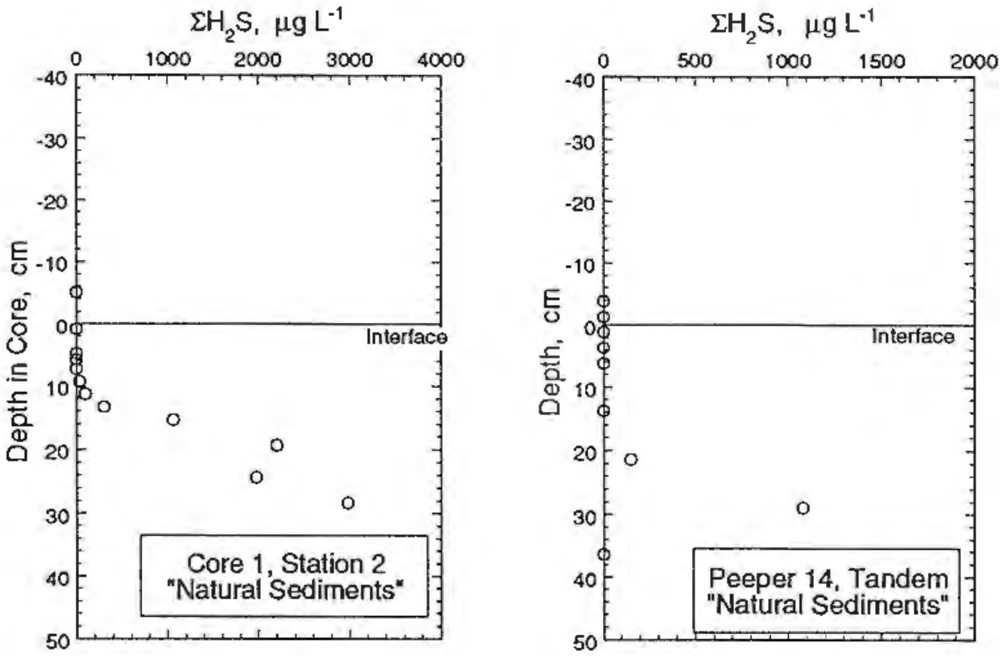

Figure 3-50: Total hydrogen sulphide distributions in the core and in the left cell bank of peeper 14 at the natural sediments site in August 1993. Sulphide was not detected in any samples from other peepers or from the right cell bank of peeper 14.

4.0 DISCUSSION

4.1 Winter Survey

4.1.1 Water Column

Previous work in Anderson Lake was carried out during summer 1990 when the water column was warm and no distinct thermocline was present (Rescan 1991; Pedersen *et al.* 1993). Oxygen was present throughout the water column at that time: concentrations were moderately high (~8 mg/L) in the upper two metres, and decreased to 1 to 4 mg/L in the lowermost metre at several sites, despite the limited stratification. The decline in the deeper waters was attributed to a high benthic oxygen demand. The contrast in water column stratification between the 1990 summer survey and the winter observations presented here indicates that the water column in Anderson Lake undergoes a pronounced seasonal change in hydrography, and consequently, in chemistry. When the lake is ice covered and wind-driven mixing is eliminated, anoxia develops in the water column, as observed in April 1993. It is not known how long such a water-column condition might persist in any given year nor whether episodes of anoxia or dysaerobia recur annually. However, as noted in Section 2.1.1, HBM & S personnel reported H_2S in the water column during the winter of 1982. Thus, Anoxia may be a frequent winter condition on the lake.

The oxygen profile extends to the bottom at Station A and indicates anoxic water between about 90 and 250 cm depth below surface (Figure 3-1). A layer of oxygenated water existed from 250 cm to the lake floor. Anoxia develops from the bottom up in stratified water bodies because the highest oxygen demand is at the sediment-water interface where settled organic matter accumulates. Thus the occurrence of the oxygenated layer between 250 and 370 cm, sandwiched between anoxic water above and anoxic sediments below (Figure 3-1), is puzzling. The sole plausible explanation for the alternation of anoxic and oxic layers in such a shallow water column is that there is significant lateral flow along the bottom. The lateral extent of such a flow is unknown, but may relate to episodic cooling, sinking and migration of oxygenated waters from the ice-free area around the end of the discharge pipeline or the shoreline. No evidence of a similar lateral influence can be seen in the oxygen profile at Station B, where a thin layer of cold oxygenated water overlaid warm anoxic deeper waters. It is possible that oxygenated bottom water was not observed at station B due to the hummocky nature of the tailings in the vicinity which would influence lateral flow along the bottom.

The distributions of dissolved metals in the water column show marked variations that are consistent with the physical stratification. Iron contents tend to be relatively low in the oxygenated waters and much higher in the anoxic zones. In most water bodies, dissolved iron as Fe^{2+} occurs only in trace concentrations in oxygenated water, since this species is readily and quickly oxidized ($t_{1/2} = k\ [H^+]^{-2}$) to $Fe^{(III)}OOH$ at neutral pH. However, a relatively low pH (~4) was measured in the upper 2 m in the lake at both stations even where oxygen was present, and this can account for the presence of ~2 mg/L of dissolved iron in this portion of the water column. Presumably, both the dissolved iron and the low pH reflect inputs from the acid-generating roadway along the north shore of the lake. Given a constant oxygen fugacity, iron will persist in solution at pH 4 about a million times longer than at pH 7. The extremely high concentration observed in the near bottom waters at Station B, and the upward concavity of the profile (Figure 3-6) suggest that dissolution of iron oxyhydroxides on the sediment surface was occurring at the time of sampling. At Station A, dissolved iron exists in solution within the anoxic portion of the water column. As expected, the oxygen-enriched layer of water on the lake floor is deplete in dissolved iron, presumably via oxide precipitation. Within the interstitial waters (accidentally sampled by the water column sampler), iron is observed to increase and then decrease in concentration sharply with depth, as also seen in pore water profiles (Figure 3-43 lower panels).

The coherence between the dissolved iron and arsenic distributions in the water column (Figure 3-7) can be attributed to the well known affinity of arsenate for iron oxyhydroxides. Solid-phase oxyhydroxides efficiently coprecipitate or scavenge AsO_4^{3-} from water and release it upon dissolution (Aggett and O'Brien 1985, Aggett and Roberts 1986, Edenborn *et al.* 1986, Aggett and Kreigman 1988, Belzile 1988, Belzile and Tessier 1990, de Vitre *et al.* 1991, Kuhn and Sigg 1993) and these phenomena probably account for the observed distributions. In contrast, the opposite distributions of dissolved zinc and iron reflect apparent consumption of zinc from the near-bottom waters (Figure 3-6). Zinc profiles in stratified lake waters and in lacustrine porewaters are commonly the mirror-image of dissolved iron distributions (Hamilton-Taylor and Davison 1995). In a number of Canadian shield lakes, this contrast has been attributed to the release of iron to solution as the Eh falls coupled with simultaneous incorporation of zinc into authigenic sulphides (Tessier *et al.* 1989). Although there is no direct evidence in this study for sulphate reduction and concomitant sulphide production just above the sediment-water interface, anoxia is indicated immediately below the sediment water interface at Station A, and, within the bottom waters at Station B. Furthermore, framboidal pyrite is common in surface deposits (Rescan 1991 and Appendix C-2), implying that zinc depletions in bottom waters may result from the precipitation of sulphide minerals at or very near sediment surface. Zinc readily co-precipitates within or is adsorbed by, mackinawite (FeS) (Morse and Arakaki 1993; Davidson *et al.* 1992) a probable precursor of pyrite.

The pH profiles (Figure 3-4) indicate slightly acidic or near neutral bottom waters at the time of sampling, and clearly acidic (pH ~4) conditions in the upper 1.5 m. As noted above, the acid is probably derived from oxidation of the pyrite- and pyrrhotite-rich tailings that were used to build the road along the lake shore. The relatively high pH values measured in the lowermost samples at each site suggest that the tailings were not generating acid, or at least not enough acid to exceed the any buffering capacity in the deposits. The tailings are limed during milling, and this may account for the observed pH increase near the bottom. Ironically, this also implies that the tailings may be buffering acid derived from the subaerially exposed tailings.

Dissolved manganese profiles are very similar to those of iron, which is a reflection of their similar redox behaviour. The principal contrast between the two elements lies in the measured concentrations, dissolved iron being nearly 100 times more abundant than manganese in the lower part of the water column. This suggests that, relative to iron oxide phases, manganese oxides are not abundant in Anderson Lake surface sediments. Porewater data discussed below support this contention. Such a disparity is unusual (see Hamilton-Taylor and Davison 1995) and may reflect the input of iron in the acid runoff from the roadway. The dissolved iron minimum seen between 15 and 45 cm above the bottom at Station A, where oxygen was present (Figure 3-5), is not matched by a comparable decline in the dissolved manganese content (Figure 3-8), probably because dissolved manganese oxidizes much more slowly than ferrous iron in the presence of oxygen at neutral pH (Stumm and Morgan 1981).

The dissolved copper and lead distributions in the water column (Figure 3-8) are opposite to those of manganese and iron, but similar to zinc. This implies that both copper and lead are removed from the anoxic bottom waters in much the same way as zinc, possibly by incorporation into authigenic sulphide minerals. No authigenic sphalerite (ZnS), covellite (CuS), or galena (PbS) were observed in the petrographic examination of polished sections of sediment samples from either site, but the concentrations in the sediments required to account for the "missing" dissolved metals in the lower 50 to 100 cm would be very low (on the order of several ppm, depending on the water residence time and the sedimentation rate) and therefore would be almost impossible to detect.

4.1.2 Sediments

The organic-rich so-called "natural sediments" in the duplicate cores collected at Station A contain significant concentrations of fine-grained tailings in the upper 10 cm, as can be seen by comparing the profiles of solid-phase metals (Zn, Cu, Pb, As and Cd) with the Fe/Al, sulphur and organic carbon plots (Figures 3-9 to 3-16). In both cores tailings are most abundant between 1 and 4 cm depth. Both cores were capped by a very thin rust-coloured veneer 1 to 2 mm thick (see Core Logs, Appendix C-1). Actively swimming zooplankton were observed in the supernatant (core-top) water of Core A1 immediately after collection. Their occurrence is consistent with the presence of oxygenated bottom water. No zooplankton were observed in the supernatant water of Core A2, which was collected the next day 3 metres away from Core A1, but "fresh" faecal casts were observed on the sediment surface of the core indicating that infauna (and therefore oxygen) either was present or had recently been present at the site.

The pair of cores collected from Station B near the outfall show significant compositional differences, despite being raised through holes in the ice only ~12 m apart. The contrasts are most obvious in the solid-phase organic carbon, Fe/Al ratio, Zn, Cu, and Cd, plots (Figures 3-9, 3-10, 3-12, 3-13 and 3-16, respectively), and imply that the tailings deposits are laterally heterogeneous. Such inhomogeneity probably results from hydraulic influences, uneven bottom topography, and compositional variations in the mill feedstock. Pyrite and pyrrhotite comprise the bulk of the deposits: the average measured sulphur content of ~20 wt. % is equivalent to about 50 wt. % FeS_2. There was no visual evidence of oxidation or oxide products on the surface of either core, and all sulphide grains examined in polished section under magnification showed fresh, unaltered surfaces and grain boundaries.

Although the tailings are deposited rapidly, they do contain low but measurable concentrations of organic matter. One interval at ~5.5 cm depth contained in excess of 1 wt. % organic carbon, and 0.12 % nitrogen, yielding a C:N weight ratio of 9.4. The high relative nitrogen content indicates that the organic material is not vascular plant debris but is more likely derived from lacustrine plankton. This is an important distinction in that organic material of planktonic origin is readily degradable by bacteria and will support a higher oxidant demand than detritus derived from vascular plants.

4.1.3 Interstitial Waters

Pedersen *et al.* (1993) described the distribution of dissolved metals in porewaters collected in summer 1990 at three sites in Anderson Lake. Their principal conclusion was that the submerged deposited tailings in Anderson Lake were not releasing metals to the overlying water column at that time. Indeed, the opposite appeared to be true: sharp decreases with depth in the concentrations of dissolved Zn, Cu, Pb, and Cd in the upper few centimetres of the deposits were interpreted as representing consumption of metals from the contaminated overlying lake water. Precipitation of authigenic sulphide phases at shallow depths in anoxic tailings and natural sediments was suggested as an explanation for the very low metals concentrations in the porewaters.

In general, the data collected in this survey show similar behaviour to that observed in summer 1990, with some exceptions. The dissolved iron distributions in both cores at both sites show relatively shallow maxima which are interpreted as representing reductive dissolution of oxyhydroxides upon burial. In summer 1990, the subsurface dissolved iron peaks were quite sharp and very shallow at the "natural sediments" and "pure tailings" sites (cores AND-1 and AND-2 respectively, Pedersen *et al.* 1993), and somewhat broader and more complex at a third site near the discharge outfall where bulk tailings sat atop natural deposits. At that time, iron was largely removed from porewaters, precipitation with sulphide, within 2 cm of the interface at AND-1 and within 4 cm of the interface at AND-2. In contrast, dissolved iron persisted in pore solution in April 1993 to depths of at least 8 cm (Figure 3-17), and the peaks were not as sharp as seen in two of the three cores studied in 1990. The difference is attributed to the seasonal shoaling of the iron redoxcline (the ferricline) in the summer when rates of chemical reaction and bacterial metabolic rates are high due to the warm temperatures. The higher temperatures accelerate early diagenesis, which tends to compress the classic biogeochemical zonation characteristic of aquatic sediments. Such a phenomenon is well known in shallow marine sediments (*e.g.*, Klump and Martens 1981), and it can have important implications for seasonal remobilization of metals such as arsenic that have an adsorptive affinity for iron oxide phases.

The iron and arsenic distributions observed in porewaters in this work correspond closely in the "natural sediments" at Station A, to the point where there appears to be an efflux of remobilized As from the near-surface deposits into the overlying bottom water (Figure 3-20). As for iron, this efflux may be supporting the small arsenic enrichment observed in the bottom waters (Figure 3-7) at this location. At Station B, a significant difference in behaviour is observed. Although there is a distinct dissolved arsenic peak at depth in both cores (Figure 3-20), there is no detectable arsenic (< 0.5 μg/L) between 0.75 and 3 cm in either core, despite the increasing dissolved iron contents in this interval. It is not clear why the arsenic and iron distributions are decoupled in this depth interval in the pair of cores. It can be concluded, however, that there was no release of remobilized arsenic to the water overlying the tailings at Station B in April 1993, unlike the case at Station A.

The water column and porewater iron profiles agree well at Station A, in that the iron enrichment in the near-bottom water is consistent with the efflux implied from the porewater profiles. In contrast, marked disagreement exists at Station B. The very high concentration seen in the near-bottom waters is several-fold higher than that in the surface porewaters, and roughly twice as high as in the underlying pore-water maxima. Thus near-surface porewaters cannot be in physical equilibrium with the overlying bottom waters at this site. This implies that the bottom waters were imported to this location shortly before the sampling was carried out. Such non-steady-state behaviour may be consistent with the lateral transport in the lake that is implied by the dissolved oxygen distribution.

Manganese distributions in the porewaters at Stations A and B are very similar in magnitude and form to the profiles observed in summer 1990 at the "natural sediments" and "pure tailings" sites. There is no obvious manganese cycling in the near-surface sediments, which is consistent with the relative paucity of MnO_2 in the sediments and tailings, as noted above.

Zinc profiles show little correlation with either iron or manganese distributions, implying that there is no association between the minor metal (Zn) and oxyhydroxide cycling in the water column-sediment continuum. The steep decline in dissolved zinc content with depth in the near-surface deposits of both cores at Station A indicates that zinc was diffusing *into* the "natural sediments" in April 1993, as was observed in summer 1990. Zinc similarly declines with depth below about 2 cm in the tailings at Station B, but the profiles hint that there may have been a slight efflux of the metal at the time of sampling; the maximum in Core B2 porewaters at 1-2 cm depth would support diffusion upward and downward from this interval. The profile in core B1 is slightly different and suggests that no efflux was occurring. Given the non-steady-state behaviour implied by the iron distributions, interpretation of the zinc profiles is problematic. Although a slight diffusive efflux of zinc from the tailings at the site of Core B2 cannot be explicitly ruled out, it is possible that the near-surface zinc maximum in the core is artificial: a change in the bottom water zinc content not long before the cores were collected could have induced a perturbed profile that does not reflect steady-state diagenesis. An additional ambiguity is that the tailings were overlain by oxygen-poor water in April 1993, and under such conditions, no zinc should be released (for example, via oxidation of the surfaces of ZnS particles). Indeed, the water column dissolved zinc data at Station B imply consumption of the metal from bottom waters, rather than addition from the underlying tailings. On balance, non-steady state perturbation, rather than active release, appears to be a better explanation for the zinc efflux implied by the dissolved zinc data in the upper centimetre of Core B2. This suggestion implies that temporally-varying chemical reactions and hydrographic processes in the overlying water column may play a major role in dictating the distributions of dissolved metals in the near-surface porewaters.

Copper, lead, cadmium and mercury concentrations in porewaters from the tailings at Station B are so low as to be essentially undetectable (Figures 3-21 to 3-24). Thus no conclusions can be drawn about their chemical or diagenetic behaviour other than to suggest that the tailings are not releasing these metals to the overlying water column. Lead and cadmium contents in the porewaters at Station A were similarly very low, being at or below detection limits (Figures 3-22 and 3-23, respectively). These data imply that there was no significant lead or cadmium efflux from the "natural sediments" nor influx at the time of sampling. In contrast, dissolved copper concentrations increased immediately below the sediment surface in both cores A1 and A2, reaching respective maxima of ~1 and ~3 µg/L at about 1.5 cm depth. These profiles imply upward diffusion from the maxima, and consumption at depth. However, the water column data (Figure 3-8) indicate removal of copper from the near bottom waters, which presumably can be attributed to active precipitation of authigenic sulphide minerals at or near the sediment surface. Thus the implied (but extremely small) efflux of dissolved copper from the natural deposits (particularly in Core A2) is at odds with the water column profile. Why this should be the case is not clear.

Mercury concentrations in the porewaters from Station A range up to ~0.25 µg/L (Figure 3-24), some five times the detection limit. Although the data are somewhat noisy they suggest that mercury is being released from the "natural" deposits to the overlying water. The absence of a clear decline in concentration with depth in the cores implies that mercury is not precipitated as a sulphide phase, but may instead be stabilized in solution by complexation with dissolved organic compounds, for which the metal has a strong affinity (*e.g.* Louchouarn *et al.* 1993).

The leading candidate for the implied sequestration of dissolved metals by the sediments and tailings in Anderson Lake is the precipitation in situ of sulphide minerals. Framboidal pyrite is a common trace constituent in the natural sediments, but was not directly observed in samples from the "pure tailings" cores. Concave-downward decreases in sulphate with depth in the sediments at Station A indicate that sulphate reduction occurs at shallow depths, and this observation is consistent with the presence of framboids in the top 5 mm in Core A1, and with the presence of dissolved sulphide in the pore waters (Figure 3-25). Dissolved sulphide was not detected in the tailings (Figure 3-25), but neither was nitrate: NO_3^- was measured only in Core B1 pore waters and all concentrations were at or below the detection limit of 0.08 mg/L (Appendix E). This implies that nitrate has been quantitatively reduced throughout the core, and that the deposits are indeed anoxic at very shallow depths. The fact that sulphate is being added to the porewaters at depth, via dissolution of sulphate salts (gypsum) in the tailings (Table 3-1), does not obviate simultaneous reduction of SO_4^{2-}. Sulphide production could easily be masked by reaction with dissolved iron to form FeS or FeS_2. Although indirect, the best evidence that dissolved sulphide production and solid-phase sulphide precipitation is occurring in the tailings is the clear removal of iron and zinc from pore solution at depth in both Cores B1 and B2.

4.2 Summer Survey

There are three main inconsistencies in the summer survey data set that require elaboration, and if possible, explanation. The first is the extremely high and variable dissolved iron contents at depth in a number of the peeper profiles, particularly at the tailings and natural sediments sites. Such distributions are not seen in past or present core profiles. The second problem is the high dissolved metal concentrations seen in the upper 10-15 cm at the natural sediments site only in the Rescan peeper profiles, and not in the core or the NWRI peeper data sets. The third inconsistency is the difference in As concentrations seen in the peeper and core pore water samples, particularly at the tailings site in the summer survey (Figure 3-38). The first problem may relate to a specific design limitation of peepers in general combined with the specific character of the sediment surface during August 1993, while the second may be due to hydraulic influences. There is no acceptable explanation for the third problem. Each will be discussed in turn.

As noted earlier, the sediments at the tailings site were capped with a very thin ferruginous algal mat which was soft but cohesive. The solid-phase iron profile, Fe:S ratio data (Figure 3-29), and consideration of the high water content of the mat material indicate that it has a very high iron content (probably > 20 wt. %). It is possible that during emplacement of the peepers, some of this material adhered to or was trapped by the faceplates or frits, and was carried downward into the anoxic deposits at depth. During the 14-day equilibration period, the advected iron oxides would have progressively (and variably) dissolved, and "excess" iron would have diffused into the cells at depth, resulting in false profiles. This hypothesis can explain the contrast between the pairs of profiles from each peeper as well as the rather wide overall differences and the large range in absolute concentrations. If this suggestion is correct, the "snap-shot" profiles yielded by the core samples should be more representative of the true distribution of dissolved iron in the tailings porewaters.

The much lower maximum absolute concentration observed in the core samples is consistent with previous results from cores, and with the entrainment hypothesis because the iron-rich surface material smeared downward during insertion of the core barrel is carefully removed during extrusion before core slices are centrifuged. As well, cores are extruded within a few hours of collection. Such a short period must limit any influence on the chemistry of the contained porewaters of the dissolution at depth of iron oxides which might have been smeared down along the inside surface of the core barrel. A test of the entrainment hypothesis is provided by the dissolved sulphide measurements. Relatively high sulphide concentrations were measured in porewaters from the core at the natural sediments site, but could not be detected in any of the samples from peeper 10, nor in samples from the right cell bank of peeper 14. However, sulphide was detected in two samples below 20 cm depth in the left cell bank of peeper 14 (Figure 3-50). Excess dissolved iron added at depth in the deposits via oxide entrainment and dissolution will titrate the H_2S produced by sulphate reduction. Thus ΣH_2S concentrations in the peeper samples where iron is high at depth should be very low or undetectable compared to those in the core porewaters from the same depth intervals. This is what is observed, suggesting that downward entrainment may be a plausible hypothesis. All of the peepers may have been affected by this to varying degrees, although the UBC-designed Rescan peepers appear to be the worst afflicted. The only significant physical difference between the Rescan and the NWRI peepers was the presence of the expanded polyethylene frit on the former, which ironically was added in an effort to avoid the very problem of downward entrainment of surface oxides. It may be that fragments of the bacterial mat more effectively adhered to the frit material than to the "unprotected" perforated faceplate on the NWRI peepers and were carried deeper.

One other difference in the iron profiles remains unexplained. The concentrations measured at shallow depths in peeper 14 are much lower than in the other peepers at the natural sediments site. Why this is the case is not clear. One possible explanation is that the oxide veneer was not uniformly distributed across the bottom of that bay, and oxides may have been less abundant at the site of peeper 14. The profile from the left bank in that peeper closely resembles the form of the core profile, and H_2S was detected at depth in this bank. These distributions are consistent with the apparent relative paucity of dissolvable iron at this specific location.

The major result of the variable iron distributions in the peeper profiles is that these data cannot be used to define the depth of the redoxcline in the deposits. However, the agreement between the dissolved iron profile and the ΣH_2S distribution in the natural sediment core implies that these data instead are reliable in establishing the diagenetic state of these deposits, and therefore, that the sediments are anoxic at very shallow depths. Note that core compression (Crusius 1991) could theoretically contribute to some steepening in the pore water gradients (*e.g.* Lebel *et al.* 1982), which would artifically shoal the redoxcline. However, the effect of this in the Anderson Lake surveys is probably insignificant for two reasons: first, the core barrel used is of large diameter (8.8 cm O.D.), which minimizes compression (Hvorslev 1949; Emery and Dietz 1941), and second, the pore water Zn, Cu, Cd and Pb profiles for both the cores and the reliable peeper emplacements are practically identical.

The second inconsistency in the data is difficult to explain. The zinc, copper, lead and cadmium profiles in peeper 14 show that high concentrations, similar to those in the bottom waters, persist to depths of about 20 cm (Figures 3-46 to 3-49) and then abruptly decline. In adjacent peeper 10, high concentrations persist to 10 cm depth, and abruptly decline. The core profiles and those from the NWRI peeper, in contrast, match the distributions observed at both the tailings and shallow tailings sites and are identical in form to the winter survey profiles and those collected in summer 1990 (Pedersen *et al.* 1993). One speculative explanation for the anomalous distributions seen in peepers 10 and 14 is that both of these peepers were rocked occasionally by currents in the lake during the 14 day emplacement. The exposed sail area of the Rescan peepers above the sediments is substantial, the lake is shallow, and winds and waves were frequent during that period. If such rocking occurred, wedge-shaped cavities could have formed on either side of the peepers. Metal-rich bottom waters might have filled the cavities and perturbed the porewater metals distributions, apparently to a depth of about 20 cm in the case of peeper 14 and 10 cm for peeper 10. The noncohesive character of the near-surface natural deposits would readily permit lateral movement of the peepers. Indeed, concern that such motion could occur led the divers to fasten dowels to the base of all peepers deployed at Station A in order to anchor them in the more consolidated sediments below. Because NWRI peepers were smaller (*i.e.* much less "sail" area) and were deployed last (after divers had experience deploying Rescan peepers with dowels), it was expected that they would offer a more realistic sampling. The NWRI peeper profiles shows no evidence of the perturbations apparent in the results from the Rescan peepers, and are highly consistent with the core data, implying that these two data sets most reliably describe the true distributions of dissolved metals in porewaters at this site.

The contrast between the dissolved As results in the peepers and the core and the tailings site in the summer survey is difficult to explain. It is possible that lateral heterogeneity may have contributed to the difference seen in Figure 3-38. The As profile in the core pore waters is independent of both the Mn and Fe distributions, and may reflect As release from the mid-depth arsenic maximum noted in the solid phase. This is speculative however, and not very satisfactory. The core profile implies a significantly higher degree of reactivity of As than the peeper results, which is consistent with the As behaviour implied by the data collected at the other sites from both cores and/or peepers. Hence, we assume in subsequent discussion that the As profile from the core at the tailings site is more representative than the unusually low-concentration profiles yielded by the peepers. This assumption may be wrong, but if the opposite is assumed, *i.e.* the peeper profiles from the tailings site are representative, then the data would imply that As is essentially not cycled at the tailings site. This is considered to be unlikely.

Given the concerns with the iron and other metal distributions in peepers 10 and 14 at the Natural Sediments site (Site A), these specific data will be given much less weight in subsequent interpretation of diagenetic processes in Anderson Lake. The iron data obtained from the Rescan peepers at the Tailings site (Site B; Figure 3-36) may also be suspect, if the surface oxide-rich mat was entrained downward during emplacement, but the other dissolved metals data at this location appear to be free of artifacts (with the possible exception arsenic). The iron results at the shallow tailings site are internally more consistent, and appear unaffected by the postulated oxide-entrainment problem. Similarly, a very high degree of consistency is seen in the Zn, Cu, Pb and Cd data from this location.

4.2.1 Interstitial Water Data and Implications for Tailings Reactivity

With the exception of the results from peepers 10 and 14 at the natural sediments site, all Zn, Cu, Pb and Cd profiles at all three locations from both peepers and cores show precipitous declines in the concentrations of these metals immediately below the sediment-water interface. This result is consistent with those seen in all previous surveys, and the implication is clear: both the natural sediments and the tailings on the floor of Anderson Lake appear to be a sink for these metals rather than a source.

One specific objective of the summer survey was to assess whether or not metal release might be occurring at very shallow locations that are probably more frequently overlain by oxic bottom water. The well-oxygenated, shallow tailings site chosen in the summer survey appears to have provided an answer to this question: triplicate profiles for each metal consistently indicate that the flux of dissolved Zn, Cu, Pb and Cd at this site was into and not from the deposited tailings, even though the bottom waters were well oxygenated. The texture of the deposits indicated reworking (*i.e.,* resuspension, redeposition, and translation on the bottom) but this does not seem to have promoted oxidation of the tailings: there was no indication in any of the visual observations or the analytical data that the tailings at this site have been even marginally oxidized. The very sharp increase in the porewater iron content within the top 2 cm of the deposits at this site strongly implies that anoxia occurs at very shallow depths, despite the reworking. Upward diffusion of iron along that concentration gradient and oxidation at the interface must be contributing to the ferruginous veneer observed on the surface sediments.

Although Zn, Cu, Pb and Cd are not being released from the tailings on the lake floor, there is clear evidence that arsenic is actively cycling within both tailings and natural sediments and, at least in winter, in the water column. The arsenic profiles at the natural sediments site show a strong correspondence with the iron distributions which can be attributed to the well-known adsorptive affinity of arsenate and FeOOH. Burial and reductive dissolution of iron oxide phases releases reduced arsenic (arsenite) to solution whereupon it will diffuse upward, be oxidized to arsenate and be readsorbed. Most reports in the literature suggest that the strong coupling between iron oxide and arsenate is much more important in natural arsenic cycling in lakes than association between manganese oxides and arsenic (*e.g.*, Belzile 1988; De Vitre *et al.* 1991; Kuhn & Sigg 1993). However, at the shallow tailings site, arsenic and manganese distributions in porewater are similar, and both contrast with the dissolved iron distributions. The Mn-As correspondence implies that manganeses oxide phases, and not just iron oxyhydroxides, are actively involved in the arsenic cycle in Anderson Lake, at least in the shallow tailings deposits. This implication is supported by recent measurements at UBC made on porewaters collected in shallow Balmer Lake, Ontario; in this case, there is an exceptionally tight correlation between dissolved manganese and arsenic, rather than between Fe and As (Alan Martin, unpublished data). The association of As with Mn in pore waters from Balmer Lake and the shallow tailings site in Anderson Lake may reflect contamination of the lake waters. Takamatsu *et al.* (1985) showed in laboratory studies that hydrous manganese oxide (HMO) has a low affinity for arsenate at the typical pH in lakes (5-7) unless unusually elevated concentrations of cations are present in solution. This is because HMO has a pH_{pzc} (point of zero charge) of about 2.3, and therefore carries a net negative charge at $pH > 5$. However, where high concentrations of cations are present, adsorptive exchange of cations for univalent protons can yield a net positive charge on HMO surfaces, which is conducive to the adsorption of anionic As(V). Because Anderson Lake waters are cation-rich, such an induced adsorptive process might contribute to the covariance of Mn and As seen at the shallow tailings site, where the concentrations of Mn in pore waters imply that HMO is more abundant in the solid phase than at the other locations.

In the tailings core, the dissolved arsenic profile shows a marked maximum at ~18 cm depth (Figure 3-38). This peak is well defined and is clearly independent of the distributions of either dissolved iron or manganese. However, the maximum in solution corresponds very closely to an arsenic- and manganese-rich interval in the sediments at the same depth, as shown by the peaks in the arsenic, manganese, and As:Mn ratio profiles in the solid phase (Figure 3-31). Manganese is not being released to solution from the sediments at this depth, which appears to rule out manganese oxides as the host for the arsenic. These data imply that there may be a third, but unknown, influence on arsenic distributions in the porewaters extracted from the tailings.

The dissolved arsenic distributions indicate that there is an upward flux of the metal toward the sediment-water interface in the summer at the shallow tailings, and natural sediments sites. The concentration gradient seen in the As profile from the core at the tailings site implies a much reduced upward As flux at this location. This implication is compromised, however, by the disagreement between the As profiles from the peepers and that from the core. In general, the extent of arsenic escape to the overlying water will depend on the rate of oxidation of iron and manganese at the sediment surface, which in turn will be a function largely of the oxygen concentration in the bottom water. The release to lake water will be highest exactly when anoxia develops at the bottom. This may happen under the ice every winter, but the existing time-series information is too sparse to determine this. Note that the upward flux of arsenic cannot be attributed directly to reactivity of the tailings. Rather, it reflects a natural cycle, which may well have been strengthened in Anderson Lake by the addition of dissolved iron and arsenic from the acid-generating sulphide-rich roadway along the north shore.

4.3 Seasonal Contrasts and Similarities in Anderson Lake

Both limited historical information (a 1982 memorandum supplied by HBM&S) and the results of the surveys described in this report indicate that anoxia may be a widespread occurrence in the Anderson Lake water column during at least the latter half of the ice-covered season. Under such conditions, oxidation of sulphide-rich tailings by oxygen is impossible. It could be argued that oxidation could result from the reaction of pyrite and ferric iron when low pH conditions occur in the lake, or that metals could be released as a result of galvanic reactions, but there is no evidence in the data collected to date to support either notion. In general, both seasonal sets of interstitial water data, from the cores and from the peepers, show that Zn, Cu, Pb and Cd are not released from the submerged tailings either in winter when the water column is depleted in oxygen, or in summer when the lake water is well mixed and well oxygenated. This appears to be true even where the tailings are being physically reworked in turbulent, oxygenated shallow waters. Apparently, the tailings act as a sink for this quartet of metals throughout the year. In contrast, arsenic undergoes diagenetic recycling which is closely allied with the precipitation, burial, and dissolution cycle of hydrous Fe oxides. A benthic efflux of arsenic is to be expected when low oxygen conditions prevail (*i.e.* winter), or if the sediments are anoxic at very shallow depths, which appears to be the case even in summer when oxygen concentrations are high in the bottom waters. Such cycling of arsenic is a natural process in lakes worldwide (Hamilton-Taylor and Davison 1995). The maximum concentrations and gradients witnessed in the Anderson Lake pore waters are similar to those seen in lacustrine pore waters elsewhere in central and eastern Canada (de Vitre *et al.* 1991). This implies that the diagenetic arsenic cycle in Anderson Lake is unlikely to pose an environmental threat either in summer or winter.

5.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary and Conclusions

Several conclusions can be drawn from the winter survey results:

1. Anoxia was widespread in the water column under the ice in April 1993. Observations made by HBM & S personnel that H_2S was present in the water column during the winter of 1982 suggest that anoxia may be a common winter-time phenomenon when wind-driven mixing of the lake water is prevented by the ice cover.
2. Lateral and vertical compositional heterogeneity was observed in the water column, as illustrated by the presence of an ~1 m thick oxygenated layer at depth at Station A sandwiched between anoxic or oxygen-depleted waters above and anoxic sediments below. This layer must have penetrated laterally to Station A (the Natural Sediments site) from another (unknown) location.
3. There is no evidence that oxidation of sulphide particles and the concomitant release of metals and/or acid was occurring in the tailings deposit on the floor of the lake. Not only would oxidation be prevented by the anoxia that existed in the bottom water in April 1993, but all sulphide grains observed at the microscope were fresh and unaltered, regardless of the sample depth within one of the tailings cores, and the pH in the water column increased with depth as the tailings on the bottom were approached.
4. Lateral motion implied by the water column data complicates interpretation of vertical exchange of dissolved solutes with the underlying sediments. Despite this, high resolution duplicate porewater profiles indicate that there was no measurable release of dissolved Cu, Pb, Cd, As or Hg from the rapidly-deposited tailings near the floating outfall in early April 1993, even though the deposits are enriched in each of these metals. Similarly, there was no observable release of dissolved Zn, Cd or Pb from "natural" but tailings-contaminated sediments cored at Station A.
5. The dissolved Zn data from the duplicate cores collected at the tailings site are equivocal in indicating the direction of zinc exchange with the overlying

water. One core implies that an influx into the tailings existed in April, 1993, and the other (B2) hints that there may have been a slight efflux to bottom water. The ambiguity in these results is complicated by the observation that the tailings were overlain by oxygen-poor water at the time of sampling, and under such conditions, no zinc should be released (for example, via oxidation of the surfaces of ZnS particles). The spatial disparity between the dissolved zinc and iron maxima in the shallow porewaters of Core B2 rules out iron oxyhydroxide dissolution as an explanation for the apparent zinc release. The contrast between the duplicate zinc profiles may have resulted from non-steady-state perturbations, but this is speculative. However, an important implication of this suggestion is that temporally-varying chemical reactions and hydrographic processes in the overlying water column may play a major role in dictating the distributions of dissolved metals in the near-surface porewaters.

6. Porewater profiles in the "natural sediments" (Station A) imply that copper and arsenic were being released to pore solution at very shallow depths and were diffusing both upward and downward from shallow maxima. Copper commonly shows a maximum in near-surface porewaters in marine sediments (*e.g.* Pedersen *et al.* 1986) which is related to metabolization of copper-bearing organic matter at or just below the sediment surface. As no similar release was seen in the natural sediments in summer 1990, it is possible that such copper recycling occurs in the organic-rich deposits in Anderson Lake only during the cooler seasons. The arsenic maximum appears to be closely related to reductive solution of FeOOH, which probably releases adsorbed arsenate to porewaters. Precipitation of arsenic-bearing sulphides at depth (arsenopyrite?) can account for the decline in the arsenic content in porewaters below about 2 cm depth.

7. The winter survey results are consistent with the hypothesis that metal release from fresh, sulphide-rich tailings is limited by submerged storage, in contrast to the behavior of sulphide-bearing tailings deposits stored subaerially. There is no indication from either the chemical data in the water column and the porewaters, or from microscopic inspection of submerged tailings samples, that sulphide phases in the tailings are chemically reacting on the lake floor.

Several conclusions can be drawn from the Summer Survey results:

1. The shallow nature of Anderson Lake in concert with the absence of an ice cover allows mixing of lake water to occur to the lake floor. As a result, temperature and dissolved oxygen profiles (as well as most metals and major ions) were uniform in the water column. Indeed, the high turbidity of the lake water observed during the Summer Survey likely resulted from resuspension of natural sediments and to some extent tailings.
2. Diurnal temperature fluctuations were present (0.6°C) affecting the entire water column, but likely reflected a longer time-scale cooling trend. Dissolved oxygen concentrations did not vary significantly on diurnal time scales.
3. As in the winter survey, there was no evidence to suggest oxidation of sulphide particles with the concomitant release of metals or acid within the tailings deposited on the lake floor. All sulphide grains observed microscopically were fresh and unaltered.
4. High resolution sampling of the interstitial waters from both peepers and cores indicate that at both the tailings and natural sites, Cd, Cu, Pb and Zn were diffusing from the overlying lake water into the deposits, *i.e.* the tailings were acting as a sink rather than a source for these metals. Further, even at the shallow (1 m deep) tailings site, where vigorous reworking of the tailings has occurred, Cd, Cu, Pb and Zn were diffusing into the lake floor; there was no visible or chemical indication of tailings oxidation.
5. Arsenic undergoes active seasonal cycling in the sediments and water column of Anderson Lake. Dissolved As and Fe distributions were similar to the pore waters and water column as expected given the known affinity of As for Fe-oxyhydroxides. However, in the interstitial waters of the shallow tailings site, there was an association between As and Mn; the As-Fe alliance was decoupled. This may reflect adsorption of arsenate by hydrous manganese oxides (HMO) as an indirect result of replacement of protons by cations on HMO surfaces. Such replacement may be a result of the high cation content of contaminated Anderson Lake water.
6. The upward flux of As toward the sediment-water interface was limited by the "oxide cap" of the surficial sediments. At the time the water column

goes anoxic (as it seems to do under ice), release of As to bottom water from dissolving oxide phases is presumably at its maximum. Such release is not associated directly with reactivity of As-bearing tailings but more likely reflects a natural As cycle (with interfacial Fe oxides) which may have been strengthened by contributions of Fe and As from the acid-generating road on the north shore of the lake.

7. The summer survey results, like the winter survey, are consistent with the hypothesis that metal release from fresh, sulphide-rich tailings is minimal in a subaqueous setting. There is no evidence (chemical or visual) to suggest that the sulphide component of the tailings submerged in Anderson Lake is oxidizing on the lake floor. This conclusion may apply to all seasons, and not just the summer and winter. This result is important because it suggests that oxidation of tailings stored permanently underwater is strongly inhibited even where tailings are reworked under shallow oxygenated water columns.

5.2 Recommendations

The Snow Lake mill ceased operations in February 1994, and tailings have not been deposited in Anderson Lake since that time. In addition, the acid-generating roadway along the north shore of the lake is scheduled for complete removal and cleanup during the summer of 1994. Thus, the chemistry of Anderson Lake water can be expected to change markedly over the next few years, as neither the alkaline tailings discharge nor metal-bearing acid runoff will be added to the basin. Because the accumulation rate of the tailings has now fallen to zero, the residence time of the sulphide particles at the sediment-water interface has significantly lengthened. It is possible (although unlikely, based on previous work) that the increased time of exposure to oxygen of the sulphide particles on the lake floor could allow some oxidation to occur during the ice-free period on the lake. If oxidation reactions do happen, they could be expected to persist until the deposits became covered with a natural organic-rich sediment veneer thick enough to reduce the oxygen fugacity substantially in the surface pore waters. After this point, metal release could not occur. This postulated "oxidation window" is likely to be on the order of a few years at most in eutrophic Anderson Lake. Because there are potential applications of the results from the Anderson studies to future engineered subaqueous disposal operations, it is suggested that the possible occurrence of oxidation at the sediment-water interface be assessed once acid inputs from the roadway area cease. The best way to assess the expected limited reaction would be to measure pH, pO_2, and possibly pS^{2-} via careful insertion of O_2, pH, and pS^{2-} microelectrodes through the benthic boundary layer into the deposited tailings. The technology to make such measurements (at least O_2 and pH) *in situ* using a programmable bottom lander is now available, and is being successfully applied in studies of oxygen consumption in British Columbian fjords impacted by pulp mill waste. The vertical resolution of the measurements is 100 µm. It is strongly recommended that consideration be given to conducting such a survey during the early summer of 1995 when the lake should be well mixed, relatively well oxygenated, and free of acid inputs from the north shore.

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APPENDIX A - QUALITY ASSURANCE AND QUALITY CONTROL

Specific quality assurance/quality control (QA/QC) procedures were rigorously followed and documented throughout the program. This report provides a summary of compliance/non-compliance with the rigorous criteria applied throughout all phases of the program. Additionally, the National Water Research Institute (NWRI) has assembled the two data sets and performed independent statistical analysis on them. The cross comparison of the data sets is discussed below.

QUALITY ASSURANCE/QUALITY CONTROL (QA/QC) METHODOLOGY

Laboratory QA/QC

The U.S. EPA defines Quality Assurance (QA) as "the total program for assuring the reliability of monitoring data." Quality Control (QC) is limited to "the routine application of procedures for controlling the measurement process." QC is primarily concerned with the tools of the measurement system. Reagents used were of the highest quality and were checked for purity, strength, deterioration with time, and contamination. Class A volumetric glassware was thoroughly cleaned and calibrated when necessary. Balances were frequently checked with certified weights and records were kept. All instruments were calibrated on a routine basis, with the maintenance of appropriate standards and operation logs on performance.

The Laboratory QA/QC program included the analysis of quality assurance samples to define the precision and accuracy of the method for the type of sample under investigation. These samples are defined as follows:

- Method Blank - reagent grade water with added reagents, which was carried through the entire analysis as a check on laboratory contamination (also called a reagent blank).

- Laboratory Replicate - a homogeneous sample was split in the laboratory with the duplicate presented to the analyst as an additional sample to check for precision.

- Spike - a known amount of analyte was added to a number of samples to provide information on matrix effects and the apparent accuracy. The spiking work was carried out because the reference material did not match the matrix of the samples. It was felt that these elements could be subject to matrix problems.

- Standard Reference Material - a material that contains a known concentration of the analyte in question. Based upon reliable documentation of the analyte concentration, a reference material is certified by agencies such as the National Institute of Standards and Technologies (NIST) and the National Research Council of Canada (NRC).

The specifics on how these Laboratory QA/QC samples were incorporated into the study are as follows:

Laboratory Quality Control:

- Total number of samples analysed:
  - 75 water column samples
  - 98 sediment samples

- Number of Sample Replicates:
  - 13 water column samples
  - 22 sediment samples

  Method Blanks:
  - 8 for the water column samples
  - 10 for the sediment samples

Sample Spikes:

35 for the water column samples

Standard Reference Materials:

38 for the water column samples

20 for the sediment samples

- Standard Reference Materials used:

National Water Research Institute of Canada (NWRI - a division of Environment Canada), Burlington, Ontario: Lake Water Reference material for Trace Metals and Other Constituents-

-- 11 NWRI - TM-02;
-- 6 NWRI - RM-ION-96;
-- 5 NWRI - RM-ANI-04.

Analytical Products Group (APG), Belpre, Ohio: Standard Reference Material for Trace Metals-

-- 11 APG Lot # 10773;
-- 5 APG Lot # 10369.

Environmental Resource Associates (ERA), Arvada, Colorado: Standard Reference material for Water Quality Parameters-

-- 6 ERA Lot #9950.

National Research Council of Canada (NRC) Certified Reference Materials

-- 7 NRC MESS-2
-- 7 NRC PACS-1
-- 6 NRC BCSS-1

Field QA/QC

The Field QA/QC program included the analysis of quality assurance samples to demonstrate that adequate contamination control and representative sampling was accomplished. These samples are defined as follows:

- Transport Blank - consists of a sample container which contains distilled /deionized water and appropriate preservative. This control sample accompanied the sample containers into the field and was returned to the laboratory unopened. The purpose of this sample was to ensure contamination control during transportation and subsequent storage of the samples.

- Field Sampler Blank - three aliquots of distilled/deionized water were pumped through the water column sampler and collected. The purpose of this sample was to ensure contamination control and to assess the possibility of metal adsorption to the water column sampler tubing (see below - Sampler Blank 1, 2 and 3).

- Field Replicate - a number of homogeneous samples were split in the field and presented (blind) to the laboratory as additional samples to check for precision.

- Field Filter Blank - one aliquot of distilled/deionized water was filtered using the field filtration equipment. The purpose of this sample was to ensure that field cleaning procedures were adequate.

- Field Sampler Spike - two solutions of known analyte concentrations were pumped through the water column sampler and collected. The purpose of this was to assess the possibility of metal adsorption to the water column sampler tubing (see below - Sampler Spike 1 and 2).

The water column samples for the Anderson Lake Winter Survey were collected using a unique water sampler that was designed for this project. This sampler contained long lines of tubing to bring samples up from specific depths in the lake. ASL prepared solutions for pumping through the sampler that assessed both contamination control and the possibility of metal adsorption to the tubing. Prior to sample collection, the following solutions were pumped through one of the sampling lines:

- Distilled deionized water - immediately after final cleaning. (SAMPLER BLANK #1 - Rescan identification "A")

- A solution of known metal concentrations (0.2-5 ppb) to assess possibility of adsorption. (SAMPLER SPIKE #1 - Rescan identification "D")

- Then after flushing - repeated with distilled deionized water (SAMPLER BLANK #2 - Rescan identification "C")

- A solution of known concentrations that matched the more contaminated locations in Anderson Lake - to assess possibility of carry-over. (SAMPLER SPIKE #2 - Rescan identification "B")

- Then after flushing - repeated with distilled deionized water as a second step in assessing carry-over. (SAMPLER BLANK #3 - Rescan identification "E")

Field Quality Control:

- Number of Transport Blanks: 15

Field Filter Blanks:	1
Field Replicates:	Unknown by ASL, these were submitted blind by Rescan.
Field Sampler Blanks:	3
Field Sampler Spikes:	2

QUALITY ASSURANCE/QUALITY CONTROL (QA/QC) RESULTS AND DISCUSSION

The laboratory and field QA/QC results are primarily reported in Appendices 3 and 4 respectively.

Laboratory QA/QC

The laboratory QA/QC is reported as follows:

- Laboratory Replicates - in Appendices 1 and 2, along with all sample results. If a sample was duplicated the second set of results is presented beside the first set and is identified as a "Dup" or "LRep".
- Method Blanks - Section I
- Reference Materials - Section II of Appendix 3 (the certified reference materials are presented in a table, along with their certified values and ranges).
- Spike Summary - Section III

The QC data was evaluated on a batch by batch basis. Pre-determined criteria was adopted for data acceptability as follows:

- Method Blanks - Below method detection limit.
- Replicate Data - Agree to within ± 10% of a calculated mean (when concentrations are more than 10x detection limit).

- Reference Materials - Meet manufacturers/suppliers 95% acceptance criteria.

If data did not meet the above criteria but met the following warning criteria, an explanation is provided:

- Method Blanks - Blank result reported is less than 5x the detection limit and less than lowest reported result.

- Replicate Data - Agree to within ± 15% of a calculated mean.

- Reference Material - Data reported meet a calculated 99% acceptance criteria.

If data had not met the above criteria the analytical batch would have been repeated. However, this was not the case for these analyses.

The results of analysis of the Method Blanks demonstrated proper contamination control in the laboratory. With few exceptions, the data acceptability criteria were met. The exceptions are as follows:

Water Column Samples

- Conductivity results for all Method Blanks fell slightly above the stated detection limit of 1.0 mg/L, but less than 5x this detection limit. The concentrations were much lower than all of the reported results.

- Nitrate Nitrogen results for one of the Method Blanks fell slightly above the stated detection limit of 0.005 mg/L, but less than 5x this detection limit.

The Reference Material results generally met the manufacturers/suppliers 95% acceptance criteria with the exceptions noted below. In all these cases, the data were just outside the 95% acceptance criteria, but still within the 99% warning limits.

Water Column Samples

- Alkalinity results for four of the five NWRI RM-Ani-04 samples.
- Hardness results for all of the six NWRI RM-ION-96 and two of the five NWRI RM-Ani-04 samples.
- Sulphate results for two of the six NWRI RM-ION-96 samples.
- Nitrate Nitrogen results for two of the five NWRI RM-Ani-04 samples.
- Calcium results for all of the six NWRI RM-ION-96 samples.
- Sodium results for four of the six NWRI RM-ION-96 and three of the five NWRI RM-Ani-04 samples.
- Cadmium results for four of the six NWRI TM-02 samples.

Sediment Samples

- Aluminum results for four of the seven NRC MESS-2 and two of the seven NRC PACS-1 samples.

- Arsenic results for two of the six NRC BCSS-1 and two of the seven NRC PACS-1 samples.

- Cadmium results for one of the seven NRC MESS-2 samples.

- Cobalt results for four of the seven NRC PACS-1 samples.

- Chromium results for three of the six NRC BCSS-1, five of the seven NRC PACS-1, and two of the seven NRC MESS-2 samples.

- Iron results for two of the seven NRC MESS-2, two of the six NRC BCSS-1, and two of the seven NRC PACS-1 samples.

- Lead results for five of the seven NRC MESS-2 samples.

- Magnesium results for two of the seven NRC PACS-1, and two of the six NRC BCSS-1 samples.

- Manganese results for one of the seven NRC MESS-2, six of the seven NRC PACS-1 samples, and two of the six NRC BCSS-1 samples.

- Nickel results for two of the seven NRC MESS-2 and one of the seven NRC PACS-1 samples.

- Potassium results for one of the six NRC BCSS-1 samples.
- Zinc results for six of the seven NRC PACS-1 samples.
- Total Carbon results for one of the NRC MESS-2 and one of the NRC PACS-1 samples.
- Total Sulfur results for one of the NRC PACS-1 sample.

It should be noted that all of these deviations reflect typical analytical variabilities for these parameters and do not in any way impact the interpretation of the sample results.

All replicate results agreed to within ±15% of a calculated mean, demonstrating good precision for all parameters tested.

All spike recoveries were within an acceptable range (75% - 118%).

Field QA/QC

The field QA/QC is reported as follows:

- Field Replicates - in Appendices 1 and 2, along with all sample results. However, it will be Rescan's responsibility to identify these since some of them were not labelled as replicates.
- Transport Blanks - Section I
- Field Sampler Blanks - Section II

- Field Sampler Spikes - Section III

The only parameters detected in the Transport Blanks were Conductivity, Alkalinity, Nitrate Nitrogen, Total Organic Carbon and Zinc. In all cases the concentrations were less than 5x the quoted detection limit and did not impact the overall interpretation of sample results.

The parameters of concern were not detected in any of the Field Sampler Blanks (Samples "A, C, and E"), indicating good contamination control in the field.

All Field Sampler Spike recoveries (Samples "B and D") were within an acceptable range (71 to 120% at concentrations near the detection limit and 99 to 104% at higher concentrations).

LABORATORY QA/QC DATA

SECTION I

Method Blanks

			Method Blank #1 May 15/93	Method Blank #2 May 15/93	Method Blank #3 May 15/93	Method Blank #4 May 15/93
Physical Tests						
Conductivity	umhos/cm		2.2	2.7	1.6	1.3
Hardness	CaCO3		<0.05	<0.05	<0.05	<0.05
Dissolved Anions						
Alkalinity - Total		CaCO3	<1.0	<1.0	1.6	<1.0
Chloride	Cl		<0.5	<0.5	<0.5	<0.5
Sulphate	SO4		<1.0	<1.0	<1.0	<1.0
Nutrients						
Ammonia Nitrogen		N	<0.005	<0.005	<0.005	<0.005
Nitrate Nitrogen		N	<0.005	<0.005	<0.005	<0.005
Total Phosphorus		P	<0.001	<0.001	<0.001	<0.001
Total Metals						
Arsenic	T-As		<0.0001	<0.0001	<0.0001	<0.0001
Cadmium	T-Cd		<0.0002	<0.0002	<0.0002	<0.0002
Calcium	T-Ca		<0.050	<0.050	<0.050	<0.050
Copper	T-Cu		<0.0005	<0.0005	<0.0005	<0.0005
Iron	T-Fe		<0.003	<0.003	<0.003	<0.003
Lead	T-Pb		<0.0005	<0.0005	<0.0005	<0.0005
Magnesium	T-Mg		<0.010	<0.010	<0.010	<0.010
Manganese	T-Mn		<0.001	<0.001	<0.001	<0.001
Mercury	T-Hg		<0.00001	<0.00001	<0.00001	<0.00001
Potassium	T-K		<0.010	<0.010	<0.010	<0.010
Sodium	T-Na		<0.010	<0.010	<0.010	<0.010
Zinc	T-Zn		<0.001	<0.001	<0.001	<0.001
Dissolved Metals						
Arsenic	D-As		<0.0001	<0.0001	<0.0001	<0.0001
Cadmium	D-Cd		<0.0002	<0.0002	<0.0002	<0.0002
Calcium	D-Ca		<0.050	<0.050	<0.050	<0.050
Copper	D-Cu		<0.0005	<0.0005	<0.0005	<0.0005
Iron	D-Fe		<0.003	<0.003	<0.003	<0.003
Lead	D-Pb		<0.0005	<0.0005	<0.0005	<0.0005
Magnesium	D-Mg		<0.010	<0.010	<0.010	<0.010
Manganese	D-Mn		<0.001	<0.001	<0.001	<0.001
Mercury	D-Hg		<0.00001	<0.00001	<0.00001	<0.00001
Potassium	D-K		<0.010	<0.010	<0.010	<0.010
Sodium	D-Na		<0.010	<0.010	<0.010	<0.010
Zinc	D-Zn		<0.001	<0.001	<0.001	<0.001
Organic Parameters						
Dissolved Organic Carbon		C	<0.50	<0.50	<0.50	<0.50
Total Organic Carbon		C	<0.50	<0.50	<0.50	<0.50

Results are expressed as milligrams per litre except where noted.
< = Less than the detection limit indicated.

			Method Blank #1 Aug 25/93	Method Blank #2 Aug 25/93	Method Blank #3 Aug 25/93	Method Blank #4 Aug 25/93
Physical Tests						
Conductivity	umhos/cm		2.0	2.0	3.0	1.0
Dissolved Anions						
Alkalinity - Total		CaCO3	<1.0	<1.0	<1.0	<1.0
Chloride	Cl		<0.5	<0.5	<0.5	<0.5
Sulphate	SO4		<1.0	<1.0	<1.0	<1.0
Nutrients						
Ammonia Nitrogen		N	<0.005	<0.005	<0.005	<0.005
Nitrate Nitrogen		N	0.007	<0.005	<0.005	<0.005
Total Phosphorus		P	<0.001	<0.001	<0.001	<0.001
Total Metals						
Arsenic	T-As		<0.0001	<0.0001	<0.0001	<0.0001
Cadmium	T-Cd		<0.0002	<0.0002	<0.0002	<0.0002
Calcium	T-Ca		<0.050	<0.050	<0.050	<0.050
Copper	T-Cu		<0.0005	<0.0005	<0.0005	<0.0005
Iron	T-Fe		<0.003	<0.003	<0.003	<0.003
Lead	T-Pb		<0.0005	<0.0005	<0.0005	<0.0005
Magnesium	T-Mg		<0.010	<0.010	<0.010	<0.010
Manganese	T-Mn		<0.001	<0.001	<0.001	<0.001
Mercury	T-Hg		<0.00001	<0.00001	<0.00001	<0.00001
Potassium	T-K		<0.010	<0.010	<0.010	<0.010
Sodium	T-Na		<0.010	<0.010	<0.010	<0.010
Zinc	T-Zn		<0.001	<0.001	<0.001	<0.001
Dissolved Metals						
Arsenic	D-As		<0.0001	<0.0001	<0.0001	<0.0001
Cadmium	D-Cd		<0.0002	<0.0002	<0.0002	<0.0002
Calcium	D-Ca		<0.050	<0.050	<0.050	<0.050
Copper	D-Cu		<0.0005	<0.0005	<0.0005	<0.0005
Iron	D-Fe		<0.003	<0.003	<0.003	<0.003
Lead	D-Pb		<0.0005	<0.0005	<0.0005	<0.0005
Magnesium	D-Mg		<0.010	<0.010	<0.010	<0.010
Manganese	D-Mn		<0.001	<0.001	<0.001	<0.001
Mercury	D-Hg		<0.00001	<0.00001	<0.00001	<0.00001
Potassium	D-K		<0.010	<0.010	<0.010	<0.010
Sodium	D-Na		<0.010	<0.010	<0.010	<0.010
Zinc	D-Zn		<0.001	<0.001	<0.001	<0.001
Organic Parameters						
Dissolved Organic Carbon		C	<0.50	<0.50	<0.50	<0.50
Total Organic Carbon		C	<0.50	<0.50	<0.50	<0.50

Results are expressed as milligrams per litre except where noted.
< = Less than the detection limit indicated.

		Method Blank #1 93 09 29	Method Blank #2 93 09 29	Method Blank #3 93 09 29	Method Blank #4 93 09 30	Method Blank #5 93 09 30	Method Blank #6 93 09 30
Total Metals							
Aluminum	T-Al	<50	<50	<50	<50	<50	<50
Arsenic	T-As	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Cadmium	T-Cd	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Chromium	T-Cr	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Cobalt	T-Co	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Copper	T-Cu	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Iron	T-Fe	<50	<50	<50	<50	<50	<50
Lead	T-Pb	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Magnesium	T-Mg	<50	<50	<50	<50	<50	<50
Manganese	T-Mn	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Mercury	T-Hg	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Nickel	T-Ni	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Potassium	T-K	<250	<250	<250	<250	<250	<250
Sodium	T-Na	<250	<250	<250	<250	<250	<250
Zinc	T-Zn	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0

Results are expressed as milligrams per dry kilogram.
< = Less than the detection limit indicated.

		Method Blank #1 93 12 29	Method Blank #2 93 12 29	Method Blank #3 93 12 29	Method Blank #4 93 12 30
Total Metals					
Aluminum	T-Al	<50	<50	<50	<50
Arsenic	T-As	<0.10	<0.10	<0.10	<0.10
Cadmium	T-Cd	<0.10	<0.10	<0.10	<0.10
Chromium	T-Cr	<2.0	<2.0	<2.0	<2.0
Cobalt	T-Co	<2.0	<2.0	<2.0	<2.0
Copper	T-Cu	<1.0	<1.0	<1.0	<1.0
Iron	T-Fe	<50	<50	<50	<50
Lead	T-Pb	<2.0	<2.0	<2.0	<2.0
Magnesium	T-Mg	<50	<50	<50	<50
Manganese	T-Mn	<0.10	<0.10	<0.10	<0.10
Mercury	T-Hg	<0.005	<0.005	<0.005	<0.005
Nickel	T-Ni	<2.0	<2.0	<2.0	<2.0
Potassium	T-K	<250	<250	<250	<250
Sodium	T-Na	<250	<250	<250	<250
Zinc	T-Zn	<1.0	<1.0	<1.0	<1.0

Results are expressed as milligrams per dry kilogram.
< = Less than the detection limit indicated.

SECTION II

Standard Reference Materials

SECTION II - Standard Reference Materials File No. 9938C

		NWRI RM-ANI-04 #1 May 15/93	NWRI RM-ANI-04 #2 May 15/93	NWRI RM-ANI-04 #3 May 15/93	NWRI RM-ANI-04 #4 May 15/93	NWRI RM-ANI-04 #5 May 15/93	NWRI RM-ANI-04 Certified
Physical Tests							
Conductivity	umhos/cm	617	611	606	602	597	607.3 ± 33.7
Hardness	CaCO3	209	221	211	209	218	199.5 ± 14.4
pH		7.96	7.97	8.04	8.00	7.92	7.82 ± 0.41
Dissolved Anions							
Alkalinity - Total	CaCO3	86.4	85.4	86.8	84.6	86.0	79.6 ± 5.52
Chloride	Cl	57.9	57.3	57.6	57.2	57.5	56.8 ± 3.59
Sulphate	SO4	114	115	116	114	116	112.3 ± 10.2
Nutrients							
Ammonia Nitrogen	N	0.340	0.330	0.330	0.320	0.320	0.30 ± 0.07
Nitrate Nitrogen	N	2.01	1.96	2.02	2.02	1.96	2.03 ± 0.6
Total Phosphorus	P	0.001	0.001	0.001	0.001	0.001	0.002 ± 0.003
Total Metals							
Calcium	T-Ca	26.5	26.1	27.3	26.5	27.2	26.6 ± 2.70
Magnesium	T-Mg	34.7	33.2	34.8	34.6	34.2	31.65 ± 3.23
Potassium	T-K	17.0	17.9	16.4	17.5	17.9	15.94 ± 1.99
Sodium	T-Na	42.0	36.7	41.2	42.0	36.3	37.74 ± 2.89
Organic Parameters							
Dissolved Organic Carbon	C	14.6	14.3	12.9	12.7	14.3	14.5 ± 3.0

Results are expressed as milligrams per litre except where noted.
< = Less than the detection limit indicated.
NWRI RM-ANI-04 is a Standard Reference Material from the National Water Research Institute certified for assorted parameters.

		NWRI TM-02 #1 May 15/93	NWRI TM-02 #2 May 15/93	NWRI TM-02 #3 May 15/93	NWRI TM-02 #4 May 15/93	NWRI TM-02 #5 May 15/93	NWRI TM-02 Certified
Total Metals							
Cadmium	T-Cd	0.0205	0.0215	0.0205	0.0215	0.0210	0.0210 ± 0.0035
Copper	T-Cu	0.0530	0.0610	0.0580	0.0540	0.0500	0.0541 ± 0.0098
Iron	T-Fe	0.052	0.045	0.043	0.053	0.048	0.050 ± 0.016
Lead	T-Pb	0.0225	0.0219	0.0251	0.0277	0.0285	0.0259 ± 0.0052
Manganese	T-Mn	0.021	0.023	0.024	0.023	0.025	0.0215 ± 0.0040
Zinc	T-Zn	0.035	0.038	0.038	0.036	0.040	0.0344 ± 0.0094

Results are expressed as milligrams per litre except where noted.
< = Less than the detection limit indicated.
NWRI TM-02 is a Standard Reference Material from the National Water Research Institute certified for trace metals.

		APG Lot#10369 #1 May 15/93	APG Lot#10369 #2 May 15/93	APG Lot#10369 #3 May 15/93	APG Lot#10369 #4 May 15/93	APG Lot#10369 #5 May 15/93	APG Lot#10369 Certified
Total Metals							
Arsenic	T-As	0.0531	0.0510	0.0552	0.0570	0.0552	0.0566 ± 0.0124

		APG Lot#10773 #1 May 15/93	APG Lot#10773 #2 May 15/93	APG Lot#10773 #3 May 15/93	APG Lot#10773 #4 May 15/93	APG Lot#10773 #5 May 15/93	APG Lot#10773 Certified
Total Metals							
Mercury	T-Hg	0.00190	0.00170	0.00175	0.00185	0.00170	0.00173 ± 0.00039

Results are expressed as milligrams per litre.
< = Less than the detection limit indicated.

APG is a Standard Reference Material from the Analytical Products Group certified for trace metals.

SECTION II - Standard Reference Materials

File No. D3551

		NWRI RM-ION-96 #1 Aug 25/93	NWRI RM-ION-96 #2 Aug 25/93	NWRI RM-ION-96 #3 Aug 25/93	NWRI RM-ION-96 #4 Aug 25/93	NWRI RM-ION-96 Certified
Physical Tests						
Conductivity	umhos/cm	820	822	810	807	807.7 ± 49.8
Hardness	CaCO3	368	365	366	368	331.0 ± 27.8
pH		8.25	8.20	8.00	8.23	8.22 ± 0.25
Dissolved Anions						
Alkalinity - Total	CaCO3	200	201	203	205	201.5 ± 14.3
Chloride	Cl	72.4	73.0	69.5	73.0	71.67 ± 5.72
Sulphate	SO4	115	112	113	110	100.3 ± 11.7
Nutrients						
Ammonia Nitrogen	N	<0.005	<0.005	<0.005	<0.005	0.008 ± 0.010
Nitrate Nitrogen	N	4.76	4.85	4.82	4.85	4.69 ± 0.53
Total Metals						
Calcium	T-Ca	106	105	106	106	94.71 ± 8.35
Magnesium	T-Mg	24.9	24.8	24.7	24.9	22.73 ± 2.71
Potassium	T-K	4.10	4.08	4.09	4.10	3.94 ± 0.48
Sodium	T-Na	42.5	49.1	49.0	48.7	43.02 ± 4.04
Organic Parameters						
Dissolved Organic Carbon	C	5.14	5.19	5.14	5.19	5.6 ± 0.8

		NWRI RM-ION-96 #5 Aug 25/93	NWRI RM-ION-96 #6 Aug 25/93	NWRI RM-ION-96 Certified
Physical Tests				
Conductivity	umhos/cm	815	820	807.7 ± 49.8
Hardness	CaCO3	367	366	331.0 ± 27.8
pH		8.25	8.37	8.22 ± 0.25
Dissolved Anions				
Alkalinity - Total	CaCO3	203	199	201.5 ± 14.3
Chloride	Cl	72.2	72.7	71.67 ± 5.72
Sulphate	SO4	111	112	100.3 ± 11.7
Nutrients				
Ammonia Nitrogen	N	<0.005	<0.005	0.008 ± 0.010
Nitrate Nitrogen	N	4.85	4.81	4.69 ± 0.53
Total Metals				
Calcium	T-Ca	106	106	94.71 ± 8.35
Magnesium	T-Mg	24.9	24.7	22.73 ± 2.71
Potassium	T-K	4.08	4.10	3.94 ± 0.48
Sodium	T-Na	48.9	47.1	43.02 ± 4.04
Organic Parameters				
Dissolved Organic Carbon	C	5.14	5.14	5.6 ± 0.8

Results are expressed as milligrams per litre except for pH and Conductivity (umbos/cm).
< = Less than the detection limit indicated.
NWRI RM-ION-96 is a Standard Reference Material from the National Water Research Institute certified for assorted parameters.

	ERA #1 Lot9950 93 08 25	ERA #2 Lot9950 93 08 25	ERA #3 Lot9950 93 08 25	ERA #4 Lot9950 93 08 25	ERA Lot9950 Certified
Nutrients					
Total Phosphorus T-P	8.41	8.24	8.54	8.58	8.6 ± 1.4

	ERA #5 Lot9950 93 08 25	ERA #6 Lot9950 93 08 25	ERA Lot9950 Certified
Nutrients			
Total phosphorus T-P	8.43	8.52	8.6 ± 1.4

Results are expressed as milligrams per litre.
ERA Lot 9950 is a Standard Reference Material certified for general water quality parameters by Environmental Resource Associates.

SECTION II - Standard Reference Materials

		NWRI TM-02 #1 Aug 25/93	NWRI TM-02 #2 Aug 25/93	NWRI TM-02 #3 Aug 25/93	NWRI TM-02 #4 Aug 25/93	NWRI TM-02 Certified
Total Metals						
Cadmium	T-Cd	0.0162	0.0170	0.0167	0.0177	0.0210 ± 0.0035
Copper	T-Cu	0.0480	0.0460	0.0460	0.0460	0.0541 ± 0.0098
Iron	T-Fe	0.044	0.043	0.044	0.043	0.050 ± 0.016
Lead	T-Pb	0.0210	0.0280	0.0280	0.0280	0.0259 ± 0.0052
Manganese	T-Mn	0.023	0.023	0.022	0.02	0.0215 ± 0.0040
Zinc	T-Zn	0.027	0.027	0.027	0.025	0.0344 ± 0.0094

		NWRI TM-02 #5 Aug 25/93	NWRI TM-02 #6 Aug 25/93	NWRI TM-02 Certified
Total Metals				
Cadmium	T-Cd	0.0170	0.0199	0.0210 ± 0.0035
Copper	T-Cu	0.0480	0.0490	0.0541 ± 0.0098
Iron	T-Fe	0.04	0.045	0.050 ± 0.016
Lead	T-Pb	0.0210	0.0220	0.0259 ± 0.0052
Manganese	T-Mn	0.023	0.023	0.0215 ± 0.0040
Zinc	T-Zn	0.027	0.028	0.0344 ± 0.0094

Results are expressed as milligrams per litre.
< = Less than the detection limit indicated.
NWRI TM-02 is a Standard Reference Material from the National Water Research Institute certified for trace metals.

		APG Lot#10773 #1 Aug 25/93	APG Lot#10773 #2 Aug 25/93	APG Lot#10773 #3 Aug 25/93	APG Lot#10773 #4 Aug 25/93	APG Lot#10773 Certified
Total Metals						
Arsenic	T-As	0.0620	0.0590	0.0584	0.0528	0.0566 ± 0.0110
Mercury	T-Hg	0.00175	0.00179	0.00178	0.00179	0.00173 ± 0.00039

		APG Lot#10773 #5 Aug 25/93	APG Lot#10773 #6 Aug 25/93	APG Lot#10773 Certified
Total Metals				
Arsenic	T-As	0.0538	0.0560	0.0566 ± 0.0110
Mercury	T-Hg	0.00181	0.00181	0.00173 ± 0.00039

Results are expressed as milligrams per litre.
< = Less than the detection limit indicated.

APG is a Standard Reference Material from the Analytical Products Group certified for trace metals.

			NRC MESS-2 #1 93 09 29	NRC MESS-2 #2 93 09 29	NRC MESS-2 #3 93 09 30	NRC MESS-2 #4 93 09 30	NRC MESS-2 Certified
Total Metals							
Aluminum	T-Al		88500	89500	89010	89300	85700 ± 2590
Arsenic	T-As		19.5	19.8	20.2	20.7	20.7 ± 0.8
Cadmium	T-Cd		0.23	0.23	0.23	0.25	0.24 ± 0.01
Chromium	T-Cr		116	115	114	111	106 ± 8
Cobalt	T-Co		13.3	14.1	13.7	14.1	13.8 ± 1.4
Copper	T-Cu		39.2	37.3	37.5	37.8	39.3 ± 2.0
Iron	T-Fe		46700	46700	46600	45200	43500 ± 2170
Lead	T-Pb		20.3	20.7	20.8	20.3	21.9 ± 1.2
Manganese	T-Mn		334	339	338	333	365 ± 21
Mercury	T-Hg		0.083	0.086	0.089	0.089	0.092 ± 0.009
Nickel	T-Ni		46.6	46.9	47.0	46.8	49.3 ± 1.8
Zinc	T-Zn		160	157	158	157	172 ± 16
Other Parameters							
Total Sulphur		%	0.79	0.76	-	-	0.72 ± 0.05
Total Carbon		%	2.92	3.02	-	-	2.99 ± 0.09

Results for Total Sulphur and Total Carbon are expressed as percent (%).
Results for Total Metals are expressed as milligrams per dry kilogram.

NRC MESS-2 is a Certified Reference Material from the National Research Council.

		NRC PACS-1 #1 93 09 29	NRC PACS-1 #2 93 09 29	NRC PACS-1 #3 93 09 30	NRC PACS-1 #4 93 09 30	NRC PACS-1 Certified
Total Metals						
Aluminum	T-Al	66500	66000	66300	65900	64700 ± 1160
Arsenic	T-As	200	216	203	216	211 ± 11
Cadmium	T-Cd	2.30	2.20	2.30	2.40	2.38 ± 0.20
Chromium	T-Cr	113	103	111	102	113 ± 8
Cobalt	T-Co	15.9	16.1	15.8	16.3	17.5 ± 1.1
Copper	T-Cu	461	436	436	458	452 ± 16
Iron	T-Fe	47500	48100	49100	48900	48700 ± 800
Lead	T-Pb	397	392	394	401	404 ± 20
Magnesium	T-Mg	14400	14700	14400	14100	14500 ± 500
Manganese	T-Mn	459	486	453	452	470 ± 12
Mercury	T-Hg	4.69	4.73	4.73	4.69	4.57 ± 0.16
Nickel	T-Ni	42.1	42.4	43.0	42.1	44.1 ± 2.0
Potassium	T-K	13000	12300	12500	12070	12500 ± 700
Sodium	T-Na	33200	33800	32900	32700	32600 ± 800
Zinc	T-Zn	856	840	850	844	824 ± 22
Other Parameters						
Total Sulphur	%	1.28	1.24	1.30	-	1.32 ± 0.08
Total Carbon	%	-	3.72	3.64	-	3.69 ± 0.11

Results for Total Sulphur and Total Carbon are expressed as percent (%).
Results for Total Metals are expressed as milligrams per dry kilogram.

NRC PACS-1 is a Certified Reference Material from the National Research Council.

SECTION II - Standard Reference Materials

		NRC BCSS-1 #1 93 09 29	NRC BCSS-1 #2 93 09 29	NRC BCSS-1 #3 93 09 30	NRC BCSS-1 Certified
Total Metals					
Arsenic	T-As	9.43	10.3	10.4	11.1 ± 1.4
Cadmium	T-Cd	0.23	0.21	0.21	0.25 ± 0.04
Cobalt	T-Co	11.7	10.6	9.4	11.4 ± 2.1
Copper	T-Cu	15.8	18.1	16.1	18.5 ± 2.7
Lead	T-Pb	20.8	20.8	20.5	22.7 ± 3.4
Magnesium	T-Mg	12900	13800	13000	14700 ± 1400
Manganese	T-Mn	209	214	207	229 ± 15
Nickel	T-Ni	54.9	53.4	51.7	55.3 ± 3.6
Zinc	T-Zn	111	116	110	119 ± 12
Other Parameters					
Total Sulphur	%	0.40	-	-	0.36 ± 0.05
Total Carbon	%	2.18	-	-	2.19 ± 0.09

Results for Total Sulphur and Total Carbon are expressed as percent (%).
Results for Total Metals are expressed as milligrams per dry kilogram.

NRC BCSS-1 is a Certified Reference Material from the National Research Council.

			NRC MESS-2 #1 93 12 29	NRC MESS-2 #2 93 12 29	NRC MESS-2 #3 93 12 30	NRC MESS-2 Certified
Total Metals						
Aluminum	T-Al		86900	88300	87500	85700 ± 2590
Arsenic	T-As		20.0	20.4	19.9	20.7 ± 0.8
Cadmium	T-Cd		0.23	0.22	0.23	0.24 ± 0.01
Chromium	T-Cr		106	112	108	106 ± 8
Cobalt	T-Co		14.1	14.4	14.1	13.8 ± 1.4
Copper	T-Cu		38.2	39.6	38.2	39.3 ± 2.0
Iron	T-Fe		40200	42500	40300	43500 ± 2170
Lead	T-Pb		20.5	20.5	20.1	21.9 ± 1.2
Manganese	T-Mn		345	345	341	365 ± 21
Mercury	T-Hg		0.099	0.098	0.098	0.092 ± 0.009
Nickel	T-Ni		46.6	47.8	47.0	49.3 ± 1.8
Zinc	T-Zn		166	165	162	172 ± 16
Other Parameters						
Total Sulphur		%	0.72	-	-	0.72 ± 0.05
Total Carbon		%	2.87	-	-	2.99 ± 0.09

Results for Total Sulphur and Total Carbon are expressed as percent (%).
Results for Total Metals are expressed as milligrams per dry kilogram.

NRC MESS-2 is a Certified Reference Material from the National Research Council.

		NRC PACS-1 #1 93 12 29	NRC PACS-1 #2 93 12 29	NRC PACS-1 #3 93 12 30	NRC PACS-1 Certified
Total Metals					
Aluminum	T-Al	63800	65900	64700	64700 ± 1160
Arsenic	T-As	203	197	195	211 ± 11
Cadmium	T-Cd	2.30	2.30	2.40	2.38 ± 0.20
Chromium	T-Cr	102	103	101	113 ± 8
Cobalt	T-Co	18.4	16.4	17.6	17.5 ± 1.1
Copper	T-Cu	451	448	466	452 ± 16
Iron	T-Fe	48700	47100	47900	48700 ± 800
Lead	T-Pb	403	395	400	404 ± 20
Magnesium	T-Mg	13800	13900	14100	14500 ± 500
Manganese	T-Mn	452	460	457	470 ± 12
Mercury	T-Hg	4.80	4.70	4.76	4.57 ± 0.16
Nickel	T-Ni	43.4	44.4	41.4	44.1 ± 2.0
Potassium	T-K	12400	12600	12600	12500 ± 700
Sodium	T-Na	32800	33900	33200	32600 ± 800
Zinc	T-Zn	855	857	851	824 ± 22
Other Parameters					
Total Sulphur	%	1.21	-	-	1.32 ± 0.08
Total Carbon	%	3.54	-	-	3.69 ± 0.11

Results for Total Sulphur and Total Carbon are expressed as percent (%).
Results for Total Metals are expressed as milligrams per dry kilogram.

NRC PACS-1 is a Certified Reference Material from the National Research Council.

		NRC BCSS-1 #1 93 12 29	NRC BCSS-1 #2 93 12 29	NRC BCSS-1 #3 93 12 30	NRC BCSS-1 Certified
Total Metals					
Aluminum	T-Al	63800	64000	64800	62600 ± 2200
Arsenic	T-As	9.42	9.72	9.47	11.1 ± 1.4
Cadmium	T-Cd	0.23	0.25	0.23	0.25 ± 0.04
Chromium	T-Cr	105	104	102	123 ± 14
Cobalt	T-Co	11.1	11.4	11.5	11.4 ± 2.1
Copper	T-Cu	15.9	15.8	16.2	18.5 ± 2.7
Iron	T-Fe	31500	33200	31600	32900 ± 1000
Lead	T-Pb	20.8	21.5	21.8	22.7 ± 3.4
Magnesium	T-Mg	13800	14300	13600	14700 ± 1400
Manganese	T-Mn	218	224	219	229 ± 15
Nickel	T-Ni	52.0	54.8	54.7	55.3 ± 3.6
Potassium	T-K	18000	18100	18400	18000 ± 300
Sodium	T-Na	20000	20400	19900	20200 ± 1600
Zinc	T-Zn	116	120	119	119 ± 12
Other Parameters					
Total Sulphur	%	0.39	-	-	0.36 ± 0.05
Total Carbon	%	2.13	-	-	2.19 ± 0.09

Results for Total Sulphur and Total Carbon are expressed as percent (%).
Results for Total Metals are expressed as milligrams per dry kilogram.

NRC BCSS-1 is a Certified Reference Material from the National Research Council.

SECTION III

Spike Summary Data

SECTION III - Spike Summary Data

File No. 9938C

Parameter		Number of Spikes Carried Out (n)	Spike Level (mg/L)	Recovery (%)	
				Minimum	Maximum
Total Metals					
Arsenic	T-As	18	0.0020	87	110
Cadmium	T-Cd	12	0.0020	75	95
Copper	T-Cu	12	0.0060	90	118
Iron	T-Fe	2	0.020	76	115
Lead	T-Pb	6	0.0020	90	106
Manganese	T-Mn	2	0.020	77	95
Zinc	T-Zn	1	0.0020	88	88
Nutrients					
Total Phosphorus		6	0.066	90	95

FIELD QA/QC DATA

SECTION I

Transport Blanks

SECTION I - Transport Blanks **File No. 9938C**

		Transport Blank 1 May 15/93	Transport Blank 2 May 15/93	Transport Blank 3 May 15/93	Transport Blank 4 May 15/93	Transport Blank 5 May 15/93
Total Metals						
Arsenic	T-As	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cadmium	T-Cd	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Calcium	T-Ca	<0.050	<0.050	<0.050	<0.050	<0.050
Copper	T-Cu	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Iron	T-Fe	<0.003	<0.003	<0.003	<0.003	<0.003
Lead	T-Pb	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Magnesium	T-Mg	<0.010	<0.010	<0.010	<0.010	<0.010
Manganese	T-Mn	<0.001	<0.001	<0.001	<0.001	<0.001
Mercury	T-Hg	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Potassium	T-K	<0.010	<0.010	<0.010	<0.010	<0.010
Sodium	T-Na	<0.010	<0.010	<0.010	<0.010	<0.010
Zinc	T-Zn	0.004	0.002	0.001	0.002	0.005

		Transport Blank 6 May 15/93	Transport Blank 7 May 15/93	Transport Blank 8 May 15/93	Transport Blank 9 May 15/93	Transport Blank 10 May 15/93
Physical Tests						
Conductivity	umhos/cm	4.4	3.8	3.7	5.0	3.2
Hardness	CaCO3	<0.05	<0.05	<0.05	<0.05	<0.05
pH		-	-	-	-	-
Dissolved Anions						
Alkalinity - Total	CaCO3	2.5	2.3	2.5	2.4	1.9
Chloride	Cl	<0.5	<0.5	<0.5	<0.5	<0.5
Sulphate	SO4	<1.0	<1.0	<1.0	<1.0	<1.0
Nutrients						
Ammonia Nitrogen	N	<0.005	<0.005	<0.005	<0.005	<0.005
Nitrate Nitrogen	N	0.014	0.013	0.008	0.005	0.010
Total Phosphorus	P	<0.001	<0.001	<0.001	<0.001	<0.001
Organic Parameters						
Dissolved Organic Carbon	C	<0.50	<0.50	<0.50	<0.50	<0.50
Total Organic Carbon	C	<0.50	<0.50	<0.50	<0.50	<0.50

Results are expressed as milligrams per litre except where noted.
< = Less than the detection limit indicated.

		Transport Blank 1 Aug 16/93	Transport Blank 2 Aug 16/93	Transport Blank 3 Aug 16/93	Transport Blank 4 Aug 16/93	Transport Blank 5 Aug 16/93
Dissolved Anions						
Alkalinity - Total	CaCO3	<1.0	<1.0	<1.0	<1.0	<1.0
Chloride	Cl	<0.5	<0.5	<0.5	<0.5	<0.5
Sulphate	SO4	<1.0	<1.0	<1.0	<1.0	<1.0
Nutrients						
Ammonia Nitrogen	N	<0.005	<0.005	<0.005	<0.005	<0.005
Nitrate Nitrogen	N	0.008	0.005	0.014	0.015	0.007
Total Phosphorus	N	<0.001	<0.001	<0.001	<0.001	<0.001
Total Metals						
Arsenic	T-As	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cadmium	T-Cd	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Calcium	T-Ca	<0.050	<0.050	<0.050	<0.050	<0.050
Copper	T-Cu	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Iron	T-Fe	<0.003	<0.003	<0.003	<0.003	<0.003
Lead	T-Pb	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Magnesium	T-Mg	<0.010	<0.010	<0.010	<0.010	<0.010
Manganese	T-Mn	<0.001	<0.001	<0.001	<0.001	<0.001
Mercury	T-Hg	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Potassium	T-K	<0.010	<0.010	<0.010	<0.010	<0.010
Sodium	T-Na	<0.010	<0.010	<0.010	<0.010	<0.010
Zinc	T-Zn	0.004	0.002	0.001	0.002	0.005
Organic Parameters						
Total Organic Carbon	C	0.68	0.53	0.58	<0.50	1.12

Results are expressed as milligrams per litre except where noted.
< = Less than the detection limit indicated.

SECTION II

Field Sampler Blanks

SECTION II - Field Sampler Blanks

		Field Sampler Blank #1 "A" May 15/93	Field Sampler Blank #2 "C" May 15/93	Field Sampler Blank #3 "E" May 15/93
Total Metals				
Arsenic	T-As	<0.0001	<0.0001	<0.0001
Cadmium	T-Cd	<0.0002	<0.0002	<0.0002
Copper	T-Cu	<0.0005	<0.0005	<0.0005
Iron	T-Fe	<0.003	<0.003	<0.003
Lead	T-Pb	<0.0005	<0.0005	<0.0005
Manganese	T-Mn	<0.001	<0.001	<0.001
Mercury	T-Hg	<0.0002	<0.0002	<0.0002
Zinc	T-Zn	<0.001	<0.001	<0.001

Results are expressed as milligrams per litre.
< = Less than the detection limit indicated.

"A", "C", and "E" are Rescan identifications.

SECTION III

Field Sampler Spikes

		Field Sampler Spike #1 (Low) "D" Apr 07/93	Field Sampler Spike #1 (Low) Target Value	Recovery (%)
Total Metals				
Arsenic	T-As	0.0049	0.0050	98.0
Cadmium	T-Cd	0.0060	0.0050	120
Copper	T-Cu	0.0047	0.0050	94.0
Iron	T-Fe	0.005	0.005	100
Lead	T-Pb	0.0048	0.0050	96.0
Manganese	T-Mn	0.004	0.005	80.0
Mercury	T-Hg	0.00025	0.00035	71.0
Zinc	T-Zn	0.002	0.002	100

		Field Sampler Spike #2 (High) "B" Apr 07/93	Field Sampler Spike #2 (High) Target Value	Recovery (%)
Total Metals				
Arsenic	T-As	<0.0001	-	-
Cadmium	T-Cd	<0.0002	-	-
Copper	T-Cu	0.052	0.050	104
Iron	T-Fe	<0.003	-	-
Lead	T-Pb	<0.0005	-	-
Manganese	T-Mn	<0.001	-	-
Mercury	T-Hg	<0.00002	-	-
Zinc	T-Zn	0.496	0.500	99.2

Results are expressed as milligrams per litre.
< = Less than the detection limit indicated.

"B" and "D" are Rescan identifications.

Appendix A-2 - UBC QA/QC

U.B.C. QUALITY ASSURANCE/QUALITY CONTROL (QA/QC) METHODOLOGY

Laboratory QA/QC

The UBC laboratory QA/QC program included the analysis of quality assurance samples to assess the precision and accuracy of the measurements of the various metals. Several types of samples were included in the program:

a) method blanks were of two types: i) laboratory blanks, consisting of high-purity water (>18 meg ohm resistivity) with added reagents (typically 0.2% Seastar HNO_3); and ii) field blanks, which consisted of samples of high purity water handled in the field in the same way as the pore water samples. These were of two types: centrifuged and filtered (to mimic pore water samples from cores), a third type was collected from the peeper shipping boxes after transit and filtered in a glove bag in the field.

b) laboratory replicates, consisting of two or three splits of the same sample, each of which was analyzed independently as a check on precision;

c) certified reference materials (CRMs), consisting of several water samples prepared by the National Water Research Institute, Burlington, Ontario, and supplied with recommended values for contents of dissolved cations and anions.

With each group of 24 samples, five to eight replicates, four CRMs and several blanks were routinely included, yielding a typical total of ~40 samples. The CRMs were run as independent samples in every fifth or sixth position during a run, and the results were continously monitored for accuracy. Reference samples used included TM-11, TM-21 and SLRS-2. Reference values for these standards are shown in Table A2-1 below.

Table A2-1

Reference Values and Twice the Standard Deviation for Dissolved Metals in Water Standards Supplied by the National Water Research Institute (TM Series) and the National Research Council (SLRS).

Standard	Fe	Mn	Zn	Cu	Pb	Cd
TM-21	6.4 ± 3.6	6.2 ± 2	7.5 ±2.2	7.6 ± 2.2	5.5 ± 1.6	4.9 ± 1.4
TM-11	249 ± 37	46 ± 12	55 ± 12	46 ± 14	275 ± 55	41 ± 8
SLRS-2	129 ± 7	10.1 ± 0.3	3.33 ± 0.15	2.76 ± 0.17	0.129 ± 0.011	0.028 ± 0.004

Concentrations in ppb.

Results and Discussion

The laboratory QA/QC results are primarily reported in the Data Appendices. Laboratory replicates are reported in the data tables along with the sample results. The repeat values shown are independently-analyzed replicates (i.e. usually in a different batch on a different day) . Third values were usually obtained if there was significant disagreement between the first and second results. Disagreement was determined subjectively but would typically refect a difference between analyses 1 and 2 of more than 25%. In general, the replicate results indicate that analytical precision was very good throughout the study.

Dissolved metals measurements in the laboratory blanks were always very low, and were used to derive the detection limits, which are reported in Table A2-2 as six times the standard deviation of the blank results. The very low lab blanks indicated good contamination control in the UBC procedure. With the exception of Pb, these are typical values, although they do vary with time either up or down depending on instrument performance and slight variations in the quality of the lab ultrapure water. The D.L. for Pb given in this table is higher than normal. Recent redeterminations yielded a D.L. for Pb of 0.03 ppb, but similar values for the other elements.

Table A2-2

Detection limits for dissolved metals in the Anderson Lake study, calculated as six times the standard deviation of laboratory blanks (high-purity acidified water, n=12)

Metal	Detection Limit (ppb)
Fe	1.8
Mn	1.6
Zn	0.5
Cu	0.12
Pb	1.0
Cd	0.024

Fe and Mn were determined by GFAAS, and the others by ICP-MS.

Results from the field blanks are reported in Table A2-3, and these indicate that the extraction of samples in the field was accomplished with minimal contamination in the case of the cores. However, the blank samples collected from the peeper boxes after about a week of transit by air and road and extensive bubbling with nitrogen were contaminated to varying degrees (Table A2-3). The contamination was particularly noticeable for Zn, Cu and Pb. The relatively high concentrations probably derive from leaching of the plexiglass box walls, from the neoprene O-ring used to seal the top of each box, and from the polyethylene tubing used in the nitrogen bubbling system in each box. The contamination does not appear to have affected the pore water results however - the profiles show much lower metals concentrations at depth in Anderson Lake sediments, which implies that the contaminated water that was inserted with the peepers exchanged with pore waters of much lower metal content during the two-week emplacement. Depending on chemical reaction versus diffusion rates, some of the contaminant metal inventory in the peeper cells may have precipitated in situ (e.g. Zn as ZnS). Portions of such precipitates may subsequently have been withdrawn from the cells during sampling but these would have been captured during filtration. There is no evidence in the peeper data set that the contaminated shipping-box water influenced the integrity of the peeper results.

CRMs were evaluated on a continuous basis during the analysis. At the beginning of each analytical run, and subsequently during the run, the CRM results were required to be within 10% of the recommended values. Where this standard was not met, which was an exceptionally rare occurrence, the sample results were discarded and the samples reanalyzed after the reason for the disparity had been determined.

Table A2-3

Analytical results for the field blanks

Blank	Fe	Mn	Zn	Cu	Pb	Cd
Centrifuged Samples						
C1	N.A.[2]	<D.L.	<D.L.	<D.L.[2]	<D.L.	0.04
C1 Rep	N.A.	<D.L.	<D.L.	0.13[1]	<D.L.	0.03
C2	<D.L.	<D.L.	<D.L.	<D.L.	<D.L.	<D.L.
Peeper Storage Water						
P1	N.A.	N.A.	16	11	2.5	0.95
P2	N.A.	N.A.	18	8.2	0.5	0.10
P3	N.A.	N.A.	18	8.5	2.6	0.13
P4	N.A.	N.A.	27	11	1.9	0.12
P5	N.A.	N.A.	133	3.8	6.2	5.4
P6	N.A.	N.A.	28	12.7	4.3	0.26

[1] These two values were both very close to the detection limit. All concentrations are in ppb.

[2] D.L. = detection limit; N.A. = not analysed.

Appendix A-3 - NWRI Report

ON THE COMPARABILITY OF LABORATORY DATA FOR WATER SAMPLES EXCHANGED BETWEEN UBC AND ASL

ANDERSON LAKE (WINTER AND SUMMER SURVEYS) MEND PROJECT 2.11

This report includes data for Cu, Cd, Fe, Mn, Pb and Zn in the Water Column, in the Pore Water and Peeper Water "Exchange Samples".

June 1994

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L7R 4A6

OVERVIEW ON THE ASSESSMENT OF DATA FOR THE EXCHANGE SAMPLES

This report concludes that most of the trace metal data for the exchange samples analyzed by the two MEND laboratories (UBC and ASL) are comparable. This position is expressed in reference to the criteria established from the information obtained from earlier NWRI trace metal round robins using "clean" water samples and adjusting this criteria to reflect a greater uncertainty normally seen in graphite furnace atomic absorption spectroscopy.

Paired data (one result from ASL and the other from UBC) were assigned a flag (i.e., to indicate they were not comparable results), when the difference of the two values exceeded five standard deviations. These standard deviations were estimated from the precision functions calculated from the trace metal round robins archived on the NWRI AQC database in Burlington. (Refer to Appendix B and C)

Specifics: (Refer to Appendix A for a visual comparison of the data sets)

- The **data for lead** are exceptionally good. This is encouraging.
- The **data for iron** are not very comparable. An immediate review is in order to identify a possible cause for this relative bias. For the peeper water (summer survey), 12 out of 29 pairs of data are considered as not comparable. For the pore water (winter survey), 3 of 9 results compare poorly.
- The **data for zinc** were often erratic. One laboratory reports a high value when the other laboratory reports an exceptionally low concentration. For the summer survey, 7 out of 29 results were flagged.
- The comparability of the **water column data was reasonable** and probably relates to the large water sample available for repeat analysis.
- The results for the pore and peeper water samples were less comparable than the water column data.
- For a visual snapshot on comparability, the reader should review the graphs in Appendix A.
- The ICP-MS has much superior detection capabilities and may have greater accuracy than flame AAS and GFAAS.

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APPENDIX

(A) Visualization of the Results Reported by the two Laboratories.

(B) NWRI Precision Functions.

(C) Calculations to Determine Non Comparable Data.

(1) INTRODUCTION

This report has been prepared to respond to the question of comparability of the two laboratories that created data for the Anderson Lake winter and summer surveys. The two laboratories are ASL, (Analytical Services Laboratory Inc.,Vancouver) and UBC, (Department of Oceanography at the University of British Columbia, Vancouver). These two laboratories will for the remaining portion of this report be referred to as simply ASL and UBC.

About ten percent of the water column samples received and analyzed by ASL were split by ASL and forwarded to the UBC laboratory for reanalysis. Likewise, about ten percent of the pore water samples received and analyzed by the UBC laboratory were split and sent to ASL for reanalysis. These split samples are referred to as the exchange samples.

(2) ON ASSESSING COMPARABILITY (ON UNKNOWN SAMPLES ANALYZED BY ONLY TWO LABORATORIES)

To assess whether the two laboratories (ASL and UBC) are comparable, the authors:

- transcribed the original exchange sample data into a simple tabular form, (See Tables 3 to 6),
- prepared a graphical comparisons of one laboratories data against the other laboratories data (These illustrations are found in Appendix A),
- and used the historical data from round robins to decide if each pair of exchange sample data were considered similar. (refer to precision functions in Appendix B and the calculations in Appendix C).

This simple approach is intended to visualize differences between the two laboratories. The key question to resolve is not that they are different results but whether the differences are considered serious or significant.

To address significant differences, the authors used information from precision functions created from interlaboratory studies carried out by the National Water Research Institute. These precision functions are simply an illustration of how interlaboratory standard deviations vary as a function of concentration. When these functions are created using data derived from laboratories that are known to perform consistently well, they would then serve as "a bench mark" for establishing the confidence intervals for assessing other laboratories.

The calculations for estimating the confidence intervals are found on the first page of Appendix C.

The precision functions, that are the reference point for judging the comparability of the ASL and UBC exchange data for the six metals (Cu, Cd, Zn, Pb, Fe and Mn), are found in Figures 1 through 6 in Appendix B. These figures (B1 to B6) were created using round robin data retrieved off the AQC database located on the main frame computer at the National Water Research Institute.

The authors recognize the above approach on comparability addresses only precision and that if both laboratories get the same results they may still have a serious bias. Recovery data from spiked samples and the data on certified reference materials would suggest bias is not a major issue.

(3) RESULTS AND INFORMATION PROVIDED BY ASL AND UBC

3.1 Information on the Methods used for the Analysis of Trace Metals

A brief description of the analytical methods used by ASL and UBC is given below in Table 1.

Table 1: Summary of Analytical Methods

METAL		ASL		UBC	
		METHOD	DETECTION LIMIT (ppb)	METHOD	DETECTION LIMIT (ppb)
Copper	PW	GFAAS	0.5	ICP - MS	Unknown
	WC	GFAAS	0.5	ICP - MS	"
Cadmium	PW	GFAAS	0.2	ICP - MS	Unknown
	WC	GFAAS	0.2	ICP - MS	"
Zinc	PW	FLAME?	1.0	ICP - MS	Unknown
	WC	GFAAS	1.0	ICP - MS	"
Lead	PW	GFAAS	0.5	ICP - MS	Unknown
	WC	GFAAS	0.5	ICP - MS	"
Iron	PW	GFAAS	3.0	GFAAS	Unknown
	WC	ICP	3.0	GFAAS	"
Manganese	PW	GFAAS	1.0	GFAAS	Unknown
	WC	ICP	1.0	GFAAS	"

NOTE: PW refers to Pore Water/Peeper Water and WC refers to the Column Water

ASL reports that where possible, all samples were screened by ICP, prior to a quantitative estimate by the GFASS.

3.2 Results for the Analysis of Certified Reference Materials and Spiked Samples.

Both the UBC and ASL laboratories analyzed NWRI certified aqueous trace metal reference standards. The results for these are summarized below. This is only a partial listing of the data available on CRMs.

It would be appear from the data on CRMs that there is a high probability that the UBC and ASL files reflect accuracy. This does not mean a complete endorsement on accuracy since the issue of a matrix effect or a spectral interference is not resolved nor addressed. The information on the recovery from fortified samples is insufficient to draw any major conclusions.

Table 2A: UBC DATA for Some CRM Samples (All data are expressed as ppb)

CRM	METAL	PROJECT	RESULT FOUND (ppb)	TARGET ASSIGNED (ppb)	CONFIDENCE INTERVAL (95%)
TM-21	Cu	Winter (WC)	7.1	7.6	± 2.2
		Summer (WC)	7.3		
		Winter (PW)	6.8, 7.2, 7,7. 7, 6.9, 8.1, 7.6)		
		Summer (PW)	---		
TM-21	Cd	Winter (WC)	4.84.	4.9	± 1.4
		Summer (WC)	5.01		
		Winter (PW)	3.52		
		Summer (PW)	---		
TM-21	Zn	Winter (CW)	7.51	7.5	± 2.2
		Summer (WC)	7.85		
		Winter (PW)	6.91		
		Summer (PW)	---		
TM-21	Pb	Winter (WC)	4.7	5.5	± 1.6
		Summer (WC)	4.8		
		Winter (PW)	5.18, 5.12		
		Summer (PW)	---		
TM-11	Fe	Winter (WC)	227	249.	± 36.9
TM-21	Fe	Summer (WC)	4.9	6.4	± 3.6
TM-21	Fe	Winter (PW)	6.15		
		Summer (PW)	---		
TM-21	Mn	Winter (WC)	5.6	6.2	± 2.0
TM-11	Mn	Summer (WC)	45.	46.0	± 11.6
		Winter (PW)	5.58, 5.99		
		Summer (PW)	---		

Note: WC refers to the Water Column samples and PW refers to the Pore Water samples.

Table 2B: ASL DATA for Some CRM Samples (All data are expressed as ppb)

CRM	METAL	PROJECT	RESULT FOUND (ppb)	TARGET ASSIGNED (ppb)	CONFIDENCE INTERVAL (95 %)
TM-02	Cu	Winter (WC)	53.0, 61.0	61.0	± 9.8
TM-02	Cd	Winter (WC)	20.5, 21.5	21.0	± 3.5
TM-02	Zn	Winter (WC)	35., 38.	34.4	± 9.4
TM-02	Pb	Winter (WC)	22.5, 21.9	25.9	± 5.2
TM-02	Fe	Winter (WC)	52., 45.	50.0	± 5.2
TM-02	Mn	Winter (WC)	21., 23.	21.5	± 4.0

Note: There were no CRM data on the above samples reported for the Pore water or for the summer survey. Some additional data on other CRMs are found in the original ASL and UBC reports.

3.3 Results Reported for all Exchange Samples (Column waters and the Pore Waters)

It is understood that ASL made the initial analysis of the water column samples and on completion sent about 10% of these to UBC for reanalysis. UBC made the first analyzes of the pore water samples and on completion sent about 10% of the pore waters to ASL for reanalysis. This process produced what are reffered to as the "exchange samples", results for which are tabulated below in Tables 3,4,5 and 6.

TABLE 3: COMPARISON OF SPLIT SAMPLE DATA (WATER COLUMN): ANDERSON LAKE SUMMER SURVEY (Total Metals)

Sample I.D.		**Metal Concentrations (as PPB)**					
I.D.	**Source**	**Cu**	**Cd**	**Zn**	**Pb**	**Fe**	**Mn**
#1	UBC	31.7	0.56	402	71	810	303
	ASL	31.0	0.4	432	64.0	906	286
#2	UBC	33.4	0.61	383	66.	850	315
	ASL	30.0	0.4	463	61.0	976	312
#3	UBC	28.0	0.55	345	69	1,220	255
	ASL	24.0	0.3	368	59.0	1,140	243
#4	UBC	28.3	0.53	354	68	1,095	280
	ASL	23.0	0.4	411	60.0	1,280	269
#5	UBC	0.0	0	3.6	0.1	0	0.2
	ASL	<0.5	<0.2	<1.0	<0.5	<3	<1.0
#6	ASL	23.0	0.4	408	63.0	1,260	267

NOTE: Identification codes used in abstracting data from the original reports are as follows:

I.D.	**UBC CODE**	**ASL CODE**
#1	D3551-4	Stn.1-4
#2	D3551-13	Stn.1-13
#3	D3551-23	Stn.2-4
#4	D3551-27	Stn.2-8
#5	D3551-39	Travel Blank #1
#6	D3551-29 **	Stn.2-10

Sample #5 above was a travel blank submitted in error to UBC by the ASL laboratory. Sample #6 was the intended exchange sample. For this reason there is only one set of data for sample #6.

TABLE 4: COMPARISON OF SPLIT SAMPLE DATA (PORE WATERS) ANDERSON LAKE SUMMER SURVEY (Dissolved Metals)

Sample I.D.		Metal Concentrations (as PPB)					
		Cu	Cd	Zn	Pb	Fe	Mn
#1	UBC	25.3/29.9	0.81	377/393	55/55	91	277
	ASL	28	0.3	290	47.9	140	400
#2	UBC	0.77	0.06	1.6	0	103/81	220/228
	ASL	<1/<1	<0.2/<0.2	1./1.	<0.5/<0.5	180/260	340/350
#3	UBC	19	0.61	324	48	129	230
	ASL	18	<0.2	380	43.4	200	300
#4	UBC	0.02	0	0.1	0	0	0
	ASL	--	--	--	--	--	--
#5	UBC	43.8	0.69	470	65	310	235
	ASL	48.	1.9	810	69.0	330	165
#6	UBC	1.9	0.04	8	2	11,400	612
	ASL	<1	<0.2	280	1.2	23,500	170
#7	UBC	1.6	0.03	10.3	1	6730/7540/7290	631
	ASL	<1.	<0.2	10.	<0.5	25,000	225
#8	UBC	40	0.78	453	72	220	261
	ASL	32	0.3	370	73.0	400	325
#9	UBC	33.1	0.79	465	62	220	270
	ASL	26.0	0.3	350	50.9	380	275
#10	UBC	1.7	0.05	8.0	0	14,900	726
	ASL	2.	<0.2	1,060	<1.0	1,200	2,050
#11	UBC	2.2	0.05	12	0	12,500	755
	ASL	<1	<0.2	450	<0.5	12,500	325
#12	UBC	46/42	0.69/0.61	475/449	93/82	325	269
	ASL	32	0.3	470	82.0	470	310
#13	UBC	38/38	0.59/0.67	481/458	67/66	436/437	299
	ASL	27	0.4	320	79.0	900	290
#14	UBC	6.7	0.03	18	1	5,430/5,340	481
	ASL	66	<0.2	230	<0.5	10,000	475

I.D.		Cu	Cd	Zn	Pb	Fe	Mn
#15	UBC	34/32	0.67/0.59	421/398	63/49	101/103	286
	ASL	26	0.4	360	46.5	160	300
#16	UBC	1.3/1.3	0.06/0.05	59/63	1/1	14,320	365
	ASL	<1.	<0.2	61	1.1	15,800	400
#17	UBC	34	0.63	406	53	83/88	292
	ASL	32	0.6	400	45.4	150	325
#18	UBC	30	0.58	373	47	154/106	255
	ASL	27	0.6	330	38.0	180	275
#19	UBC	1.2	0.05	61	1	12,200	325
	ASL	<1./<1.	<0.2/<0.2	79/62	<0.5/0.6	18,500/20,000	325/275
#20	UBC	24	0.43	329	46	92	266
	ASL	34	0.4	280	37.1	140	325
#21	UBC	24	0.63	304	34	160	288
	ASL	27	0.6	350	31.4	260	375
#22	UBC	28	0.46	263	54	85	252
	ASL	37.	0.5	370	41.9	190	375
#23	UBC	0.6	0.05	5	0	166	340
	ASL	<1	<0.2	40	0.5	260	425
#24	UBC	24	0.63	368	58	169	275
	ASL	36/41	0.4/0.4	450/420	52.8/51.0	260/240	375/350
#25	UBC	27	0.49	407	60	309/249	287
	ASL	40	0.5	390	47.0	440	350
#26	UBC	3.1	0.03	19	1	102,700	744
	ASL	9.	<0.2	90	0.8	130,000	950
#27	UBC	27	0.55	380	53	150/136	312
	ASL	33	0.4	370	46.9	180	375
#28	UBC	1.3/1.2	0.07/0.09	41/44	1/1	48,900	684
	ASL	1.	<0.2	51.0	0.8	65,000	825
#29	UBC	32/33	0.55/0.52	385/393	61/58	110	269
	ASL	40	0.4	360	49.4	150	350
#30	UBC	1/1	0.02/0.02	17/17	1/1	55,200	1,124
	ASL	1.	<0.2	24.	0.8	70,000	1,330

TABLE 4b: IDENTIFICATION CODES for the Split Sample Data (ANDERSON LAKE, SUMMER SURVEY) PORE WATERS

I.D.	UBC CODE	ASL CODE	
#1	C2	C2	
#2	C15	C15	LRep
#3	C19	C19	
#4	C39	C39	LRep
#5	P4	P4	
#6	P24	P24	
#7	P29	P29	
#8	P33	P33	
#9	P36	P36	
#10	P51	P51	
#11	P58	P58	
#12	P63	P63	
#13	P95	P95	
#14	P117	P117	
#15	P122	P122	
#16	P143	P143	
#17	P150	P150	
#18	P151	P151	
#19	P167	P167	LRep
#20	P178	P178	
#21	P197	P197	
#22	P208	P208	
#23	P235	P235	
#24	P240	P240	LRep
#25	P271	P271	
#26	P292	P292	
#27	P300	P300	
#28	P315	P315	
#29	P330	P330	
#30	P350	P350	

TABLE 5: COMPARISON OF SPLIT SAMPLE DATA (WATER COLUMN): ANDERSEN LAKE WINTER SURVEY (Total Metals)

Sample I.D.		Metal Concentrations (as PPB)					
I.D.	**Source**	**Cu**	**Cd**	**Zn**	**Pb**	**Fe**	**Mn**
#1	UBC	3.5	0.02	29.4	3.2	8,415	587
	ASL	1.5	<.2	28	2.5	9,790	559
#2	UBC	24.5	0.53	378	36.	780	296
	ASL	28.0	0.4	384	30.5	760	275
#3	UBC	6.3	0.14	64.5	15	53,490	840
	ASL	6.2	<.2	43	7.1	70,100	796
#4	UBC	7.4	0.13	129	6	12,800	310
	ASL	6.5	<.2	125	3.6	13,500	290
#5	UBC	18.4	0.46	79.9	3.6	1,470	247
	ASL	15.0/15.0	0.3/0.3	396/385	12.3/11.9	1,880/1,940	262/272

NOTE: Identification codes used in abstracting data from the original reports are as follows:

I.D.	UBC CODE	ASL CODE
#1	9938-7	Stn.A-7
#2	9938-12	Stn.A-12
#3	9938-23	Stn.B-5
#4	9938-29	Stn.B-11
#5	9938-36	Stn.B-18

TABLE 6: COMPARISON OF SPLIT SAMPLE DATA (PORE WATERS) ANDERSON LAKE WINTER SURVEY (Total Metals)

Sample I.D.		Metal Concentrations** (as PPB)					
		Cu	Cd	Zn	Pb	Fe	Mn
#1	UBC	.71/.58	.181/.204	143/168	0/0.18	11,390/11,820	289
	ASL	4	.2	170	<0.5	5,100	200
#2	UBC	0	.138	154/155	0.018	11,430	278
	ASL	<1/<1	.2/.2	160/150	0.5/<0.5	5,100/5,100	190/190
#3	UBC	0	.003/.005	1.32/1.8	0.06	46	126
	ASL	<1	<.2	<1	<1.0	46	130
#4	UBC	0.06	0.002	1.75	0	1.27	137
	ASL	2/<1	<.2/<.2	<1/<1	<1/<1	<3/<3	120/130
#5	UBC	11.4	0.49	313	1.18/0.8	907	244
	ASL	7	0.4	220	10.0	760	190
#6	UBC	0	0	0.27	0.24	13.7	301
	ASL	<1/<1	<.2/<.2	<1/<1	<.5/<.5	20/19	270/270
#7	UBC	0/0	0	0.54/0.47	0.13	737/761	445/461
	ASL	<1	<.2	<1	<1	490	490
#8	UBC	8.85	.378	297	15.3	1,654	246
	ASL	8./8.	.3/.3	220/220	16.0/15.0	1,100/1,200	200/190
#9	UBC	0.34	0.001	0.22	0.08	15.1	365
	ASL	<1	<.2	<1.	<.5	18	410
#10	UBC	0.29	0	0.48	0.05	180	486
	ASL	<1/<1	<.2/<.2	2./2.	<.5/<.5	180/190	560/570

** Where two results are shown, it is understood that the laboratory made at least two measurements.

TABLE 6b: IDENTIFICATION CODES for the Split Sample Data (ANDERSON LAKE WINTER SURVEY)

I.D.	UBC CODE	ASL CODE
#1	AND 1	AND 1 Met
#2	AND 2	AND 2 Met LRep
#3	AND 21	AND 21 Met
#4	AND 43	AND 43 Met Lrep
#5	AND 46	AND 46 Met
#6	AND 64	AND 64 Met LRep
#7	AND 66	AND 66 Met
#8	AND 68	AND 68 Met LRep
#9	AND 86	AND 86 Met
#10	AND 89	AND 89 Met LRep

Note: The LRep for ASL refers to these samples being analyzed twice, i.e., there are two sets of data.

(4) DISCUSSION OF RESULTS

The following are the summary comments of the authors on the comparability of the UBC and ASL data files provided for review.

Analytical Methods:

The reports made available to the authors provided very limited information on the analytical methods used by the two laboratories. The information available was inadequate to make inferences on the adequacy of the methods or any comment as to whether the methods had any influence on the comparability of the data.

The dilutions required for analysis of the iron and manganese in the test samples may have contributed to the large variance in the data for these two metals. It may be the dilution errors or the contaminants introduced in handling that contributed to the often large differences seen in the pore and peeper water.

The ICP-MS method is clearly the more sensitive instrument and can provide estimates on the low concentrations of Cd, Cu, Pb and Zn. How successful this technique is may become apparent this fall when the NWRI round robins are presented to the 37 users of the ICP-MS in Canada.

Accuracy of the two laboratories is implied from the use of CRMs and from the spiked recovery. Only ASL provided this information.

The authors remain curious on the success in handling the field blanks and how clean were the filtration (or centrifugation) process. It been known in some circles that the raw data can sometimes reflect not the field sample but only the contamination. Hopefully this area was in control as it is critical to the success of the very sensitive ICP-MS method.

Precision Functions:

The precision functions used for estimating the anticipated uncertainties are given in Appendix B. They are reasonably good estimates for the water column data but may be too tight a criteria for use with the pore water and peeper water data sets.

If time were available, precision functions for within lab and for interlab data should be constructed using large reference samples with the pore water matrix. Such functions would help define a more correct relationship to judge the performance of labs analyzing pore and peeper water for these metals.

It's quite probable that the functions in Appendix B are valid for these waters and what is being observed in the non-comparability is the uncertainties introduced by dilution errors and the contaminants introduced by handling very small samples.

Exchange Sample Data:

The data for all of the exchange samples are found in Tables 3 to 6. In the tabular format one may get a false sense of success since there are some very good data. There are also some severe differences. The graphic comparison in Appendix A visualize the comparison more effectively and especially for iron, the data are clearly not comparable.

The data for iron is graphed with several scales to visualize the low and the high ranges. Either way the graphics illustrate a problem in comparability. The users of the program data are urged to be cautious if they are to estimate a flux from the sediments in the water column.

The comparison for copper and cadmium are reasonable. The copper data for the summer survey have distinctly higher values than for the winter surveys. This is perhaps expected. The comparison on cadmium is clouded by the lack of data. For Zinc, there are a number of anomalous data and examination of the graphs in Appendix A suggests that either ASL has contaminants introduced (for instance dandruff) or that UBC has a case of under recovery (volatilization loss). The analysts may need to discuss these options or provide a review on the various blanks.

Lead presents an interesting situation. Virtually all data appears to be comparable. This metal has often been a difficult, but certainly not in these exchange samples. Only three pairs of data are considered different and not comparable.

The manganese data for the column water appears acceptable. For the pore waters and peeper waters, there is a high frequency of flagged data. The correlation is good for the winter survey (pore water) but appears poor for the peeper water (summer survey).

On the Flagging of Results

To define a pair of results as not comparable requires an estimate of what is considered an acceptable difference. The differences have been calculated from the precision functions (refer to Appendix B) and the summary of the process is tabulated in Appendix C.

If the difference for the water column data are greater than two standard deviations then the pair of data were considered as not comparable. For the pore water and the peeper water the authors chose to accept three standard deviations.

A summary of the flagged data is given below in Table 7. The results for iron clearly indicate that most of the data are not comparable. For lead the comparison is very good. It remains an unknown as to which laboratory is more accurate when the two results are not comparable. Insufficient data exists here. Are the high values due to contamination or do the low values reflect poor recovery?

Table 7: **Summary of Flagged or Non-Comparable Data**

SURVEY	METAL	NUMBER OF PAIRED RESULTS AVAILABLE **	NUMBER OF FLAGS ASSIGNED ##	COMMENTS
Summer and Winter Surveys **(Water Column)** (10 samples)	Cu	9	0 flag (0%)	Note: 1 set of data out of a possible 51 sets was non comparable. (2%) The criteria was 5 standard deviations, derived from the precision functions.
	Cd	6	0 flags (0%)	
	Zn	9	1 flags (11%)	
	Pb	9	0 flags (0%)	
	Fe	9	0 flags (0%)	
	Mn	9	0 flags (0%)	
Pore Water Winter Survey (10 samples)	Cu	4	0 flag (0%)	Note: 5 sets of data out of a possible 35 sets are not comparable. (14%) The criteria was 5 standard deviations, derived from the precision functions.
	Cd	4	0 flags (0%)	
	Zn	5	0 flags (0%)	
	Pb	3	0 flags (0%)	
	Fe	9	3 flags (33%)	
	Mn	10	2 flags (20%)	
Peeper Water Summer Survey (30 samples)	Cu	22	1 flag (5%)	Note: 27 sets of data out of a possible 148 sets are not comparable. (18%) The criteria was 5 standard deviations, derived from the precision functions.
	Cd	16	0 flags (0%)	
	Zn	29	7 flags (24%)	
	Pb	23	0 flags (0%)	
	Fe	29	12 flags (41%)	
	Mn	29	7 flags (24%)	

NOTE:

** The number of paired samples are few, since one lab often reported a "less than" value.

A flag reflects two results that differ by more than 5 standard deviations. In the round robins carried out by the authors, such results would be defined as possibly extreme values and reflect poor performance.

The specific details on defining a flagged result are found in Appendix C.

(5) SUMMARY COMMENTS

This report concludes that most of the trace metal data for the exchange samples analyzed by the two MEND laboratories (UBC and ASL) are comparable. This position is expressed in reference to the criteria established from the information obtained from earlier NWRI trace metal round robins using "clean" water samples and adjusting this criteria to reflect a greater uncertainty normally seen in graphite furnace atomic absorption spectroscopy.

Paired data (one result from ASL and the other from UBC) were assigned a flag (i.e., to indicate they were not comparable results), when the difference of the two values exceeded five standard deviations. These standard deviations were estimated from the precision functions calculated from the trace metal round robins archived on the NWRI AQC database in Burlington. (Refer to Appendix B and C)

Specifics: (Refer to Appendix A for a visual comparison of the data sets)

- The **data for lead** are exceptionally good. This is encouraging.
- The **data for iron** are not very comparable. An immediate review is in order to identify a possible cause for this relative bias. For the peeper water (summer survey), 12 out of 29 pairs of data are considered as not comparable. For the pore water (winter survey), 3 of 9 results compare poorly.
- The **data for zinc** were often erratic. One laboratory reports a high value when the other laboratory reports an exceptionally low concentration. For the summer survey, 7 out of 29 results were flagged.
- The comparability of the **water column data was reasonable** and probably relates to the large water sample available for repeat analysis.
- The results for the pore and peeper water samples were less comparable than the water column data.
- For a visual snapshot on comparability, the reader should review the graphs in Appendix A.
- The ICP-MS has much superior detection capabilities and may have greater accuracy than flame AAS and GFAAS.

(6) REFERENCES

The following references have not been cited in the text but are provided here to initiate and stimulate discussion.

Of particular interest are (i) the ASTM concept of reporting low level concentration (ASTM, A Standard Practise 1983), (ii) King's and Brossman's concepts of QA Project Plans and the QA Management Plans and QA Policy and (iii) Hunter's position paper that provides a powerful statement on the need for the intercomparison study.

The bottom line from these references is future studies should provide proof positive that the project needs verification that delivery is possible, before any funding is released and the analytical program is initiated.

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- Youden, W.J., and E.H. Steiner. 1975. Statistical Manual of the Association of Official Analytical Chemists. AOAC, Washington, D.C.

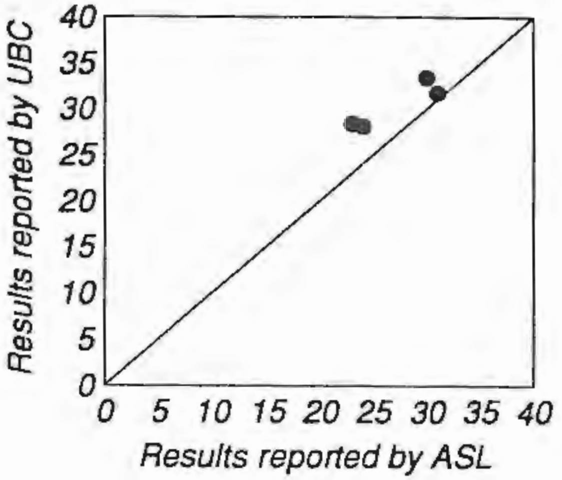
APPENDIX A: VISUALIZATION OF THE COMPARABILITY OF THE UBC AND ASL DATA FOR THE EXCHANGE SAMPLES.

The following six Figures illustrate in a graphic format how the data report by UBC relate to the data reported by ASL

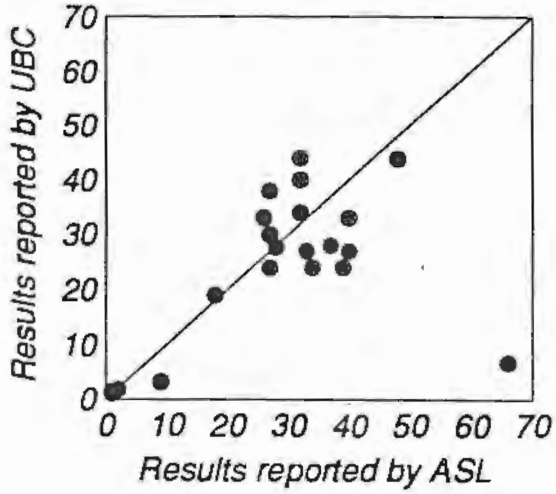
When one laboratory reports a "less than value", no point for that sample appears on the figure. The column water figures should have 5 points in each figure and the pore water figures should have 10 points. The absence of points reflects on the large number of less than values.

The PORE WATER, SUMMER SURVEY figures have most of the data derived from the peepers.

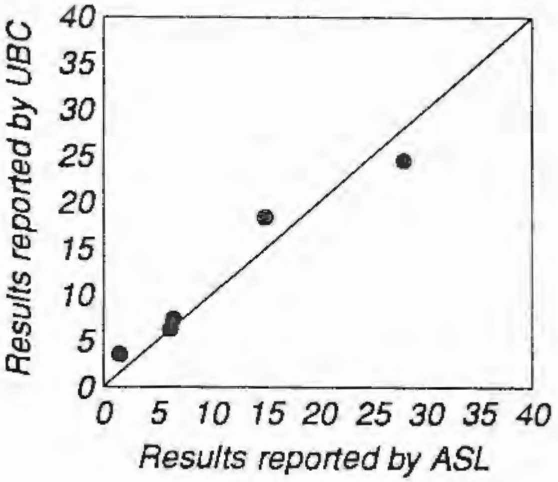
COPPER



Water Column, Summer Survey



Pore Water, Summer Survey



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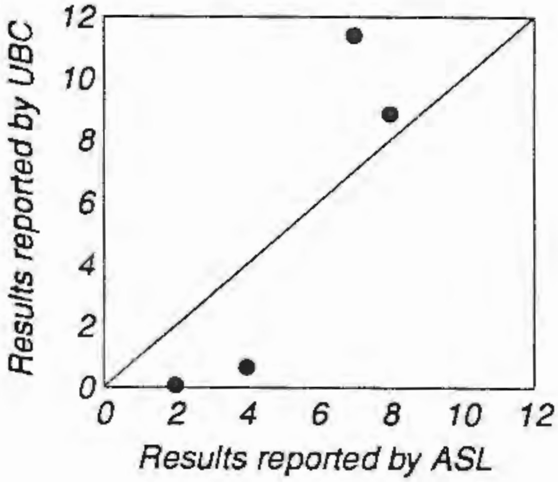
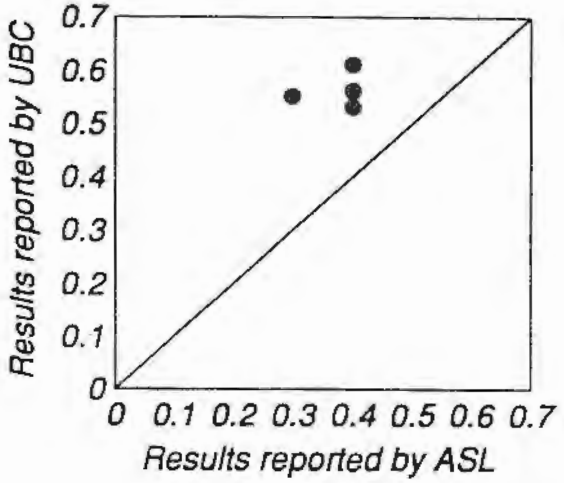


Pore Water, Winter Survey

CADMIUM

Water Column, Summer Survey



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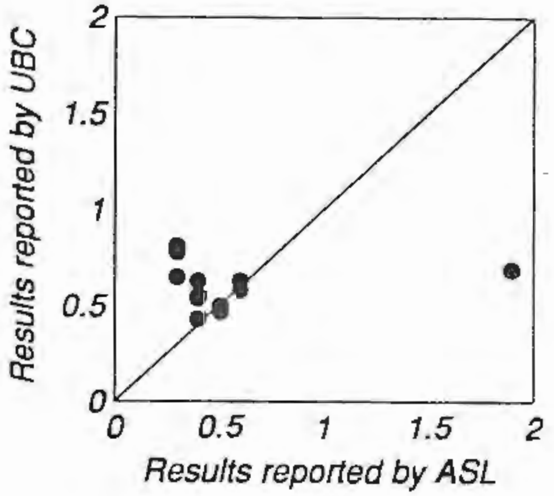

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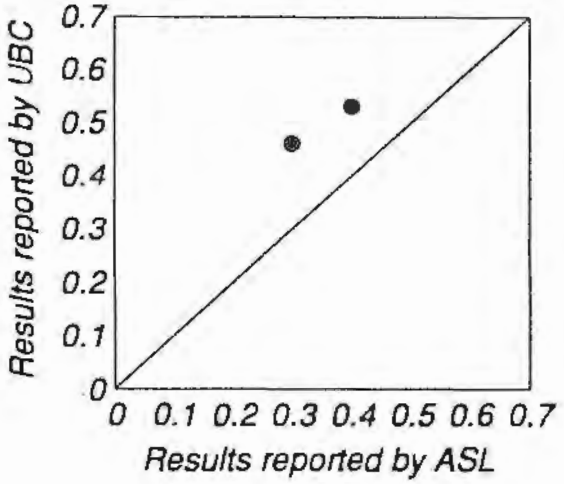

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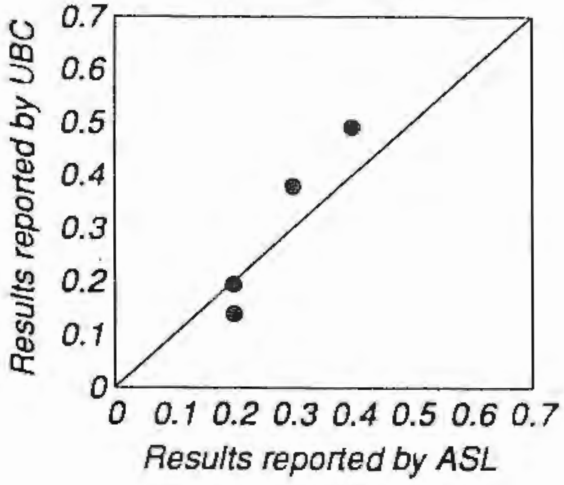
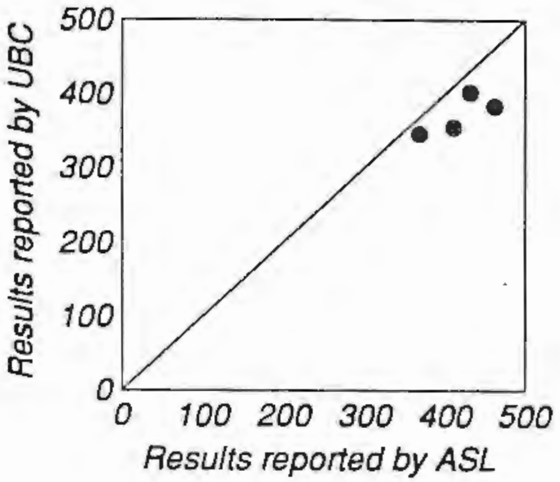


ZINC

Water Column, Summer Survey



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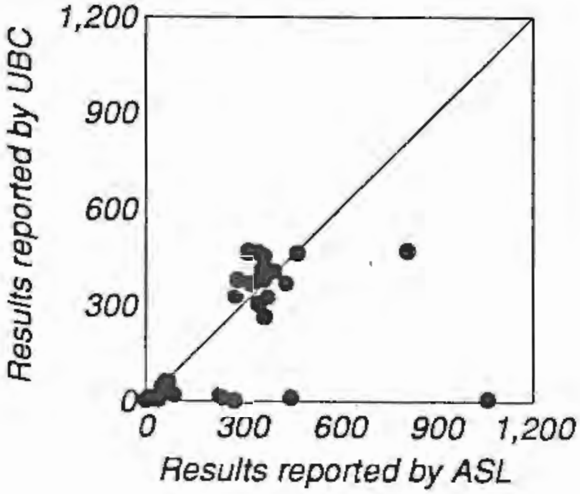

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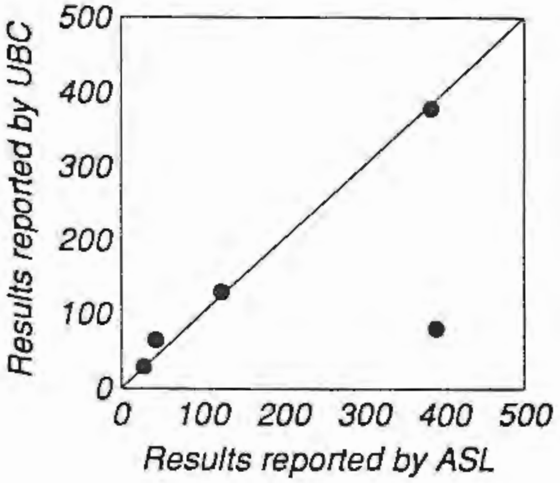

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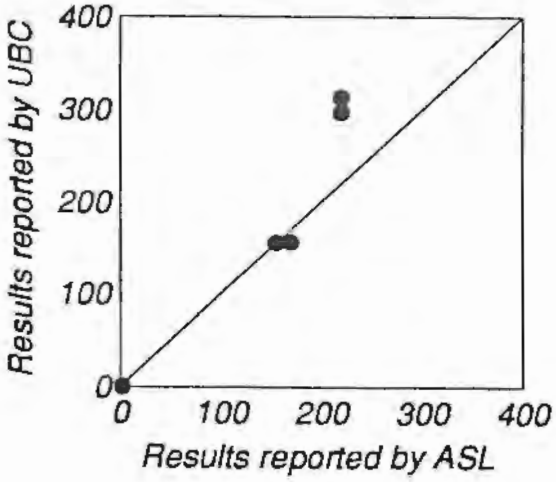

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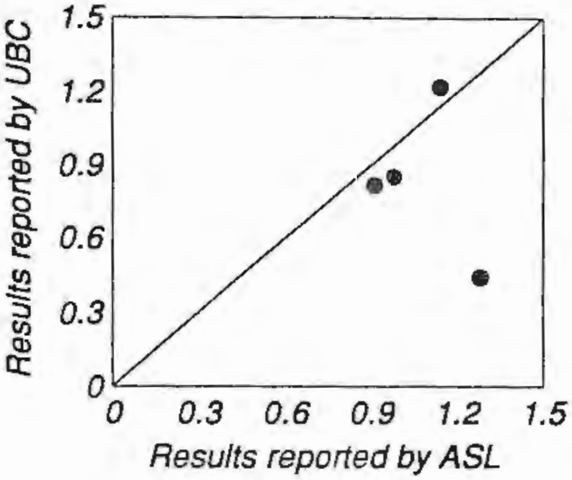
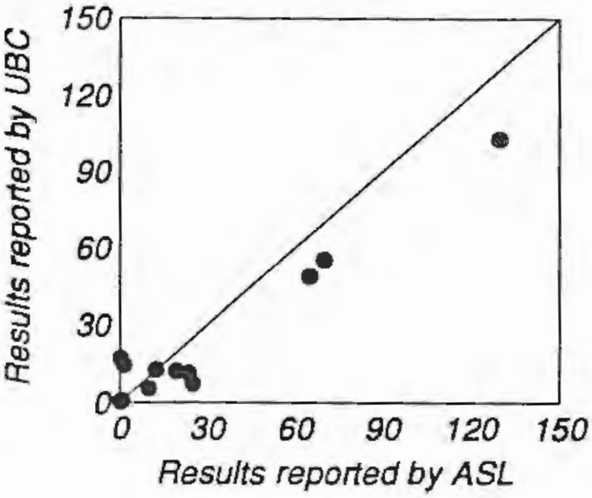

Water Column, Summer Survey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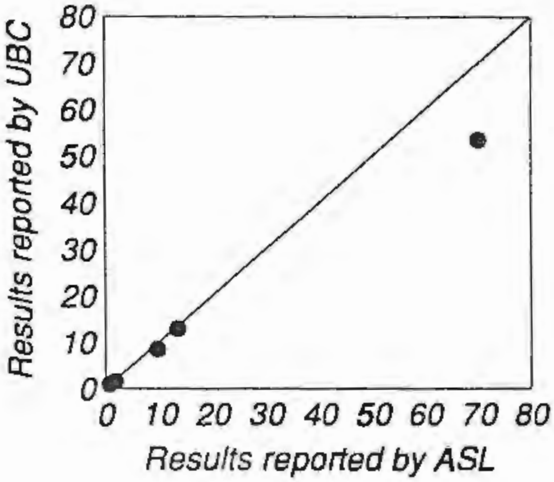
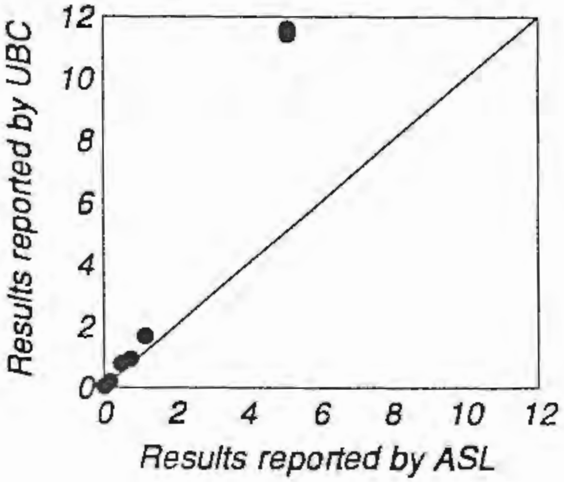

Water Column, Winter Survey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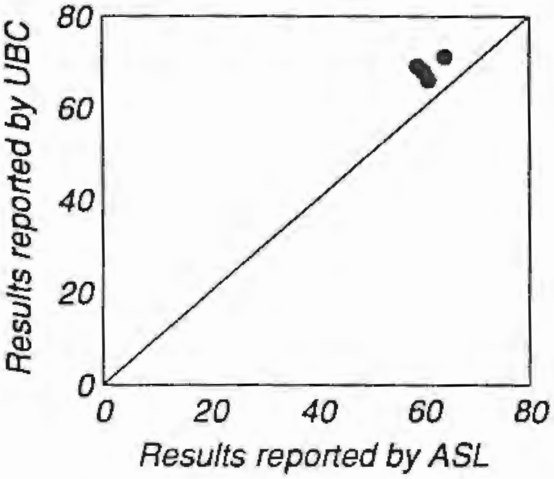
LEAD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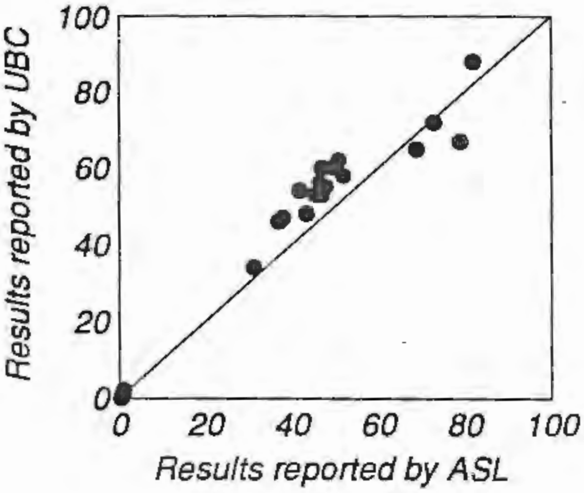
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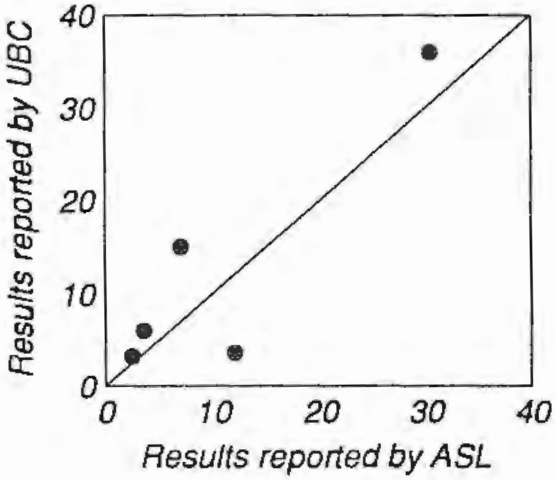
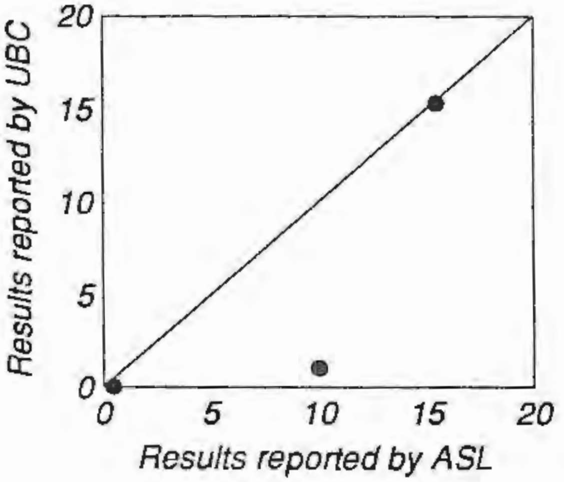
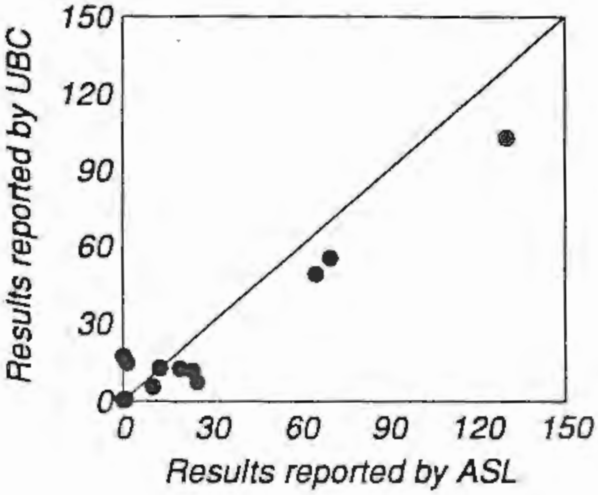
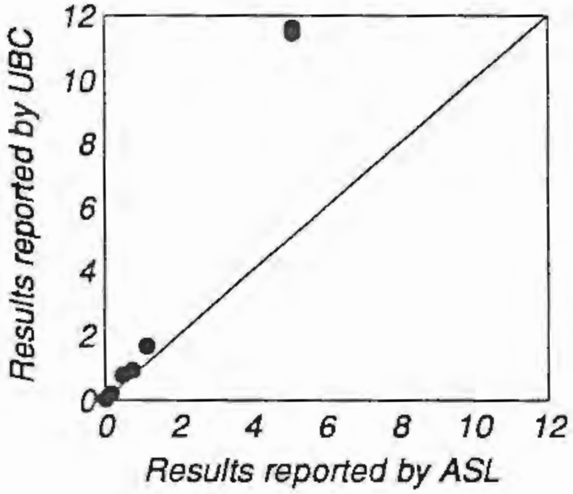

Water Column, Winter Survey

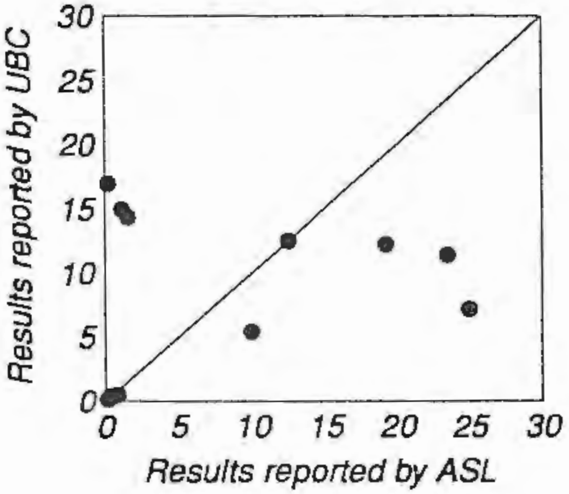

Pore Water, Winter Survey

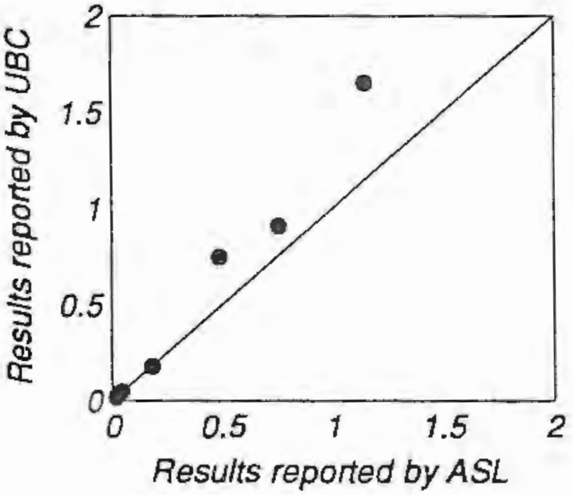
IRON as ppm

Pore Water

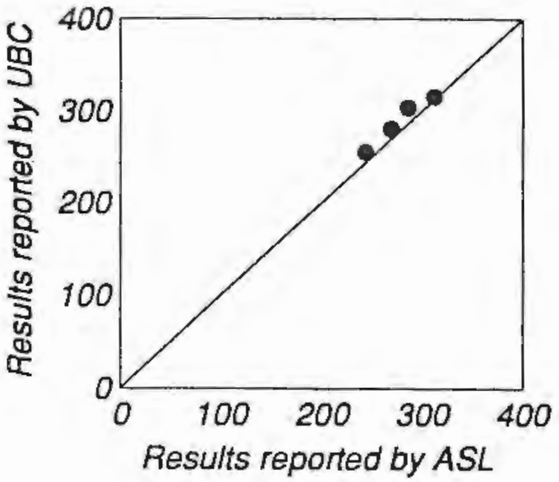

Summer Survey

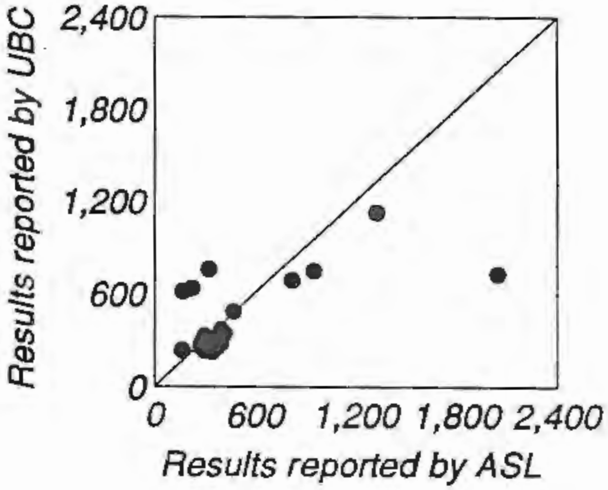

Winter Survey

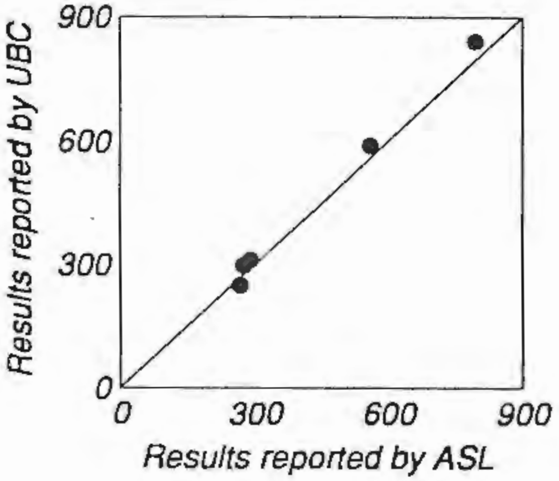

Summer Survey

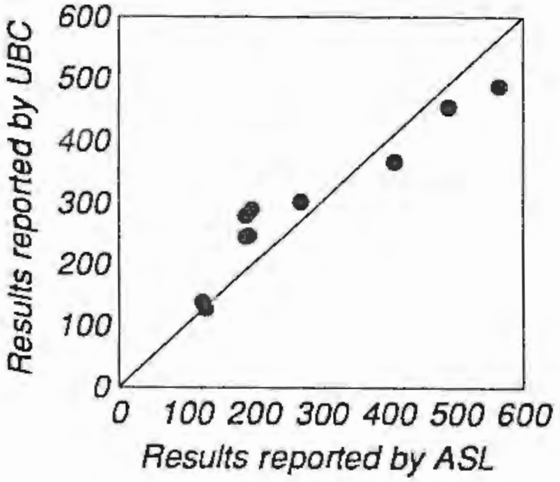

Winter Survey

MANGANESE


Water Column, Summer Survey


Pore Water, Summer Survey


Water Column, Winter Survey


Pore Water, Winter Survey

APPENDIX B: NWRI PRECISION FUNCTIONS FOR TRACE METALS IN WATER.

The following precision functions were created off the NWRI database for Cu, Cd, Zn, Pb, Fe and Mn.

Each point on these figures represent the interlaboratory standard deviation for a test sample used in a recent interlaboratory study. Approximately 15 to 30 different laboratory results were used in estimating the standard deviation and the mean value.

In estimating the standard deviations, a few extreme values, that were flagged by the NWRI system of flagging data, were rejected. The various options available are described on the next page. The figures that follow reflect equations developed using the preferred data

Table B1: Precision Functions Derived from NWRI QA Studies for Some Metals In Water

Metal	Group of Data	Equation of the Precision Function $y = mx + b$	Correlation Coefficient "r"	Range (ppb)
Cu	All Data	$y = 0.0383x + 1.7000$	0.462	0 to 500
	Some Data	$y = 0.0228x + 0.2300$	0.888	0 to 500
	Preferred Data	$y = 0.0847x + 0.4927$	0.980	0 to 30
Cd	All Data	$y = 0.1259x + 0.1850$	0.921	0 to 240
	Some Data	$y = 0.0427x + 0.0790$	0.934	0 to 240
	Preferred Data	$y = 0.1145x + 0.2976$	0.946	0 to 12
Zn	All Data	$y = 0.0785x + 1.3450$	0.621	0 to 500
	Some Data	$y = 0.0380x + 0.0810$	0.975	0 to 500
	Preferred Data	$y = 0.0578x + 1.0398$	0.969	0 to 500
Pb	All Data	$y = 0.1274x + 0.3510$	0.873	0 to 600
	Some Data	$y = 0.0377x + 0.1240$	0.954	0 to 300
	Preferred Data	$y = 0.0755x + 1.0667$	0.979	0 to 120
Fe	All Data	$y = 0.0705x + 0.6010$	0.987	0 to 3,000
	Some Data	$y = 0.0310x + 0.2090$	0.994	0 to 3,000
	Preferred Data	$y = 0.0498x + 3.3377$	0.994	0 to 3,000
Mn	All Data	$y = 0.0442x + 0.0030$	0.784	0 to 500
	Some Data	$y = 0.0296x + 0.0003$	0.996	0 to 500
	Preferred Data	$y = 0.4673x + 0.8671$	0.985	0 to 500

Notes:

The equation for the precision function is almost always linear. This line is defined as $y = mx + b$, where m is the slope of the line and b is the y intercept. If the correlation coefficient is high (over 0.8) this line almost never has a negative intercept.

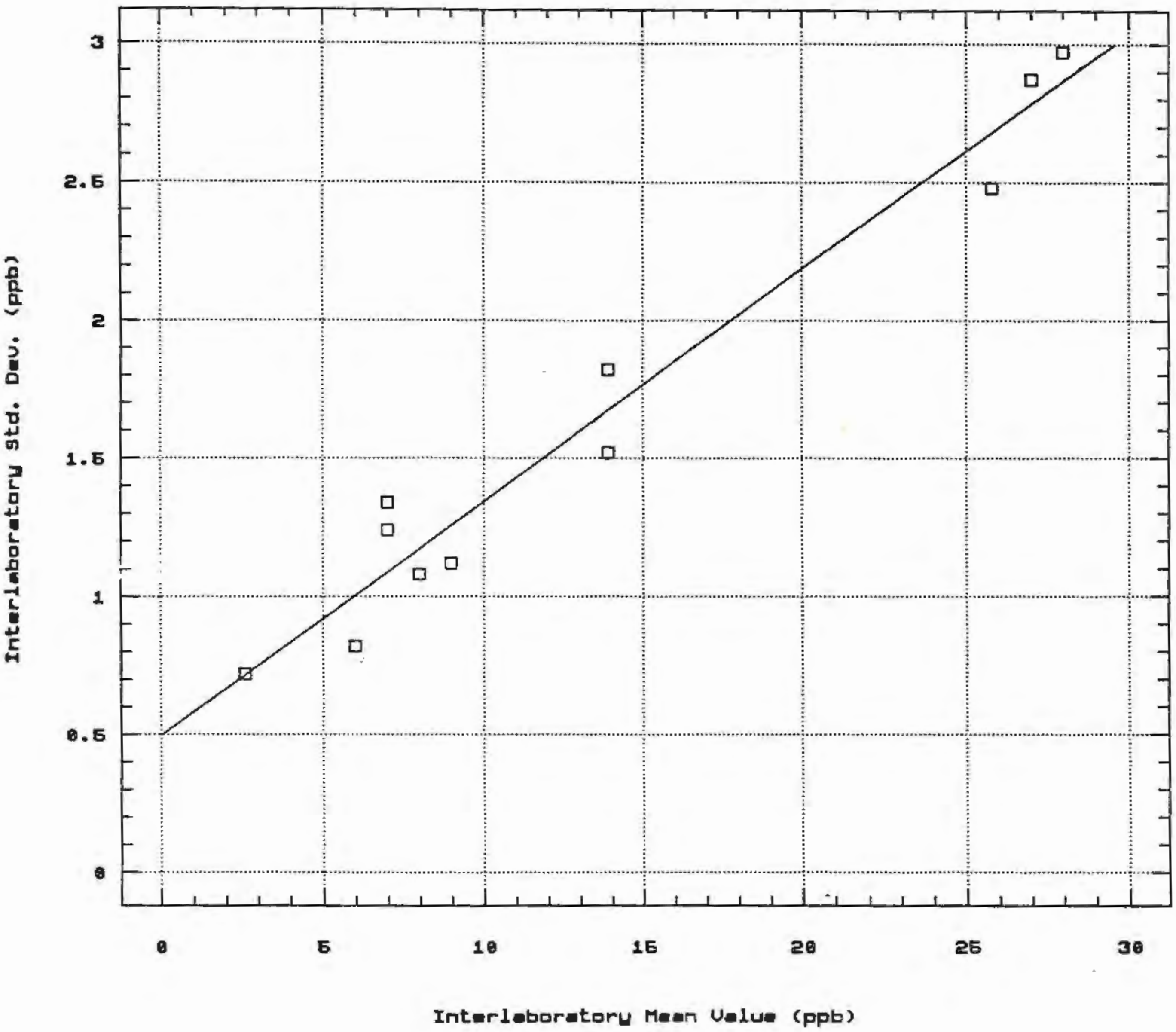
The above equations were derived from the same series of NWRI interlaboratory studies. (20 samples and about 30 different laboratories). Three files of data were selected in developing a criteria. These selections were:

ALL DATA: For this function all data were used, including outliers.

SOME DATA: To create this function, 10% of the high values and 10% of the low values were arbitrarily rejected. These functions were very smooth and highly correlated.

PREFERRED DATA: For this file, all data that were flagged as extremely high or low by the NWRI flagging formula were rejected. Refer to the figures on the next 6 pages.

Copper In Water



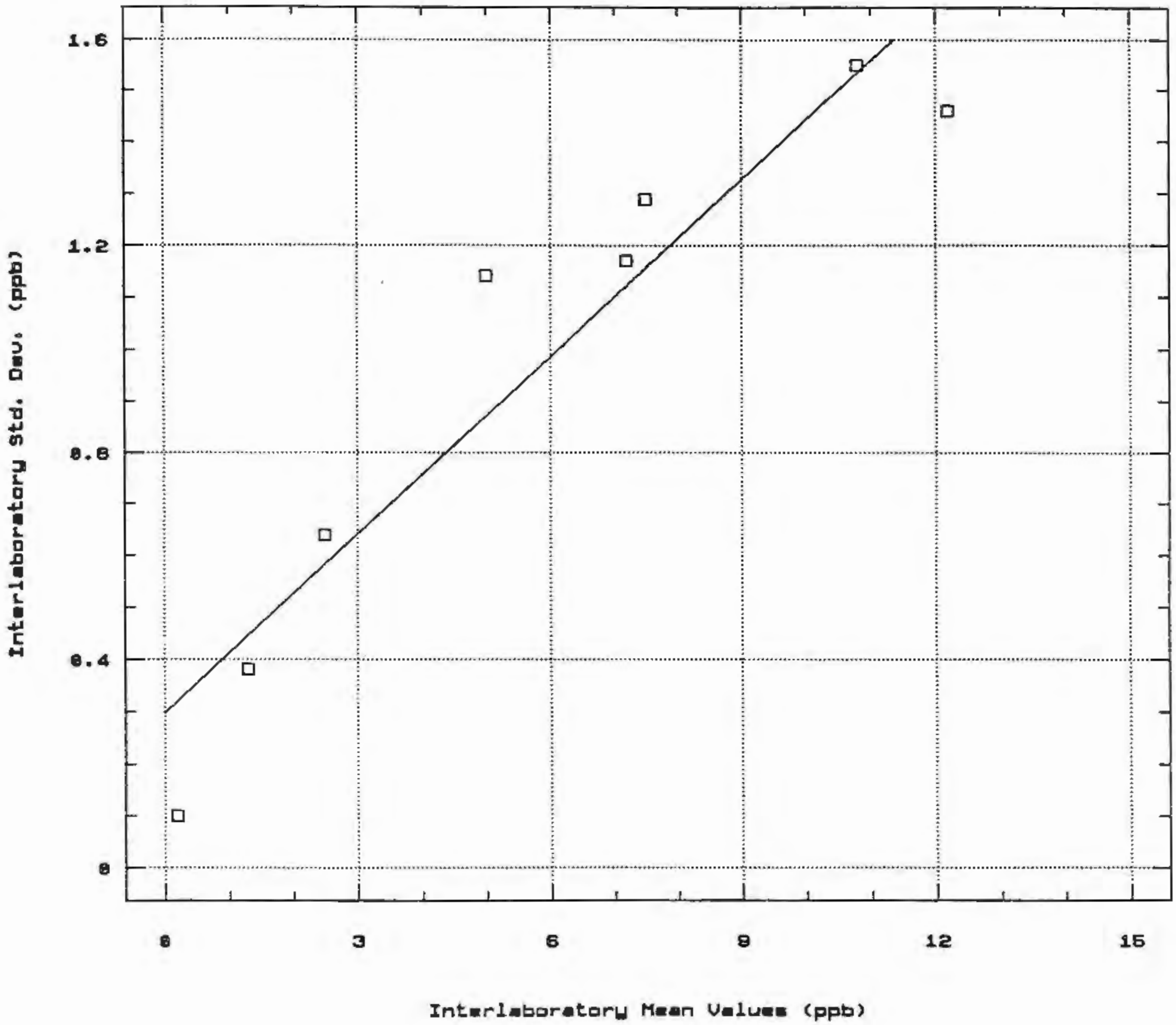
```
: 0.4927   SE: 0.092032  T:  5.3535

: 0.084753 SE: 5.7168E-3 T: 14.825

RR: 0.98013  MSE: 0.027816  DF: 9

INTS DELETED:
```

Cadmium In Water



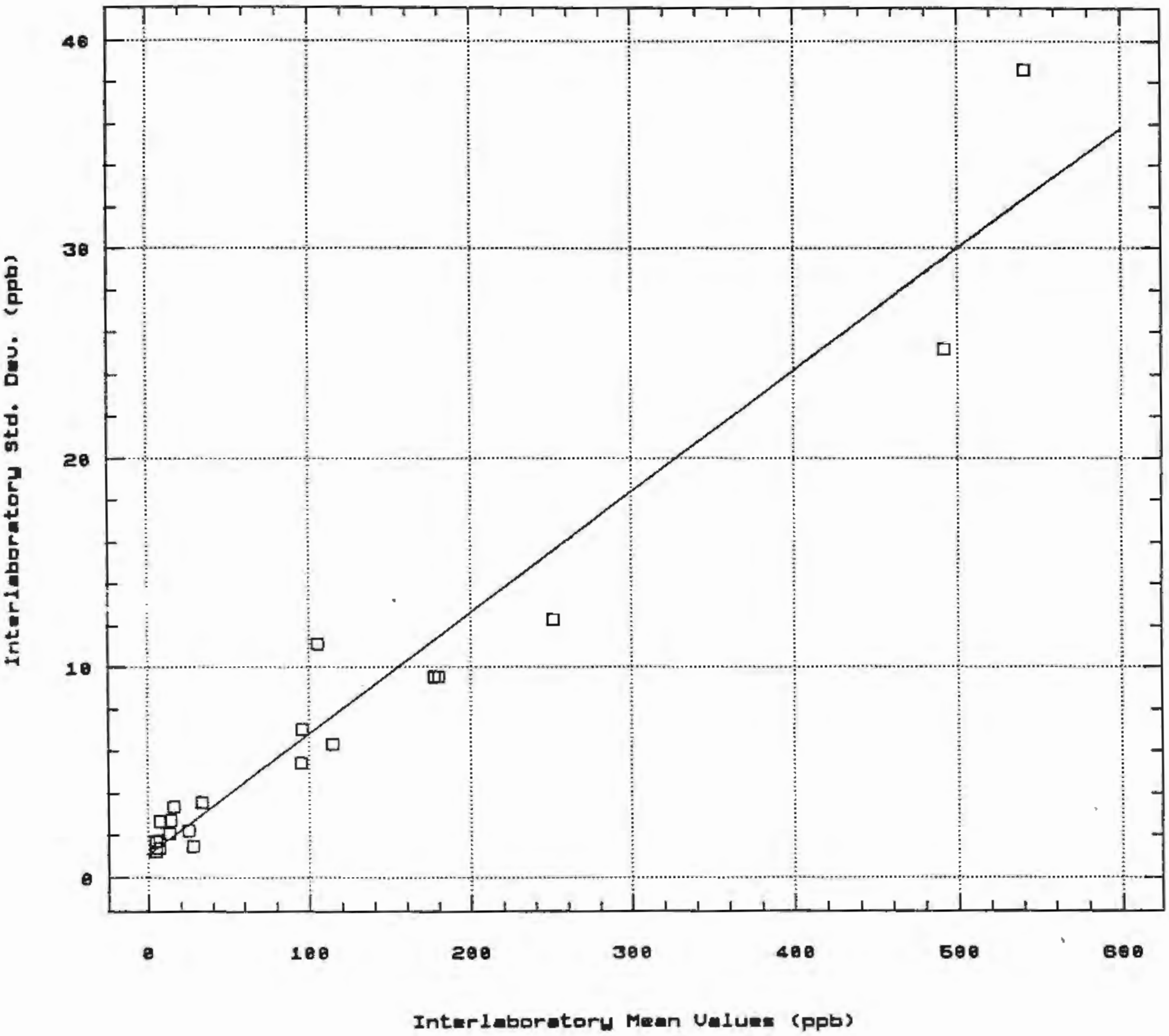
B0: 0.29763 SE: 0.1137 T: 2.6177

B1: 0.11454 SE: 0.01595 T: 7.1812

CORR: 0.94646 MSE: 0.034073 DF: 6

POINTS DELETED:

Zinc In Water



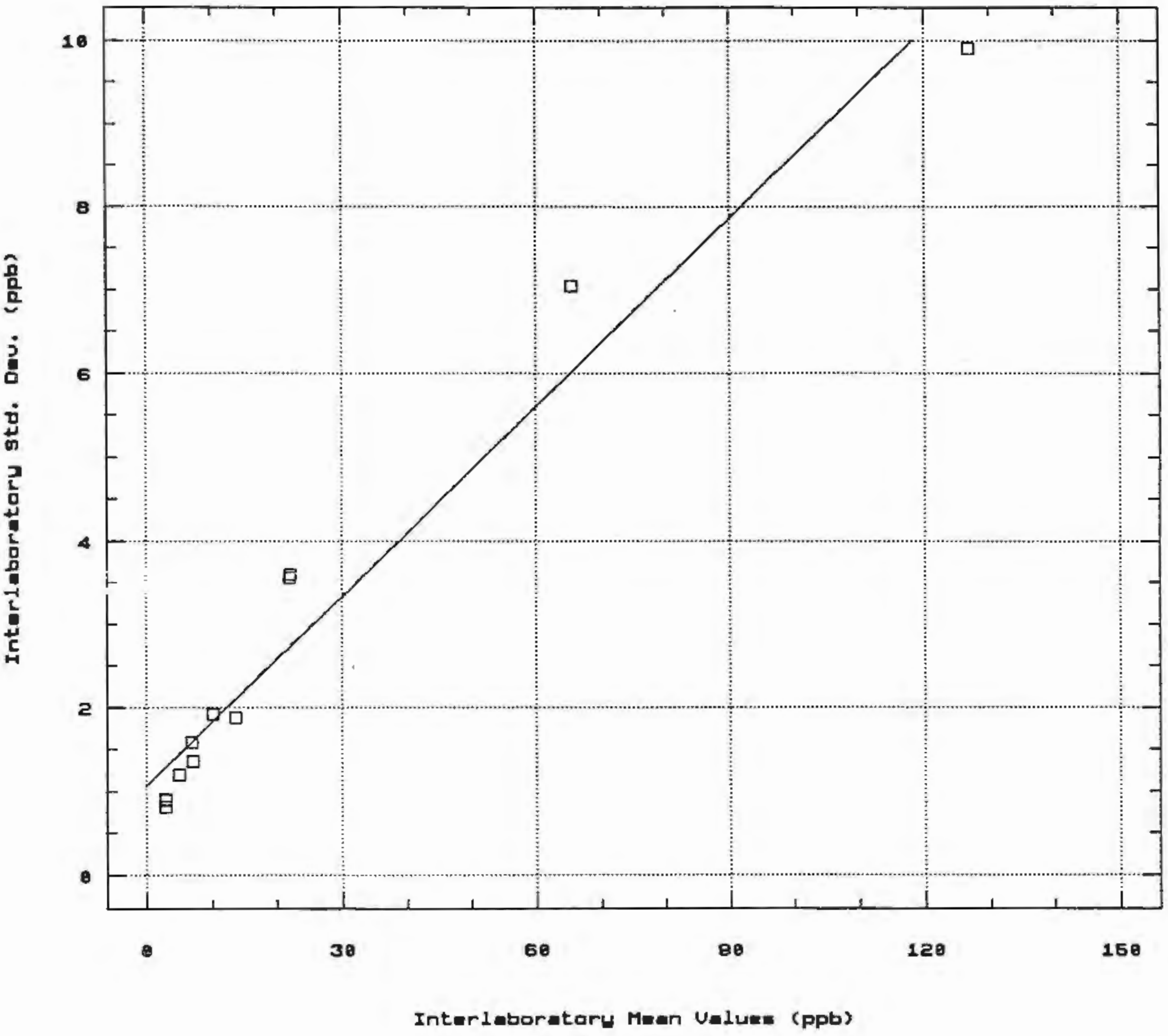
```
3: 1.0398   SE: 0.65058   T:  1.5983

1: 0.057837 SE: 3.4573E-3 T: 16.729

RR: 0.96931  MSE: 5.6344  DF: 18

INTS DELETED:
```

Lead In Water



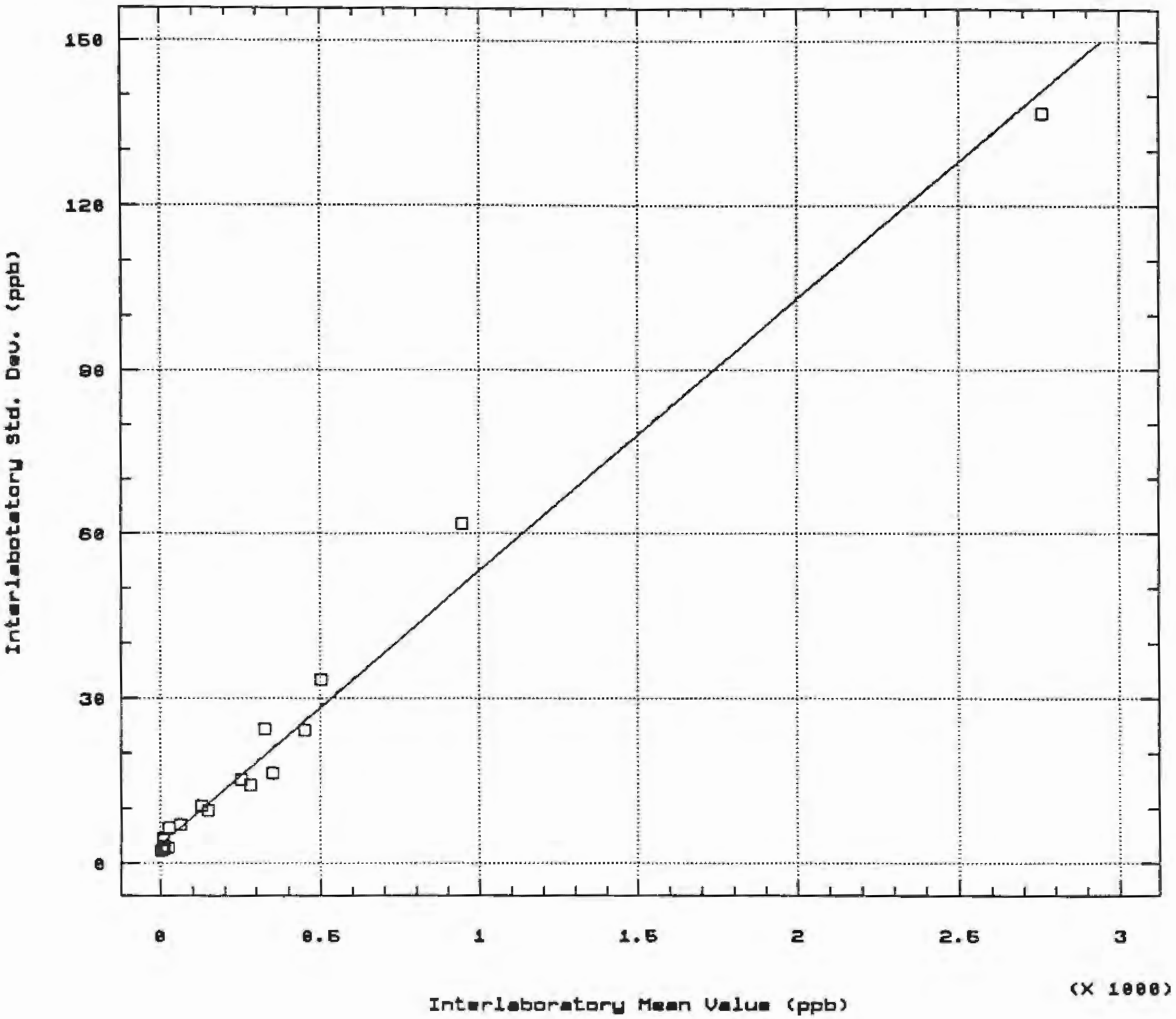
```
B0: 1.0667   SE: 0.21448   T:  4.9733

B1: 0.076454 SE: 5.0265E-3 T: 15.011

CORR: 0.97862  MSE: 0.37611  DF: 10

POINTS DELETED:
```

Iron In Water



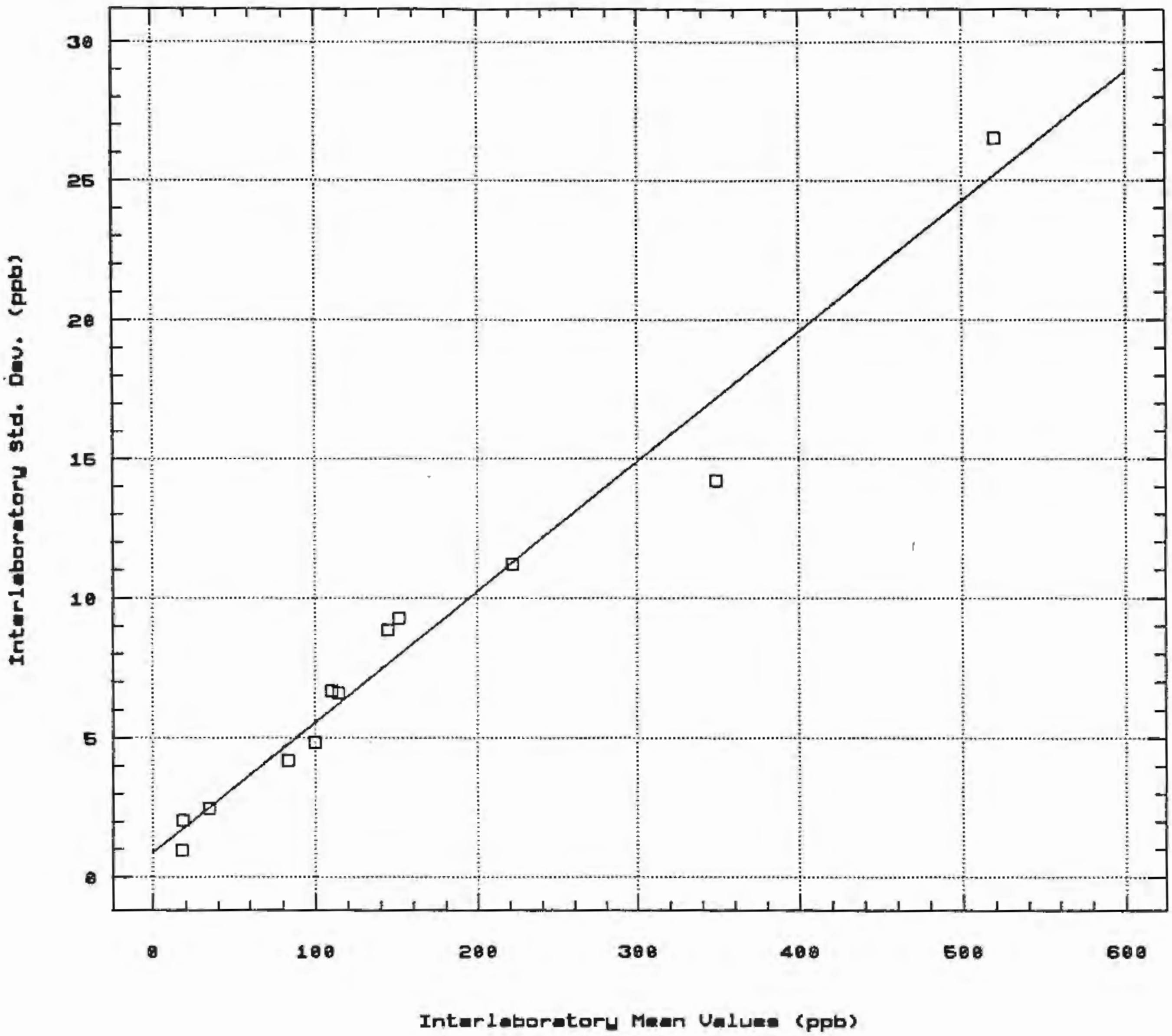
```
0: 3.3377    SE: 0.91083  T:  3.6644

1: 0.049795 SE: 1.329E-3 T: 37.468

ORR: 0.99365   MSE: 13.049  DF: 18

OINTS DELETED:
```

Manganese In Water



```
: 0.86705   SE: 0.54038    T:   1.6045

: 0.046733 SE: 2.5726E-3 T: 18.166

RR: 0.98518  MSE: 1.5811  DF: 10

INTS DELETED:
```

APPENDIX C: Calculations to Determine Non Comparable Data.

Determination of Non comparable data:

To identify if the pairs of data were comparable, the authors identified the confidence intervals for the difference between the results.

The precision functions (y = mx + b) for each metal were solved, first for x_1 (the ASL result) and then for x_2, the UBC result.

These y_{x1} and the y_{x2} values were then inserted into the following formula and the confidence intervals for each metal was estimated.

$$\text{Confidence interval} = 5 \times \sqrt{y^2_{x1} + y^2_{x2}}$$

When the difference between pairs of results differed by more than five standard deviations the pair of data were considered as unacceptable and the pair were flagged as not comparable. Where the difference exceeded three standard deviations, the symbol * appears on the righthand column.

The details for all calculations are found on the following pages of this appendix.

A summary of the flagged data (i.e., non comparable data) is found in the text as Table 7.

Copper - Water Column - Winter Survey

Precision equation: $y = Ax + B$

A	B
0.0848	0.493

ID	ASL Result (x_1)	UBC Result (x_2)	ASL y_1	UBC y_2	5xSTD	$\vert(x_1-x_2)\vert$/ 5xSTD	DECISION
1	1.5	3.5	0.620	0.790	5.021	0.398	accept
2	28.0	24.5	2.867	2.571	19.255	0.182	accept
3	6.2	6.3	1.019	1.027	7.234	0.014	accept
4	6.5	7.4	1.044	1.121	7.658	0.118	accept
5	15.0	18.4	1.765	2.053	13.538	0.251	accept

N/A = not applicable

Cadmium - Water Column - Winter Survey

Precision equation: $y = Ax + B$

A	B
0.1145	0.298

ID	ASL Result (x_1)	UBC Result (x_2)	ASL y_1	UBC y_2	5xSTD	$\vert(x_1-x_2)\vert$/ 5xSTD	DECISION
1	<0.2	0.02	- -	- -	- -	- -	N/A
2	0.4	0.53	0.344	0.359	2.484	0.052	accept
3	<0.2	0.14	- -	- -	- -	- -	N/A
4	<0.2	0.13	- -	- -	- -	- -	N/A
5	0.3	0.46	0.332	0.351	2.416	0.066	accept

N/A = not applicable

Zinc - Water Column - Winter Survey

Precision equation: $y = Ax + B$

A	B
0.0578	1.040

ID	ASL Result (x_1)	UBC Result (x_2)	ASL y_1	UBC y_2	5xSTD	$\vert(x_1-x_2)\vert$/ 5xSTD	DECISION
1	28	29.4	2.658	2.739	19.086	0.073	accept
2	384	378	23.235	22.888	163.076	0.037	accept
3	43	64.5	3.525	4.768	29.649	0.725	accept *
4	125	129	8.265	8.496	59.265	0.067	accept
5	391	79.9	23.640	5.658	121.538	2.560	**flagged**

N/A = not applicable

Lead - Water Column - Winter Survey

Precision equation: $y = Ax + B$

A	B
0.0755	1.067

ID	ASL Result (x_1)	UBC Result (x_2)	ASL y_1	UBC y_2	5xSTD	$\|(x_1-x_2)\|$/ 5xSTD	DECISION
1	2.5	3.2	1.256	1.309	9.068	0.077	accept
2	30.5	36	3.370	3.785	25.338	0.217	accept
3	7.1	15	1.603	2.200	13.608	0.581	accept
4	3.60	6	1.339	1.520	10.128	0.237	accept
5	12.1	3.6	1.981	1.339	11.953	0.711	accept *

N/A = not applicable

Iron - Water Column - Winter Survey

Precision equation: $y = Ax + B$

A	B
0.0498	3.34

ID	ASL Result (x_1)	UBC Result (x_2)	ASL y_1	UBC y_2	5xSTD	$\|(x_1-x_2)\|$/ 5xSTD	DECISION
1	9790	8415	490.882	422.407	3238	0.425	accept
2	760	780	41.188	42.184	294.786	0.068	accept
3	70100	53490	3494	2667	21979	0.756	accept *
4	13500	12800	675.640	640.780	4656	0.150	accept
5	1470	1920	76.546	98.956	625.531	0.719	accept *

N/A = not applicable

Manganese - Water Column - Winter Survey

Precision equation: $y = Ax + B$

A	B
0.0467	0.867

ID	ASL Result (x_1)	UBC Result (x_2)	ASL y_1	UBC y_2	5xSTD	$\|(x_1-x_2)\|$/ 5xSTD	DECISION
1	559	587	26.972	28.280	195.401	0.143	accept
2	275	296	13.710	14.690	100.468	0.209	accept
3	796	840	38.040	40.095	276.345	0.159	accept
4	290	310	14.410	15.344	105.248	0.190	accept
5	267	247	13.336	12.402	91.057	0.220	accept

N/A = not applicable

Copper - Water Column - Summer Survey

Precision equation: $y = Ax + B$

A	B
0.0848	0.493

ID	ASL Result (x_1)	UBC Result (x_2)	ASL y_1	UBC y_2	5xSTD	$\lvert(x_1-x_2)\rvert/$ 5xSTD	DECISION
1	31.0	31.7	3.122	3.181	22.285	0.031	accept
2	30.0	33.4	3.037	3.325	22.517	0.151	accept
3	24.0	28.0	2.528	2.867	19.114	0.209	accept
4	23.0	28.3	2.443	2.893	18.933	0.280	accept
5	<0.5	0.0	- -	- -	- -	- -	N/A

N/A = not applicable

Cadmium - Water Column - Summer Survey

Precision equation: $y = Ax + B$

A	B
0.1145	0.298

ID	ASL Result (x_1)	UBC Result (x_2)	ASL y_1	UBC y_2	5xSTD	$\lvert(x_1-x_2)\rvert/$ 5xSTD	DECISION
1	0.4	0.56	0.344	0.362	2.497	0.064	accept
2	0.4	0.61	0.344	0.368	2.517	0.083	accept
3	0.3	0.55	0.332	0.361	2.453	0.102	accept
4	0.4	0.53	0.344	0.359	2.484	0.052	accept
5	<0.2	0	- -	- -	- -	- -	N/A

N/A = not applicable

Zinc - Water Column - Summer Survey

Precision equation: $y = Ax + B$

A	B
0.0578	1.040

ID	ASL Result (x_1)	UBC Result (x_2)	ASL y_1	UBC y_2	5xSTD	$\lvert(x_1-x_2)\rvert/$ 5xSTD	DECISION
1	432	402	26.010	24.276	177.891	0.169	accept
2	463	383	27.801	23.177	180.977	0.442	accept
3	368	345	22.310	20.981	153.130	0.150	accept
4	411	354	24.796	21.501	164.099	0.347	accept
5	<1	3.6	- -	- -	- -	- -	N/A

N/A = not applicable

Lead - Water Column - Summer Survey

Precision equation: $y = Ax + B$

A	B
0.0755	1.067

ID	ASL Result (x_1)	UBC Result (x_2)	ASL y_1	UBC y_2	5xSTD	$\lvert(x_1-x_2)\rvert/$ 5xSTD	DECISION
1	64.0	71	5.899	6.428	43.621	0.160	accept
2	61.0	66	5.673	6.050	41.467	0.121	accept
3	59.0	69	5.522	6.277	41.798	0.239	accept
4	60.0	68	5.597	6.201	41.767	0.192	accept
5	<0.5	0.1	- -	- -	- -	- -	N/A

N/A = not applicable

Iron - Water Column - Summer Survey

Precision equation: $y = Ax + B$

A	B
0.0498	3.34

ID	ASL Result (x_1)	UBC Result (x_2)	ASL y_1	UBC y_2	5xSTD	$\lvert(x_1-x_2)\rvert/$ 5xSTD	DECISION
1	906	810	48.459	43.678	326.191	0.294	accept
2	976	850	51.945	45.670	345.833	0.364	accept
3	1140	1220	60.112	64.096	439.367	0.182	accept
4	1280	1095	67.084	57.871	442.982	0.418	accept
5	<3	0	- -	- -	- -	- -	N/A

N/A = not applicable

Manganese - Water Column - Summer Survey

Precision equation: $y = Ax + B$

A	B
0.0467	0.867

ID	ASL Result (x_1)	UBC Result (x_2)	ASL y_1	UBC y_2	5xSTD	$\lvert(x_1-x_2)\rvert/$ 5xSTD	DECISION
1	286	303	14.223	15.017	103.418	0.164	accept
2	312	315	15.437	15.578	109.655	0.027	accept
3	243	255	12.215	12.776	88.377	0.136	accept
4	269	280	13.429	13.943	96.793	0.114	accept
5	<1	0.2	- -	- -	- -	- -	N/A

N/A = not applicable

Copper - Pore Water - Winter Survey

Precision equation: $y = Ax + B$

A	B
0.0848	0.493

ID	ASL Result (x_1)	UBC Result (x_2)	ASL y_1	UBC y_2	5xSTD	$\lvert(x_1-x_2)\rvert/$ 5xSTD	DECISION
1	4	0.645	0.832	0.548	4.981	0.674	accept *
2	<1	0	- -	- -	- -	- -	N/A
3	<1	0	- -	- -	- -	- -	N/A
4	2	0.06	0.663	0.498	4.145	0.468	accept
5	7	11.4	1.087	1.460	9.099	0.484	accept
6	<1	0	- -	- -	- -	- -	N/A
7	<1	0	- -	- -	- -	- -	N/A
8	8	8.85	1.171	1.243	8.542	0.100	accept
9	<1	0.34	- -	- -	- -	- -	N/A
10	<1	0.29	- -	- -	- -	- -	N/A

N/A = not applicable

Cadmium - Pore Water - Winter Survey

Precision equation: $y = Ax + B$

A	B
0.1145	0.298

ID	ASL Result (x_1)	UBC Result (x_2)	ASL y_1	UBC y_2	5xSTD	$\lvert(x_1-x_2)\rvert/$ 5xSTD	DECISION
1	0.2	0.192	0.321	0.320	2.266	0.004	accept
2	0.2	0.138	0.321	0.314	2.244	0.028	accept
3	<0.2	0.004	- -	- -	- -	- -	N/A
4	<0.2	0.002	- -	- -	- -	- -	N/A
5	0.4	0.49	0.344	0.354	2.468	0.036	accept
6	<0.2		- -	- -	- -	- -	N/A
7	<0.2		- -	- -	- -	- -	N/A
8	0.3	0.378	0.332	0.341	2.382	0.033	accept
9	<0.2		- -	- -	- -	- -	N/A
10	<0.2		- -	- -	- -	- -	N/A

N/A = not applicable

Zinc - Pore Water - Winter Survey

Precision equation: $y = Ax + B$

A	B
0.0578	1.040

ID	ASL Result (x_1)	UBC Result (x_2)	ASL y_1	UBC y_2	5xSTD	$\lvert(x_1-x_2)\rvert$ / 5xSTD	DECISION
1	170	155.5	10.866	10.028	73.930	0.196	accept
2	155	154.5	9.999	9.970	70.602	0.007	accept
3	<1	1.5	- -	- -	- -	- -	N/A
4	<1	1.75	- -	- -	- -	- -	N/A
5	220	313	13.756	19.131	117.817	0.789	accept *
6	<1	0.27	- -	- -	- -	- -	N/A
7	<1	0.505	- -	- -	- -	- -	N/A
8	220	297	13.756	18.207	114.095	0.675	accept *
9	<1		- -	- -	- -	- -	N/A
10	2	0.48	1.156	1.068	7.867	0.193	accept

N/A = not applicable

Lead - Pore Water - Winter Survey

Precision equation: $y = Ax + B$

A	B
0.0755	1.067

ID	ASL Result (x_1)	UBC Result (x_2)	ASL y_1	UBC y_2	5xSTD	$\lvert(x_1-x_2)\rvert$ / 5xSTD	DECISION
1	<0.5	0.18	- -	- -	- -	- -	N/A
2	0.5	0.018	1.105	1.068	7.684	0.063	accept
3	<1	0.06	- -	- -	- -	- -	N/A
4	<1	0	- -	- -	- -	- -	N/A
5	10.0	0.99	1.822	1.142	10.751	0.838	accept *
6	<0.5	0.24	- -	- -	- -	- -	N/A
7	<1	0.13	- -	- -	- -	- -	N/A
8	15.5	15.3	2.237	2.222	15.766	0.013	accept
9	<0.5	0.08	- -	- -	- -	- -	N/A
10	<0.5	0.05	- -	- -	- -	- -	N/A

N/A = not applicable

Iron - Pore Water - Winter Survey

Precision equation: $y = Ax + B$

A	B
0.0498	3.34

ID	ASL Result (x_1)	UBC Result (x_2)	ASL y_1	UBC y_2	5xSTD	$\lvert(x_1-x_2)\rvert$/ 5xSTD	DECISION
1	5100	11605	257.320	581.269	3178	2.047	**flagged**
2	5100	11430	257.320	572.554	3139	2.017	**flagged**
3	46	46	5.631	5.631	39.816	0.000	accept
4	<3	1.27	- -	- -	- -	- -	N/A
5	760	907	41.188	48.509	318.180	0.462	accept
6	19.5	13.7	4.311	4.022	29.481	0.197	accept *
7	490	749	27.742	40.640	246.031	1.053	**flagged**
8	1150	1654	60.610	85.709	524.872	0.960	accept
9	18	15.1	4.236	4.092	29.450	0.098	accept
10	185	180	12.553	12.304	87.887	0.057	accept

N/A = not applicable

Manganese - Pore Water - Winter Survey

Precision equation: $y = Ax + B$

A	B
0.0467	0.867

ID	ASL Result (x_1)	UBC Result (x_2)	ASL y_1	UBC y_2	5xSTD	$\lvert(x_1-x_2)\rvert$/ 5xSTD	DECISION
1	200	289	10.207	14.363	88.103	1.010	**flagged**
2	190	278	9.740	13.850	84.658	1.039	**flagged**
3	130	126	6.938	6.751	48.403	0.083	accept
4	125	137	6.705	7.265	49.429	0.243	accept
5	190	244	9.740	12.262	78.297	0.690	accept *
6	270	301	13.476	14.924	100.538	0.308	accept
7	490	453	23.750	22.022	161.944	0.228	accept
8	195	246	9.974	12.355	79.392	0.642	accept *
9	410	365	20.014	17.913	134.296	0.335	accept
10	565	486	27.253	23.563	180.134	0.439	accept

N/A = not applicable

Copper - Pore Water - Summer Survey

Precision equation: $y = Ax + B$

A	B
0.0848	0.493

ID	ASL Result (x_1)	UBC Result (x_2)	ASL y_1	UBC y_2	5xSTD	$\lvert(x_1-x_2)\rvert$/ 5xSTD	DECISION
1	28	27.5	2.867	2.825	20.126	0.025	accept
2	<1	0.77	- -	- -	- -	- -	N/A
3	18	19	2.019	2.104	14.582	0.069	accept
4	<1	0.02	- -	- -	- -	- -	N/A
5	48	43.8	4.563	4.207	31.034	0.135	accept
6	<1	1.9	- -	- -	- -	- -	N/A
7	<1	1.6	- -	- -	- -	- -	N/A
8	32	40	3.207	3.885	25.187	0.318	accept
9	26.0	33.1	2.698	3.300	21.312	0.333	accept
10	2	1.7	0.663	0.637	4.596	0.065	accept
11	<1	2.2	- -	- -	- -	- -	N/A
12	32	44	3.207	4.224	26.517	0.453	accept
13	27	38	2.783	3.715	23.209	0.474	accept
14	66	6.7	6.090	1.061	30.908	1.919	**flagged**
15	26	33	2.698	3.291	21.279	0.329	accept
16	<1	1.3	- -	- -	- -	- -	N/A
17	32	34	3.207	3.376	23.281	0.086	accept
18	27	30	2.783	3.037	20.595	0.146	accept
19	<1	1.2	- -	- -	- -	- -	N/A
20	34	24	3.376	2.528	21.089	0.474	accept
21	27	24	2.783	2.528	18.798	0.160	accept
22	37	28	3.631	2.867	23.132	0.389	accept
23	<1	0.6	- -	- -	- -	- -	N/A
24	38.5	24	3.758	2.528	22.646	0.640	accept *
25	40	27	3.885	2.783	23.894	0.544	accept
26	9	3.1	1.256	0.756	7.330	0.805	accept *
27	33	27	3.291	2.783	21.550	0.278	accept
28	1	1.25	0.578	0.599	4.161	0.060	accept
29	40	32.5	3.885	3.249	25.323	0.296	accept
30	1	1	0.578	0.578	4.086	0.000	accept

N/A = not applicable

Cadmium - Pore Water - Summer Survey

Precision equation: $y = Ax + B$

A	B
0.1145	0.298

ID	ASL Result (x_1)	UBC Result (x_2)	ASL y_1	UBC y_2	5xSTD	$\lvert(x_1-x_2)\rvert/$ 5xSTD	DECISION
1	0.32	0.81	0.335	0.391	2.572	0.190	accept
2	<0.2	0.06	- -	- -	- -	- -	N/A
3	<0.2	0.61	- -	- -	- -	- -	N/A
4	<0.2	0	- -	- -	- -	- -	N/A
5	1.9	0.69	0.516	0.377	3.193	0.379	accept
6	<0.2	0.04	- -	- -	- -	- -	N/A
7	<0.2	0.03	- -	- -	- -	- -	N/A
8	0.3	0.78	0.332	0.387	2.552	0.188	accept
9	0.3	0.79	0.332	0.388	2.556	0.192	accept
10	<0.2	0.05	- -	- -	- -	- -	N/A
11	<0.2	0.05	- -	- -	- -	- -	N/A
12	0.3	0.65	0.332	0.372	2.496	0.140	accept
13	0.4	0.63	0.344	0.370	2.526	0.091	accept
14	<0.2	0.03	- -	- -	- -	- -	N/A
15	0.4	0.63	0.344	0.370	2.526	0.091	accept
16	<0.2	0.055	- -	- -	- -	- -	N/A
17	0.6	0.63	0.367	0.370	2.605	0.012	accept
18	0.6	0.58	0.367	0.364	2.585	0.008	accept
19	<0.2	0.05	- -	- -	- -	- -	N/A
20	0.4	0.43	0.344	0.347	2.443	0.012	accept
21	0.6	0.63	0.367	0.370	2.605	0.012	accept
22	0.5	0.46	0.355	0.351	2.496	0.016	accept
23	<0.2	0.05	- -	- -	- -	- -	N/A
24	0.4	0.63	0.344	0.370	2.526	0.091	accept
25	0.5	0.49	0.355	0.354	2.508	0.004	accept
26	<0.2	0.03	- -	- -	- -	- -	N/A
27	0.4	0.55	0.344	0.361	2.492	0.060	accept
28	<0.2	0.08	- -	- -	- -	- -	N/A
29	0.4	0.535	0.344	0.359	2.486	0.054	accept
30	<0.2	0.02	- -	- -	- -	- -	N/A

N/A = not applicable

Zinc - Pore Water - Summer Survey

Precision equation: $y = Ax + B$

A	B
0.0578	1.040

ID	ASL Result (x_1)	UBC Result (x_2)	ASL y_1	UBC y_2	5xSTD	$\|(x_1-x_2)\|/$ 5xSTD	DECISION
1	290	385	17.802	23.293	146.584	0.648	accept *
2	1	1.6	1.098	1.132	7.886	0.076	accept
3	380	324	23.004	19.767	151.651	0.369	accept
4		0.1	- -	- -	- -	- -	N/A
5	810	470	47.858	28.206	277.757	1.224	**flagged**
6	280	8	17.224	1.502	86.447	3.146	**flagged**
7	10	10.3	1.618	1.635	11.502	0.026	accept
8	370	453	22.426	27.223	176.355	0.471	accept
9	350	465	21.270	27.917	175.483	0.655	accept *
10	1060	8.0	62.308	1.502	311.631	3.376	**flagged**
11	450	12	27.050	1.734	135.527	3.232	**flagged**
12	470	461	28.206	27.686	197.616	0.046	accept
13	320	469	19.536	28.148	171.317	0.870	accept
14	230	18	14.334	2.080	72.421	2.927	**flagged**
15	360	410	21.848	24.738	165.023	0.303	accept
16	61	61	4.566	4.566	32.285	0.000	accept
17	400	406	24.160	24.507	172.067	0.035	accept
18	330	373	20.114	22.599	151.270	0.284	accept
19	71	61	5.144	4.566	34.389	0.291	accept
20	280	329	17.224	20.056	132.185	0.371	accept
21	350	304	21.270	18.611	141.314	0.326	accept
22	370	263	22.426	16.241	138.448	0.773	accept *
23	40	5	3.352	1.329	18.029	1.941	**flagged**
24	435	368	26.183	22.310	171.996	0.390	accept
25	390	407	23.582	24.565	170.259	0.100	accept
26	90	19	6.242	2.138	32.990	2.152	**flagged**
27	370	380	22.426	23.004	160.632	0.062	accept
28	51.0	42.5	3.988	3.497	26.518	0.321	accept
29	360	389	21.848	23.524	160.524	0.181	accept
30	24	17	2.427	2.023	15.797	0.443	accept *

N/A = not applicable

Lead - Pore Water - Summer Survey

Precision equation: $y = Ax + B$

A	B
0.0755	1.067

ID	ASL Result (x_1)	UBC Result (x_2)	ASL y_1	UBC y_2	5xSTD	$\lvert(x_1-x_2)\rvert/$ 5xSTD	DECISION
1	47.9	55	4.683	5.220	35.063	0.202	accept
2	<0.5	0	– –	– –	– –	– –	N/A
3	43.4	48	4.344	4.691	31.966	0.144	accept
4		0	– –	– –	– –	– –	N/A
5	69.0	65	6.277	5.975	43.327	0.092	accept
6	1.2	2	1.158	1.218	8.402	0.095	accept
7	<0.5	1	– –	– –	– –	– –	N/A
8	73.0	72	6.579	6.503	46.251	0.022	accept
9	50.9	62	4.910	5.748	37.798	0.294	accept
10	<1.0	0	– –	– –	– –	– –	N/A
11	<0.5	0	– –	– –	– –	– –	N/A
12	82.0	87	7.258	7.636	52.673	0.095	accept
13	79	66.5	7.032	6.088	46.503	0.269	accept
14	<0.5	1	– –	– –	– –	– –	N/A
15	46.5	56	4.578	5.295	34.997	0.271	accept
16	1.1	1	1.150	1.143	8.105	0.012	accept
17	45.4	53	4.495	5.069	33.872	0.224	accept
18	38.0	47	3.936	4.616	30.329	0.297	accept
19	0.6	1	1.112	1.143	7.973	0.050	accept
20	37.1	46	3.868	4.540	29.822	0.298	accept
21	31.4	34	3.438	3.634	25.012	0.104	accept
22	41.9	54	4.230	5.144	33.301	0.363	accept
23	0.5	0	1.105	1.067	7.679	0.065	accept
24	51.9	58	4.985	5.446	36.917	0.165	accept
25	47.0	60	4.616	5.597	36.273	0.358	accept
26	0.8	1	1.127	1.143	8.025	0.025	accept
27	46.9	53	4.608	5.069	34.250	0.178	accept
28	0.8	1	1.127	1.143	8.025	0.025	accept
29	49.4	59.5	4.797	5.559	36.713	0.275	accept
30	0.8	1	1.127	1.143	8.025	0.025	accept

N/A = not applicable

Iron - Pore Water - Summer Survey

Precision equation: $y = Ax + B$

A	B
0.0498	3.34

ID	ASL Result (x_1)	UBC Result (x_2)	ASL y_1	UBC y_2	5xSTD	$\|(x_1-x_2)\|/$ 5xSTD	DECISION
1	140	91	10.312	7.872	64.866	0.755	accept *
2	220	92	14.296	7.922	81.720	1.566	**flagged**
3	200	129	13.300	9.764	82.497	0.861	accept *
4		0	- -	- -	- -	- -	N/A
5	330	310	19.774	18.778	136.347	0.147	accept
6	170	612	11.806	33.818	179.096	2.468	**flagged**
7	25000	7187	1248	361.253	6498	2.741	**flagged**
8	400	220	23.260	14.296	136.510	1.319	**flagged**
9	380	220	22.264	14.296	132.293	1.209	**flagged**
10	1200	14900	63.100	745.360	3740	3.663	**flagged**
11	12500	12500	625.840	625.840	4425	0.000	accept
12	470	325	26.746	19.525	165.573	0.876	accept *
13	900	437	48.160	25.103	271.548	1.705	**flagged**
14	10000	5385	501.340	271.513	2851	1.619	**flagged**
15	160	102	11.308	8.420	70.491	0.823	accept *
16	15800	14320	790.180	716.476	5333	0.278	accept *
17	150	85	10.810	7.573	65.994	0.985	accept *
18	180	130	12.304	9.814	78.693	0.635	accept *
19	19250	12200	961.990	610.900	5698	1.237	**flagged**
20	140	92	10.312	7.922	65.017	0.738	accept *
21	260	160	16.288	11.308	99.143	1.009	**flagged**
22	190	85	12.802	7.573	74.371	1.412	**flagged**
23	260	166	16.288	11.607	100.002	0.940	accept *
24	250	169	15.790	11.756	98	0.823	accept *
25	440	278	25.252	17.184	152.723	1.061	**flagged**
26	130000	102700	6477	5118	41276	0.661	accept *
27	180	142	12.304	10.412	80.590	0.472	accept
28	65000	48900	3240	2439	20277	0.794	accept *
29	150	110	10.810	8.818	69.752	0.573	accept
30	70000	55200	3489	2752	22221	0.666	accept *

N/A = not applicable

Manganese - Pore Water - Summer Survey

Precision equation: $y = Ax + B$

A	B
0.0467	0.867

ID	ASL Result (x_1)	UBC Result (x_2)	ASL y_1	UBC y_2	5xSTD	$\lvert(x_1-x_2)\rvert/$ 5xSTD	DECISION
1	400	277	19.547	13.803	119.646	1.028	**flagged**
2	345	224	16.979	11.328	102.053	1.186	**flagged**
3	300	230	14.877	11.608	94.349	0.742	accept *
4		0	- -	- -	- -	- -	N/A
5	165	235	8.573	11.842	73.094	0.958	accept *
6	170	612	8.806	29.447	153.679	2.876	**flagged**
7	225	631	11.375	30.335	161.986	2.506	**flagged**
8	325	261	16.045	13.056	103.426	0.619	accept *
9	275	270	13.710	13.476	96.119	0.052	accept
10	2050	726	96.602	34.771	513.346	2.579	**flagged**
11	325	755	16.045	36.126	197.641	2.176	**flagged**
12	310	269	15.344	13.429	101.954	0.402	accept
13	290	299	14.410	14.830	103.391	0.087	accept
14	475	481	23.050	23.330	163.978	0.037	accept
15	300	286	14.877	14.223	102.911	0.136	accept
16	400	365	19.547	17.913	132.565	0.264	accept
17	325	292	16.045	14.503	108.140	0.305	accept
18	275	255	13.710	12.776	93.697	0.213	accept
19	300	325	14.877	16.045	109.402	0.229	accept
20	325	266	16.045	13.289	104.167	0.566	accept
21	375	288	18.380	14.317	116.487	0.747	accept *
22	375	252	18.380	12.635	111.519	1.103	**flagged**
23	425	340	20.715	16.745	133.181	0.638	accept *
24	362	275	17.772	13.710	112.228	0.775	accept *
25	350	287	17.212	14.270	111.790	0.564	accept
26	950	744	45.232	35.612	287.843	0.716	accept *
27	375	312	18.380	15.437	120.012	0.525	accept
28	825	684	39.395	32.810	256.340	0.550	accept
29	350	269	17.212	13.429	109.156	0.742	accept *
30	1330	1124	62.978	53.358	412.713	0.499	accept

N/A = not applicable

Appendix B-1
Water Column Data-Anderson Lake Winter Survey

ANDERSON LAKE WINTER SURVEY

RESULTS OF ANALYSIS **File No. 9938C**

		Stn.A-1[1]	Stn.A-2	Stn.A-3	Stn.A-4	Stn.A-5
Physical Tests						
Conductivity	umhos/cm	-	1710	1750	1750	1780
Hardness	CaCO3	-	912	892	903	881
pH		-	7.40	6.90	6.80	6.95
Dissolved Anions						
Alkalinity - Total	CaCO3	-	35.4	36.2	34.9	31.8
Chloride	Cl	-	74.4	52.2	51.0	70.7
Sulphate	SO4	-	813	833	871	863
Nutrients						
Ammonia Nitrogen	N	-	4.50	3.00	3.00	2.80
Nitrate Nitrogen	N	-	<0.005	0.010	<0.005	<0.005
Total Phosphorus	P	-	0.040	0.037	0.034	0.036
Organic Parameters						
Dissolved Organic Carbon	C	-	4.99	4.63	4.46	4.18
Total Organic Carbon	C	-	5.04	4.81	4.64	4.33
Total Metals						
Arsenic	T-As	0.0019	0.0015	0.0013	0.0014	0.0018
Cadmium	T-Cd	<0.0002	<0.0002	<0.0002	0.0002	<0.0002
Calcium	T-Ca	331	328	326	336	335
Copper	T-Cu	0.0032	0.0030	0.0010	0.0032	0.0030
Iron	T-Fe	3.76	3.67	3.60	2.08	2.11
Lead	T-Pb	0.0030	0.0020	0.0013	0.0031	0.0033
Magnesium	T-Mg	23.1	22.8	22.6	22.6	22.5
Manganese	T-Mn	0.500	0.489	0.483	0.427	0.424
Mercury	T-Hg	0.00003	0.00002	0.00001	0.00001	<0.00001
Potassium	T-K	15.0	14.7	14.3	15.2	15.1
Sodium	T-Na	46.6	46.1	45.5	46.3	46.1
Zinc	T-Zn	0.014	0.008	0.008	0.114	0.117
Dissolved Metals						
Arsenic	D-As	0.0009	0.0009	0.0010	0.0014	0.0015
Cadmium	D-Cd	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Calcium	D-Ca	331	328	320	325	317
Copper	D-Cu	<0.0005	0.0025	0.0005	0.0010	0.0010
Iron	D-Fe	3.42	3.39	3.31	1.51	1.47
Lead	D-Pb	0.0029	0.0020	<0.0005	<0.0005	0.0005
Magnesium	D-Mg	22.4	22.8	22.3	21.9	21.5
Manganese	D-Mn	0.500	0.489	0.481	0.418	0.406
Mercury	D-Hg	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Potassium	D-K	15.0	14.4	14.0	14.5	14.3
Sodium	D-Na	45.6	46.0	44.8	44.8	43.5
Zinc	D-Zn	0.003	0.007	0.007	0.108	0.115

Results are expressed as milligrams per litre except where noted.
< = Less than the detection limit indicated.
Dup. = Duplicate.

[1] For the sample "Stn.A-1", both glass bottles broke while thawing.

RESULTS OF ANALYSIS

File No. 9938C

		Stn.A-5 Dup.	Stn.A-6	Stn.A-7	Stn.A-8	Stn.A-9
Physical Tests						
Conductivity	umhos/cm	1800	1670	1670	1930	1860
Hardness	CaCO3	946	848	880	972	963
pH		7.45	7.37	7.70	6.73	5.90
Dissolved Anions						
Alkalinity - Total	CaCO3	31.9	46.2	48.0	28.6	11.2
Chloride	Cl	69.5	74.6	53.2	73.1	75.0
Sulphate	SO4	795	832	794	785	938
Nutrients						
Ammonia Nitrogen	N	2.80	3.40	3.40	1.30	2.10
Nitrate Nitrogen	N	<0.005	<0.005	0.012	0.050	0.030
Total Phosphorus	P	0.038	0.070	0.081	0.682	0.034
Organic Parameters						
Dissolved Organic Carbon	C	4.33	5.52	5.39	10.1	3.73
Total Organic Carbon	C	4.43	5.55	5.77	10.1	4.23
Total Metals						
Arsenic	T-As	0.0018	0.0064	0.0064	0.0015	0.0014
Cadmium	T-Cd	0.0002	<0.0002	<0.0002	0.0003	0.0002
Calcium	T-Ca	348	307	315	375	356
Copper	T-Cu	0.0030	0.0015	0.0015	0.0160	0.0100
Iron	T-Fe	2.21	9.56	9.79	1.03	1.06
Lead	T-Pb	0.0036	0.0020	0.0025	0.0294	0.0101
Magnesium	T-Mg	23.6	23.0	23.6	22.8	22.3
Manganese	T-Mn	0.445	0.545	0.559	0.325	0.316
Mercury	T-Hg	<0.00001	0.00001	0.00001	<0.00001	<0.00001
Potassium	T-K	15.8	14.1	14.3	17.4	16.4
Sodium	T-Na	48.8	44.2	45.3	50.0	48.8
Zinc	T-Zn	0.121	0.026	0.028	0.288	0.272
Dissolved Metals						
Arsenic	D-As	0.0015	0.0048	0.0048	0.0007	0.0005
Cadmium	D-Cd	<0.0002	<0.0002	<0.0002	0.0002	0.0002
Calcium	D-Ca	325	302	314	339	349
Copper	D-Cu	0.0010	0.0005	0.0005	0.0060	0.0080
Iron	D-Fe	1.59	9.44	9.15	0.079	0.068
Lead	D-Pb	0.0005	<0.0005	<0.0005	0.0028	0.0028
Magnesium	D-Mg	23.2	22.9	23.6	22.2	22.1
Manganese	D-Mn	0.437	0.545	0.559	0.316	0.312
Mercury	D-Hg	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Potassium	D-K	15.7	13.8	14.1	15.9	15.9
Sodium	D-Na	45.8	43.3	45.2	48.5	48.4
Zinc	D-Zn	0.121	0.018	0.019	0.271	0.269

Results are expressed as milligrams per litre except where noted.
< = Less than the detection limit indicated.
Dup. = Duplicate.

RESULTS OF ANALYSIS **File No. 9938C**

		Stn.A-10	Stn.A-10 Dup.	Stn.A-11	Stn.A-12	Stn.A-13
Physical Tests						
Conductivity	umhos/cm	1850	1870	1860	1820	1830
Hardness	CaCO3	1010	1070	975	912	982
pH		6.30	6.30	6.50	4.55	4.01
Dissolved Anions						
Alkalinity - Total	CaCO3	11.0	11.4	10.9	6.5	7.8
Chloride	Cl	77.7	69.8	61.5	73.4	45.7
Sulphate	SO4	959	1000	989	944	975
Nutrients						
Ammonia Nitrogen	N	2.10	2.00	2.00	2.00	2.00
Nitrate Nitrogen	N	0.046	0.042	0.016	0.186	0.255
Total Phosphorus	P	0.024	0.025	0.032	0.016	0.007
Organic Parameters						
Dissolved Organic Carbon	C	3.53	3.63	3.22	3.40	3.63
Total Organic Carbon	C	3.61	3.63	3.35	3.53	3.83
Total Metals						
Arsenic	T-As	0.0012	0.0013	0.0012	0.0006	0.0006
Cadmium	T-Cd	<0.0002	0.0002	0.0002	0.0004	0.0003
Calcium	T-Ca	365	391	359	339	358
Copper	T-Cu	0.0100	0.0100	0.0110	0.0280	0.0170
Iron	T-Fe	1.08	1.17	1.06	0.760	1.16
Lead	T-Pb	0.0100	0.0095	0.0125	0.0305	0.0159
Magnesium	T-Mg	23.1	24.9	22.8	20.9	22.3
Manganese	T-Mn	0.327	0.352	0.320	0.275	0.283
Mercury	T-Hg	<0.00001	0.00001	<0.00001	<0.00001	0.00001
Potassium	T-K	16.5	17.8	16.6	14.8	16.8
Sodium	T-Na	50.9	55.3	50.0	45.8	50.8
Zinc	T-Zn	0.278	0.299	0.278	0.384	0.385
Dissolved Metals						
Arsenic	D-As	0.0007	0.0008	0.0007	0.0006	0.0006
Cadmium	D-Cd	<0.0002	0.0002	<0.0002	0.0003	0.0003
Calcium	D-Ca	365	388	353	333	357
Copper	D-Cu	0.0080	0.0080	0.0080	0.0270	0.0130
Iron	D-Fe	0.092	0.092	0.076	0.685	1.16
Lead	D-Pb	0.0033	0.0033	0.0030	0.0267	0.0144
Magnesium	D-Mg	23.1	24.6	22.4	19.4	22.1
Manganese	D-Mn	0.327	0.350	0.316	0.257	0.283
Mercury	D-Hg	<0.00001	<0.00002	<0.00001	<0.00001	<0.00001
Potassium	D-K	16.4	17.7	16.0	12.9	16.2
Sodium	D-Na	50.3	54.3	48.8	38.4	49.9
Zinc	D-Zn	0.278	0.292	0.267	0.381	0.385

Results are expressed as milligrams per litre except where noted.
< = Less than the detection limit indicated.
Dup. = Duplicate.

RESULTS OF ANALYSIS **File No. 9938C**

		Stn.A-14	Stn.A-15	Stn.A-15 Dup.	Stn.A-16	Stn.A-17
Physical Tests						
Conductivity	umhos/cm	1540	1840	1850	1850	1820
Hardness	CaCO3	1000	940	912	873	886
pH		7.25	3.98	4.02	3.87	4.06
Dissolved Anions						
Alkalinity - Total	CaCO3	21.3	8.8	8.5	9.1	7.6
Chloride	Cl	19.2	77.6	76.7	75.7	70.6
Sulphate	SO4	912	930	923	944	938
Nutrients						
Ammonia Nitrogen	N	0.670	2.00	2.00	2.10	2.00
Nitrate Nitrogen	N	0.104	0.247	0.258	0.171	0.087
Total Phosphorus	P	0.024	0.010	0.011	0.012	0.007
Organic Parameters						
Dissolved Organic Carbon	C	2.97	3.47	3.93	3.78	3.68
Total Organic Carbon	C	3.15	4.09	3.93	3.79	3.68
Total Metals						
Arsenic	T-As	0.0006	0.0006	0.0006	0.0005	0.0008
Cadmium	T-Cd	0.0004	0.0003	0.0004	0.0003	0.0003
Calcium	T-Ca	365	348	360	349	323
Copper	T-Cu	0.0170	0.0170	0.0170	0.0130	0.0110
Iron	T-Fe	1.22	1.16	1.20	1.07	1.74
Lead	T-Pb	0.0160	0.0160	0.0158	0.0137	0.0125
Magnesium	T-Mg	22.5	21.4	21.2	21.6	20.2
Manganese	T-Mn	0.289	0.274	0.274	0.274	0.260
Mercury	T-Hg	0.00001	0.00001	0.00001	0.00001	<0.00001
Potassium	T-K	16.8	16.0	14.9	16.7	15.3
Sodium	T-Na	51.1	48.1	45.1	49.5	45.4
Zinc	T-Zn	0.391	0.371	0.381	0.389	0.319
Dissolved Metals						
Arsenic	D-As	0.0006	0.0006	0.0006	0.0004	0.0008
Cadmium	D-Cd	0.0003	0.0003	0.0003	0.0003	0.0002
Calcium	D-Ca	364	342	331	349	321
Copper	D-Cu	0.0140	0.0140	0.0140	0.0090	0.0080
Iron	D-Fe	1.17	1.11	1.07	0.951	1.72
Lead	D-Pb	0.0143	0.0144	0.0148	0.0121	0.0125
Magnesium	D-Mg	22.4	20.9	20.5	21.4	20.1
Manganese	D-Mn	0.287	0.268	0.263	0.246	0.258
Mercury	D-Hg	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Potassium	D-K	16.3	15.7	14.9	14.9	15.3
Sodium	D-Na	50.7	46.7	45.0	48.6	45.1
Zinc	D-Zn	0.391	0.371	0.378	0.361	0.319

Results are expressed as milligrams per litre except where noted.
< = Less than the detection limit indicated.
Dup. = Duplicate.

RESULTS OF ANALYSIS **File No. 9938C**

		Stn.A-18	Stn.B-1[1]	Stn.B-2	Stn.B-2 Dup.	Stn.B-3
Physical Tests						
Conductivity	umhos/cm	1820	2410	2360	2330	2380
Hardness	CaCO3	910	1520	1310	1300	1260
pH		4.10	6.30	6.55	6.53	6.35
Dissolved Anions						
Alkalinity - Total	CaCO3	7.6	21.0	15.8	15.1	29.2
Chloride	Cl	49.9	64.2	72.1	70.9	45.5
Sulphate	SO4	962	1270	1360	1400	1270
Nutrients						
Ammonia Nitrogen	N	1.90	5.70	5.70	5.60	5.50
Nitrate Nitrogen	N	0.219	0.044	<0.005	<0.005	<0.005
Total Phosphorus	P	0.011	0.003	0.002	0.002	0.012
Organic Parameters						
Dissolved Organic Carbon	C	3.73	8.59	7.77	8.28	7.52
Total Organic Carbon	C	3.86	8.64	8.54	8.54	8.03
Total Metals						
Arsenic	T-As	0.0008	-	-	-	-
Cadmium	T-Cd	0.0002	-	-	-	-
Calcium	T-Ca	343	-	-	-	-
Copper	T-Cu	0.0120	-	-	-	-
Iron	T-Fe	1.84	-	-	-	-
Lead	T-Pb	0.0123	-	-	-	-
Magnesium	T-Mg	21.6	-	-	-	-
Manganese	T-Mn	0.277	-	-	-	-
Mercury	T-Hg	<0.00001	-	-	-	-
Potassium	T-K	16.3	-	-	-	-
Sodium	T-Na	49.8	-	-	-	-
Zinc	T-Zn	0.337	-	-	-	-
Dissolved Metals						
Arsenic	D-As	0.0008	0.0013	0.0013	0.0013	0.0011
Cadmium	D-Cd	0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Calcium	D-Ca	330	489	476	470	456
Copper	D-Cu	0.0080	<0.0005	<0.0005	<0.0005	<0.0005
Iron	D-Fe	1.77	53.5	53.8	53.5	54.7
Lead	D-Pb	0.0123	<0.0005	<0.0005	<0.0005	<0.0005
Magnesium	D-Mg	20.9	30.9	30.4	30.1	28.7
Manganese	D-Mn	0.266	0.763	0.740	0.733	0.723
Mercury	D-Hg	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Potassium	D-K	16.3	17.3	19.4	19.4	18.6
Sodium	D-Na	47.4	48.5	51.6	51.1	48.5
Zinc	D-Zn	0.328	0.007	0.004	0.004	0.003

Results are expressed as milligrams per litre except where noted.
< = Less than the detection limit indicated.
Dup. = Duplicate.
[1] There were no Total Metals cuts submitted for samples "Stn.B-1,B-2 & B-3."

RESULTS OF ANALYSIS **File No. 9938C**

		Stn.B-4	Stn.B-5	Stn.B-6	Stn.B-7	Stn.B-7 Dup.
Physical Tests						
Conductivity	umhos/cm	2230	2220	2160	2230	2210
Hardness	CaCO3	1240	1340	1060	1110	1110
pH		6.05	6.02	5.95	5.90	5.95
Dissolved Anions						
Alkalinity - Total	CaCO3	11.3	10.2	17.0	16.2	16.2
Chloride	Cl	53.1	66.1	57.9	62.2	69.5
Sulphate	SO4	1190	1420	1130	1000	996
Nutrients						
Ammonia Nitrogen	N	5.20	5.60	4.40	4.40	4.50
Nitrate Nitrogen	N	<0.005	<0.005	<0.005	<0.005	<0.005
Total Phosphorus	P	0.008	0.011	0.005	0.002	0.003
Organic Parameters						
Dissolved Organic Carbon	C	6.35	8.13	6.40	6.81	6.81
Total Organic Carbon	C	7.62	9.76	7.27	9.76	9.76
Total Metals						
Arsenic	T-As	0.0006	0.0005	0.0006	0.0006	0.0005
Cadmium	T-Cd	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Calcium	T-Ca	452	488	392	427	422
Copper	T-Cu	0.0032	0.0062	0.0035	0.0062	0.0035
Iron	T-Fe	64.3	70.1	55.1	59.0	59.7
Lead	T-Pb	0.0028	0.0071	0.0040	0.0034	0.0028
Magnesium	T-Mg	27.4	29.8	24.2	26.5	26.1
Manganese	T-Mn	0.727	0.796	0.618	0.636	0.668
Mercury	T-Hg	0.00001	0.00001	<0.00001	<0.00001	<0.00001
Potassium	T-K	17.9	19.8	17.0	18.5	18.5
Sodium	T-Na	47.6	52.0	45.6	48.4	49.7
Zinc	T-Zn	0.030	0.043	0.032	0.031	0.034
Dissolved Metals						
Arsenic	D-As	0.0005	0.0005	0.0004	0.0004	0.0004
Cadmium	D-Cd	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Calcium	D-Ca	451	488	385	403	404
Copper	D-Cu	<0.0005	0.0032	0.0010	0.0005	0.0005
Iron	D-Fe	63.5	69.1	52.8	56.6	56.4
Lead	D-Pb	<0.0005	<0.0005	0.0005	0.0005	0.0005
Magnesium	D-Mg	27.3	29.4	23.9	25.1	25.4
Manganese	D-Mn	0.723	0.796	0.602	0.631	0.641
Mercury	D-Hg	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Potassium	D-K	17.8	19.6	17.0	18.4	18.1
Sodium	D-Na	47.5	51.5	45.4	48.4	48.5
Zinc	D-Zn	0.020	0.015	0.018	0.012	0.015

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RESULTS OF ANALYSIS **File No. 9938C**

		Stn.B-8	Stn.B-9	Stn.B-10	Stn.B-11	Stn.B-12
Physical Tests						
Conductivity	umhos/cm	2090	1960	1960	1850	1840
Hardness	CaCO3	1020	1030	1020	983	982
pH		5.90	5.70	5.64	6.00	6.45
Dissolved Anions						
Alkalinity - Total	CaCO3	11.7	13.6	9.9	12.3	17.2
Chloride	Cl	61.3	64.9	54.1	72.2	91.3
Sulphate	SO4	968	1090	1070	953	960
Nutrients						
Ammonia Nitrogen	N	4.00	3.30	3.30	2.30	2.30
Nitrate Nitrogen	N	0.009	0.013	0.026	0.080	0.302
Total Phosphorus	P	0.010	0.012	0.001	0.006	0.009
Organic Parameters						
Dissolved Organic Carbon	C	6.81	5.34	5.18	4.27	3.81
Total Organic Carbon	C	9.76	6.51	6.00	4.42	3.91
Total Metals						
Arsenic	T-As	0.0005	0.0004	0.0004	0.0003	0.0004
Cadmium	T-Cd	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Calcium	T-Ca	387	377	388	360	360
Copper	T-Cu	0.0038	0.0042	0.0042	0.0065	0.0062
Iron	T-Fe	51.8	37.3	38.6	13.5	2.42
Lead	T-Pb	0.0068	0.0061	0.0038	0.0036	0.0038
Magnesium	T-Mg	24.1	22.3	23.0	21.6	21.3
Manganese	T-Mn	0.569	0.424	0.440	0.290	0.232
Mercury	T-Hg	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Potassium	T-K	17.1	16.1	16.7	15.7	15.9
Sodium	T-Na	48.0	46.2	48.1	46.9	47.6
Zinc	T-Zn	0.037	0.041	0.038	0.125	0.226
Dissolved Metals						
Arsenic	D-As	0.0003	0.0003	0.0003	0.0003	0.0003
Cadmium	D-Cd	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Calcium	D-Ca	372	376	372	358	359
Copper	D-Cu	<0.0005	<0.0005	<0.0005	0.0005	0.0025
Iron	D-Fe	47.9	36.8	38.0	13.5	1.99
Lead	D-Pb	<0.0005	<0.0005	<0.0005	<0.0025	0.0008
Magnesium	D-Mg	23.3	22.1	22.0	21.5	20.7
Manganese	D-Mn	0.543	0.422	0.433	0.289	0.232
Mercury	D-Hg	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Potassium	D-K	16.5	15.9	15.5	15.6	15.9
Sodium	D-Na	46.6	45.8	45.2	46.9	47.5
Zinc	D-Zn	0.013	0.010	0.013	0.125	0.226

Results are expressed as milligrams per litre except where noted.
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Dup. = Duplicate.

RESULTS OF ANALYSIS **File No. 9938C**

		Stn.B-12 Dup.	Stn.B-13	Stn.B-14	Stn.B-15	Stn.B-16
Physical Tests						
Conductivity	umhos/cm	1870	5.0	1840	1820	1820
Hardness	CaCO3	964	0.19	962	983	912
pH		6.30	6.20	4.00	3.90	3.97
Dissolved Anions						
Alkalinity - Total	CaCO3	17.2	<1.0	9.9	8.8	9.9
Chloride	Cl	89.7	<0.5	58.2	70.3	58.0
Sulphate	SO4	896	<1.0	932	951	896
Nutrients						
Ammonia Nitrogen	N	2.20	<0.005	2.00	2.00	2.00
Nitrate Nitrogen	N	0.283	0.007	0.317	0.302	0.300
Total Phosphorus	P	0.014	0.010	0.007	0.012	0.004
Organic Parameters						
Dissolved Organic Carbon	C	4.01	<0.50	3.76	3.71	3.86
Total Organic Carbon	C	4.12	<0.50	4.17	4.01	4.01
Total Metals						
Arsenic	T-As	0.0004	<0.0001	0.0005	0.0005	0.0004
Cadmium	T-Cd	<0.0002	<0.0002	0.0003	0.0003	0.0004
Calcium	T-Ca	352	0.229	348	362	343
Copper	T-Cu	0.0062	<0.0005	0.0160	0.0170	0.0150
Iron	T-Fe	2.37	0.023	1.99	2.09	1.92
Lead	T-Pb	0.0030	<0.0005	0.0139	0.0122	0.0121
Magnesium	T-Mg	21.4	<0.010	22.8	22.8	21.2
Manganese	T-Mn	0.231	<0.001	0.275	0.289	0.264
Mercury	T-Hg	<0.00001	<0.00001	0.00001	<0.00001	0.00001
Potassium	T-K	15.7	<0.010	15.5	15.8	15.0
Sodium	T-Na	47.0	0.020	47.1	50.0	45.3
Zinc	T-Zn	0.228	0.010	0.421	0.443	0.403
Dissolved Metals						
Arsenic	D-As	0.0003	<0.0001	0.0004	0.0004	0.0004
Cadmium	D-Cd	<0.0002	<0.0002	0.0002	0.0003	0.0003
Calcium	D-Ca	352	0.075	348	357	332
Copper	D-Cu	0.0022	<0.0005	0.0090	0.0110	0.0110
Iron	D-Fe	2.02	<0.003	1.92	1.93	1.69
Lead	D-Pb	0.0013	<0.0005	0.0072	0.0079	0.0064
Magnesium	D-Mg	20.6	<0.010	22.8	22.2	20.4
Manganese	D-Mn	0.231	<0.001	0.275	0.282	0.254
Mercury	D-Hg	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Potassium	D-K	15.6	<0.010	15.5	15.8	13.8
Sodium	D-Na	46.2	<0.010	46.5	48.0	43.4
Zinc	D-Zn	0.228	0.002	0.421	0.443	0.403

Results are expressed as milligrams per litre except where noted.
< = Less than the detection limit indicated.
Dup. = Duplicate.

RESULTS OF ANALYSIS **File No. 9938C**

		Stn.B-17	Stn.B-18	Stn.B-18 Dup.	Combined Tailings	Combined Tailings Dup.
Physical Tests						
Conductivity	umhos/cm	1290	1960	1820	2490	-
Hardness	CaCO3	901	936	953	1300	-
pH		7.00	3.90	3.92	7.10	-
Dissolved Anions						
Alkalinity - Total	CaCO3	21.7	11.4	10.5	17.5	-
Chloride	Cl	28.0	82.6	78.4	574	-
Sulphate	SO4	689	990	930	1190	-
Nutrients						
Ammonia Nitrogen	N	1.00	2.20	2.00	3.43	-
Nitrate Nitrogen	N	0.209	0.226	0.266	2.14	-
Total Phosphorus	P	0.015	0.005	0.006	0.031	-
Organic Parameters						
Dissolved Organic Carbon	C	3.41	4.22	3.91	13.0	-
Total Organic Carbon	C	3.66	4.47	3.91	15.0	-
Total Metals						
Arsenic	T-As	0.0005	0.0004	0.0004	-	-
Cadmium	T-Cd	0.0003	0.0003	0.0003	-	-
Calcium	T-Ca	342	342	347	-	-
Copper	T-Cu	0.0150	0.0150	0.0150	-	-
Iron	T-Fe	1.88	1.88	1.94	-	-
Lead	T-Pb	0.0118	0.0123	0.0119	-	-
Magnesium	T-Mg	20.5	21.3	21.7	-	-
Manganese	T-Mn	0.256	0.262	0.272	-	-
Mercury	T-Hg	0.00001	0.00001	0.00001	-	-
Potassium	T-K	13.7	15.1	16.5	-	-
Sodium	T-Na	41.9	47.3	49.6	-	-
Zinc	T-Zn	0.396	0.396	0.385	-	-
Dissolved Metals						
Arsenic	D-As	0.0004	0.0004	0.0004	0.0089	0.0092
Cadmium	D-Cd	0.0003	0.0003	0.0003	<0.0002	<0.0002
Calcium	D-Ca	327	340	347	511	498
Copper	D-Cu	0.0110	0.0120	0.0120	0.0150	0.0140
Iron	D-Fe	1.64	1.78	1.86	0.015	0.016
Lead	D-Pb	0.0061	0.0074	0.0075	0.0010	0.0026
Magnesium	D-Mg	20.4	21.0	21.0	5.58	5.46
Manganese	D-Mn	0.251	0.262	0.272	0.002	0.002
Mercury	D-Hg	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Potassium	D-K	13.4	15.0	16.3	21.4	21.4
Sodium	D-Na	41.0	47.3	49.6	52.2	50.8
Zinc	D-Zn	0.387	0.396	0.385	0.007	0.008

Results are expressed as milligrams per litre except where noted.
< = Less than the detection limit indicated.
Dup. = Duplicate.

Table B-1

Winter Survey Dissolved Oxygen and Temperature Data in Anderson Lake

Depth cm from surface (top of ice)	Temperature (°C)	DO (mg/L)	Depth cm from surface (top of ice)	Temperature (°C)	DO (mg/L)
STATION A			**STATION B**		
10	0.43	4.83	10	0.95	4
25	0.5	4.8	20	1	3.65
50	0.67	4.53	50	2.5	2.93
60	1.1	4.6	55	5.7	0.7
70	4.9	1.3	60	5.4	1
80	6.1	0.4	75	6.3	0.18
90	6.3	0.13	100	6.3	0.1
100	6.4	0.11	150	6.3	0.1
125	6.5	0.1	200	6.3	0.1
150	6.5	0.09	250	6.3	0.1
200	6.4	0.09	300	6.2	0.1
250	6.2	0.12			
275	6.2	0.35			
290	6.2	0.55			
300	6.2	0.55			
310	6.2	1.15			
320	6.2	1.3			
330	6.2	1.35			
340	6.2	1.5			
350	6.2	1.1			
360	6.4	0.7			
370	6.5	0.55			

Appendix B-2

Water Column Data-Anderson Lake Summer Survey

ANDERSON LAKE SUMMER SURVEY

RESULTS OF ANALYSIS **File No. D3551**

			Stn.1-1	Stn.1-2	Stn.1-3	Stn.1-4	Stn.1-5
			93 08 16	93 08 16	93 08 16	93 08 16	93 08 16
Physical Tests							
Conductivity	umhos/cm		1450	1480	1480	1520	1510
Hardness	CaCO3		682	659	685	811	822
pH			4.56	5.07	4.63	4.59	4.38
Dissolved Anions							
Alkalinity - Total		CaCO3	3.1	3.0	3.6	3.5	3.2
Chloride	Cl		61.6	61.4	60.5	61.3	60.9
Sulphate	SO4		792	775	782	777	797
Nutrients							
Ammonia Nitrogen		N	1.98	2.02	1.94	1.88	1.98
Nitrate Nitrogen		N	0.061	0.057	0.063	0.057	0.061
Total Phosphorus		P	0.012	0.010	0.010	0.010	0.010
Total Metals							
Arsenic	T-As		0.0024	0.0022	0.0022	0.0024	0.0023
Cadmium	T-Cd		0.0004	0.0005	0.0004	0.0004	0.0008
Calcium	T-Ca		320	282	279	295	298
Copper	T-Cu		0.0420	0.0330	0.0340	0.0310	0.0390
Iron	T-Fe		1.14	0.757	0.811	0.906	0.912
Lead	T-Pb		0.0620	0.0640	0.0670	0.0640	0.0650
Magnesium	T-Mg		18.3	17.6	17.4	18.3	18.8
Manganese	T-Mn		0.297	0.228	0.237	0.286	0.293
Mercury	T-Hg		<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Potassium	T-K		12.3	11.5	11.3	13.2	13.6
Sodium	T-Na		37.1	37.1	36.5	39.0	40.2
Zinc	T-Zn		0.442	0.344	0.358	0.432	0.442
Dissolved Metals							
Arsenic	D-As		0.0010	0.0010	0.0010	0.0010	0.0009
Cadmium	D-Cd		0.0004	0.0004	0.0004	0.0004	0.0004
Calcium	D-Ca		283	282	279	295	298
Copper	D-Cu		0.0400	0.0320	0.0310	0.0310	0.0380
Iron	D-Fe		0.103	0.094	0.098	0.102	0.096
Lead	D-Pb		0.0610	0.0610	0.0580	0.0560	0.0550
Magnesium	D-Mg		17.8	17.6	17.4	18.3	18.7
Manganese	D-Mn		0.237	0.228	0.237	0.286	0.293
Mercury	D-Hg		<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Potassium	D-K		11.6	11.5	11.3	13.2	13.6
Sodium	D-Na		37.1	37.0	36.5	39.0	39.9
Zinc	D-Zn		0.357	0.344	0.358	0.432	0.442
Organic Parameters							
Dissolved Organic Carbon		C	1.69	1.70	1.76	2.02	1.63
Total Organic Carbon		C	1.87	1.76	1.87	2.18	2.64

Results are expressed as milligrams per litre except for pH and Conductivity (umhos/cm).
< = Less than the detection limit indicated.

RESULTS OF ANALYSIS **File No. D3551**

			Stn.1-6	Stn.1-6[1] LRep.	Stn.1-7	Stn.1-8	Stn.1-9
			93 08 16	93 08 16	93 08 16	93 08 16	93 08 16
Physical Tests							
Conductivity	umhos/cm		1520	1510	1510	1520	1510
Hardness	CaCO3		778	783	777	812	803
pH			4.39	4.42	6.29	4.92	4.72
Dissolved Anions							
Alkalinity - Total		CaCO3	3.5	3.5	3.3	3.4	2.9
Chloride	Cl		61.6	60.1	60.4	60.7	60.3
Sulphate	SO4		811	771	790	800	799
Nutrients							
Ammonia Nitrogen		N	1.94	1.86	1.92	1.78	1.92
Nitrate Nitrogen		N	0.062	0.056	0.067	0.061	0.061
Total Phosphorus		P	0.012	0.013	0.012	0.009	0.011
Total Metals							
Arsenic	T-As		0.0021	0.0022	0.0023	0.0024	0.0023
Cadmium	T-Cd		0.0003	0.0004	0.0004	0.0004	0.0004
Calcium	T-Ca		288	288	283	298	295
Copper	T-Cu		0.0310	0.0310	0.0310	0.0310	0.0320
Iron	T-Fe		0.868	0.880	0.868	0.893	0.944
Lead	T-Pb		0.0620	0.0660	0.0560	0.0610	0.0620
Magnesium	T-Mg		17.3	17.7	17.3	19.3	18.3
Manganese	T-Mn		0.275	0.280	0.274	0.317	0.300
Mercury	T-Hg		<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Potassium	T-K		12.4	12.5	12.1	13.0	12.6
Sodium	T-Na		36.4	37.2	36.2	42.6	40.1
Zinc	T-Zn		0.411	0.418	0.418	0.445	0.443
Dissolved Metals							
Arsenic	D-As		0.0010	0.0010	0.0011	0.0010	0.0010
Cadmium	D-Cd		0.0003	0.0003	0.0003	0.0004	0.0004
Calcium	D-Ca		283	285	283	295	292
Copper	D-Cu		0.0290	0.0280	0.0300	0.0300	0.0320
Iron	D-Fe		0.142	0.142	0.099	0.122	0.121
Lead	D-Pb		0.0520	0.0540	0.0560	0.0540	0.0560
Magnesium	D-Mg		17.3	17.4	17.3	18.4	17.9
Manganese	D-Mn		0.275	0.277	0.274	0.300	0.296
Mercury	D-Hg		<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Potassium	D-K		12.3	12.5	12.1	12.7	12.6
Sodium	D-Na		36.4	36.6	36.2	40.2	39.0
Zinc	D-Zn		0.411	0.415	0.418	0.444	0.437
Organic Parameters							
Dissolved Organic Carbon		C	1.58	1.41	2.03	2.50	1.52
Total Organic Carbon		C	1.76	1.87	3.52	2.66	1.87

Results are expressed as milligrams per litre except for pH and Conductivity (umhos/cm).

< = Less than the detection limit indicated.

[1] LRep. = Laboratory Replicate.

			Stn.1-10 93 08 16	Stn.1-11 93 08 16	Stn.1-12 93 08 16	Stn.1-12[1] LRep. 93 08 16	Stn.1-13 93 08 16
Physical Tests							
Conductivity	umhos/cm		1520	1510	1500	1500	1770
Hardness	CaCO3		796	818	839	852	852
pH			4.58	5.29	5.97	6.02	10.3
Dissolved Anions							
Alkalinity - Total		CaCO3	3.3	3.2	3.2	4.9	3.4
Chloride	Cl		60.5	60.3	61.6	60.0	61.0
Sulphate	SO4		792	786	790	775	775
Nutrients							
Ammonia Nitrogen		N	1.78	1.82	1.74	1.88	1.88
Nitrate Nitrogen		N	0.063	0.054	0.059	0.059	0.054
Total Phosphorus		P	0.010	0.012	0.012	0.012	0.012
Total Metals							
Arsenic	T-As		0.0022	0.0023	0.0022	0.0021	0.0021
Cadmium	T-Cd		0.0004	0.0003	0.0004	0.0004	0.0004
Calcium	T-Ca		299	298	308	313	317
Copper	T-Cu		0.0390	0.0310	0.0310	0.0310	0.0300
Iron	T-Fe		0.957	0.954	0.982	0.999	0.976
Lead	T-Pb		0.0600	0.0640	0.0640	0.0620	0.0610
Magnesium	T-Mg		18.6	18.3	18.4	18.9	19.0
Manganese	T-Mn		0.305	0.302	0.305	0.309	0.312
Mercury	T-Hg		<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Potassium	T-K		12.8	12.9	13.0	13.4	13.3
Sodium	T-Na		40.7	40.1	40.3	41.5	41.7
Zinc	T-Zn		0.448	0.445	0.445	0.455	0.463
Dissolved Metals							
Arsenic	D-As		0.0010	0.0013	0.0009	0.0009	0.0008
Cadmium	D-Cd		0.0003	0.0003	0.0004	0.0003	0.0004
Calcium	D-Ca		289	298	306	311	310
Copper	D-Cu		0.0390	0.0300	0.0300	0.0310	0.0300
Iron	D-Fe		0.118	0.263	0.128	0.135	0.976
Lead	D-Pb		0.0520	0.0580	0.0540	0.0600	0.0600
Magnesium	D-Mg		17.7	18.0	18.4	18.7	18.7
Manganese	D-Mn		0.295	0.297	0.302	0.307	0.312
Mercury	D-Hg		<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Potassium	D-K		12.4	12.4	12.9	12.9	13.3
Sodium	D-Na		38.5	39.0	40.3	41.2	41.1
Zinc	D-Zn		0.436	0.439	0.441	0.450	0.453
Organic Parameters							
Dissolved Organic Carbon		C	1.52	1.74	1.76	1.76	1.74
Total Organic Carbon		C	2.42	2.09	1.92	1.87	1.76

Results are expressed as milligrams per litre except for pH and Conductivity (umhos/cm).

< = Less than the detection limit indicated.

[1] LRep. = Laboratory Replicate.

2-C

RESULTS OF ANALYSIS **File No. D3551**

			Stn.1-14 93 08 16	Stn.1-15 93 08 16	Stn.1-16 93 08 16	Stn.1-17 93 08 16	Stn.1-18 93 08 16
Physical Tests							
Conductivity	umhos/cm		1510	1500	1510	1510	1530
Hardness	CaCO3		800	817	820	836	842
pH			5.89	4.67	4.44	4.40	4.42
Dissolved Anions							
Alkalinity - Total		CaCO3	2.9	3.3	3.0	3.3	3.0
Chloride	Cl		60.3	60.0	60.4	60.0	59.9
Sulphate	SO4		803	793	773	786	787
Nutrients							
Ammonia Nitrogen		N	3.68	1.84	1.92	1.82	1.96
Nitrate Nitrogen		N	0.055	0.071	0.066	0.069	0.072
Total Phosphorus		P	0.008	0.010	0.008	0.008	0.009
Total Metals							
Arsenic	T-As		0.0021	0.0022	0.0022	0.0021	0.0020
Cadmium	T-Cd		0.0004	0.0004	0.0004	0.0004	0.0004
Calcium	T-Ca		292	301	299	309	317
Copper	T-Cu		0.0310	0.0400	0.0300	0.0300	0.0310
Iron	T-Fe		0.898	0.921	0.908	0.942	0.963
Lead	T-Pb		0.0630	0.0630	0.0630	0.0580	0.0600
Magnesium	T-Mg		17.3	17.9	18.0	19.0	19.5
Manganese	T-Mn		0.287	0.296	0.296	0.308	0.316
Mercury	T-Hg		<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Potassium	T-K		12.1	12.4	13.0	13.5	13.4
Sodium	T-Na		37.7	39.3	40.9	42.3	43.5
Zinc	T-Zn		0.426	0.438	0.434	0.449	0.464
Dissolved Metals							
Arsenic	D-As		0.0009	0.0008	0.0009	0.0009	0.0009
Cadmium	D-Cd		0.0004	0.0004	0.0004	0.0004	0.0004
Calcium	D-Ca		292	298	299	304	306
Copper	D-Cu		0.0300	0.0390	0.0300	0.0300	0.0310
Iron	D-Fe		0.095	0.092	0.104	0.100	0.101
Lead	D-Pb		0.0560	0.0550	0.0590	0.0570	0.0580
Magnesium	D-Mg		17.3	17.9	18.0	18.5	18.6
Manganese	D-Mn		0.287	0.295	0.296	0.302	0.306
Mercury	D-Hg		<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Potassium	D-K		12.1	12.4	13.0	12.8	13.2
Sodium	D-Na		37.7	39.3	40.9	41.1	41.4
Zinc	D-Zn		0.426	0.435	0.434	0.445	0.447
Organic Parameters							
Dissolved Organic Carbon		C	1.63	1.63	1.46	1.58	1.97
Total Organic Carbon		C	1.70	2.20	1.87	2.42	3.02

Results are expressed as milligrams per litre except for pH and Conductivity (umhos/cm).
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RESULTS OF ANALYSIS **File No. D3551**

			Stn.1-18^1 LRep.	Stn.1-19	Stn.2-4	Stn.2-5	Stn.2-5^1 LRep.
			93 08 16	93 08 16	93 08 16	93 08 18	93 08 16
Physical Tests							
Conductivity	umhos/cm		1520	1520	1560	1500	1510
Hardness	CaCO3		842	783	787	794	770
pH			4.42	4.42	4.85	4.93	4.90
Dissolved Anions							
Alkalinity - Total		CaCO3	4.2	3.2	4.9	4.8	4.7
Chloride	Cl		60.8	60.0	61.3	59.5	60.2
Sulphate	SO4		777	792	897	786	759
Nutrients							
Ammonia Nitrogen		N	1.84	1.82	1.56	1.84	1.72
Nitrate Nitrogen		N	0.071	0.070	0.107	0.105	0.109
Total Phosphorus		P	0.009	0.008	0.007	0.007	0.008
Total Metals							
Arsenic	T-As		0.0020	0.0020	0.0020	0.0019	0.0019
Cadmium	T-Cd		0.0005	0.0004	0.0003	0.0004	0.0004
Calcium	T-Ca		306	312	288	294	300
Copper	T-Cu		0.0300	0.0400	0.0240	0.0240	0.0240
Iron	T-Fe		0.923	0.922	1.14	1.17	1.19
Lead	T-Pb		0.0590	0.0610	0.0590	0.0600	0.0580
Magnesium	T-Mg		18.9	19.4	16.5	16.9	17.4
Manganese	T-Mn		0.306	0.313	0.243	0.250	0.258
Mercury	T-Hg		<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Potassium	T-K		13.1	13.7	12.1	12.4	13.0
Sodium	T-Na		42.0	43.4	38.0	39.5	40.7
Zinc	T-Zn		0.452	0.456	0.368	0.376	0.384
Dissolved Metals							
Arsenic	D-As		0.0008	0.0008	0.0010	0.0009	0.0008
Cadmium	D-Cd		0.0004	0.0004	0.0003	0.0003	0.0004
Calcium	D-Ca		306	285	288	290	282
Copper	D-Cu		0.0300	0.0380	0.0220	0.0220	0.0220
Iron	D-Fe		0.093	0.143	0.109	0.099	0.097
Lead	D-Pb		0.0550	0.0560	0.0340	0.0340	0.0310
Magnesium	D-Mg		18.9	17.6	16.5	16.9	16.2
Manganese	D-Mn		0.306	0.284	0.243	0.247	0.239
Mercury	D-Hg		<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Potassium	D-K		13.1	12.2	12.1	12.4	12.0
Sodium	D-Na		42.0	39.4	38.0	39.4	37.4
Zinc	D-Zn		0.451	0.423	0.365	0.363	0.351
Organic Parameters							
Dissolved Organic Carbon		C	2.03	1.74	1.97	1.86	1.86
Total Organic Carbon		C	3.13	3.08	2.34	2.09	2.09

Results are expressed as milligrams per litre except for pH and Conductivity (umhos/cm).
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[1]LRep. = Laboratory Replicate.

RESULTS OF ANALYSIS

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		Stn.2-6	Stn.2-7	Stn.2-8	Stn.2-9	Stn.2-10
		93 08 16	93 08 16	93 08 16	93 08 16	93 08 16
Physical Tests						
Conductivity	umhos/cm	1510	1510	1500	1510	1500
Hardness	CaCO3	775	820	854	834	798
pH		5.00	4.99	4.91	4.91	4.91
Dissolved Anions						
Alkalinity - Total	CaCO3	5.5	5.2	4.6	4.7	5.0
Chloride	Cl	60.0	60.1	59.6	60.1	59.3
Sulphate	SO4	780	792	810	806	806
Nutrients						
Ammonia Nitrogen	N	1.76	1.82	1.88	1.94	1.88
Nitrate Nitrogen	N	0.107	0.104	0.105	0.100	0.100
Total Phosphorus	P	0.007	0.007	0.007	0.009	0.008
Total Metals						
Arsenic	T-As	0.0020	0.0019	0.0020	0.0020	0.0019
Cadmium	T-Cd	0.0004	0.0004	0.0004	0.0004	0.0004
Calcium	T-Ca	286	300	311	311	305
Copper	T-Cu	0.0240	0.0230	0.0230	0.0230	0.0230
Iron	T-Fe	1.12	1.18	1.28	1.27	1.26
Lead	T-Pb	0.0580	0.0610	0.0600	0.0640	0.0630
Magnesium	T-Mg	16.4	17.2	18.9	19.1	19.1
Manganese	T-Mn	0.243	0.255	0.269	0.269	0.267
Mercury	T-Hg	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Potassium	T-K	12.3	12.6	13.3	13.5	13.3
Sodium	T-Na	38.0	39.8	43.5	43.9	44.4
Zinc	T-Zn	0.369	0.386	0.411	0.412	0.408
Dissolved Metals						
Arsenic	D-As	0.0009	0.0009	0.0009	0.0009	0.0010
Cadmium	D-Cd	0.0003	0.0003	0.0003	0.0003	0.0004
Calcium	D-Ca	284	300	311	303	289
Copper	D-Cu	0.0220	0.0230	0.0210	0.0220	0.0210
Iron	D-Fe	0.109	0.120	0.132	0.106	0.093
Lead	D-Pb	0.0360	0.0530	0.0350	0.0320	0.0280
Magnesium	D-Mg	16.2	17.2	18.9	18.6	18.5
Manganese	D-Mn	0.241	0.255	0.269	0.265	0.255
Mercury	D-Hg	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Potassium	D-K	12.0	12.6	13.3	13.2	12.6
Sodium	D-Na	37.6	39.8	43.5	43.0	43.3
Zinc	D-Zn	0.356	0.386	0.401	0.395	0.386
Organic Parameters						
Dissolved Organic Carbon	C	1.63	2.42	3.66	2.36	1.63
Total Organic Carbon	C	2.42	--	--	--	2.31

Results are expressed as milligrams per litre except for pH and Conductivity (umhos/cm).

< = Less than the detection limit indicated.

RESULTS OF ANALYSIS **File No. D3551**

			Stn.2-11	Stn.2-11[1] LRep.	Stn.2-12	Stn.2-13	Stn.2-14
			93 08 16	93 08 16	93 08 16	93 08 16	93 08 16
Physical Tests							
Conductivity	umhos/cm		1620	1620	1510	1510	1500
Hardness	CaCO3		826	800	781	811	804
pH			4.91	4.90	4.85	4.71	5.64
Dissolved Anions							
Alkalinity - Total		CaCO3	5.4	6.8	4.7	4.4	4.6
Chloride	Cl		63.7	63.0	60.2	60.5	60.7
Sulphate	SO4		945	918	891	815	806
Nutrients							
Ammonia Nitrogen		N	1.68	1.64	1.86	1.78	1.92
Nitrate Nitrogen		N	0.109	0.111	0.097	0.100	0.100
Total Phosphorus		P	0.008	0.010	0.007	0.007	0.007
Total Metals							
Arsenic	T-As		0.0019	0.0019	0.0021	0.0020	0.0020
Cadmium	T-Cd		0.0004	0.0004	0.0004	0.0003	0.0004
Calcium	T-Ca		302	290	288	301	299
Copper	T-Cu		0.0230	0.0230	0.0240	0.0240	0.0230
Iron	T-Fe		1.24	1.19	1.09	1.16	1.14
Lead	T-Pb		0.0650	0.0640	0.0650	0.0650	0.0640
Magnesium	T-Mg		18.8	18.7	17.4	17.4	17.6
Manganese	T-Mn		0.265	0.259	0.263	0.250	0.249
Mercury	T-Hg		<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Potassium	T-K		13.1	12.8	12.5	12.0	12.1
Sodium	T-Na		43.8	43.8	43.2	37.3	38.3
Zinc	T-Zn		0.407	0.406	0.401	0.385	0.386
Dissolved Metals							
Arsenic	D-As		0.0009	0.0009	0.0009	0.0009	0.0010
Cadmium	D-Cd		0.0004	0.0004	0.0004	0.0003	0.0004
Calcium	D-Ca		300	290	283	296	293
Copper	D-Cu		0.0210	0.0220	0.0230	0.0230	0.0230
Iron	D-Fe		0.093	0.069	0.069	0.072	0.072
Lead	D-Pb		0.0300	0.0310	0.0340	0.0340	0.0340
Magnesium	D-Mg		18.8	18.4	17.0	17.3	17.3
Manganese	D-Mn		0.265	0.240	0.250	0.245	0.243
Mercury	D-Hg		<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Potassium	D-K		13.1	12.4	12.4	11.7	11.8
Sodium	D-Na		43.8	41.6	43.2	37.3	37.9
Zinc	D-Zn		0.400	0.365	0.384	0.373	0.370
Organic Parameters							
Dissolved Organic Carbon		C	1.69	1.69	1.91	2.34	1.86
Total Organic Carbon		C	2.36	2.25	2.09	2.36	1.92

Results are expressed as milligrams per litre except for pH and Conductivity (umhos/cm).

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RESULTS OF ANALYSIS File No. D3551

		Stn.2-15 93 08 16	Stn.2-16 93 08 16	Stn.2-17 93 08 16	Stn.2-17[1] LRep. 93 08 16	Stn.2-18 93 08 16
Physical Tests						
Conductivity	umhos/cm	1530	1520	1590	1590	1480
Hardness	CaCO3	801	801	809	820	812
pH		4.84	5.37	5.03	5.03	5.04
Dissolved Anions						
Alkalinity - Total	CaCO3	5.2	4.7	5.0	6.3	5.2
Chloride	Cl	60.7	57.7	64.3	63.9	61.3
Sulphate	SO4	815	806	922	867	822
Nutrients						
Ammonia Nitrogen	N	1.74	1.72	1.56	1.52	1.70
Nitrate Nitrogen	N	0.094	0.100	0.097	0.095	0.101
Total Phosphorus	P	0.007	0.007	0.008	0.009	0.010
Total Metals						
Arsenic	T-As	0.0020	0.0020	0.0018	0.0019	0.0019
Cadmium	T-Cd	0.0004	0.0004	0.0003	0.0004	0.0003
Calcium	T-Ca	301	291	298	298	324
Copper	T-Cu	0.0240	0.0240	0.0240	0.0240	0.0240
Iron	T-Fe	1.15	1.13	1.24	1.22	0.195
Lead	T-Pb	0.0660	0.0670	0.0680	0.0610	0.0650
Magnesium	T-Mg	17.5	18.2	18.5	18.5	19.8
Manganese	T-Mn	0.249	0.237	0.263	0.261	0.285
Mercury	T-Hg	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Potassium	T-K	12.0	11.3	12.6	12.5	13.5
Sodium	T-Na	37.9	35.1	40.3	39.3	42.6
Zinc	T-Zn	0.387	0.376	0.415	0.400	0.438
Dissolved Metals						
Arsenic	D-As	0.0009	0.0010	0.0008	0.0009	0.0009
Cadmium	D-Cd	0.0004	0.0004	0.0003	0.0004	0.0003
Calcium	D-Ca	293	291	294	298	295
Copper	D-Cu	0.0230	0.0230	0.0230	0.0230	0.0240
Iron	D-Fe	0.069	0.064	0.064	0.064	0.055
Lead	D-Pb	0.0320	0.0640	0.0350	0.0280	0.0300
Magnesium	D-Mg	16.9	18.2	18.3	18.5	18.1
Manganese	D-Mn	0.241	0.237	0.261	0.261	0.262
Mercury	D-Hg	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Potassium	D-K	11.2	11.3	12.2	12.5	12.2
Sodium	D-Na	36.4	35.1	39.7	39.3	39.1
Zinc	D-Zn	0.365	0.376	0.398	0.400	0.395
Organic Parameters						
Dissolved Organic Carbon	C	1.80	1.54	1.76	1.76	2.64
Total Organic Carbon	C	2.47	1.76	2.61	2.64	3.24

Results are expressed as milligrams per litre except for pH and Conductivity (umhos/cm).

< = Less than the detection limit indicated.

[1] LRep. = Laboratory Replicate.

RESULTS OF ANALYSIS **File No. D3551**

			Stn.2-19 93 08 16
Physical Tests			
Conductivity	umhos/cm		1500
Hardness	CaCO3		832
pH			4.61
Dissolved Anions			
Alkalinity - Total		CaCO3	3.9
Chloride	Cl		60.2
Sulphate	SO4		794
Nutrients			
Ammonia Nitrogen		N	1.84
Nitrate Nitrogen		N	0.101
Total Phosphorus		P	0.008
Total Metals			
Arsenic	T-As		0.0018
Cadmium	T-Cd		0.0004
Calcium	T-Ca		301
Copper	T-Cu		0.0380
Iron	T-Fe		0.846
Lead	T-Pb		0.0640
Magnesium	T-Mg		19.3
Manganese	T-Mn		0.285
Mercury	T-Hg		<0.00001
Potassium	T-K		12.9
Sodium	T-Na		41.5
Zinc	T-Zn		0.447
Dissolved Metals			
Arsenic	D-As		0.0010
Cadmium	D-Cd		0.0004
Calcium	D-Ca		301
Copper	D-Cu		0.0360
Iron	D-Fe		0.090
Lead	D-Pb		0.0440
Magnesium	D-Mg		19.3
Manganese	D-Mn		0.285
Mercury	D-Hg		<0.00001
Potassium	D-K		12.9
Sodium	D-Na		41.5
Zinc	D-Zn		0.447
Organic Parameters			
Dissolved Organic Carbon		C	1.92
Total Organic Carbon		C	2.23

Results are expressed as milligrams per litre except for pH and Conductivity (umhos/cm).
< = Less than the detection limit indicated.

Table B-2

Diurnal Dissolved Oxygen Measurements in Anderson Lake (Summer Survey)

Depth m 0000 H 12 August 1993 Station 1 Tails	Temperature (°C)	Oxygen (mg/L)	Depth m 1300 H 12 August 1993 Station 1 Tails	Temperature (°C)	Oxygen (mg/L)	Depth m 0020 H 13 August 1993 Station 2 Nat	Temperature (°C)	Oxygen (mg/L)
0.1	19.9	7.4	0.1	19.1	7.3	0.1	19.1	7.1
0.5	19.9	6.9	0.5	19.1	7.1	0.5	19.1	6.4
1	19.9	6.9	1	19.1	7.1	1	19.1	6.4
1.5	19.9	7.1	1.5	19.1	7	1.5	19.1	7.3
2	19.9	7.2	2	19.1	7.1	2	19.1	6.7
2.5	19.9	7.2	2.5	19.1	7.1	2.5	19.1	7
			2.7	19.1	7.1	3	19.1	6.5
						3.5	19.1	6.3

Appendix C-1 - Core Logs

APPENDIX C-1 - CORE LOGS

Core A-1 Notes - Winter Survey

- Collected 15 April 1993 at 2:30 p.m.
- Overcast, snowing moderately.
- Core collected with Pedersen corer through the ice.
- Core length 50 cm, undisturbed interface.

Core Log

0 to 2 cm - orange, brown oxic top - abundant organic fragment. Lots of daphnia (zooplankton ~1/2 mm "swarming" on interface and burrowing). (Interface has abundant flocculent-like orange to "rust-coloured" aggregates up to 3 mm diameter.

- Probably very fine-grained
- Layer grades to charcoal grey at the base

2 to 12 cm - charcoal grey, containing occasional light-coloured specks and linear bodies up to 5 mm long (possible burrow traces or faecal casts).

12 to 28 cm - brown, very soft, gelatinous, homogenous ooze. Occasional light-coloured specks (presumably organic) up to 3 mm diameter.

28 to 40 cm - more consolidated. Slightly darker brown. Methane bubbles developing >30 cm depth.

- very fine-grained
- Organic ooze

40 to 50 cm - several light-grey, green patches up to 6 mm diameter. Origin unknown.

Core A-2 Notes - Winter Survey

- Collected 16 April 1993 at 9:30 a.m.
- Sunny, clear -1°C.
- Core collected with Pedersen corer (~7 m from water column sampler; 2-3 m west of Core A-1).
- ~50 cm long, undisturbed interface except for some methane degassing up the side of the barrel.
- Abundant worm casts; presence of Daphnia?

Core Log

0 to 1.5 cm - oxic veneer ~15 mm thick but possibly smeared down the barrel wall.

1.5 to 8 cm - very dark charcoal, grey-brown layer.

8 to 30 cm - grades to chocolate brown, gelatine ooze.

- First methane bubble appears at 10 cm.

30 to 35 cm - Subtle change to lighter brown; white specks randomly dispersed from 10 cm to core bottom. Essentially identical to Core A-1.

Core B-1 Notes - Winter Survey

- Core collected 13 April 1993 at 11:00 a.m.
- Clear, sunny.
- Core collected with Pedersen corer through the ice.
- Core length ~63 cm long, slightly disturbed interface.

Core Log

0 to 33 cm - undifferentiated tailings (interface undisturbed supernat very clear on collection).

- Tailings replete with sparkling pyrite.

33 to 43 cm - band of natural sediments admixed with tailings.

43 to 63 cm - looks like homogenous tails.

- Grains size very fine to fine sand.

Core B-2 Notes - Winter Survey

- Core collected 14 April 1993 at 3:30 p.m.
- Clear, sunny.
- Core collected with Pedersen corer through the ice.
- Core length 59 cm long, slightly disturbed interface, slime's resistant to settling.

Note: When selecting site for core And B-2, three holes were drilled. These holes were approximately 12-15 m apart; however, bottom relief varied by over 1.0 m between sites. At the site of Core B-2 over 3.0 m depth was encountered; at the previons reconnaissance site only 2.3 m was observed.

Core Log

0 to 59 cm - undifferentiated tailings, slight differentiation of pyrite with depth.

29 cm - break (~0.5 to 2 mm width) in core.

Core A Notes (Natural Site) - Summer Survey

- Diver - recovered core on 11 August 1993 at ~1200 h.
- Overcast, breezy, slight chop, poor underwater visibility.
- Recovered first attempt, no problems, ≤ 5 m from buoy, very near winter location. Perhaps better than 30 m.
- Top cap taped underwater core then raised to near surface, piston placed on underwater, then seated on deck.
- Transported back to lab by 1230 h, logged, processing commenced by 1300 h.

Core Log

68 cm long - slightly tilted interface (~1 cm across barrel) - diver observation suggest bottom relief rather than non-vertical coring artifact.

- Surface - abundant faecal cast and several protruding worm tubes.
- Diver observation suggest abundant benthic infauna.

0 to 2 mm - oxide-rich veneer punctuated repeatedly by many worm tubes.

- Bioturb. evident (oxidized burrows) to at least 10 cm.
- Extremely gelatinous - diver easily immersed 1 to 2 feet into sediments.
- Unconsolidated, poorly compacted.

2 mm to 12 cm - dark charcoal, olive-grey.

12 cm to 14 cm - grades - pale chocolate brown.

14 cm to 40 cm - extremely unconsolidated.

40 cm to 50 cm - grade to slightly darker, slightly more compact ooze.

50 cm to end - very fine grained, organic-rich.

35 cm - white/yellow pod (8 mm by 2 mm diameter) possibly larval case??

- Light coloured organic fragments abundant throughout core.

Core B Notes (Tailings Site) - Summer Survey

- 12 August 1993 - stiff breeze, 15 cm chop on water, broken cloud/sunny/cool.
- Core ~48 cm long core, excellent condition, diver-recovered.
- Interface highly lobate with ≤ 4 cm relief (characteristic of bottom according to diver; local relief up to 1 m in area of station (lobes, hummocks, *etc.*)
- Appears to be natural sediments > 25 cm depth.
- Surface characterized by ~3 mm thick "carpet" of ferruginous gels - distinct filamentous character of layer is evocative of bacterial mats.
- Layer is "draped" on tussocks of tailings.
- 1 vertical face 1.5 by 1.5 cm is strong orange-rust colour and may represent *in situ* tailings oxidation - top of face has thin layer of unoxidized tailings.
- Bright shiny flecks within carpet (medium-fine silt) possibly pyrite.
- Core appears to contain lobes admixed within natural sediments.

Core Log

Underlying carpet:

0 to 25 cm - lobate admixture of tailings and natural sediments.

0 to 10 cm - mostly tails within some natural sediments. Tails are dark grey medium silt and fresh.

10 to 18 cm - higher proportion of natural sediments.

18 to 24 cm - grey/black layer of tails.

24 to bottom - (uneven contact at 24 cm ~3 cm variation). Looks like natural sediments within spots of tails to 30 cm then 100% natural to bottom.

- Natural sediments = pale, olive, chocolate/brown - very fine grained.

Core C Notes (Shallow Tailings Site) - Summer Survey

- Collected 12 August 1993 within 10 feet of peeper location.
- 16 cm sediment collected.
- Excellent interface - diver collected water depth was ~1.0 metre. Collection conditions were the same as for the tailings core.
- Interface - blade of grass lying on top of interface.
- ~0.5 cm of orange to olive green oxic layer - grades into grey black tailings which have peculiar texture consisting of chunks or clasts from sub-millimetre to cm size.
- Abundant pore spaces between clasts. Rapidly dewatered during extrusion - highly porous core!
- oxic floc on interface has similar characteristics to that described at tailings site.
- The clasts may represent a reworked lag deposit.

Core Log

Underlying carpet:

0 to 0.5 cm - (Actually top 3-4 mm) fresh, bright pyrite grains noted on surface (note that this site is relatively far from outfall, say ~500 m). Gravelly texture.

0.4 to 10 cm - Dark grey/black gravel (clasts well-indurated), fresh pyrite evident (common) - no sign of oxidation.

1 to 1.5 cm - Ditto (but occasional (rare) specks with orange tinge). These may have been entrained downwind during coring/sectioning.

1.5 to 2 cm - Ditto.

2 to 4 cm - Ditto.

4 to 6 cm - Ditto.

Rest of core consists of same material as in 4 to 6 cm. Undifferentiated tailings 'gravel' no sign of oxidation. Discarded after visual examination.

Appendix C-2 - Petrographic Analysis

Harris
**EXPLORATION
SERVICES**

MINERALOGY AND GEOCHEMISTRY

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Report 93-100

December 31st, 1993

PETROGRAPHIC EXAMINATION OF SEDIMENTS FROM ANDERSON LAKE
(PROJECT 409)

Introduction:

The following samples, representing sediment from various depths at two sites, plus one sample of terrestrial tailings, were submitted for study. Each was prepared as a smear-mount polished thin section.

Station B-1 (Tailings Site)		Depth (cm)	Slide No.
	AL- 1	0 - 0.5	93-392X
	AL- 2	1.0 - 1.5	93-393X
	AL- 6	3.0 - 4.0	93-394X
	AL- 9	5.0 - 6.0	93-395X
	AL-13	10.0 - 12.0	93-396X
	AL-15	14.0 - 18.0	93-397X
	AL-19	26.0 - 30.0	93-398X
Station A-1 (Natural)			
	AL-37	0 - 0.5	93-399X
	AL-39	1.0 - 1.5	93-406X
	AL-42	3.0 - 4.0	93-400X
	AL-44	5.0 - 6.0	93-401X
	AL-47	10.0 - 12.0	93-402X
	AL-49	14.0 - 18.0	93-403X
	AL-52	26.0 - 30.0	93-404X
Oxidized land tailings			
	AL-LND		93-405X

Summary:

The samples from Station B-1 (the disposal site) are all composed almost entirely of mineral grains, representing mine tailings.

Organic-rich lake sediment was noted in minor amounts (estimated 1 and 5% respectively) in AL-1 and AL-9 - presumably representing thin natural accumulations built up during periods of non-addition of tailings.

The character of the tailings (particle size and mineral proportions) shows substantial variations with increasing sampling depth - indicative of changes in milling procedures and/or feed type over the period of mine operation.

The uppermost three samples, AL-1, 2 and 6 (representing comparatively recent operations) are all very similar. They show an overall particle size range of 2 - 100 microns, with sulfide particles mainly 50 microns or less.

These samples contain about 35% sulfides, the remainder being silicate gangue (quartz/feldspars and accessory hornblende, chlorite and biotite). The sulfides are predominantly pyrite and pyrrhotite, in approximately equal proportions. Liberation is essentially complete. Contents of sphalerite and chalcopyrite (representing production losses) are low, being estimated as about 0.3 and 0.6% respectively.

The deeper samples show a distinctly larger mean particle size, with a range of 5 - 180 microns, and have successively higher total sulfide contents.

Samples AL-9, 13 and 15 are similar to the overlying tailings (having pyrrhotite$\approx$pyrite), but total sulfide contents are high (42%, 50% and 60% respectively). Other distinctive features are an anomalously high content (estimated 3.5%) of sphalerite in AL-9 - mainly as coarse, liberated grains; and the presence of significant accessory proportions of magnetite, along with the lower proportions of sphalerite, in AL-13 and 15.

The deepest sample, AL-19, has the highest total sulfide content (almost 70%), and differs from all the overlying tailings in that pyrite is grossly dominant over pyrrhotite. Sphalerite is also relatively high (2%).

Sulfides throughout the sequence are consistently fresh, without physical evidence of oxidation or leaching.

The sample of tailings from a terrestrial site (AL-LND) is of uncertain significance. This material is extensively oxidized, and contains only about 7% of surviving sulfides (pyrite and minor chalcopyrite). There is a high content of limonite, as earthy and cellular pseudomorphs, and as dispersed coatings on silicate grains. This suggests an original sulfide content of possibly in the order of 50%. No pyrrhotite survives, but there is evidence that it was once present - though in unknown ratio to pyrite.

The pyrite shows no peripheral limonitization, but the grains are often ragged and embayed, indicative of leaching. An unknown proportion of pyrite has probably been removed (and/or reprecipitated as limonite). This material differs from the lake tailings in its relatively high content of magnetite, of primary aspect.

The sequence of natural lake sediments at Station A-1 (distant from the tailings disposal area) are similar throughout the sample section, consisting largely (95-99%) of organic-rich mull and biogenic detritus.

They contain very small proportions of mineral grains (quartz, plus minor accessory mafic silicates) of clastic aspect, typically 20 - 200 microns in size, and of angular shape. These are most abundant (6%) and coarsest in the deepest sample, AL-52, and least abundant (1-2%) and finest in the uppermost two samples, AL-37 and 39.

Crystalline sulfides are extremely rare in all these samples. They are seen as a few individual grains, 20 - 50 microns in size, consisting of fresh pyrite plus lesser pyrrhotite and chalcopyrite. One or two coarser pyrite grains were noted in AL-47, together with recognizable magnetite. The uppermost two samples include a component of dust-sized sulfides (0.2 - 2.0 microns) incorporated within organic flocs. These are of uncertain origin (slimes-sized clastics, or biogenically precipitated?).

It is unclear whether the clastic sulfides - and, for that matter, the clastic silicates - represent (in whole, or in part) redistributed tailings, or are of natural (bedrock) origin from elsewhere in the Anderson Lake drainage basin. The lack of correlation between the abundance of clastic sulfides and clastic silicates tends to favour the latter possibility - although it could be explained by hydrological sorting in the dispersion of tailings, the heavier sulfides travelling less widely.

Pyrite of biogenic origin is seen in all the Station A-1 samples, though in very low abundance. It typically occurs as sparsely scattered individual framboids, 5 - 30 microns in size. These are sometimes incorporated in organic flocs, and sometimes appear "free floating". Framboids are most abundant (estimated 0.2%) in AL-47. That sample and AL-44 also include a brownish variant of precipitated Fe sulfide which sometimes cements small clusters of framboids.

There is no recognizable correlation between framboidal pyrite abundance and that of clastic sulfides.

Individual microscopic descriptions are attached, together with a set of photomicrographs illustrating typical features of the tailings and lake sediment samples.

JF Harris

J.F. Harris Ph.D.

PHOTOMICROGRAPHS

All photos are of typical fields by reflected light, at a scale of 1cm = 42 microns except where otherwise stated.

STATION B-1

SAMPLE AL-2:

Neg. 313-10: Shows relatively sparse sulfides. Cream-coloured grains (e.g. largest one at left centre) are pyrite. Slightly darker, buff-coloured grains (e.g. right) are pyrrhotite. Sulfides are fully liberated. Silicate gangue particles are dark, barely distinguishable from the background.

SAMPLE AL-9:

Neg. 313-12: Shows wide particle size range, including coarse, liberated sphalerite (medium grey). Large buff-coloured grain at upper centre is pyrrhotite. Small triangular grain adjacent to it (less brownish) is pyrite.

SAMPLE AL-13

Neg. 313-13: Liberated sulfides. These are mainly pyrrhotite (buff colour) and pyrite (cream colour). Grey grain at lower right centre is magnetite. Slightly more brownish grey grain at extreme bottom right is sphalerite. Silicate gangue particles are dark grey, just distinguishable from the background. Note wide size range, including some notably coarse particles (e.g. rectangular grain, bottom left).

SAMPLE AL-15

Neg. 313-14: Note increased sulfide content compared with previous samples. Principal sulfides are pyrrhotite and pyrite (colour key as before). Grey grains at bottom left are magnetite. Small grey grain with lighter speckles (lower centre) is sphalerite.

SAMPLE AL-19

Neg. 313-15: High content of liberated sulfides. Note extreme dominance of pyrite (cream colour) over pyrrhotite (two brecciated buff-coloured grains, centre right). Grey grains are magnetite (upper left) and sphalerite (two grains at lower right centre).

LAND TAILS

Neg. 313-16: Cream-coloured grains are pyrite. Yellow grains locked in a silicate particle (centre) are chalcopyrite. Adjacent grey grain is magnetite. Diffuse lighter rims and cellular textures in some of the gangue particles are limonite. Pyrite has no limonite rims, but shows irregular, corroded shapes indicative of leaching.

Neg. 313-17: Shows chalcopyrite (yellow) as a fresh, liberated particle (centre top) and as core to earthy limonite (centre bottom).

STATION A-1

SAMPLE AL-39

Neg. 313-20: Shows area of relatively abundant small pyrite framboids. These are sometimes within organic flocs (darker grey outlines) and partly "free floating". Note speckling of dust-sized pyrite specks (cream colour) in some of the organic flocs. These may represent redistributed slimes-sized tailings, or could be of biogenic origin.

Neg. 313-21: Same field as 313-20, but transmitted light. Shows sub-opaque, brownish, organic flocs. Note skeletal micro-organisms at bottom right.

Neg. 313-22: Scale 1cm = 21 microns. High magnification to show detail of authigenic Fe sulfides. Note colour variation (sharply-defined, cream-coloured pyrite framboids, cemented by a loosely aggregated brownish variant).

Neg. 313-23: Shows rare particles of crystalline pyrite (cream colour). Organic flocs (dark smudges) are sometimes speckled with dust-sized pyrite (compare Neg. 313-20).

SAMPLE AL-42

Neg. 313-19: Field showing a pyrite framboid (top left) of authigenic origin, and an angular grain of crystalline pyrite (top right) of clearly detrital (possibly tailings-related) origin. Diffuse, dark smudges are organic flocs. Field also includes several grains of detrital silicates (distinguishable by their thin dark outlines; e.g. upper left centre).

SAMPLE AL-47

Neg. 313-24: Example of the slightly larger individual pyrite framboids seen in this sample. Note that these are all "free floating" rather than enveloped in organic ooze (dark smudges). Note occasional detrital silicate grains (outlined by thin dark rims: e.g. centre right; bottom left centre).

SAMPLE AL-1 (Slide 93-392X)

Estimated mode

Pyrite	14.5
Pyrrhotite	20
Arsenopyrite	trace
Chalcopyrite	0.7
Sphalerite	0.3
Magnetite	trace
Silicates	63
Organic ooze	1

This sample has a particle size range of 2 - 100 microns. Sulfide particles rarely exceed 70 microns in size, and are predominantly 50 microns or less.

Sulfides consist principally of pyrrhotite and pyrite. Very minor accessory chalcopyrite and sphalerite are also present. The sulfides are almost entirely in the form of liberated particles.

Both pyrrhotite and pyrite appear fresh, without visible indication of oxidation.

The bulk of the sample is made up of silicate grains - constituting the gangue fraction of the tailings. This consists predominantly of quartz and/or feldspar, with accessory hornblende, chlorite and biotite.

A very minor proportion of translucent, brown, flocculated, organic/ferruginous material is present. This presumably derives from a thin skin of lake bottom ooze overlying the tailings accumulation.

SAMPLE AL-2 (Slide 93-393X)

Estimated mode

Pyrite	17.5
Pyrrhotite	19.5
Arsenopyrite	trace
Chalcopyrite	0.7
Sphalerite	0.5
Galena	trace
Magnetite	0.2
Silicates	61.5
Organic ooze	trace

This sample has a particle size range of 2 - 80 microns, plus rare grains to 100 microns. Sulfide particles (liberated grains) do not exceed 50 microns.

Mineralogically it is essentially identical to Sample AL-1. The gangue component includes rare traces of carbonate.

SAMPLE AL-6 (Slide 93-394X)

Estimated mode

Pyrite	17
Pyrrhotite	17.5
Chalcopyrite	0.3
Sphalerite	0.2
Magnetite	trace
Galena	trace
Silicates	64.5
Organic ooze	0.5

This sample has a predominant particle size range of 2 - 70 microns, plus occasional grains to 100 microns. Sulfides seldom exceed 60 microns.

The sulfide mineralogy is similar to that of the previous two samples, consisting essentially of pyrite and pyrrhotite in approximately equal proportions.

SAMPLE AL-9 (Slide 93-395X)

Estimated mode

Pyrite	22.5
Pyrrhotite	15
Arsenopyrite	trace
Chalcopyrite	0.5
Sphalerite	3.4
Magnetite	0.1
Silicates	53.5
Organic ooze	5

This sample has a particle size range of 2 - 100 microns, plus occasional grains to 170 microns. The mean particle size is significantly higher than in previous samples.

As in the previous samples, pyrite and pyrrhotite are the principal sulfides; however, this sample is distinctive in that pyrite is substantially more abundant than pyrrhotite. There is also a greatly increased abundance of sphalerite, often as relatively coarse grains (to 150 microns or more).

These features suggest that the tailings from this depth were produced under different mill operating conditions (increased grind size and lower efficiency of sphalerite recovery) and/or by treatment of feed of a somewhat different mineralogy compared with that yielding the overlying (more recent) tails.

Another distinctive feature is the relatively high content of brown organic/ferruginous flocs - possibly reflecting a hiatus in the influx of tailings and a resultant period of accumulation of natural lake-bottom ooze.

SAMPLE AL-13 (Slide 93-396X)

Estimated mode

Pyrite	23
Pyrrhotite	25
Arsenopyrite	trace
Chalcopyrite	trace
Sphalerite	0.5
Magnetite	1.5
Silicates	50

This sample has a particle size range of 5 - 180 microns.

The total abundance of pyrite plus pyrrhotite is substantially higher in this material than in previous samples, and these minerals constitute some of the coarsest grains in the product. This sample has a similar pyrite content to AL-9, but a pyrrhotite:pyrite ratio of around unity, as in AL-1, 2 and 6.

Grey, low-reflective grains are relatively abundant, but the majority of these seem to be opaque rather than translucent - suggesting magnetite rather than sphalerite. These two minerals have similar colour and reflectivity, and are difficult to differentiate in particulate form. Chalcopyrite is notably rare.

SAMPLE AL-15 (Slide 93-397X)

Estimated mode

Pyrite	27.5
Pyrrhotite	32
Arsenopyrite	trace
Chalcopyrite	0.2
Sphalerite	0.7
Magnetite	1.5
Silicates	38
Organic ooze	trace

This sample has a predominant size range of 5 - 100 microns, plus scattered grains (including pyrite and pyrrhotite) to 180 microns.

It continues the trend of increasing total sulfide content with depth apparent in the previous sample. In this case the combined pyrite and pyrrhotite content is still higher. As in Al-13, pyrrhotite is slightly dominant over pyrite, and many of the grey medium reflective grains appear to be magnetite rather than sphalerite.

SAMPLE AL-19 (Slide 93-398X)

Estimated mode

Pyrite	57
Pyrrhotite	8.5
Sphalerite	2
Magnetite	0.5
Silicates	32
Organic ooze	trace

This sample has a particle size of 5 - 150 microns.

It is unique in having the highest total sulfide content of all the tailings in the suite, and especially for the fact that pyrite is strikingly dominant over pyrrhotite. Both Fe sulfides are homogenous and fresh.

Most of the grey, moderately reflective grains in this sample appear to be sphalerite rather than magnetite. Chalcopyrite, on the other hand, is notably absent.

The markedly different (pyrite-rich) composition of this sample strongly suggests that it relates to a period of processing of different feed material to that represented by the overlying tailings.

SAMPLE AL-LND (Slide 93-405X)

Estimated mode

Pyrite	6.5
Chalcopyrite	0.8
Magnetite	5.5
Limonite	39
Silicates	48

This is a relatively coarse product, having a predominant particle size range of 20 - 200 microns, plus occasional grains to 400 microns.

The sulfide content is low, but was probably originally much higher - as indicated by the abundance of limonite. This occurs ubiquitously as diffuse stains on silicate particles, but the bulk of it is in the form of discrete, earthy to compact or boxwork-textured particles, comparable in size to the silicates, and presumably representing totally oxidized pseudomorphs of original sulfide particles.

The surviving sulfides consist of pyrite and minor chalcopyrite. These mostly appear fresh and unaltered, without evidence of oxidation (in the form of peripheral rimming by limonite). However, the pyrite grains sometimes show ragged, embayed outlines indicative of the effect of leaching. Very rare examples were seen of specks of chalcopyrite as cores to compact limonite grains.

A proportion of the limonite grains show streaky/platy features suggestive of their derivation by alteration of pyrrhotite. No fresh pyrrhotite survives. It seems likely (though cannot be proved) that the majority of the limonite pseudomorphs represent original pyrrhotite. If so, this mineral may have predominated over pyrite in the original composition. On the other hand, a large proportion of original pyrite may have been totally reshaped by leaching.

The apparent absence of sphalerite, the abundance of magnetite, and the overall coarseness of the grind suggest that this tailings may relate to an early milling operation, possibly processing a different feed material to that represented by the lake tailings.

SAMPLE AL-37 (Slide 93-399X)

Estimated mode

Organic detritus	99
Silicate grains	1
Crystalline sulfides	trace
Framboidal pyrite	trace

This sample consists (as do all the normal lake sediments) predominantly of brown, translucent, organic debris, often showing cellular structures of vegetal origin and incorporating skeletal micro-organisms.

Sparsely scattered silicate grains, 20 - 100 microns in size, appear to be mainly quartz.

Very rare, small grains of crystalline sulfides, 20 - 50 microns in size, are mainly pyrite, though pyrrhotite and chalcopyrite were also recognized. These sulfide particles all appear fresh. A component of extremely fine-grained sulfide specks, 0.2 - 2.0 microns in size, which also appear to be of crystalline type, occurs incorporated within the organic flocs.

Rare traces of biogenic pyrite are also present, as tiny, individual framboids, 5 - 20 microns in size (rarely to 30 microns). These are sometimes free, and sometimes incorporated within organic flocs.

SAMPLE AL-39 (Slide 93-406X)

Estimated mode

Organic detritus	97.5
Silicate grains	2
Crystalline sulfides	trace
Framboidal pyrite	0.3

This sample is of similar general character to the previous one, being composed essentially of brown organic flocs.

Silicates are somewhat more abundant than in Al-37, occurring mainly as tiny specks 10 - 20 microns in size, plus rare, coarser grains to 120 microns. They appear to be mainly quartz, possibly with a little accessory feldspar and hornblende.

Crystalline sulfides are present in similar (low trace) concentration to the previous sample. They are seen as grains 20 - 50 microns in size and include recognizable pyrite, pyrrhotite and chalcopyrite. Occasional Fe oxide grains are also seen. Sub-micron sized sulfide specks incorporated within organics are rather widespread. These presumably represent dispersed slimes-sized tailings material. All sulfides appear fresh.

Pyrite framboids are perceptibly more abundant than in Al-37, though no larger. They are typically occur as discrete individuals, 5 - 20 microns in size, mostly independent of the organic flocs. Very rare examples of small clusters of tiny framboids within organic ooze were also seen.

SAMPLE AL-42 (Slide 93-400X)

Estimated mode

Organic detritus	96
Silicate grains	4
Crystalline sulfides	trace
Framboidal pyrite	trace

This sediment is distinctive for its relatively high content of silicate mineral grains. These mainly range from 20 - 150 microns in size, but rare individuals to 300 microns were seen. They are mainly quartz, plus accessory feldspar, biotite, hornblende and rare carbonate. They are typically angular, occasionally sub-rounded.

These scattered silt to sand-sized silicate grains may represent a component of redistributed tailings, or may be of normal detrital derivation (introduced by natural drainage into the lake). The fact that there is no increased abundance of crystalline sulfides in this sample tends to suggest that the second mechanism is the dominant one.

Crystalline sulfides are, in fact, particularly low (even more so than in the previous two samples). The occasional grains seen include pyrrhotite as well as pyrite. Sub-micron sulfide slimes are seldom seen.

Framboidal pyrite is also extremely rare in this sample.

SAMPLE AL-44 (Slide 93-401X)

Estimated mode

Organic detritus	97
Silicate grains	3
Crystalline sulfides	faint trace
Framboidal pyrite	trace

The abundance of silicate grains (quartz, feldspar and hornblende) is similar to that in Al-42. They are angular particles ranging up to 200 microns in size.

Crystalline sulfides (including the sub-micron specks in organics noted in Samples AL-37 and 39) are rare to the point of virtual absence.

Individual pyrite framboids are likewise very sparse. However, this sample is distinguished by the presence of occasional coarser fragments (to 100 microns) of compact, minutely fine-grained Fe sulfides of biogenic/precipitated aspect, exhibiting a distinctive brownish colour.

SAMPLE AL-47 (Slide 93-402X)

Estimated mode

Organic detritus	95.5
Silicate grains	4
Crystalline sulfides	trace
Framboidal pyrite	0.2

Silicates are of similar abundance as in AL-42. They occur as liberated grains, 20 - 200 microns in size, mainly of sharply angular shape. They consist mainly of quartz, with accessory feldspar and hornblende.

Crystalline sulfides are extremely rare, but do include one or two relatively coarse, sharply angular grains of pyrite, to 100 microns in size - almost certainly indicative of a minor component of tailings. One or two similar-sized grains of magnetite were also seen.

Framboidal pyrite is slightly more abundant than in some other samples, but still very minor. Framboids are less numerically abundant than in, say, AL-39, but tend to be somewhat larger (individuals to 50 microns). One example was seen of a small cluster of tiny framboids cemented by the brownish cryptocrystalline Fe sulfide variant.

SAMPLE AL-49 (Slide 93-403X)

Estimated mode

Organic detritus	97
Silicate grains	3
Framboidal pyrite	trace

This sample contains a silicate component comparable in abundance and form to that of Samples 42, 44 and 47. This consists of individual liberated grains, 20 - 150 microns in size - mainly quartz, plus accessory hornblende.

The sample appears to be totally devoid of crystalline sulfides, though one or two grains of Fe oxide were noted.

Biogenic pyrite is at a similar (low) level to that seen in most of the samples, consisting of very sparse, individual framboids, 5 - 30 microns in size.

SAMPLE AL-52 (Slide 93-404X)

Estimated mode

Organic detritus	94
Silicate grains	6
Crystalline sulfides	faint trace
Framboidal pyrite	faint trace

This sample has the highest content of silicate grains of all the "normal" sediment samples. These are angular to sub-angular liberated grains, 20 - 200 microns in size, plus rare, coarser clasts to 500 microns. Quartz is the dominant mineral, plus feldspar, biotite and hornblende.

Interestingly, there is no correlation between the relatively abundant silicate component and the content of sulfides - crystalline pyrite being extremely rare (and of very small average particle size - never exceeding 30 microns), and the framboidal form almost equally so.

Appendix D - Sediment Data

APPENDIX D-1 - SEDIMENT DATA

The distribution of sediment samples for both Winter and Summer Surveys was identical; major and minor element analyses were performed by ASL while C, N and S measurements were conducted at UBC. Concentrations of major and minor elements including Si, Al, K, Mg, Na, Fe, Mn, S, organic C, carbonate C, total N, Zn, Cu, Pb, Cd, Ni, Co, Cr, Hg and As were determined on the solid-phase portion of the core sections. Water content of these samples was also determined. The methods employed in the analyses of these samples can be found in Appendix F.

Appendix D-1
Sediment Data-Anderson Lake Winter Survey

ANDERSON LAKE WINTER SURVEY

		AND A1 0-0.5	AND A1 0-0.5 LRep.	AND A1 0.5-1	AND A1 1-1.5	AND A1 1.5-2
Total Metals						
Aluminum	T-Al	41800	-	49600	46500	40900
Arsenic	T-As	171	-	194	208	213
Cadmium	T-Cd	4.11	-	6.23	7.63	6.16
Chromium	T-Cr	66.4	-	62.7	61.4	51.3
Cobalt	T-Co	42.9	-	58.3	60.2	50.9
Copper	T-Cu	1140	-	1500	1600	1400
Iron	T-Fe	80900	-	72000	85100	81300
Lead	T-Pb	606	-	768	822	603
Magnesium	T-Mg	9430	-	10700	10100	9180
Manganese	T-Mn	254	-	293	278	273
Mercury	T-Hg	1.22	-	1.51	1.48	1.06
Nickel	T-Ni	26.7	-	28.5	32.1	29.9
Potassium	T-K	12200	-	13900	12800	11200
Sodium	T-Na	6550	-	7080	6540	6000
Zinc	T-Zn	2410	-	3680	4060	3120
Other Parameters						
Total Sulphur	%S	3.00	-	3.94	5.46	5.86
Total Nitrogen	%N	1.92	-	1.78	1.68	1.74
Total Carbon	%C	18.6	-	17.2	16.3	17.8
Calcium Carbonate	%$CaCO_3$	0.127	0.169	0.097	0.066	0.072

Results are expressed as milligrams per dry kilogram except where noted.
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LRep. = Laboratory Replicate.

		AND A1 2-3	AND A1 3-4	AND A1 4-5	AND A1 5-6	AND A1 6-8
Total Metals						
Aluminum	T-Al	38100	32900	28900	32100	30000
Arsenic	T-As	144	117	87.0	59.4	35.2
Cadmium	T-Cd	3.38	1.48	0.78	0.64	0.90
Chromium	T-Cr	49.5	44.6	45.2	49.3	39.5
Cobalt	T-Co	36.9	25.9	20.9	17.5	15.3
Copper	T-Cu	1020	715	539	490	361
Iron	T-Fe	68700	49500	37500	35000	28300
Lead	T-Pb	330	191	135	123	88.3
Magnesium	T-Mg	7690	6870	5820	5500	5450
Manganese	T-Mn	238	198	150	138	136
Mercury	T-Hg	0.750	0.491	0.315	0.234	0.157
Nickel	T-Ni	25.8	22.9	23.9	23.0	23.9
Potassium	T-K	10900	9560	8320	8490	7590
Sodium	T-Na	5800	5480	4930	4770	4360
Zinc	T-Zn	1560	798	439	369	311
Other Parameters						
Total Sulphur	%S	4.86	3.74	2.66	2.45	2.27
Total Nitrogen	%N	1.92	2.18	2.19	2.42	2.46
Total Carbon	%C	20.4	24.1	24.5	27.0	27.3
Calcium Carbonate	%$CaCO_3$	0.041	0.041	0.030	0.035	0.071

Results are expressed as milligrams per dry kilogram except where noted.
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RESULTS OF ANALYSIS **File No. D2918**

		AND A1 6-8 LRep.	AND A1 8-10	AND A1 8-10 LRep.	AND A1 10-12	AND A1 12-14
Total Metals						
Aluminum	T-Al	-	31600	30600	29000	27300
Arsenic	T-As	37.6	20.9	-	18.2	9.08
Cadmium	T-Cd	0.82	1.56	-	1.14	0.35
Chromium	T-Cr	-	41.4	38.9	36.7	34.9
Cobalt	T-Co	16.9	18.1	-	22.2	12.8
Copper	T-Cu	364	233	-	122	54.0
Iron	T-Fe	-	28200	27300	25600	21600
Lead	T-Pb	91.8	54.6	-	29.5	14.7
Magnesium	T-Mg	5690	5330	-	5310	5510
Manganese	T-Mn	141	139	-	155	166
Mercury	T-Hg	0.180	0.083	-	0.066	0.057
Nickel	T-Ni	25.3	25.1	-	25.5	21.7
Potassium	T-K	-	8000	7750	7260	6910
Sodium	T-Na	-	4430	4300	4010	3770
Zinc	T-Zn	316	489	-	520	136
Other Parameters						
Total Sulphur	%S	-	2.25	-	2.16	1.85
Total Nitrogen	%N	-	2.43	-	2.50	2.45
Total Carbon	%C	-	27.2	-	27.9	27.9
Calcium Carbonate	%$CaCO_3$	0.073	0.034	-	0.026	0.035

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		AND A1 12-14 LRep.	AND A1 14-18	AND A1 18-22	AND A1 22-26	AND A1 26-30
Total Metals						
Aluminum	T-Al	-	31400	35100	38700	38000
Arsenic	T-As	9.26	5.30	2.34	1.97	1.95
Cadmium	T-Cd	0.37	0.30	0.14	0.12	0.26
Chromium	T-Cr	-	39.2	47.8	48.5	52.8
Cobalt	T-Co	12.5	10.1	9.7	11.5	10.0
Copper	T-Cu	52.9	48.9	46.1	45.9	43.1
Iron	T-Fe	-	22200	22000	21500	20000
Lead	T-Pb	14.5	10.1	7.7	7.3	6.4
Magnesium	T-Mg	5350	6270	6810	7590	7610
Manganese	T-Mn	161	191	224	251	237
Mercury	T-Hg	0.055	0.048	0.045	0.040	0.038
Nickel	T-Ni	24.5	25.7	30.4	33.7	34.0
Potassium	T-K	-	7640	8710	9270	10800
Sodium	T-Na	-	4080	4310	4560	5300
Zinc	T-Zn	132	85.4	86.8	87.9	88.3
Other Parameters						
Total Sulphur	%S	-	1.57	1.35	1.08	0.93
Total Nitrogen	%N	-	2.42	2.44	2.40	2.35
Total Carbon	%C	-	28.1	28.4	28.1	27.7
Calcium Carbonate	%$CaCO_3$	-	0.021	0.014	0.004	0.082

Results are expressed as milligrams per dry kilogram except where noted.
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RESULTS OF ANALYSIS **File No. D2918**

		AND A1 26-30 LRep.	AND A2 0-0.5	AND A2 0.5-1	AND A2 0.5-1 LRep.	AND A2 1-1.5
Total Metals						
Aluminum	T-Al	36200	58000	42400	-	42300
Arsenic	T-As	2.00	233	215	-	226
Cadmium	T-Cd	0.22	5.11	7.64	-	7.23
Chromium	T-Cr	51.5	76.2	95.0	-	51.8
Cobalt	T-Co	10.1	39.3	48.4	-	57.1
Copper	T-Cu	42.6	1220	1600	-	1480
Iron	T-Fe	18900	31500	68300	-	79500
Lead	T-Pb	6.2	745	858	-	733
Magnesium	T-Mg	7500	9530	10300	-	9410
Manganese	T-Mn	234	260	284	-	273
Mercury	T-Hg	0.036	1.63	1.76	-	1.67
Nickel	T-Ni	34.1	26.5	29.4	-	29.4
Potassium	T-K	10400	14400	11200	-	11100
Sodium	T-Na	4950	6660	5840	-	5940
Zinc	T-Zn	87.8	2590	3890	-	3540
Other Parameters						
Total Sulphur	%S	-	3.18	4.77	-	5.71
Total Nitrogen	%N	-	1.91	1.70	-	1.70
Total Carbon	%C	-	38.1	17.0	-	17.4
Calcium Carbonate	%$CaCO_3$	0.086	0.149	0.098	0.112	0.097

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		AND A2 1.5-2	AND A2 2-3	AND A2 3-4	AND A2 4-5	AND A2 5-6
Total Metals						
Aluminum	T-Al	40800	36200	31400	29600	26300
Arsenic	T-As	243	171	117	73.2	62.6
Cadmium	T-Cd	5.72	3.81	1.96	1.20	1.27
Chromium	T-Cr	51.0	44.1	39.1	43.9	35.5
Cobalt	T-Co	50.2	40.0	29.9	24.0	21.8
Copper	T-Cu	1330	1040	715	497	374
Iron	T-Fe	71700	58900	45300	34300	29600
Lead	T-Pb	535	359	228	157	117
Magnesium	T-Mg	8870	7630	6310	5810	5140
Manganese	T-Mn	270	225	177	148	132
Mercury	T-Hg	1.34	0.927	0.528	0.328	0.172
Nickel	T-Ni	31.1	26.6	23.6	25.0	22.1
Potassium	T-K	10990	9550	8430	7840	7260
Sodium	T-Na	5780	5330	4900	4670	4040
Zinc	T-Zn	2710	1760	1030	623	488
Other Parameters						
Total Sulphur	%S	5.39	4.82	4.08	2.96	2.79
Total Nitrogen	%N	1.79	1.90	2.15	2.35	2.43
Total Carbon	%C	19.2	20.5	24.0	26.4	26.8
Calcium Carbonate	%$CaCO_3$	0.084	0.072	0.057	0.054	0.075

Results are expressed as milligrams per dry kilogram except where noted.
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LRep. = Laboratory Replicate.

		AND A2 5-6 LRep.	AND A2 6-8	AND A2 6-8 LRep.	AND A2 8-10	AND A2 8-10 LRep.
Total Metals						
Aluminum	T-Al	-	28800	-	26900	27700
Arsenic	T-As	-	40.8	40.7	21.0	-
Cadmium	T-Cd	-	1.72	1.68	1.13	-
Chromium	T-Cr	-	39.1	-	35.7	35.1
Cobalt	T-Co	-	20.2	22.8	21.0	-
Copper	T-Cu	-	252	252	143	-
Iron	T-Fe	-	30500	-	25500	25400
Lead	T-Pb	-	84.8	82.9	62.0	-
Magnesium	T-Mg	-	5260	5460	5150	-
Manganese	T-Mn	-	138	145	140	-
Mercury	T-Hg	-	0.127	0.132	0.092	-
Nickel	T-Ni	-	25.0	26.1	26.4	-
Potassium	T-K	-	7730	-	7150	7160
Sodium	T-Na	-	4220	-	3980	3970
Zinc	T-Zn	-	601	615	524	-
Other Parameters						
Total Sulphur	%S	-	2.56	-	2.29	-
Total Nitrogen	%N	-	2.53	-	2.46	-
Total Carbon	%C	-	27.4	-	27.2	-
Calcium Carbonate	%$CaCO_3$	0.075	0.064	-	0.036	-

Results are expressed as milligrams per dry kilogram except where noted.
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RESULTS OF ANALYSIS **File No. D2918**

		AND A2 10-12	AND A2 12-14	AND A2 14-18	AND A2 18-22	AND A2 18-22 LRep.
Total Metals						
Aluminum	T-Al	25900	25500	26400	32700	32300
Arsenic	T-As	14.3	11.2	6.42	2.36	2.32
Cadmium	T-Cd	0.65	0.45	0.27	0.17	0.15
Chromium	T-Cr	34.8	35.3	37.5	42.0	43.7
Cobalt	T-Co	16.2	11.4	10.3	10.2	10.7
Copper	T-Cu	83.2	63.9	44.7	45.2	44.3
Iron	T-Fe	21100	18000	16500	19300	19400
Lead	T-Pb	46.5	25.3	11.8	7.3	8.5
Magnesium	T-Mg	5100	5160	5280	6660	6590
Manganese	T-Mn	145	155	178	238	235
Mercury	T-Hg	0.083	0.073	0.060	0.051	0.048
Nickel	T-Ni	22.1	23.2	23.4	28.0	28.6
Potassium	T-K	6860	6660	6780	8250	8160
Sodium	T-Na	3720	3710	3670	4280	4260
Zinc	T-Zn	253	140	72.7	84.5	77.6
Other Parameters						
Total Sulphur	%S	1.89	1.54	1.43	1.21	-
Total Nitrogen	%N	2.47	2.48	2.47	2.48	-
Total Carbon	%C	27.2	27.6	28.0	27.6	-
Calcium Carbonate	%$CaCO_3$	0.061	0.042	0.065	0.080	0.067

Results are expressed as milligrams per dry kilogram except where noted.
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LRep. = Laboratory Replicate.

RESULTS OF ANALYSIS **File No. D2918**

		AND A2 22-26	AND A2 26-30	AND A2 0-0.5	AND B1 0.5-1	AND B1 0.5-1 LRep.
Total Metals						
Aluminum	T-Al	35700	39600	38700	37700	-
Arsenic	T-As	1.84	1.57	140	147	-
Cadmium	T-Cd	0.12	0.22	11.7	10.5	-
Chromium	T-Cr	48.3	53.8	56.2	87.6	-
Cobalt	T-Co	10.0	10.7	219	224	-
Copper	T-Cu	44.8	50.0	2470	2660	-
Iron	T-Fe	20700	22100	314000	332000	-
Lead	T-Pb	7.2	8.5	679	955	-
Magnesium	T-Mg	7310	8500	20100	17800	-
Manganese	T-Mn	279	320	845	729	-
Mercury	T-Hg	0.043	0.040	1.26	1.49	-
Nickel	T-Ni	30.5	37.5	28.9	22.7	-
Potassium	T-K	9180	10100	7720	6350	-
Sodium	T-Na	4420	4700	4900	4900	-
Zinc	T-Zn	78.6	94.8	6740	6130	-
Other Parameters						
Total Sulphur	%S	1.14	1.03	20.3	20.5	-
Total Nitrogen	%N	2.51	2.43	0.04	<0.01	-
Total Carbon	%C	27.9	28.2	0.23	0.14	-
Calcium Carbonate	%$CaCO_3$	0.083	0.034	0.222	0.314	0.452

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		AND B1 1-1.5	AND B1 1.5-2	AND B1 1.5-2 LRep.	AND B1 2-3	AND B1 2-3 LRep.
Total Metals						
Aluminum	T-Al	38100	38100	37200	38600	36800
Arsenic	T-As	185	204	206	185	-
Cadmium	T-Cd	10.1	10.9	10.7	8.85	-
Chromium	T-Cr	65.1	45.0	56.9	26.0	29.1
Cobalt	T-Co	263	249	253	245	-
Copper	T-Cu	3850	4830	5050	2480	-
Iron	T-Fe	339000	329000	324000	336000	332000
Lead	T-Pb	2810	2670	2570	2250	-
Magnesium	T-Mg	21600	22500	23400	21100	-
Manganese	T-Mn	765	778	805	787	-
Mercury	T-Hg	1.98	1.80	1.94	1.54	-
Nickel	T-Ni	22.7	22.2	18.5	16.2	-
Potassium	T-K	6660	5790	6040	6260	-
Sodium	T-Na	4000	3620	3820	3600	-
Zinc	T-Zn	6510	7030	7230	6040	-
Other Parameters						
Total Sulphur	%S	20.5	20.6	-	20.9	-
Total Nitrogen	%N	0.03	0.03	-	0.02	-
Total Carbon	%C	0.15	0.15	-	0.15	-
Calcium Carbonate	%$CaCO_3$	0.806	1.127	-	0.501	-

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RESULTS OF ANALYSIS **File No. D2918**

		AND B1 3-4	AND B1 4-5	AND B1 5-6	AND B1 5-6 LRep.	AND B1 6-8
Total Metals						
Aluminum	T-Al	42500	50700	46900	-	40900
Arsenic	T-As	256	511	819	728	933
Cadmium	T-Cd	12.9	14.5	23.4	27.4	11.3
Chromium	T-Cr	22.2	16.1	24.5	-	13.8
Cobalt	T-Co	199	243	253	258	320
Copper	T-Cu	1920	1630	1840	1830	1060
Iron	T-Fe	318000	283000	281000	-	323000
Lead	T-Pb	1770	1480	1940	-	611
Magnesium	T-Mg	24300	23300	18300	18400	18100
Manganese	T-Mn	844	669	671	673	673
Mercury	T-Hg	2.50	3.46	5.47	4.77	2.06
Nickel	T-Ni	5.2	12.6	22.4	18.1	21.8
Potassium	T-K	7350	8150	9530	-	7690
Sodium	T-Na	3720	3480	4830	-	4460
Zinc	T-Zn	7890	8940	15800	17000	7470
Other Parameters						
Total Sulphur	%S	19.8	20.1	20.6	-	22.8
Total Nitrogen	%N	0.04	0.06	0.12	-	0.02
Total Carbon	%C	0.30	0.48	1.13	-	0.09
Calcium Carbonate	%$CaCO_3$	0.869	1.022	1.107	-	1.457

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		AND B1 8-10	AND B1 8-10 LRep.	AND B1 10-12	AND B1 12-14	AND 12-14 LRep.
Total Metals						
Aluminum	T-Al	37500	37000	33800	30200	-
Arsenic	T-As	1000	1040	923	802	-
Cadmium	T-Cd	10.8	11.1	11.7	11.4	-
Chromium	T-Cr	7.9	15.9	15.4	10.0	-
Cobalt	T-Co	366	377	321	338	-
Copper	T-Cu	1120	1150	1080	1190	-
Iron	T-Fe	335000	326000	333000	353000	-
Lead	T-Pb	430	425	390	356	-
Magnesium	T-Mg	19600	19700	17900	17200	-
Manganese	T-Mn	812	775	772	709	-
Mercury	T-Hg	1.63	1.70	1.51	1.54	-
Nickel	T-Ni	16.1	19.1	21.3	13.5	-
Potassium	T-K	6640	6740	5490	5030	-
Sodium	T-Na	4585	4540	4380	4000	-
Zinc	T-Zn	7600	7740	7500	7780	-
Other Parameters						
Total Sulphur	%S	22.3	-	21.7	22.6	-
Total Nitrogen	%N	0.03	-	0.05	0.05	-
Total Carbon	%C	0.08	-	0.07	0.10	-
Calcium Carbonate	%$CaCO_3$	1.477	-	1.435	0.929	1.293

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RESULTS OF ANALYSIS **File No. D2918**

		AND B1 14-18	AND B1 18-22	AND B1 18-22 LRep.	AND B1 22-26	AND B1 26-30
Total Metals						
Aluminum	T-Al	30500	31000	-	38700	36500
Arsenic	T-As	869	970	962	834	733
Cadmium	T-Cd	11.5	11.1	12.1	17.3	16.7
Chromium	T-Cr	17.6	8.0	-	15.4	15.4
Cobalt	T-Co	339	321	324	261	267
Copper	T-Cu	1200	1170	1150	893	905
Iron	T-Fe	356000	351000	-	302000	332000
Lead	T-Pb	360	352	405	620	740
Magnesium	T-Mg	17800	16900	16700	18100	17900
Manganese	T-Mn	784	753	763	638	571
Mercury	T-Hg	1.56	1.49	1.39	2.92	3.28
Nickel	T-Ni	14.2	11.7	13.0	8.4	17.9
Potassium	T-K	5320	5650	-	7120	7250
Sodium	T-Na	3940	3790	-	3560	2790
Zinc	T-Zn	7940	7390	7690	11200	10600
Other Parameters						
Total Sulphur	%S	22.5	22.2	-	23.2	26.3
Total Nitrogen	%N	<0.01	0.07	-	0.03	0.02
Total Carbon	%C	0.06	0.07	-	0.05	0.14
Calcium Carbonate	%$CaCO_3$	1.197	1.183	-	1.215	0.816

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		AND B1 26-30 LRep.	**AND B2 0-0.5**	**AND B2 0-0.5 LRep.**	**AND B2 0.5-1**	**AND B2 1-1.5**
Total Metals						
Aluminum	T-Al	36200	34700	-	36800	35400
Arsenic	T-As	732	498	-	238	197
Cadmium	T-Cd	16.7	14.5	-	11.7	10.8
Chromium	T-Cr	15.7	51.8	-	88.0	71.7
Cobalt	T-Co	270	272	-	249	255
Copper	T-Cu	909	3180	-	3330	3650
Iron	T-Fe	327000	325000	-	331000	328000
Lead	T-Pb	724	1780	-	1620	1640
Magnesium	T-Mg	18300	17700	-	20500	19800
Manganese	T-Mn	608	710	-	810	729
Mercury	T-Hg	3.16	2.02	-	1.94	1.88
Nickel	T-Ni	13.9	17.1	-	31.6	13.6
Potassium	T-K	6690	5900	-	6370	6260
Sodium	T-Na	2745	3880	-	4270	3920
Zinc	T-Zn	10800	8880	-	7040	6700
Other Parameters						
Total Sulphur	%S	-	21.8	-	20.8	20.4
Total Nitrogen	%N	-	0.03	-	0.02	0.02
Total Carbon	%C	-	0.19	-	0.15	0.12
Calcium Carbonate	%CaCO$_3$	0.898	0.619	0.699	0.607	0.685

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		AND B2 1-1.5 LRep.	AND B2 1.5-2	AND B2 2-3	AND B2 3-4	AND B2 3-4 LRep.
Total Metals						
Aluminum	T-Al	-	35600	35800	36300	37100
Arsenic	T-As	213	193	184	203	205
Cadmium	T-Cd	12.2	10.4	9.95	10.1	9.77
Chromium	T-Cr	-	60.0	56.9	49.0	44.2
Cobalt	T-Co	267	263	248	256	265
Copper	T-Cu	3610	3510	3500	3530	3590
Iron	T-Fe	-	334000	339000	324000	330000
Lead	T-Pb	1800	1500	1950	2140	2120
Magnesium	T-Mg	20500	21200	21300	22900	23600
Manganese	T-Mn	805	824	808	802	852
Mercury	T-Hg	1.67	1.80	1.88	2.06	1.73
Nickel	T-Ni	15.3	19.3	24.3	23.7	19.0
Potassium	T-K	-	6530	6300	6540	6950
Sodium	T-Na	-	3800	3820	3630	3650
Zinc	T-Zn	7290	6570	6380	6660	6890
Other Parameters						
Total Sulphur	%S	-	21.0	20.6	20.4	-
Total Nitrogen	%N	-	0.02	0.02	0.02	-
Total Carbon	%C	-	0.14	0.13	0.14	-
Calcium Carbonate	%CaCO$_3$	-	0.603	0.696	0.873	-

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		AND B2 4-5	AND B2 5-6	AND B2 5-6 LRep.	AND B2 6-8	AND B2 8-10
Total Metals						
Aluminum	T-Al	38100	39400	-	44600	46500
Arsenic	T-As	229	336	332	804	1000
Cadmium	T-Cd	9.78	10.4	12.1	13.8	13.4
Chromium	T-Cr	24.0	17.9	-	18.5	16.2
Cobalt	T-Co	256	234	233	249	274
Copper	T-Cu	2630	1840	1760	1620	1400
Iron	T-Fe	327000	318000	-	295000	285000
Lead	T-Pb	1900	1830	2050	1240	1940
Magnesium	T-Mg	21200	22300	21500	20900	18700
Manganese	T-Mn	700	801	788	779	704
Mercury	T-Hg	1.72	1.94	1.79	2.83	2.75
Nickel	T-Ni	14.6	14.0	10.2	16.3	21.5
Potassium	T-K	7580	7080	-	8530	9160
Sodium	T-Na	3500	3590	-	4480	5400
Zinc	T-Zn	6630	7150	7400	9300	9650
Other Parameters						
Total Sulphur	%S	20.2	20.8	-	15.3	19.1
Total Nitrogen	%N	0.02	0.03	-	0.04	0.02
Total Carbon	%C	0.20	0.24	-	0.29	0.11
Calcium Carbonate	%$CaCO_3$	0.723	0.802	0.830	1.527	1.742

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RESULTS OF ANALYSIS **File No. D2918**

		AND B2 10-12	AND B2 12-14	AND B2 14-14 LRep.	AND B2 14-18	AND B2 14-18 LRep.
Total Metals						
Aluminum	T-Al	47000	43300	43000	38000	-
Arsenic	T-As	868	967	1040	919	-
Cadmium	T-Cd	11.3	17.0	17.2	15.8	-
Chromium	T-Cr	22.5	13.5	16.0	12.9	-
Cobalt	T-Co	263	268	284	314	-
Copper	T-Cu	1180	1150	1230	1130	-
Iron	T-Fe	301000	313000	315000	347000	-
Lead	T-Pb	3180	1830	1760	810	-
Magnesium	T-Mg	17600	14600	15700	17300	-
Manganese	T-Mn	703	548	592	698	-
Mercury	T-Hg	2.13	2.47	2.19	2.27	-
Nickel	T-Ni	11.5	21.5	15.2	20.1	-
Potassium	T-K	8860	8200	8260	6940	-
Sodium	T-Na	5640	5030	4980	4270	-
Zinc	T-Zn	8070	11700	12500	11400	-
Other Parameters						
Total Sulphur	%S	21.0	23.2	-	23.4	-
Total Nitrogen	%N	0.08	0.08	-	0.05	-
Total Carbon	%C	0.06	0.07	-	0.06	-
Calcium Carbonate	%$CaCO_3$	1.424	1.362	-	1.284	1.336

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		AND B2 18-22	AND B2 22-26	AND B2 22-26 LRep.1	AND B2 22-26 LRep.2	AND B2 26-30
Total Metals						
Aluminum	T-Al	39100	41600	-	-	38500
Arsenic	T-As	875	1250	1210	1190	854
Cadmium	T-Cd	14.6	11.5	14.2	13.0	15.0
Chromium	T-Cr	9.6	15.6	-	-	13.9
Cobalt	T-Co	282	266	263	262	278
Copper	T-Cu	1020	894	868	876	1510
Iron	T-Fe	357000	15000	-	-	327000
Lead	T-Pb	639	524	619	623	1400
Magnesium	T-Mg	16600	6300	15700	16000	16700
Manganese	T-Mn	585	627	612	623	621
Mercury	T-Hg	2.73	3.06	2.76	2.86	3.50
Nickel	T-Ni	2.4	22.4	17.8	19.7	4.0
Potassium	T-K	7310	7710	-	-	6610
Sodium	T-Na	4380	3910	-	-	3490
Zinc	T-Zn	10400	8280	8620	8690	10800
Other Parameters						
Total Sulphur	%S	24.6	24.5	-	-	20.0
Total Nitrogen	%N	<0.01	0.05	-	-	<0.01
Total Carbon	%C	5.00	0.04	-	-	0.04
Calcium Carbonate	%$CaCO_3$	1.152	1.472	-	-	1.228

Results are expressed as milligrams per dry kilogram except where noted.
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Appendix D-2

Sediment Data-Anderson Lake Summer Survey

ANDERSON LAKE SUMMER SURVEY

		AND Tail 0-0.5 cm	AND Tail 0-0.5 cm LRep.	AND Tail 0.5-1 cm	AND Tail 0.5-1 cm LRep.	AND Tail 1-1.5 cm
Total Metals						
Aluminum	T-Al	47900	-	40100	-	40100
Arsenic	T-As	47.1	48.4	169	-	162
Cadmium	T-Cd	3.67	-	13.7	-	13.3
Chromium	T-Cr	69.6	-	72.8	-	65.0
Cobalt	T-Co	59.6	58.1	180	180	161
Copper	T-Cu	691	711	2450	2390	2030
Iron	T-Fe	69400	-	205000	-	204000
Lead	T-Pb	294	295	781	-	681
Magnesium	T-Mg	11700	11100	19500	18300	16700
Manganese	T-Mn	332	340	707	692	631
Mercury	T-Hg	0.211	0.196	0.873	-	0.827
Nickel	T-Ni	37.6	27.1	27.3	-	22.7
Potassium	T-K	14300	-	9130	-	10100
Sodium	T-Na	7260	-	6410	-	6160
Zinc	T-Zn	1850	1890	7400	7350	6830
Other Parameters						
Total Sulphur	% S	3.90	-	5.75	-	5.22
Total Nitrogen	% N	1.53	-	0.32	-	0.39
Total Carbon	% C	14.43	-	2.98	-	3.62
Calcium Carbonate	% $CaCO_3$	0.04	-	0.21	-	0.14

Results for Total Metals are expressed as milligrams per dry kilogram.
Results for Total Sulphur, Total Nitrogen, Total Carbon and Calcium Carbonate are expressed as percent.
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File No. D5958

		AND Tail 1.5-2 cm	AND Tail 2-3 cm	AND Tail 2-3 cm LRep	AND Tail 3-4 cm	AND Tail 4-5 cm
Total Metals						
Aluminum	T-Al	41000	43700	42300	44300	42300
Arsenic	T-As	163	135	130	101	153
Cadmium	T-Cd	12.3	8.85	8.85	8.50	13.0
Chromium	T-Cr	66.4	82.3	80.4	77.2	69.9
Cobalt	T-Co	154	117	110	109	145
Copper	T-Cu	1980	1660	1580	1560	1930
Iron	T-Fe	203000	142000	139000	132000	190000
Lead	T-Pb	674	546	526	498	646
Magnesium	T-Mg	17100	16200	15500	15300	16800
Manganese	T-Mn	640	562	542	539	641
Mercury	T-Hg	0.830	0.604	0.615	0.513	0.806
Nickel	T-Ni	27.9	34.8	32.5	29.8	27.2
Potassium	T-K	8570	9570	10800	11800	11200
Sodium	T-Na	6370	6970	6810	6940	6590
Zinc	T-Zn	6520	4760	4530	4410	6310
Other Parameters						
Total Sulphur	% S	4.74	1.32	-	0.32	3.66
Total Nitrogen	% N	0.44	0.80	-	0.91	0.61
Total Carbon	% C	4.07	7.34	-	8.39	5.48
Calcium Carbonate	% $CaCO_3$	0.09	0.16	-	0.24	0.17

Results for Total Metals are expressed as milligrams per dry kilogram.
Results for Total Sulphur, Total Nitrogen, Total Carbon and Calcium Carbonate are expressed as percent.
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		AND Tail 5-6 cm	AND Tail 6-9 cm	AND Tail 6-9 cm LRep	AND Tail 9-11 cm	AND Tail 9-11 cm LRep.
Total Metals						
Aluminum	T-Al	42900	45200	45500	47700	-
Arsenic	T-As	147	122	118	134	-
Cadmium	T-Cd	10.9	6.28	5.67	3.80	-
Chromium	T-Cr	80.0	83.9	76.7	61.8	-
Cobalt	T-Co	126	102	95.0	53.0	49.9
Copper	T-Cu	1880	1220	1150	624	659
Iron	T-Fe	160000	98400	99000	59900	-
Lead	T-Pb	614	370	363	182	196
Magnesium	T-Mg	15500	13500	11800	10600	11000
Manganese	T-Mn	552	495	427	435	490
Mercury	T-Hg	0.740	0.489	0.462	0.426	-
Nickel	T-Ni	29.0	31.7	31.7	34.6	26.4
Potassium	T-K	11200	12000	10100	13900	-
Sodium	T-Na	6850	6970	7000	6880	-
Zinc	T-Zn	5650	3060	2820	1630	1760
Other Parameters						
Total Sulphur	% S	3.25	7.48	-	4.09	-
Total Nitrogen	% N	0.59	1.24	-	1.76	-
Total Carbon	% C	5.51	11.62	-	16.39	-
Calcium Carbonate	% $CaCO_3$	0.21	0.12	-	0.23	-

Results for Total Metals are expressed as milligrams per dry kilogram.
Results for Total Sulphur, Total Nitrogen, Total Carbon and Calcium Carbonate are expressed as percent.
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RESULTS OF ANALYSIS

File No. D5958

		AND Tail 11-13 cm	AND Tail 13-15 cm	AND Tail 13-15 cm LRep.	AND Tail 15-19 cm	AND Tail 15-19 cm LRep.
Total Metals						
Aluminum	T-Al	47800	47400	48200	46800	48500
Arsenic	T-As	64.4	361	-	772	792
Cadmium	T-Cd	2.00	9.86	-	16.0	14.0
Chromium	T-Cr	61.1	40.2	45.1	30.5	35.2
Cobalt	T-Co	42.0	139	-	223	211
Copper	T-Cu	338	2490	-	4010	3520
Iron	T-Fe	44500	110000	114000	142000	151000
Lead	T-Pb	91.0	533	-	936	887
Magnesium	T-Mg	9620	12100	-	15400	13000
Manganese	T-Mn	357	522	-	710	695
Mercury	T-Hg	0.240	1.82	-	3.00	2.37
Nickel	T-Ni	37.4	26.4	-	30.6	33.9
Potassium	T-K	13700	11800	12300	9950	11100
Sodium	T-Na	6910	6060	6000	5610	5650
Zinc	T-Zn	846	4970	-	8180	7540
Other Parameters						
Total Sulphur	% S	2.69	8.55	-	1.49	-
Total Nitrogen	% N	1.94	1.29	-	1.04	-
Total Carbon	% C	17.81	11.59	-	9.06	-
Calcium Carbonate	% $CaCO_3$	0.09	0.22	-	0.46	-

Results for Total Metals are expressed as milligrams per dry kilogram.
Results for Total Sulphur, Total Nitrogen, Total Carbon and Calcium Carbonate are expressed as percent.
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RESULTS OF ANALYSIS File No. D5958

		AND Tail 19-23 cm	AND Tail 19-23 cm LRep	AND Tail 23-27 cm	AND Tail 27-31 cm	AND Tail 27-31 cm LRep.
Total Metals						
Aluminum	T-Al	43100	42900	45200	52300	59000
Arsenic	T-As	135	130	11.7	7.60	7.50
Cadmium	T-Cd	3.27	3.63	<0.10	<0.10	<1.0
Chromium	T-Cr	52.3	51.9	61.7	71.5	77.5
Cobalt	T-Co	136	134	66.9	42.3	44.1
Copper	T-Cu	838	812	67.3	52.3	62.2
Iron	T-Fe	52100	51100	28000	29500	31800
Lead	T-Pb	210	219	27.9	32.7	35
Magnesium	T-Mg	9680	9380	8300	10400	11500
Manganese	T-Mn	361	345	324	356	413
Mercury	T-Hg	0.622	0.598	0.077	0.058	0.067
Nickel	T-Ni	33.3	36.7	39.8	41.0	38.0
Potassium	T-K	13100	12600	14100	11700	11200
Sodium	T-Na	6130	6130	6610	7650	8140
Zinc	T-Zn	1760	1720	185	169	186
Other Parameters						
Total Sulphur	% S	3.66	-	1.08	0.69	-
Total Nitrogen	% N	1.73	-	1.82	1.66	-
Total Carbon	% C	15.76	-	16.83	16.27	-
Calcium Carbonate	% $CaCO_3$	0.04	-	0.01	0.02	-

Results for Total Metals are expressed as milligrams per dry kilogram.
Results for Total Sulphur, Total Nitrogen, Total Carbon and Calcium Carbonate are expressed as percent.
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		AND Tail 31-35 cm	AND Tail 35-39 cm	AND Tail 35-39 cm LRep	AND Nat. 0-0.5 cm	AND Nat. 0.5-1.4
Total Metals						
Aluminum	T-Al	49100	57900	-	44800	39600
Arsenic	T-As	12.3	3.37	3.24	250	249
Cadmium	T-Cd	<0.10	<0.10	<0.10	5.78	7.40
Chromium	T-Cr	65.7	79.6	-	350	46.9
Cobalt	T-Co	53.2	20.4	18.8	56.4	64.9
Copper	T-Cu	57.7	45.4	43.5	1260	1550
Iron	T-Fe	28900	32100	-	66900	68100
Lead	T-Pb	31.1	9.6	10.8	766	768
Magnesium	T-Mg	10700	11700	11400	10400	9730
Manganese	T-Mn	384	435	423	287	296
Mercury	T-Hg	0.066	0.038	0.049	1.04	1.33
Nickel	T-Ni	43.6	50.6	44.5	28.7	32.4
Potassium	T-K	14000	16900	-	14100	11500
Sodium	T-Na	7150	8420	-	7020	5610
Zinc	T-Zn	210	143	128	3040	3900
Other Parameters						
Total Sulphur	% S	0.70	0.52	-	2.93	4.87
Total Nitrogen	% N	1.64	1.62	-	1.54	1.63
Total Carbon	% C	16.26	16.21	-	15.11	16.37
Calcium Carbonate	% $CaCO_3$	0.02	0.01	-	0.14	0.12

Results for Total Metals are expressed as milligrams per dry kilogram.
Results for Total Sulphur, Total Nitrogen, Total Carbon and Calcium Carbonate are expressed as percent.
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RESULTS OF ANALYSIS

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		AND Nat. 1.4-1.9	AND Nat. 1.9-2.4	AND Nat. 2.4-3.4	AND Nat. 3.4-4.4	AND Nat. 4.4-5.4
Total Metals						
Aluminum	T-Al	37200	34100	32100	28300	26800
Arsenic	T-As	180	142	142	102	91.8
Cadmium	T-Cd	6.74	6.46	5.71	4.23	3.40
Chromium	T-Cr	45.0	41.1	39.4	34.0	34.3
Cobalt	T-Co	60.0	55.0	46.7	33.8	32.8
Copper	T-Cu	1400	1390	1440	1130	1050
Iron	T-Fe	60800	50500	44200	32700	29000
Lead	T-Pb	617	531	500	377	348
Magnesium	T-Mg	8700	8230	8410	6670	6310
Manganese	T-Mn	275	264	269	206	188
Mercury	T-Hg	1.13	1.000	1.000	0.731	0.640
Nickel	T-Ni	32.6	22.9	29.0	24.2	23.6
Potassium	T-K	11100	9800	9530	8160	8200
Sodium	T-Na	5530	5230	4920	4460	4310
Zinc	T-Zn	3240	2860	2480	1620	1480
Other Parameters						
Total Sulphur	% S	4.59	4.16	3.47	2.87	2.61
Total Nitrogen	% N	1.74	1.93	2.08	2.22	2.27
Total Carbon	% C	18.31	20.38	22.14	24.30	25.05
Calcium Carbonate	% $CaCO_3$	0.11	0.15	0.04	0.03	0.04

Results for Total Metals are expressed as milligrams per dry kilogram.
Results for Total Sulphur, Total Nitrogen, Total Carbon and Calcium Carbonate are expressed as percent.
< = Less than the detection limit indicated.
LRep. = Laboratory Replicate.

RESULTS OF ANALYSIS File No. D5958

		AND Nat. 5.4-6.4	AND Nat. 6.4-8.4	AND Nat. 8.4-10.4	AND Nat. 10.4 - 12.4	AND Nat. 12.4 - 14.4
Total Metals						
Aluminum	T-Al	26400	26900	25300	24900	24200
Arsenic	T-As	82.1	86.1	56.4	34.3	21.4
Cadmium	T-Cd	3.85	4.55	3.11	2.04	1.47
Chromium	T-Cr	32.4	32.8	30.8	31.0	32.3
Cobalt	T-Co	35.8	40.0	39.6	23.3	18.0
Copper	T-Cu	1010	861	451	176	90.6
Iron	T-Fe	26100	27900	30800	24000	18700
Lead	T-Pb	306	243	102	54.1	36.3
Magnesium	T-Mg	6040	5820	5030	4990	4790
Manganese	T-Mn	183	186	176	174	157
Mercury	T-Hg	0.479	0.432	0.198	0.102	0.088
Nickel	T-Ni	30.4	20.5	25.5	23.5	23.3
Potassium	T-K	7870	7590	7140	7350	7020
Sodium	T-Na	4230	4250	3980	4060	3960
Zinc	T-Zn	1610	1940	1400	709	344
Other Parameters						
Total Sulphur	% S	2.53	2.87	3.24	2.51	1.93
Total Nitrogen	% N	2.29	2.32	2.38	2.40	2.45
Total Carbon	% C	24.96	25.10	25.60	26.24	26.57
Calcium Carbonate	% $CaCO_3$	0.14	0.05	0.05	0.06	0.08

Results for Total Metals are expressed as milligrams per dry kilogram.
Results for Total Sulphur, Total Nitrogen, Total Carbon and Calcium Carbonate are expressed as percent.
< = Less than the detection limit indicated.
LRep. = Laboratory Replicate.

		AND Nat. 14.4 - 18.4	AND Nat. 18.4 - 22.4	AND Nat. 18.4 - 22.4 LRep	AND Nat. 22.4 - 26.4	AND Nat. 26.4 - 30.4
Total Metals						
Aluminum	T-Al	25300	23700	23100	21800	19800
Arsenic	T-As	9.42	7.75	6.00	6.63	5.38
Cadmium	T-Cd	0.86	0.78	0.80	0.86	0.66
Chromium	T-Cr	35.0	33.1	32.5	30.1	28.2
Cobalt	T-Co	31.5	11.4	12.0	11.9	15.1
Copper	T-Cu	46.5	43.9	44.0	55.4	49.4
Iron	T-Fe	15600	12700	12500	11800	11500
Lead	T-Pb	25.0	17.6	16.0	18.3	13.2
Magnesium	T-Mg	5140	4960	5060	4830	4760
Manganese	T-Mn	165	157	161	158	163
Mercury	T-Hg	0.067	0.059	0.060	0.067	0.075
Nickel	T-Ni	24.8	22.5	21.0	19.8	22.5
Potassium	T-K	7780	7130	6660	6310	5760
Sodium	T-Na	4290	3980	3880	3580	3410
Zinc	T-Zn	147	86.5	88.2	106	96.8
Other Parameters						
Total Sulphur	% S	1.42	1.22	-	1.18	1.28
Total Nitrogen	% N	2.39	2.42	-	2.36	2.43
Total Carbon	% C	26.37	26.67	-	26.60	27.18
Calcium Carbonate	% $CaCO_3$	0.16	0.05	-	0.08	0.14

Results for Total Metals are expressed as milligrams per dry kilogram.
Results for Total Sulphur, Total Nitrogen, Total Carbon and Calcium Carbonate are expressed as percent.
< = Less than the detection limit indicated.
LRep. = Laboratory Replicate.

		AND Nat. 26.4 - 30.4 LRep
Total Metals		
Aluminum	T-Al	20500
Arsenic	T-As	5.48
Cadmium	T-Cd	0.72
Chromium	T-Cr	34.2
Cobalt	T-Co	13.1
Copper	T-Cu	47.3
Iron	T-Fe	11800
Lead	T-Pb	15.4
Magnesium	T-Mg	4660
Manganese	T-Mn	159
Mercury	T-Hg	0.067
Nickel	T-Ni	24.0
Potassium	T-K	6000
Sodium	T-Na	3470
Zinc	T-Zn	92.1
Other Parameters		
Total Sulphur	% S	-
Total Nitrogen	% N	-
Total Carbon	% C	-
Calcium Carbonate	% $CaCO_3$	-

Results for Total Metals are expressed as milligrams per dry kilogram.
Results for Total Sulphur, Total Nitrogen, Total Carbon and Calcium Carbonate are expressed as percent.
< = Less than the detection limit indicated.
LRep. = Laboratory Replicate.

Appendix E-1 - Porewater Data

APPENDIX E-1 - POREWATER DATA

Porewater analyses included dissolved Fe, Mn, Cu, Cd, Pb, Zn, Hg, and As in samples filtered sequentially through 0.45 μm and 0.1 μm filters, and ΣH_2S (fixed with Zn acetate), as well as SO_4^{2-} and NO_3^- where sample size permited. Measurements of pH were made on a select suite of porewaters where volume permitted. All porewater analyses were performed at UBC with the exception of As and Hg which were analyzed at ASL. Following are the data tables for the porewaters of both Anderson Lake Surveys.

Table E-1

Interstitial Water Data - Winter Survey

Depth (cm)	Fe µg/L	Rep	Mn µg/L	Rep	Zn µg/L	Rep	Cd µg/L	Rep	Pb µg/L	Rep	Cu µg/L	Rep	As µg/L	Hg µg/L	SO_4 µg/L	H_2S µg/L
Core And A-1																
Super	954		243		312	318	0.522	0.51	16.55	16	17.8	17.5				
Super	907		244		313		0.49		1.18	0.8	11.4					
0.25	12070	11890	227	229	21.4		0.016		0.53		0.4		0.6	0.06	1235	
0.75	6980		232		4.95		0.006		0.64		0.8		0	0	1323	
1.25	11530		243		8.26		0.032		0.34		0.37		0	0	1271	
1.75	10830		234		3.29		0.022		0.43		0.8		0	0.06	1090	
2.5	9400	10140	258		1.82		0.016		0.49		0.32		0	0	1359	
3.5	8790		259		1.33		0.001		0.18		0		2.8	0	1387	
4.5	12640		265		1.42		0.011		0.09		0.12		13.5	0	1422	
5.5	4400		278		1.34		0.008		0.25		0.2		11.1	0	1503	
7	3540		287		0.55		0.004		-0.05		-0.32		4.3	0	1592	
9	1690		304	314	0.42		0.008		0		-0.28		1.7	0	1643	
9	1613		309		0.42	0.3	0.004	0	-0.06		-0.26					
11	818		306		0.36		0.001		-0.09		-0.39		1.3	0	1744	
11	119		296		0.47		0.007		0.25		-0.11					
13	120		315		0.45		0.002		0.08		-0.3	-0.2	1.4	0.06	1700	
16	45.7	43.2	280		0.18		0.002		0		-0.07		1.6	0.05	1935	
16	43.3		272		0.59		0.01		0.17		0					
20	32.6		284		0.37		0		0.1		-0.31		0.8	0.06	2022	
24	13.7		301		0.27		-0.002		0.24		-0.22		0.7	0	1978	
24	13.7		305		0.49		0.002		0.22		-0.11					
28	737	761	445	461	0.54	0.5	0		0.13		-0.07	-0.2	4.3	0.07	1862	

Table E-2

Interstitial Water Data - Winter Survey

Depth (cm)	Fe µg/L	Rep	Mn µg/L	Rep	Zn µg/L	Rep	Cd µg/L	Rep	Pb µg/L	Rep	Cu µg/L	Rep	As µg/L	Hg µg/L	SO_4 µg/L	H_2S µg/L
Core And A-2																
Super	1596		243		301	309	0.392	0.394	13.6	12.2	8.05					
Super	1654		246		297		0.378		15.32		8.85					
0.25	12550		262		30.3		0.012		0.48		1.02		1.1	0.06		
0.75	21480		263		3.11		0.005		0.99		1.58		0	0.07	1182	
1.25	18580		237		3.54		0.008		0.66		2.74		0	0.08		
1.75	13610	12880	193		2.89		0.007		0.58		0.88		0	0		
2.5	15110		244		1		0		0.37		0.97		0	0	1306	
3.5	14050		265		1.71		0.01		0.23		0.81		1.3	0	1374	
4.5	9210		277	273	2.05		0.008		0.48		0.83		3.1	0.08	1431	
5.5	5610	6310	276		1.55		0.006		0.22		0.71		3.7	0.08	1479	
7	4080		327		0.78		0.002		0.48		0.35		8.6	0.15	1518	
7	4020		310		0.77		0.009		0.21		0.29					
9	1770		339		0.62		0.004		0.05		0.4		6	0	1671	
11	805	915	350	348	0.52	0.5	0.006	0.007	0.67	0.47	0.49		3	0	1671	
11	801		356		0.37		0.005		0.52		0.36					
13	198		359		0.31		0.004		0.57		0.5		2	0.06	1719	
16	30.5		344	360	1.39		-0.004		0.49		0.43		1.9	0	1931	
16	33.4		338		0.76		0.002		0.56		0.48					
20	12		356		0.39		0		0.57		0.15		0.8	0	1960	
20	15.1		365		0.22		0.001		0.08		0.34					
24	5.82	6.08	414		0.19		-0.001		0.15		0.22		0.9	0	1979	
24	6.31		405		0.42		0.001		0.11		0.37					
28	180		486		0.48		-0.005		0.05		0.29		0	0.07	2267	
28	191		450		0.89		0.005		0.07		0.3					
28	177		480		0.69	0.7	-0.001	0	0.09	0.02	0.17					

Table E-3

Interstitial Water Data - Winter Survey

Depth (cm)	Fe µg/L	Rep	Mn µg/L	Rep	Zn µg/L	Rep	Cd µg/L	Rep	Pb µg/L	Rep	Cu µg/L	Rep	As µg/L	Hg µg/L	SO_4 µg/L	H_2S µg/L	NO_3^- mmol/L
Core And B-1																	
Super	11390	11820	289		143	168	0.181	0.204	-0.076	0.18	0.71	0.58					0.021
Super	11430		278		154	155	0.138		0.018		-0.07						0.017
0.25	17300		615		9.39		0.007		-0.072		-0.82		30.5	0			0.004
0.75	22300		665		10.92		0.006		-0.036		-0.69		10.5	0			0.001
1.25	44000		686	658	4.87		0.007		0.067		-1.1		50	0.11			0.005
1.75	33800		712		4.95		0.012		-0.085		-1.34		81	0.09			0.01
2.5	30450		681		1.32		0.01		-0.247		-1.9		41	0.17	822		0.001
3.5	39700		645		1.82		-0.001		-0.25		-0.68		34.5	0.2	827		0.005
4.5	26300		635		1.51		0.006		-0.21		-1.1		19.4	0.14	826		0.005
5.5	23000		662		1.29		0.002		-0.23		-1.5		12.9	0.12	793		0.005
7	14300		616		0.77		0.001		-0.29		-1.7		4.6	0.13	786	42	0.004
7	17600		631		0.67		0		-0.32		-1.8						0.004
9	6200		597		0.92		0.002		-0.27		-2.1		3	0.08	798		0.002
9	5440	4700	587		0.82		0.004		-0.36		-1.2						0.004
11	425		294	289	0.79		0.003		-0.36		-1.8		4.1	0.1	740	74	0.002
13	227		193		0.11		0.005		-0.46	0.07	-2.3	-2.1	1.7	0.11	734		0.003
16	151		150		0.09		0.002		-0.36		-2.4		1.8	0.13	705	377	0.001
16	113	129	152		0.18		0.003		-0.39		-2.2						0.004
20	50.2		138		0.11		0.004		0.03		-2.5		0.9	0.1	693		0.002
20	39.3		137		0.18		0.002		-0.2		-2.3						0.001
24	46		126		1.32	1.8	0.003	0.005	0.06		-1.7		0	0.23	650	259	0.001
28	137		204		0.34	1.2	0.002		0.02	-0.09	-2.3	-2.3	0	0.17	623	237	0.001

Table E-4

Interstitial Water Data - Winter Survey

Depth (cm)	Fe µg/L	Rep	Mn µg/L	Rep	Zn µg/L	Rep	Cd µg/L	Rep	Pb µg/L	Rep	Cu µg/L	Rep	As µg/L	Hg µg/L	SO$_4$ µg/L	H$_2$S µg/L
Core And B-2																
Super	5110		253		137	130	0.033	0.031	0.06	0.14	-0.51					
Super	6520	6780	279	290	137		0.034		0.1		-0.25					
0.25	6360		626		11.3		0.007		0.18		-0.66		31	0.25	890	
0.75	7390		719		27.1		0.011		0.4		-0.42		29	0.19		
1.25	10670		655		21.4		0.007		0.32		0.14		37	0.23		
1.75	3820		575		26.1		0.006		0.36		-0.16		41	0.21		
2.5	23800		695		6.49		0.006		0.07		-0.25		30.5	0.18		
3.5	30700		791		2.4	2.9	0.001		0		-0.43		20	0.15		
4.5	20300		799		3.64		0		0.13		-0.47		19.9	0.17	736	
5.5	21620		828		4.64		0.001	0.005	0.27		-0.43	-0.4	15.9	0.24	720	
7	27080		839		4		0.001		0.22		-0.52		6.4	0.16	683	
9	13000		808		1.68		0.006		0.05		-0.62		4.8	0.18	670	89
11	3800		700		1.23		0.008		-0.09		-0.95		3.3	0.14	635	70
11	4240		744		1.28		0.007		0		-0.73					
13	595		461	455	0.77		0.009		0.07		-0.15		2.4	0.14	584	225
13	174		463		0.76		0.009		0.01		0.07					
16	31.5		225		0.19		0.004		-0.04		0.19		1.1	0.18	553	556
16	30.5		205		0.19		0.007		0.19		-0.27					
20	67		190		0.2		0.006		-0.03		-0.35		0	0.16	494	792
20	71.9		145		0.24		0.01		-0.01		0.02					
24	1.27		137		1.75		0.002		-0.21		0.06		0	0.06	445	704
28	0.19		114		2.04	2	0.023	0.012	-0.08	-0.14	-0.21		0	0.17	405	234

Table E-5

Anderson Lake Summer Survey 1993
Rescan Peeper #13 Right - Tailings Site

Depth (cm)	Fe (ppb)	Rep (ppb)	Mn (ppb)	Rep (ppb)	Cu (ppb)	Rep (ppb)	Pb (ppb)	Rep (ppb)	Cd (ppb)	Rep (ppb)
-10.08	278.3		200		42.4	39.8	65	68	0.69	
-8.82	293.7		247		42		66		0.69	
-7.56	297.4		244		43.1		66		0.67	
-6.3	309.1		235		43.8		65		0.69	
-5.04	270.1		260		42.8		65		0.7	
-3.78	267.5		243		41.2		62		0.74	
-2.52	499.4		252		37.4		56		0.72	
-1.26	665.5		282		30.6		43		0.69	
0	8517		417		1.7	1.6	1.1	1	0.11	0.1
1.26	9255		395		1.9		1.1		0.05	
2.52	7433	7344	499		2.3		1.2		0.05	
3.78	8890		493		1.8		1.9		0.04	
5.04	9151		520		1.9		1.3		0.04	
6.3	9054		471		1.9		0.9		0.03	
7.56	9641		516		2.1	2	0.9	1.8	0.04	0.03
8.82	10932		568		2.4		2.3		0.04	
10.08	12110		546		2.3		1.2		0.05	
11.34	11421		487		2		0.8		0.04	
12.6	10277		523		2		0.7		0.06	
13.86	9955		549		2		0.8		0.04	
15.12	10550		547		1.9		1.1		0.04	
16.38	11484		618		2.1		1.3		0.03	
17.64	13883		545		3.2		4.2		0.06	
20.16	11381		612		1.9		2.3		0.04	
22.68	12853		546		2.1	2.1	1.6	1.6	0.04	0.04
25.2	11605		642		1.8		0.5		0.04	
27.72	11363		607		1.6		0.2		0.03	
30.24	8520		620		1.6		0.3		0.03	
32.76	6727	7539	631		1.6		0.6		0.03	
35.28	8175	7388	647		1.9		0.5		0.03	

Table E-5 (cont.)

Anderson Lake Summer Survey 1993
Rescan Peeper #13 Right - Tailings

Depth (cm)	Zn (ppb)	Rep (ppb)	As (ppm)	Rep (ppm)	Hg (ppm)	NO_3^- (µg/L)	Ca (mg/L)	SO_4 (mg/L)	H_2S (uM)
-10.08	471	450	0.0016		<0.0001		331	798	
-8.82	504		0.0014		<0.0001		321	796	
-7.56	491		0.0014		<0.0001		321	775	
-6.3	470		0.0014		<0.0001			790	
-5.04	475		0.0021		<0.0001		339	783	
-3.78	484		0.0018		<0.0001			783	
-2.52	470		0.0016	0.0014	<0.0001			805	
-1.26	470		0.0015		<0.0001				0
0	77		0.0008		<0.0001				0
1.26	42		0.001		<0.0001				0
2.52	39		<0.0005		<0.0001				0
3.78	31		0.0005		<0.0001		676	1850	
5.04	24		0.0005		<0.0001		653	1802	
6.3	21		0.0006	0.0006	<0.0001		636	1817	
7.56	18	17	0.0007		<0.0001				0
8.82	16		0.0005		<0.0001			1687	
10.08	10		0.0005		<0.0001			1767	
11.34	8.3		0.0005		<0.0001				
12.6	9		<0.0005		<0.0001		677	1703	
13.86	8.1		<0.0005		<0.0001				0
15.12	9.4		0.0006		-				
16.38	11.2		<0.0005		<0.0001		685	1803	
17.64	21		-		<0.0001				
20.16	7.5		0.0005		<0.0001				
22.68	8.6	8.9	<0.0005		<0.0001				
25.2	9.4		0.0008		<0.0001		688	1768	
27.72	6.7		0.0005		<0.0001				0
30.24	7.7		<0.0005		<0.0001				
32.76	10.3		<0.0005		<0.0001			1812	
35.28	13.9		0.0005	0.0005	<0.0001				0

Table E-6

Anderson Lake Summer Survey 1993
Rescan Peeper #13 Left - Tailings Site

Depth (cm)	Fe (ppb)	Rep (ppb)	Mn (ppb)	Rep (ppb)	Cu (ppb)	Rep (ppb)	Pb (ppb)	Rep (ppb)	Cd (ppb)	Rep (ppb)
-8.82	185.2		265		38		72		0.73	
-7.56	196.4		218		38.4	39	68	78	0.68	0.59
-6.3	219.7		261		40		72		0.78	
-5.04	183.8		272		37.4		68		0.75	
-3.78	189.4		271		35.6		67		0.82	
-2.52	219.5		270		33.1		62		0.79	
-1.26	985.3		300		29		50		0.76	
0	7668		532		4.4		3.8		0.14	
1.26	8636		603		1.6		0.6		0.03	
2.52	8898		514		1.5	3.3	0.4	0.4	0.03	0.01
3.78	8484		611		1.5		0.2		0.03	
5.04	9848		538		1.6		0.5		0.03	
6.3	11262		649		1.6		0.7		0.03	
7.56	11181		574		2.4		2.6		0.03	
8.82	11171		633		2.1		2.1		0.05	
10.08	12123		623		1.4		0.2		0.03	
11.34	12373		707		1.4		0.1		0.03	
12.6	13940		713		1.6		0.3		0.03	
13.86	13656		690		1.7		0.4		0.03	
15.12	13079		664		1.4		0.2		0.03	
16.38	14887		726		1.7		0.2		0.05	
17.64	14981		708		2		0.2		0.06	
18.9	13294		686		3.2		0.1		0.06	
21.42	12829		705		2.6		0.3		0.05	
23.94	10375		675		2	2	0.1	0.1	0.05	0.05
26.46	11632		669		2.2		0.1		0.06	
28.98	11865		627		2		0.4		0.05	
31.5	12493		755		2.2		0.2		0.05	
35.28	12743		746		2.2		1.1		0.05	
37.8	11727		707		2		0.7		0.05	

Table E-6 (cont.)

Anderson Lake Summer Survey 1993
Rescan Peeper #13 Left - Tailings Site

Depth (cm)	Zn (ppb)	Rep (ppb)	As (ppm)	Rep (ppm)	Hg (ppm)	NO_3^- (µg/L)	pH	SO_4 (mg/L)	H_2S (uM)
-8.82	428		0.0018		<0.0001			780	
-7.56	422	442	0.0014		<0.0001			802	
-6.3	453		0.0014		<0.0001			822	
-5.04	458		0.0014		<0.0001			808	
-3.78	464		0.0012	0.0014	<0.0001			807	
-2.52	465		0.0011		<0.0001			835	
-1.26	433		0.001		<0.0001			915	
0	99	84	0.0006		<0.0001				0
1.26	22		0.0009		<0.0001				0
2.52	12	15	0.0006		<0.0001				0
3.78	7.5		0.0009		<0.0001				0
5.04	7.2		0.0008		<0.0001			1809	
6.3	7.8		0.0008		<0.0001			1820	
7.56	15.9		0.0014		<0.0001			1762	
8.82	13.8		0.0013		<0.0002				0
10.08	7.2		0.0011		<0.0001			1912	
11.34	6.4		0.0009		<0.0001			1961	
12.6	6.5		0.0008	0.0007	<0.0001				
13.86	8				<0.0001			1937	
15.12	6		0.0006		<0.0001				0
16.38	8		0.0005		<0.0001				
17.64	10		0.0007		<0.0001			1837	
18.9	12.1		0.0008		<0.0001				
21.42	11.9		<0.0005		<0.0001				
23.94	11.5	10.8	0.0007		<0.0002				
26.46	11.1		0.0007		<0.0001				
28.98	10.6		0.0007	0.0008	<0.0001			1672	
31.5	12.4		<0.0005		<0.0001				0
35.28	12.4		0.0008		<0.0001			1789	
37.8	11.4		0.001		<0.0001				0

Table E-7

Anderson Lake Summer Survey 1993
Rescan Peeper #12 Right - Tailings Site

Depth (cm)	Fe (ppb)	Rep (ppb)	Mn (ppb)	Rep (ppb)	Cu (ppb)	Rep (ppb)	Pb (ppb)	Rep (ppb)	Cd (ppb)	Rep (ppb)
-10.08	298.8		283		41		80		0.61	
-8.82	232.5		247		41		81		0.56	
-7.56	324.9		269		46	42	93	82	0.69	0.61
-6.3	223.7		280		40		79		0.58	
-5.04	243.6		294		41		91	78	0.71	0.66
-3.78	252.2		276		38		77		0.59	
-2.52	979.5	1028	305		35		83		0.64	
-1.26	644.9		319		21		48		0.49	
0	1541	1533	394		7.8	8.6	14	17	0.34	0.26
1.26	7405	7606	588		3.7	3.7	5.1		0.04	
2.52	3961	4625	560		2.2		2.9		0.03	
3.78	4185	4063	551		3.7		4.9		0.03	
5.04	6552	6753	631		3.8		3.1		0.04	
6.3	3900	5990	530		3.5		2		0.03	
7.56	7077		573		6		5.4		0.05	
8.82	8557		385		4.1		2.4		0.05	
10.08	0		0	0	0.1	0	0.03	0.04	0.05	0.03
11.34	7343		599		4.2		2.2		0.04	
12.6	7171		555		4		2.2		0.04	
13.86	9332		614		3.9	4.3	2.4	2.5	0.04	0.03
15.12	0		0		0	0	0.02	0.02	0.05	0.04
16.38	7856		604		4.6		3.9		0.05	
17.64	7798		611		3.8		3.4		0.04	
20.16	8639		600		4.7		3.2		0.05	
22.68	9311		605		4.1		1.7		0.04	
25.2	8528		558		3.7		0.9		0.04	
27.72	8848		536		3.4		0.8		0.03	
30.24	7097		542		3.7		2		0.03	
32.76	6367		536		3.2		1.3		0.02	
35.28			527		3.5	3.4	1.3	1.3	0.02	0.02

Table E-7 (cont.)

Anderson Lake Summer Survey 1993
Rescan Peeper #12 Right - Tailings Site

Depth (cm)	Zn (ppb)	Rep (ppb)	As (ppm)	Rep (ppm)	Hg (ppm)	NO_3^- (µg/L)	pH	SO_4 (mg/L)	H_2S (uM)
-10.08	433		0.0013		<0.0001			828	
-8.82	443		0.001		<0.0001			827	
-7.56	475	449	0.0013	0.0014	<0.0001			866	
-6.3	444		0.0013		<0.0001			861	
-5.04	452	471	0.0013		<0.0001			850	
-3.78	457		0.0011		<0.0001			830	
-2.52	480		0.0011		<0.0001			885	
-1.26	427		0.001		<0.0001				0
0	312		0.0005		<0.0001				0
1.26	62		0.0009	0.001	<0.0001				0
2.52	51		0.0005		<0.0001				0
3.78	51		0.0006		<0.0001			1792	
5.04	41		0.0005		<0.0001			1701	
6.3	31		<0.0005		<0.0001			1991	
7.56	40		<0.0005		<0.0001				0
8.82	26		0.0007	0.001	<0.0001			1778	
10.08	0.4	0.5	<0.0005		<0.0002			1835	
11.34	20		<0.0005		<0.0001				
12.6	17		<0.0005		<0.0001			1733	
13.86	16	16	0.0006		<0.0001				0
15.12	0.3	0.2	<0.0005		<0.0001				
16.38	19		<0.0005		<0.0001			1744	
17.64	17		<0.0005		<0.0001				
20.16	32		0.0005	,0005	<0.0001				
22.68	14		0.0054		<0.0001				
25.2	11		<0.0005		<0.0001			1828	
27.72	10		<0.0005		<0.0001				0
30.24	15		<0.0005		<0.0001				
32.76	18		<0.0005		<0.0001			2185	
35.28	18	16	0.0007		<0.0001				0

Table E-8

Anderson Lake Summer Survey 1993
Rescan Peeper #12 Left - Tailings Site

Depth (cm)	Fe (ppb)	Rep (ppb)	Mn (ppb)	Rep (ppb)	Cu (ppb)	Rep (ppb)	Pb (ppb)	Rep (ppb)	Cd (ppb)	Rep (ppb)
-10.08	372.5		306		46		79		0.64	
-8.82	382.8		308		43		80		0.68	
-7.56	364.6		311		42		80		0.7	
-6.3	406.7		297		40		77		0.66	
-5.04	436.2	436.7	299		38	38	67	66	0.59	0.67
-3.78	369		235	255.8	34		66		0.56	
-2.52	756.9		331		23		49		0.65	
-1.26	1533		360		12		16		0.44	
0	8722		572		11		40		0.15	
1.26	10928		775		3.7		2.8	2.9	0.04	0.04
2.52	11804		669		4.1		4		0.04	
3.78	10969		303		0.04		0		0	
5.04	13018		636		4.6		4.1		0.04	
6.3	14792		626		4.4		3.1		0.03	
7.56	18434		624		4.4		6.7		0.03	
8.82	14137		619		5		3.4		0.06	
10.08	11185		614		4.6	4.4	4.8	4.56	0.05	0.04
11.34	9299		567		4		1.4		0.03	
12.6	9170		583		4.2		1.7		0.03	
13.86	8791		490	446.1	3.7		1		0.03	
15.12	9927		547		4.5		3.9		0.04	
16.38	7870		554		3.8		1.9		0.03	
17.64	7439		522		4.2		1.7		0.03	
20.16	6415		477		3.6		0.7		0.02	
22.68	6587		476		3.9	3.7	0.9	1	0.03	0.02
25.2	6977	7072	444		3.7		0.9		0.03	
27.72	5430	5399	481		6.7		0.9		0.03	
30.24	6138		451		3.4		1.4		0.02	
34.02	4091	4235	445		3.3		0.9		0.02	
36.54	3558		433		3.5		0.6		0.02	

Table E-8 (cont.)

Anderson Lake Summer Survey 1993
Rescan Peeper #12 Left - Tailings Site

Depth (cm)	Zn (ppb)	Rep (ppb)	As (ppm)	Rep (ppm)	Hg (ppm)	NO_3^- (µg/L)	pH	SO_4 (mg/L)	H_2S (uM)
-10.08	497		0.0016	0.0014	<0.0001			829	
-8.82	490		0.0015		<0.0001			833	
-7.56	497		0.0015		<0.0001			839	
-6.3	500		<0.0005		<0.0001			853	
-5.04	481	458	0.0012		<0.0001			855	
-3.78	465		0.001		<0.0001			878	
-2.52	402		0.0008		<0.0001			908	
-1.26	350		0.0007	0.0007	<0.0001				0
0	134		0.0014		<0.0001				0
1.26	46	45	0.0005		<0.0001				0
2.52	42		0.0006		<0.0001				0
3.78	0		0.0006		<0.0001			1763	
5.04	38		0.0005		<0.0001			1746	
6.3	28		0.0008	0.0008	<0.0001			1690	
7.56	19		0.0014		<0.0001				0
8.82	32		0.0027		<0.0002			1740	
10.08	18	18	0.0005		<0.0001			1955	
11.34	13		<0.0005		<0.0001				
12.6	16		0.0005		<0.0001			1817	
13.86	11		<0.0005		<0.0001				0
15.12	16		0.0006		<0.0001				
16.38	8		<0.0005		<0.0001			1811	
17.64	14		<0.0005		<0.0001				
20.16	8.5		<0.0005		<0.0001				
22.68	9.4	9	<0.0005		<0.0001				
25.2	11		<0.0005		<0.0001				
27.72	18		<0.0005		<0.0001			2013	
30.24	14		<0.0005		<0.0001				0
34.02	13		<0.0005		<0.0001			1802	
36.54	13		<0.0005		<0.0001				0

Table E-9

Anderson Lake Summer Survey 1993
Rescan Peeper #10 Right - Natural Sediments

Depth (cm)	Fe (ppb)	Rep (ppb)	Mn (ppb)	Rep (ppb)	Cu (ppb)	Rep (ppb)	Pb (ppb)	Rep (ppb)	Cd (ppb)	Rep (ppb)
-31.5	106.9	101.5	276		41		64		0.72	
-17.64	101.2	102.5	286		34	32	63	49	0.67	0.59
-10.08	800.1		335		30		45		0.56	
-5.04	1677		317		21		15		0.39	
-3.78	2294		293		19		20		0.41	
-2.52	3761	3570	294		17		21		0.31	
-1.26	3180	2935	283		18		9.5		0.4	
0	4406		367		3.9		6.1		0.2	
1.26	5791	5399	291		2.2		3		0.07	
2.52	4781		333		2.8		3.7		0.08	
3.78	3856		358		3		3.7		0.08	
5.04	3513		358		2.3		2.3		0.05	
6.3	3702	3315	302		2.3		3.5		0.07	
8.82	5853		334		1.9	1.6	1.6	1.5	0.05	0.05
10.08	7631		348		2		0.4		0.02	
11.34	9755		368		1.1		0.2		0.03	
12.6	10358		344		1.4		0.5		0.05	
13.86	9850		369		1.9		0.7		0.06	
15.12	11890		337		1.5		0.3		0.05	
16.38	11271		328		1.4		0.4		0.05	
17.64	11804		338		1.5		0.4		0.06	
20.16	11658		347		1.2		0.3		0.03	
22.68	14318		365		1.3	1.3	0.7	0.7	0.06	0.05
25.2	14990		342		1.4		0.7		0.05	
27.72	19483		388		1.4		0.6		0.06	
30.24	23551		454		1.2		0.4		0.05	
32.76	20861		492		1.4		0.6		0.06	
35.28	14255		496		1.6		0.9		0.07	

Table E-9 (cont.)

Anderson Lake Summer Survey 1993

Rescan Peeper #10 Right - Natural Sediments

Depth (cm)	Zn (ppb)	Rep (ppb)	As (ppm)	Rep (ppm)	Hg (ppm)	NO_3^- (µg/L)	pH	SO_4 (mg/L)	H_2S (uM)
-31.5	438		0.0008		<0.0001			783	
-17.64	421	398	0.001		<0.0001			799	
-10.08	349		0.0009		<0.0001				
-5.04	278		0.0017		<0.0001				
-3.78	265		0.0022		<0.0001				
-2.52	237		0.0028		<0.0001				
-1.26	243		0.0042	0.0041	<0.0001				0
0	219		0.0079		<0.0001				
1.26	115		0.0074		<0.0001				
2.52	87		0.0067		<0.0001				
3.78	83		0.0047		<0.0001				0
5.04	82		0.004		<0.0001			817	
6.3	90		0.0047		<0.0001				
8.82	86	79	0.0065	0.0066	<0.0001			779	
10.08	30		0.0063		<0.0001				0
11.34	16		0.0084		<0.0001				
12.6	15		0.0086		<0.0001			603	
13.86	22		0.0093		<0.0001				
15.12	19		0.0102		<0.0001				
16.38	18		0.0094		<0.0001				0
17.64	16		0.01	0.0098	<0.0001			760	
20.16	38		0.0118		<0.0001				
22.68	59	63	0.0151		<0.0001			710	
25.2	55		0.0173		<0.0001				0
27.72	48		0.0219		<0.0001			605	
30.24	39		0.024		<0.0001				
32.76	40		0.022		<0.0001				0
35.28	47		0.0118	0.0113	<0.0001				

Table E-10

Anderson Lake Summer Survey 1993
Rescan Peeper #10 Left - Natural Sediments

Depth (cm)	Fe (ppb)	Rep (ppb)	Mn (ppb)	Rep (ppb)	Cu (ppb)	Rep (ppb)	Pb (ppb)	Rep (ppb)	Cd (ppb)	Rep (ppb)
-31.5	107.9	118.3	285		27		50		0.57	
-17.64	83.16	88.22	292		34		53		0.63	
-10.08	153.8	105.6	255		30		47		0.58	
-5.04	499.8	485.4	317		22		22		0.43	
-3.78	1510	1285	333		14		7.7		0.26	
-2.52	5389	5313	329		4		2.2		0.18	
-1.26	7753	7721	340		2.2		3.8		0.06	
0	5755	5656	342		1.6		5.8		0.08	
1.26	3008	2864	293		3.5		18		0.33	
2.52	1936	1921	303		16		42		0.77	
3.78	3256	994.9	333		23		42		0.75	
5.04	1339	685.9	321		29		47		0.85	
6.3	945.9		346		20		23		0.54	
8.82	3532		381		2.8		5		0.12	
10.08	5651		329		1.5		1		0.04	
11.34	9146		328		1.2		1		0.05	
12.6	10986		334		1.4		1		0.04	
13.86	12015		335		1.3		1		0.05	
15.12	12243		325		1.2		0.9		0.05	
16.38	13440		324		1.1		0.9		0.07	
17.64	14112		321		1.1		1		0.06	
20.16	14680		343		1		1		0.06	
22.68	13587		348		0.9		0.8		0.05	
25.2	13724		365		0.9		0.7		0.05	
27.72	14017		365		1		0.9		0.08	
30.24	15670		401		0.8		0.6		0.03	
32.76	17398	15481	371		0.8		0.8		0.05	
35.28	16070		402		1.3		1.1		0.06	

Table E-10 (cont.)

Anderson Lake Summer Survey 1993
Rescan Peeper #10 Left - Natural Sediments

Depth (cm)	Zn (ppb)	Rep (ppb)	As (ppm)	Rep (ppm)	Hg (ppm)	NO_3^- (µg/L)	pH	SO_4 (mg/L)	H_2S (uM)
-31.5	406		0.0012		<0.0001			815	
-17.64	406		0.0011		<0.0001			862	
-10.08	373		0.0011		<0.0001				
-5.04	338		0.0009		<0.0001			785	
-3.78	271		0.0019		<0.0001				0
-2.52	240		0.0044		<0.0001			759	
-1.26	190		0.0124	0.0119	<0.0001				0
0	208		0.0154		<0.0001			794	
1.26	287		0.011		<0.0001				0
2.52	316		0.007		<0.0001			852	
3.78	304		0.0051		<0.0001				0
5.04	300		0.0048		<0.0001			787	
6.3	261		0.0041		<0.0001				0
8.82	156		0.0083	0.0086	<0.0001				
10.08	104		0.0081		<0.0001			825	
11.34	71		0.01		<0.0001				
12.6	61		0.0094		<0.0001			770	
13.86	64		0.0105		<0.0001				
15.12	61		0.0101		<0.0001				
16.38	55		0.0107		<0.0001				0
17.64	52		0.0121	0.0118	<0.0001			769	
20.16	55		0.0107		<0.0001				
22.68	51		0.0114		<0.0001			726	
25.2	47		0.0141		<0.0001				0
27.72	45		0.0152		<0.0001			684	
30.24	46		0.0159		<0.0001				
32.76	47		0.0147		<0.0001				0
35.28	47		0.0129	0.0132	<0.0001			644	

Table E-11

Anderson Lake Summer Survey 1993
Rescan Peeper #14 Right - Natural Sediments

Depth (cm)	Fe (ppb)	Rep (ppb)	Mn (ppb)	Rep (ppb)	Cu (ppb)	Rep (ppb)	Pb (ppb)	Rep (ppb)	Cd (ppb)	Rep (ppb)
-21.42	117.59		272		26		52		0.54	
-12.6	91.85		266		24		46		0.43	
-7.56	97.02		273		19		35		0.38	
-6.3	107.1		282		16		29		0.32	
-5.04	142.3		286		14		26		0.32	
-3.78	265.9		268		14		21		0.31	
-2.52	446.9		276		15		28		0.39	
-1.26	204.2	193.8	265		19		27		0.35	
0	103.7	102.5	267		22		31		0.53	
1.26	190.7	183.1	261		26		34		0.51	
2.52	155.2		274		28		33		0.51	
3.78	104.2		277		26		30		0.46	
5.04	90.64		278		25		29		0.45	
6.3	74.36		277		23		26		0.44	
7.56	61.26		260		18		25		0.37	
8.82	94.92		255		19		24		0.4	
10.08	238.6		251		19		23		0.35	
11.34			266		19		24		0.37	
12.6	102.5		294		17		20		0.37	
13.86	99		287		20		18		0.41	
15.12	160.4		288		24		34		0.63	
16.38	200.4		291		12		36		0.54	
18.9	245.3		310		1.4		10		0.08	
21.42	264.4		299		0.8		1.2		0.02	
23.94	269.2		300		1		1.1		0.1	
26.46	234.6		310		1		1		0.09	
28.98	258.1		321		0.8		0.5		0.05	
31.5	219.2		326		0.8		0.5		0.04	
34.02	199.7		340		0.8		0.6		0.05	

Table E-11 (cont.)

Anderson Lake Summer Survey 1993

Rescan Peeper #14 Right - Natural Sediments

Depth (cm)	Zn (ppb)	Rep (ppb)	As (ppm)	Rep (ppm)	Hg (ppm)	NO_3^- (µg/L)	pH	SO_4 (mg/L)	H_2S (uM)
-21.42	365		0.0013		<0.0001				
-12.6	329		0.0008		<0.0001			803	
-7.56	298		0.0008		<0.0001			814	
-6.3	274		0.0006		<0.0001			842	
-5.04	288		0.0008		<0.0001			819	
-3.78	277		0.0012		<0.0001				0
-2.52	283		0.0013	0.0015	<0.0001			831	
-1.26	300		0.0017		<0.0001				0
0	303		0.0011		<0.0001			795	
1.26	300		0.0012		<0.0001				0
2.52	300		0.0014		<0.0001			795	
3.78	294		0.0011		<0.0001				0
5.04	295		0.0008		<0.0001			797	
6.3	287		0.0008		<0.0001				0
7.56	255		0.001	0.001	<0.0001				
8.82	257		0.0012		<0.0001			781	
10.08	261		0.0013		<0.0001				
11.34	265		0.0012		<0.0001			813	
12.6	264		0.0012		<0.0001				
13.86	267		0.0012		<0.0001				
15.12	304		0.0016	0.0016	<0.0001				0
16.38	304		0.0015		<0.0001			783	
18.9	158		0.0013		<0.0001				
21.42	185		0.002		<0.0001				
23.94	44		0.002		<0.0001				0
26.46	52		0.0016		<0.0001			812	
28.98	11		0.0011		<0.0001				
31.5	9.7		0.0011	0.0012	<0.0001				0
34.02	10		0.0007		<0.0001			700	

Table E-12

Anderson Lake Summer Survey 1993
Rescan Peeper #14 Left - Natural Sediments

Depth (cm)	Fe (ppb)	Rep (ppb)	Mn (ppb)	Rep (ppb)	Cu (ppb)	Rep (ppb)	Pb (ppb)	Rep (ppb)	Cd (ppb)	Rep (ppb)
-15.12	88.41		278		30		59		0.56	
-12.6	81.73		260		30		58		0.54	
-10.08	85.32		252		28		54		0.46	
-7.56	76.86		258		22		42		0.35	
-5.04	59.4	48.35	266		24		40		0.4	
-3.78	79.2		257		22		36		0.32	
-2.52	77.76		254		23		31		0.36	
-1.26	235.2		256		28		27		0.34	
0	1536		249		4.2		28		0.31	
1.26	1869		266		1.6		12		0.11	
2.52	1366		275		4.3		13		0.13	
3.78	703	704.8	275		2.6		18		0.21	
5.04	1071	832.2	291		7.7		26		0.43	
6.3	529.3		265		11		24		0.4	
7.56	442.8		304		16		23		0.38	
8.82	355.1		296		18		26		0.47	
10.08	371.1		304		14		22		0.43	
11.34	435.3	375.5	291		15		22		0.46	
12.6	375.1		320		15		21		0.51	
13.86	294.8		307		14		23		0.59	
15.12	330.3		302		16		25		0.67	
16.38	579.8		311		17		25		0.54	
17.64	592.5		298		13		21		0.43	
18.9	407.1		288		11		17		0.33	
21.42	322.4		312		1.4		1.1		0.04	
23.94	358.1		314		0.9		0.5		0.03	
26.46	390.4		319		0.8		0.3		0.03	
28.98	214		320		0.5		0.3		0.05	
31.5	198.7		330		0.6		0.3		0.03	
34.02	165.9		340		0.6		0.4		0.05	
36.54	317	270.7	320		0.5		0.2		0.03	
39.06	172.8		345		0.6		0.4		0.05	

Table E-12 (cont.)

Anderson Lake Summer Survey 1993

Rescan Peeper #14 Left - Natural Sediments

Depth (cm)	Zn (ppb)	Rep (ppb)	As (ppm)	Rep (ppm)	Hg (ppm)	NO_3^- (µg/L)	pH	SO_4 (mg/L)	H_2S (uM)
-15.12	390		0.0011		<0.0001				
-12.6	382		0.0009		<0.0001			809	
-10.08	263		0.0007		<0.0001			767	
-7.56	293		0.0005		<0.0001			812	
-5.04	299		<0.0005		<0.0001			791	
-3.78	270		0.0006	0.0005	<0.0001				0
-2.52	267		0.0007		<0.0001			829	
-1.26	262		0.0009		<0.0001				0
0	209		0.0021		<0.0001			800	
1.26	184		0.0026		<0.0001				0
2.52	201		0.0031		<0.0001			860	
3.78	260		<0.0005		<0.0001				0
5.04	317		0.0032	0.0034	<0.0001			819	
6.3	293		0.0019		<0.0001				0
7.56	305		0.0019		<0.0001				
8.82	312		0.0015		<0.0001			815	
10.08	296		0.0016		<0.0001				
11.34	255		0.0013		<0.0001			793	
12.6	286		0.0013		<0.0001				
13.86	313		0.0012	0.0014	<0.0001				0
15.12	320		0.0012		<0.0001				
16.38	292		0.0013		<0.0001			806	
17.64	269		0.001		<0.0001				
18.9	272		0.001		<0.0001			785	
21.42	160		0.0012		<0.0001				150
23.94	43		0.0013		<0.0001			763	
26.46	7.5		0.0009	0.0007	<0.0001				
28.98	4.2		0.0005		<0.0001				1080
31.5	3.9		<0.0005		<0.0001				
34.02	5.3		0.0005		<0.0001			559	
36.54	3.6		0.0006		<0.0001				
39.06	5.8		0.0007		<0.0001			615	

Table E-13

Anderson Lake Summer Survey 1993
Rescan Peeper #15 Left - Shallow Tailings

Depth (cm)	Fe (ppb)	Rep (ppb)	Mn (ppb)	Rep (ppb)	Cu (ppb)	Rep (ppb)	Pb (ppb)	Rep (ppb)	Cd (ppb)	Rep (ppb)
-27.72	265	250.5	260		27		114		0.6	
-18.9	105	107.1	268		22		51		0.45	
-11.34	16901		275		24		58		0.63	
-6.3	442.9		265		25		57		0.62	
-5.04	488.3		265		24		56		0.54	
-3.78	2312		271		34		54		0.4	
-2.52	35300		272		23		46		0.25	
-1.26	84806		256		3		6.1		0.12	
0	118662		281		0		0.8		0.01	
1.26	110855		343		1.1		0.8		0.04	
2.52	111351		309		1		0.7		0.02	
3.78	112014		341		1.2		0.7		0.02	
5.04	113381		365		1		0.6		0.02	
6.3	120545		382		0.8		0.4		0.01	
7.56	123402		433		0.9		0.4		0.01	
8.82	130069		468		0.6		0.4		0.01	
10.08	130442		528		0.7		0.3		0	
11.34	128785		570		0.7		0.3		0.01	
12.6	123857		681		0.7		0.7		0.01	
13.86	125679		661		0.6		0.7		0.01	
15.12	126673		642		0.6		0.5		0	
16.38	126466		634		0.7		0.6		0	
17.64	121289		649		1		1.1		0	
20.16	116611		638		0.5		0.7		0.01	
22.68	104974		690		1.2		0.8		0	
25.2	94332		836		1		0.5		0	
27.72	93504		955		0.9		0.4		0	
30.24	83731		862		0.9		0.3		0	
32.76	66422		853		0.8		0.1		0	
35.28	65593		817		0.6		0.1		0	

Table E-13 (cont.)

Anderson Lake Summer Survey 1993
Rescan Peeper #15 Left - Shallow Tailings

Depth (cm)	Zn (ppb)	Rep (ppb)	As (ppm)	Rep (ppm)	Hg (ppm)	NO_3^- (µg/L)	pH	SO_4 (mg/L)	H_2S (uM)
-27.72	376		0.0017		<0.0001				
-18.9	326		0.0012		<0.0001				
-11.34	368		0.0014		<0.0001				
-6.3	366		0.0012		<0.0001	72	6.97	796	
-5.04	351		0.0013		<0.0001	85		771	
-3.78	310		0.0011		<0.0001	59	6.98	768	
-2.52	212		0.0012	0.0014	<0.0001	21		845	
-1.26	115		0.0029		<0.0001	0		877	
0	50		0.0086		<0.0001				0
1.26	45		0.0234		<0.0001				0
2.52	37		0.0255		<0.0001	7		8.72	
3.78	31		0.024		<0.0001	0	6.99	857	
5.04	24		0.0255		<0.0001				0
6.3	21		0.015	0.0126	<0.0001				0
7.56	18		0.023		<0.0001	0		838	
8.82	18		0.0305		<0.0001	0		804	
10.08	15		0.0315		<0.0001	10	7.01	817	
11.34	15		0.0405		<0.0001				
12.6	15		0.047		<0.0001				0
13.86	14		0.0585		<0.0001				
15.12	15		0.0675	0.069	<0.0001	0		801	
16.38	14		0.055		<0.0001	0		802	
17.64	21		0.0625		<0.0001				
20.16	21		0.046		<0.0001			746	
22.68	20		0.0425		<0.0001				0
25.2	13		0.051		<0.0001	0		664	
27.72	9.7		0.0905		<0.0001				
30.24	8.2		0.0505	0.052	<0.0001	0	7.03		
32.76	5.3		0.0125		<0.0001				0
35.28	5.3		0.0185		<0.0001				

Table E-14

Anderson Lake Summer Survey 1993
Rescan Peeper #15 Right - Shallow Tailings

Depth (cm)	Fe (ppb)	Rep (ppb)	Mn (ppb)	Rep (ppb)	Cu (ppb)	Rep (ppb)	Pb (ppb)	Rep (ppb)	Cd (ppb)	Rep (ppb)
-27.72	237.5		288		29		64		0.55	
-18.9	117.2		281		27		65		0.43	
-11.34	138.8		281		27		63		0.46	
-6.3	309.3		287		27		60		0.49	
-5.04	258.5		284		28		59		0.49	
-3.78	675.3		299		30		58		0.5	
-2.52	9445		304		29		43		0.32	
-1.26	38221		331		12		6		0.15	
0	97521		356		0		0.6		0	
1.26	119675		382		0.8		0.5		0	
2.52	107583		424		0.8		1		0.1	
3.78	120006		431		0.8		0.5		0.1	
5.04	125969		477		0.7		0.4		0	
6.3	123982		477		0.7		0.3		0	
7.56	114126		533		0.7		0.3		0	
8.82	117687		591		0.7		0.4		0	
10.08	128205		613		0.7		0.5		0	
11.34	114623		615		1.3		0.4		0.02	
12.6	112304		604		1.4		0.3		0.02	
13.86	113463		596		1.4		0.4		0.01	
15.12	113049		592		1.4		0.4		0.02	
16.38	110730		579		1.4		0.5		0.01	
17.64	106921		562		1.6		1.1		0.02	
20.16	104436		586		1.2		0.5		0.01	
22.68	102697		744		3.1		0.7		0.03	
25.2	95491		1138		1.1		0.4		0.01	
27.72	96071		977		1.6		0.5		0.01	
30.24	81246		1184		1.1		0.2		0	
32.76	77064		1353		1.1		0.4		0.01	
35.28	63937		1437		1		0.3		0	

Table E-14 (cont.)

Anderson Lake Summer Survey 1993
Rescan Peeper #15 Right - Shallow Tailings

Depth (cm)	Zn (ppb)	Rep (ppb)	As (ppm)	Rep (ppm)	Hg (ppm)	NO_3^- (µg/L)	pH	SO_4 (mg/L)	H_2S (uM)
-27.72	427		0.0016		<0.0001				
-18.9	412		0.0014		<0.0001				
-11.34	409		0.0007		<0.0001				
-6.3	407		0.0012		<0.0001	103		797	
-5.04	394		0.001	0.0012	<0.0001	112		798	
-3.78	369		0.001		<0.0001	98		800	
-2.52	286		0.0015		<0.0001	43		771	
-1.26	193		0.0016		<0.0001	3	6.99	836	
0	66		0.0045		<0.0001				0
1.26	35		0.0113		<0.0001				0
2.52	30		0.0235		<0.0001			841	
3.78	25		0.03	0.0305	<0.0001			809	
5.04	25		0.028		<0.0001				0
6.3	24		0.025		<0.0001				0
7.56	21		0.033		<0.0001	6		779	
8.82	19		0.041		<0.0001	0		780	
10.08	24		0.0435		<0.0001	0	6.99	781	
11.34	36		0.0335		<0.0001				
12.6	37		0.034	0.034	<0.0001				0
13.86	34		0.0076		<0.0001				
15.12	37		0.05		<0.0001			757	
16.38	37		0.045		<0.0001	0		736	
17.64	45		0.0345		<0.0001				
20.16	32		0.0285		<0.0001	0		680	
22.68	19		0.036		<0.0001				0
25.2	11		0.051	0.0495	<0.0001	0		604	
27.72	15		0.0545		<0.0001				
30.24	8.5		0.052		<0.0001	0		551	
32.76	8.7		0.0845		<0.0001				0
35.28	6.1		0.069		<0.0001				

Table E-15

Anderson Lake Summer Survey 1993
Rescan Peeper #11 Left - Shallow Tailings

Depth (cm)	Fe (ppb)	Rep (ppb)	Mn (ppb)	Rep (ppb)	Cu (ppb)	Rep (ppb)	Pb (ppb)	Rep (ppb)	Cd (ppb)	Rep (ppb)
-39.06	182.5		299		30	24	53	40	0.63	0.48
-30.24	110	98.89	295		31		57		0.53	
-20.16	149.5	135.7	312		27		53		0.55	
-10.08	158.6		295		26		55		0.49	
-5.04	3156		320		35		59		0.47	
-3.78	9666	7138	346		30		39		0.42	
-2.52	18710		351		24		17		0.35	
-1.26	57255		425		3.4	3.6	1	1	0.08	0.11
0	66422		516		1.8		1.3		0.06	
1.26	88783		558		2.1		3		0.07	
2.52	83234		693		2		3.1		0.07	
3.78	78927		727		2.1		3		0.06	
5.04	166634	1E+05	707		n/a		n/a		n/a	
6.3	70314		695		1.4		1.6		0.06	
7.56	61121		707		1.9		2.3		0.06	
8.82	59548		703		1.3		1		0.06	
10.08	55365		674		1.2		0.8		0.05	
11.34	48905		684		1.3	1.2	0.7	0.7	0.07	0.09
12.6	49651		776		1.2		0.5		0.05	
13.86	42942		823		1		0.5		0.04	
15.12	40706		948		1		0.4		0.04	
16.38	39381		1055		0.6		0.3		0.03	
17.64	35654		1186		0.5		0.3		0.02	
18.9	33459		1386		1		0.5		0.03	
20.16	31182		1561		0.9		0.4		0.02	
22.68	26526		1967		0.9		0.3		0.02	
25.2	23668		1018		0.8		0.3		0.01	
27.72	21769		1852		0.6	0.9	0.5	0.5	0.01	0.02
-40.32					n/a		n/a		n/a	
32.76	18743		1894		0.6		0.4		0.01	

Table E-15 (cont.)

Anderson Lake Summer Survey 1993

Rescan Peeper #11 Left - Shallow Tailings

Depth (cm)	Zn (ppb)	Rep (ppb)	As (ppm)	Rep (ppm)	Hg (ppm)	NO_3^- (µg/L)	pH	SO_4 (mg/L)	H_2S (uM)
-39.06	398	287	0.0017		<0.0001				
-30.24	293		0.0015		<0.0001			774	
-20.16	380		0.0014	0.0015	<0.0001				
-10.08	373		0.0012		<0.0001	86	7.01	763	
-5.04	345		0.0015		<0.0001				0
-3.78	303		0.0014		<0.0001				
-2.52	234		0.0019		<0.0001	18		774	
-1.26	87	81	0.0031		<0.0001				0
0	51		0.0064		<0.0001				
1.26	50		0.027		<0.0001				0
2.52	44		0.0285		<0.0001	9		787	
3.78	44		0.0525		<0.0001		7.00	780	
5.04	n/a		0.031		<0.0001				
6.3	43				<0.0001				0
7.56	47		0.019		<0.0001			743	
8.82	44		0.0155		<0.0001	5		741	
10.08	42		0.014		<0.0001				0
11.34	41	44	0.016	0.0155	<0.0001	6		696	
12.6	37		0.0185		<0.0001	13		679	
13.86	33		0.017		<0.0001				0
15.12	33		0.0255		<0.0001	7		642	
16.38	27		0.036		<0.0001				0
17.64	23		0.0396		<0.0001	13	7.00	639	
18.9	28		0.042		<0.0001				0
20.16	23		0.0249	0.0261	<0.0001				
22.68	17		0.0222		<0.0001				
25.2	15		0.0843		<0.0001				0
27.72	19	19	0.0141		<0.0001				
-40.32	n/a		0.0114		<0.0001				
32.76	21		0.0081		<0.0001				

Table E-16

Anderson Lake Summer Survey 1993
Rescan Peeper #11 Right - Shallow Tailings

Depth (cm)	Fe (ppb)	Rep (ppb)	Mn (ppb)	Rep (ppb)	Cu (ppb)	Rep (ppb)	Pb (ppb)	Rep (ppb)	Cd (ppb)	Rep (ppb)
-39.06	147.4	148.8	228		34		64		0.68	
-30.24	92.07		271		33		61		0.57	
-20.16	110.2		269		32	33	61	58	0.55	0.52
-10.08	163.2		280		31		57		0.53	
-5.04	3689		305		40		63		0.47	
-3.78	8722		315		33		42		0.41	
-2.52	42613		349		12		5.4		0.19	
-1.26	46172		382		2.9		1		0.07	
0	59009		435		1.9		1		0.07	
1.26	59382		502		1.8		1.8		0.07	
2.52	60127		572		1.7		1.2		0.07	
3.78	70314		568		1.5		1.3		0.06	
5.04	77520		616		1.3	1.3	1.3	1.3	0.08	0.08
6.3	82116		640		1.6		1.5		0.09	
7.56	81205		686		1.1		1.1		0.05	
8.82	72923		638		1.1		0.8		0.05	
10.08	72592		672		1.1		1.1		0.05	
11.34	73710		707		1.2		0.7		0.05	
12.6	72685		728		1.1		0.6		0.05	
13.86	65800		759		1.1		0.6		0.03	
15.12	62363		842		1		0.5		0.02	
16.38	59962		928		0.9		0.6		0.02	
17.64	55158		1124		1	1	0.7	0.7	0.02	0.02
18.9	47704		1180		1.1		0.7		0.02	
20.16	43770		1117		1		0.8		0.02	
22.68	43807		1550		0.8		0.4		0.01	
25.2	36780		1801		0.8		0.2		0.01	
27.72	28812		1943		0.9		0.3		0.01	
30.24	26190		1660		16		16		0.1	
32.76	23114		1486		1		0.8		0.02	

Table E-16 (cont.)

Anderson Lake Summer Survey 1993

Rescan Peeper #11 Right - Shallow Tailings

Depth (cm)	Zn (ppb)	Rep (ppb)	As (ppm)	Rep (ppm)	Hg (ppm)	NO_3^- (µg/L)	pH	SO_4 (mg/L)	H_2S (uM)
-39.06	406		0.0012		<0.0001				
-30.24	406		0.0013	0.0013	<0.0001				
-20.16	385	393	0.0015		<0.0001				
-10.08	391		0.0008		<0.0001				
-5.04	335		0.0017		<0.0001				0
-3.78	273		0.0017		<0.0001				
-2.52	157		0.0022		<0.0001				
-1.26	71		0.0029		<0.0001				0
0	54		0.0051	0.0053	<0.0001				
1.26	45		0.0071		<0.0001				0
2.52	40		0.0101		<0.0001				
3.78	38		0.0152		<0.0001				
5.04	40	41	0.032		<0.0001				
6.3	41		0.0375		<0.0001				0
7.56	35		0.0295		<0.0001				
8.82	31		0.022	0.02	<0.0001				
10.08	31		0.0305		<0.0001				0
11.34	29		0.0325		<0.0001				
12.6	26		0.038		<0.0001				
13.86	24		0.0485		<0.0001				0
15.12	21		0.047		<0.0001				
16.38	19		0.064		<0.0001				0
17.64	17	17	0.05	0.0475	<0.0001				
18.9	16		0.0655		<0.0001				0
20.16	13		0.061		<0.0001				
22.68	12		0.034		<0.0001				
25.2	10		0.0265		<0.0001				0
27.72	8		0.0135		<0.0001				
30.24	48		0.0145		<0.0001				
32.76	15		0.0095	0.0085	<0.0001				

Table E-17

Anderson Lake Summer Survey 1993
NWRI Peeper 1A - Tailings Site

Depth (cm)	Fe (ppb)	Fe Rep (ppb)	Mn (ppb)	Mn Rep (ppb)	Cu (ppb)	Cu Rep (ppb)	Cd (ppb)	Cd Rep (ppb)	Zn (ppb)	Zn Rep (ppb)	Pb (ppb)	Pb Rep (ppb)
-12	1656	1600	347.6		38		0.59		378		69	
-10	319.6		384.1									
-8	344		243		30		0.56		375		61	
-6	374.4		268.4									
-4	427.6		278.5		30		0.61		484		63	
-3	466.2		294.8		27	26	0.46	0.53	366	362	60	63
-2	506.4		309.1		26		0.4		335		57	
-1	701.1		297.7		27		0.44		349		60	
0	7007		350.6		14		0.6		431		85	
1	36033		592.8	570.3	1.5		0.06		36		6.5	
2	14440		755.2	717.1	4.4		0.16		50		8.3	
3	3261	3043	425.6	377.6	3.4	3.2	0.12	0.1	32	31	4.3	4.5
4	1312	1117	211.2		4.9		0.1		33		6.1	
5	4412	4132	239.4		12		0.48		175		19	
6	1655		289.9	308.7	4.9		0.18		52		6.6	
7	1633		272.7		2.5		0.07		25		1.6	
9	1759		200.5		2.8		0.06		18		3	
11	1188		208.5		4.4	4.4	0.14	0.13	26	27	2.8	2.8
13	440.4	720.8	216.5		3.1		0.07		21		2	
15	527.7		242.1		2.8		0.09		15		1	
19	8046		427.2	380.5	4.4		0.07		18		1.5	
23	5597		347.3		4.5		0.06		17		38	
27	25382		362.4		46		0.95		398		138	
31	3444	2749	347.8		3.5		0.06		12		1.2	
35	5520		524.8		4		0.05		12		0.9	

Table E-18

Anderson Lake Summer Survey 1993
NWRI Peeper 1B - Tailings Site

Depth (cm)	Fe (ppb)	Fe Rep (ppb)	Mn (ppb)	Mn Rep (ppb)	Cu (ppb)	Cu Rep (ppb)	Cd (ppb)	Cd Rep (ppb)	Zn (ppb)	Zn Rep (ppb)	Pb (ppb)	Pb Rep (ppb)
-12	375.3		300.3		38		0.69		402		84	
-8	378.6		294.2		35		0.69		412		84	
-4	537.9	495.3	300.1		34		0.87		449		86	
-3	760.6		312		36		0.81		465		93	
-2	820.4		313.7		34		0.72		442		93	
-1	2127		327.6		34		0.69		451		87	
0	18477		486.3		11		0.36		279		46	
1	13665	13767	576.5		2.7	2.7	0.06	0.06	19	19	2.2	2
2	1784		275.1		3.6		0.08		19		2.1	
3	1018		278.8		3.5		0.07		16		1.3	
4	1268		277.2		6.5		0.35		38		4.7	
5	1251		272.7		4		0.07		16		1.4	
6	1228		233.7		3.4		0.06		14		1.6	
7	979.7		244.8		3.7		0.08		13		0.7	
9	698.9		221.8		2.8		0.05		15		1	
11					6.1	6	0.29	0.27	32	32	2.7	2.7
13	3133		257.9		5.7		0.14		15		2	
15	6738		360		5.3		0.08		17		1.7	
19	9367		368.6		8		0.28		23		3	
23	5439		289.5	251.3	9.3		0.6		62		4.5	
27	6711		350.1		5.2	5.2	0.15	0.14	15	15	1.5	1.4
31	9615		510.9		6.3		0.21		13		2	
35	12687		1004		6.4		0.84		14		2	

Table E-19

Anderson Lake Summer Survey 1993
NWRI Peeper 2A - Natural Site

Depth (cm)	Fe (ppb)	Fe Rep (ppb)	Mn (ppb)	Mn Rep (ppb)	Cu (ppb)	Cu Rep (ppb)	Cd (ppb)	Cd Rep (ppb)	Zn (ppb)	Zn Rep (ppb)	Pb (ppb)	Pb Rep (ppb)
-11	150.6		301.98		29		0.56		393		54	
-6	154.4		310.8		32	34	0.65	0.63	369	374	59	61
-4	176.8		322.77		31		0.53		363		57	
-3	139.7		319.62		31		0.59		368		59	
-2	149.5		279.51		30		0.6		360		56	
-1	226.1		284.55		33		0.7		397		60	
0	5824		276.99		42	41	1.1	1.15	547	537	89	91
1	33837	30376	299.71		2.5		0.09		35		9	
2	22778		272.65		1.6		0.04		15		1.4	
3	25854		281.67		2		0.04		14		2.5	
4	28779		303.81		2.9		0.05		14		1.1	
5	30678		288.23		1.7		0.04		4.8		0.4	
6	36898		283.72		2.6		0.04		7.2		8.4	
8	33294		286.18		3.1		0.23		9.8		1.3	
10	32376		299.71		3.3	3.1	0.4	0.43	25	27	2	2.2
12	24963		345.22		4.5		0.38		24		1.8	
14	14574		354.24		23		2.3		45		3.7	
17	9716	9841	351.78		11		0.11		15		0.6	
21	4271	4636	387.04		2.5		0.1		11		0.7	
25	1123	1123	388.27		1.9		0.13		3.1		1.1	
29	1271		333.33		1.8		0.14		7.7		1.1	

Table E-20

Anderson Lake Summer Survey 1993
NWRI Peeper 2B - Natural Site

Depth (cm)	Fe (ppb)	Fe Rep (ppb)	Mn (ppb)	Mn Rep (ppb)	Cu (ppb)	Cu Rep (ppb)	Cd (ppb)	Cd Rep (ppb)	Zn (ppb)	Zn Rep (ppb)	Pb (ppb)	Pb Rep (ppb)
-11	173.6		278.0		35		0.57		381		63	
-6	200.5		270.5		34	33	0.58	0.64	399	395	61	61
-4	238.5		273.4		34		0.57		376		60	
-3	173.9		253.1		35		0.57		386		62	
-2	165.6		258.1		32		0.6		378		60	
-1	542.6		272.6		33		0.63		399		67	
0	13286		274.3		19	18	0.24	0.3	259	254	19	20
1	27568		270.2		2.7		0.07		13		7.9	
2	27787		259.1		2.2		0.14		14		1.2	
3	31788		269.0		2.7		0.11		14		1.2	
4	25686		287.4		3.3		0.13		20		1.4	
5	21046		308.3		2.5		0.14		15		1.3	
6	22206		271.4		1.9		0.11		15		0.9	
8	14742		296.4		2.5		0.11		14		1.1	
10					2.5	2.5	0.16	0.15	15	15	2	2
11	7161	7843	282.5									
12	9744	8464	303.8		3.3		0.23		19		2.4	
14	12276		326.4		2.3		0.16		15		1.8	
17	9884		336.6		2.5		0.16		18		2	
21	2200		358.3		1.7		0.17		23		1.7	
25	1125		347.3		1.9		0.13		9.2		1.6	
29	863.5		372.7		1.4		0.11		8		1.3	

Table E-21

Core Porewater Data - Anderson Lake Summer Survey - Natural Site A

Depth (cm)	Fe (ppb)	Fe Rep (ppb)	Mn (ppb)	Mn Rep (ppb)	Cu-ICP* (ppb)	Cu-AA* (ppb)	Cd (ppb)	Cd-Rep (ppb)	Zn (ppb)	Zn Rep (ppb)	Pb (ppb)	Pb Rep (ppb)	As (ppm)	As Rep (ppm)	Hg (ppm)
-5	99.54		279.2		24.4	27.2	0.91	0.79	383	376	54.7	58.2	0.0022		<0.005
-5	90.51		276.8		25.3	29.9	0.81		377	393	54.8	54.8	0.0021		<0.005
0.25	13161		238.6		1.11	0.4	0.02		28.7	41.9	1.87	0.55	0.0131		<0.005
0.95	6469		239		1.76	1.27	0	0	5.47	7.4	2.75	0.89	0.035		<0.005
1.65	6701		176.6		2.27		0.01		6.14		1.28		0.0575		<0.005
2.15	3163		254.8		1.87		0.06		6.83		0.79		0.048		
2.9	2795		205.8		1.85		0.06		6.15		0.59		0.028	0.028	<0.005
3.9	2763		203.7		1.17	0.6	0	0	4.23	4.5	0.82	0.33	0.029		<0.005
4.9	1865		195.7		1.56		0.06		4		0.39		0.0205		<0.005
5.9	490.9		215.9		1.73		0.06		7.8		0.42		0.0205		<0.005
7.4	248.5		215.5		1.4		0.06		2.25		0.16		0.0235		<0.005
9.4	295.5		218.6		0.51	0	0	0	1.53	2.5	0.02	0.08	0.0096		<0.005
11.4	161.3		213.2		0.98		0.06		1.77		0		0.0105		<0.005
13.4	56.76	63.7	115.7		0.88		0.05		1.48		0		0.0092	0.0092	<0.005
15.4	103.2	81	227.9		0.77		0.06		1.59		0		0.0067		<0.005
19.4	91.1		298.8		0.36	0	0	0	1.03	0.9	0.05	0.07	0.0048		<0.005
24.4	83.3		337.7		0.76		0.05		1.33		0		0.0061		<0.005
28.4	70.7		292.5		0.74		0.05		1.6		0		0.0045		<0.005

*Cu-ICP and Cu-AA denote measurements of Cu by GFAAS and ICP-MS, respectively.

Table E-22

Core Porewater Data - Anderson Lake Summer Survey - Tailings Site B

Depth (cm)	Fe (ppb)	Fe Rep (ppb)	Mn (ppb)	Mn Rep (ppb)	Cu-ICP (ppb)	Cu-AA (ppb)	Cd (ppb)	Cd-Rep (ppb)	Zn (ppb)	Zn Rep (ppb)	Pb (ppb)	Pb Rep (ppb)	As (ppm)	As Rep (ppm)	Hg (ppm)
-5	129.1		229.7		19		0.61		324		48.1		0.0015		0.09
-5	168.9		215.1		11.8	30.7	0.65	0.47	328	990	43	43.5	0.0016	0.0017	0.06
0.25	869.1		234.7		3.07		0.41		211		24.4		0.0064		
0.75	2027		549.4		2.46		0.05		18		4.6		0.0054		
1.25	3886		530.3		0.84		0.03		12.6		2.5		0.0071		0.09
1.75	1966		602		0.45	0	0	0	8.44	9.3	4.57	1.68	0.0084		0.05
2.5	2393		669.6		0.95		0.05		5.49		0.93		0.0094		<0.005
3.5	2098		687.8		0.89		0.05		4.28		0.77		0.0092		0.08
5.5	1333		483.8	485.8	0.66		0.02		2.9		0.36		0.0125		<0.005
7.5	361.6	258.6	626.3		0.6		0		2.61		0.62		0.026	0.0255	<0.005
7.5	1819		719.1		0.39	0	0.01	0	2.4	2.4	1.02	0.45	0.026		<0.005
10	83.6		273.7		0.72		0.02		1.66		1.28		0.105		<0.005
12	52.61		272.7		1.06		0		3.38		0.89		0.105		<0.005
14	184.5		251.2		0.69		0		2.3		0.4				<0.005
17	331.7		286.4		0.69		0.02		1.29		0.54		0.195		<0.005
21	69.21		307.4		0.72		0.02		1.7		0.85		0.174		<0.005
25	22.66		417.3		0.69		0.01		1.74		0.2		0.113		<0.005
25	19.8		422.3		0.66		0.02		1.71		0.2		0.0116		<0.005
29	1013		656.3		0.75		0.02		7.89		0.11		0.0023		<0.005
29	1242		735.3		0.71		0.02		8.14		0.11		0.0021		<0.005
33	1256		843.4		0.82		0.02		3.15		0.18		0.0018		<0.005
37	3520		1250.4		0.63		0.01		1.7		0.08		0.0008		<0.005

*Cu-ICP and Cu-AA denote measurements of Cu by GFAAS and ICP-MS, respectively.

Appendix F-1 - ASL Methods

1.0 INTRODUCTION

ASL Analytical Service Laboratories Limited was contracted by Rescan Environmental Services Limited to provide chemical analyses on water column and sediment samples for the MEND Project 2.11 Anderson Lake Survey in north-central Manitoba.

All Carbon, Nitrogen, Sulphur and Calcium Carbonate analyses for the sediments were carried out by the University of British Columbia, Department of Oceanography, under the direction of Dr. Tom Pedersen.

This report covers all methodologies used, the results of analysis, and the quality assurance/quality control data.

2.0 SAMPLE RECEIPT AND STORAGE

The samples were collected by Rescan Environmental Services Ltd. personnel and the procedures used are described elsewhere.

Water Column Samples

The bottles for the water column samples were supplied and prepared by ASL. The bottle preparation involved the following procedures:

- Plastic bottles (125 ml) for total and dissolved metal analyses were filled with a 2% Nitric Acid solution and left for 24 hours. The bottles were then rinsed several times with reagent grade water, shaken dry and capped.
- Plastic bottles (250 ml) for general water quality analyses were filled with reagent grade water and left for 24 hours. The bottles were then shaken dry and capped.
- Glass purge and trap vials (40 ml) for total and dissolved organic carbon analyses were filled with reagent grade water and left for 24 hours. The vials were then shaken dry and capped.

Other sampling materials supplied by ASL included:

- Seastar Nitric Acid - (high-purity grade) for preservation of all samples for metals analyses.
- Reagent Grade Water - for rinsing.

- Transport Blanks

All water column samples for trace metal, water quality and organic carbon analyses arrived at ASL on April 28, 1993 and August 20, 1993 in 125 ml plastic bottles, 250 ml plastic bottles and 40 ml glass purge and trap vials respectively. The filtration and acidification of all samples was carried out by Rescan Environmental Services Ltd. prior to their delivery to ASL.

For the Anderson Lake Winter Survey, all of the samples were frozen upon arrival at ASL and, while thawing, several bottles cracked. The sample labelled "Stn.A-1" was the only sample for which both bottles were broken and no water quality analyses could be performed.

It was noted upon receipt, that the samples labelled "Stn.A-1" to "Stn.A-10" (inclusive) contained visible amounts of suspended matter. After discussion with Mr. David Flather (Rescan), these samples were decanted prior to analysis for total metals.

The sample labelled "Stn.A-8" appeared to contain some type of organism, possibly zooplankton.

For the Anderson Lake Summer Survey, there were no samples delivered to ASL from the following sites: Stn. 2-1, Stn. 2-2 and Stn. 2-3. For the samples labelled "Stn. 2-7, Stn. 2-8 and Stn. 2-9", the Total Organic Carbon (TOC) vials were broken upon receipt and the TOC analysis could not be performed.

Sediment Samples

All sediment samples for trace metals analyses were delivered to the University of British Columbia (U.B.C.), Department of Oceanography, where they were freeze-dried, finely-ground and analysed for Carbon, Nitrogen, Sulphur and Calcium Carbonate.

After U.B.C. had completed their analyses, the samples were delivered to ASL for further analyses.

3.0 ANALYTICAL METHODOLOGY

3.1 Conventional Parameters in Water

These analyses were carried out in accordance with procedures described in "Standard Methods for the Examination of Water and Wastewater" 18th Edition published by the American Public Health Association (APHA), 1992. Specific details are as follows:

pH was analyzed electrometrically using a combination reference-potential glass electrode (APHA Method 4500-H^+, A and B).

Conductivity was analysed by the direct measurement of resistance using a HACH Conductivity/TDS Meter Model 44600 (APHA Method 2510, A and B).

Hardness was determined by calculation using calcium and magnesium concentrations (APHA Method 2340, A and B).

Alkalinity was analyzed using a Roche Model COBAS FARA II spectrophotometer by potentiometric titration with sulphuric acid using methyl orange at a pH of 4.5 as an end point indicator (APHA Method 4500-CO_2, A and C).

Chloride was determined colorimetrically using mercuric thiocyanate and ferric nitrate reagents (APHA Method 4500-Cl^-, A and C).

Sulphate was analysed turbidimetrically using barium chloride reagent (APHA Method 4500-SO_4^{2-}, A and E).

Ammonia Nitrogen was determined colourimetrically using a phenol and hypochlorite reagent in the presence of a manganous salt (APHA Method 4500-NH_3, A, D and F).

Nitrate Nitrogen was determined by the difference between the colourimetric nitrate/nitrite analysis by a Roche Model COBAS FARA II spectrophotometer using hydrazine red and the colourimetric nitrite analysis using diazotization with N-1-naphthylethylenediamine dihydrochloride (APHA Method 4500-NO_3, A and H).

Total Phosphorus was analyzed colourimetrically with a Perkin-Elmer Model Lambda 2 UV/Visible spectrophotometer using an acid hydrolysis with sulphuric acid and ammonium persulphate (APHA Method 4500-P, A and B).

3.2 Metals in Water

These analyses were carried out using procedures that are consistent with the requirements of the appropriate regulatory agencies and adapted from U.S. Environmental Protection Agency Method 3050 (Publ. # SW-836, 3rd ed., Washington, DC 20460). The procedures involve analysis by hydride-vapour atomic absorption spectrophotometry (HVAAS), graphite-furnace atomic absorption spectrophotometry (GFAAS), inductively coupled plasma (ICP) and cold-vapour atomic absorption spectrophotometry (CVAAS) to obtain the required detection limits. Specific details are as follows:

Arsenic was analyzed using a Perkin-Elmer Model 5000 dual-beam atomic absorption spectrophotometer coupled to a Perkin-Elmer Model MHS-20 automated hydride generation system (U.S. EPA Method 7000).

Calcium, iron, magnesium, manganese, potassium and sodium were analyzed using a Thermo Jarrel Ash Model ICAP61 simultaneous inductively coupled argon plasma spectrophotometer coupled with a cross-flow nebulizer (U.S. EPA Method 6010).

Cadmium, copper, lead, and zinc were analyzed using a Varian Model Spectra AA-300 single-beam atomic absorption spectrophotometer equipped with an automatic Zeeman background-corrected electrothermal atomizer (U.S. EPA Method 7000).

Mercury was analyzed using an automated LDC Elemental Mercury Analyzer Model 3200 equipped with a 10-centimetre absorption cell (U.S. EPA Method 7000).

3.3 Organic Parameters in Water

These analyses were carried out in accordance with procedures described in "Standard Methods for the Examination of Water and Wastewater" 18th Edition published by the American Public Health Association, 1992 (APHA). Specific details are as follows:

Total and Dissolved Organic Carbon were determined colourimetrically after persulfate-UV digestion, using phenolphthalein reagent (APHA Method 5310, A and C).

3.4 Metals in Sediment - Aqua-Regia Digestion

These analyses were carried out using procedures that are consistent with the requirements of the appropriate regulatory agencies and adapted from U.S.

Environmental Protection Agency Method 3050 (Publ. # SW-836, 3rd ed., Washington, DC 20460). The procedure involves a digestion using a combination of nitric and hydrochloric acid (aqua-regia). The resulting extract is bulked to volume with deionized/distilled water. The digested portion is then analysed by a variety of instrumental techniques, which may include inductively coupled plasma (ICP), direct-flame atomic absorption spectrophotometry (DFAAS), hydride-vapour atomic absorption spectrophotometry (HVAAS) and cold-vapour atomic absorption spectrophotometry (CVAAS) to obtain the required detection limits. Specific details are as follows:

Arsenic was analyzed using a Perkin Elmer Model 5000 dual-beam atomic absorption spectrophotometer coupled to a Perkin-Elmer Model MHS-20 automated hydride generation system (U.S. EPA Method 7000).

Cadmium and Lead were analysed using a Perkin Elmer Model 3100 dual beam atomic absorption spectrophotometer (flame model) equipped with automatic deuterium background correction (U.S. EPA Method 7000).

Mercury was analysed using a Pharmacia Model U.V. mercury monitor equipped with a 30 centimetre absorption cell (U.S. EPA Method 7000).

Cobalt, Copper, Magnesium, Manganese, Nickel and Zinc were analysed using a Thermo Jarrel Ash Model ICAP61 simultaneous inductively coupled argon plasma spectrophotometer interfaced with an IBM PS/2 286 data acquisition system (U.S. EPA Method 6010).

3.5 Metals in Sediment - Four-Acid Digestion

The procedure involves a digestion using a combination of nitric, hydrofluoric, hydrochloric, and perchloric acids. The resulting extract is bulked to volume with deionized/distilled water. The digested portion is then analysed by atomic emission spectrophotometry (ICP) to obtain the required detection limit for each element. Specific details are as follows:

> **Aluminum, Chromium, Iron, Potassium and Sodium** were analysed using a Thermo Jarrel Ash model ICAP61 simultaneous inductively coupled argon plasma spectrophotometer interfaced with an IBM PS/2 286 data acquisition system (U.S. EPA Method 6010).

Silicon analysis was initially requested, but was not possible due to the methodologies selected. The four-acid digestion was carried out in open digestion vessels and the silicon forms silicon tetrafluoride which is volatile.

3.6 Carbon, Nitrogen, Sulphur and Calcium Carbonate in Sediment

Freeze-dried and finely-ground sediment powders were analysed for Total Carbon, Nitrogen and Sulphur using Carlo-Erba NA-1500 CNS and 1106 CHN elemental analyzers. These instruments combust a sample in a stream of O_2, pass the combustion products across a suite of columns to convert evolved gases quantitatively to CO_2, N_2 and SO_2,separate the gases chromatographically, and determine their concentrations by thermal conductivity detection. The pair of instruments were used where the samples were pyrite-rich because a very high sulphur concentration swamps the carbon and nitrogen channels on the CNS analyzer. Carbon and Nitrogen were therefore determined separately on the

Carlo-Erba Model 1106 CHN analyzer, the performance of which is not affected by high Sulphur content.

The inorganic carbon (carbonate) content was determined electrochemically using a Coulometrics Inc. coulometer. The CO_2 evolved during the addition of HCl to a sample is swept into a reaction flask filled with a proprietary solution. Protons released by the reaction between the CO_2 and triethanolamine in the solution are neutralized by the generation of OH- at an immersed electrode. The integrated current required to bring the solution back to neutrality is directly proportional to the CO_2 content. Organic carbon was calculated as the difference between the total carbon and inorganic carbon measurements.

3.7 Method Detection Limits (MDL)

The MDL is considered the most realistic approach to calculating a detection limit because it is based on a complete analytical procedure; it includes matrix effects and is derived from the analysis of samples, or standards rather than blanks. The process involves an actual determination of detection limit by analysing a number of low-level spikes in reagent grade water. The MDL method has been adopted by the U.S. Environmental Protection Agency (EPA) and the Canadian Association of Environmental Analytical Laboratories (CAEAL) and was used to define detection limits for the present program.

All detection limits quoted for the water column samples for this project are MDLs. In some cases, the MDLs were re-verified specifically for this project (these were Arsenic, Cadmium, Copper, Iron, Lead, Manganese, Mercury, and Zinc). The resulting detection limits for these elements are shown below in comparison with the proposed detection limits.

Parameter	Verified MDL (µg/L)	Proposed MDL (µg/L)
Arsenic	0.1	0.5
Cadmium	0.2	0.2
Copper	0.5	0.5
Iron	3.0	1.0
Lead	0.5	0.2-0.5
Manganese	1.0	1.0
Mercury	0.01	0.02
Zinc	1.0	1.0

With the exception of total and dissolved iron, all detection limits were at or below those originally specified in our original scope of work.

Appendix F-2 - UBC Methods

APPENDIX F-2 - UBC METHODS

Sample analysis by UBC, with the exception of solid C, N and S, was restricted to porewaters from the cores and peepers. Analytical methodologies for C, N and S are described in Appendix F-1; porewater analyses are described below.

Dissolved Fe and Mn in porewaters were determined by direct-injection graphite furnace atomic absorption specrophotometry (GFAAS) using a Varian SpectrAA 300 spectrophotometer with Zeeman background correction and a PSD 96 autosampler. Samples were calibrated against diluted NBS standards and referenced against the same reference materials used by ASL.

The trace metals Cd, Cu, Pb and Zn were measured simultaneously on a VG PlasmaQuad Inductively Coupled Plasma Mass Spectrometer (ICP-MS). Samples were first spiked with an internal indium standard and then introduced to the nebulizer by peristaltic pump. Calibration and standard reference were the same as used by GFAAS. The trace metals Hg and As were analysed by ASL as described previously.

Total sulphides were measured spectrophotometrically after the Method of Cline (1969). A predetermined volume of a mixed diamine reagent was added to the preserved sample creating a violet colour that was measured at 640 nm. Calibration was performed with standards made from reagent grade $Na_2S{\cdot}9H_2O$ in DDW preserved with Zn-acetate.

Nitrate, sulphate and phosphate samples were measured by ion chromatography on a Dionex DX 100 ion chromatograph. Samples were calibrated against standards made from reagent grade salts as well as the NBS reference material ANI-04.

Appendix G
Continued Monitoring of Anderson Lake 1995 Program Final Report, March 1996

APPENDIX G - POST-CLOSURE STUDY

1.0 Introduction

The first study program of MEND Project 2.11 involved a detailed geochemical, under-ice study of the sediment and water column of Anderson Lake in northern Manitoba. At that time, Anderson Lake was highly stratified, with a cold, "fresh" surface layer of water (adjacent to the ice) overlying a more dense, warmer layer of anoxic water having a temperature of approximately 6°C. This observation (and others) lead to the suggestion that Anderson Lake did not behave in the "classic" limnologic sense. That is to say, because of its shallow nature, Anderson Lake would not "turn over" in spring or fall. Rather, it was suggested that mixing would occur immediately after ice out and would occur as complete wind-induced homogenization of the water column. Because lake water chemistry had direct bearing on assessing tailings reactivity, it was deemed important by the scientific reviewers that the nature of mixing in Anderson Lake be further addressed.

A second issue to address was the question of whether an improvement of lake water quality would occur after tailings deposition had ceased and the acid-generating roadway to the North of Anderson Lake was removed. By monitoring water quality through that period and after tailings deposition recommenced, it was felt that the relative importance of the various sources of metal to the lake could be better quantified.

A final issue related more to the effects of heating and cooling of the tailings and the potential for advection of pore waters. This was deemed important as metal fluxes have always been based on the assumption that diffusion was the sole transport mechanism. By assessing the distribution of temperature with time and depth in the upper 15 cm of tailings on the lake floor, it was hoped that the issue of pore water advection could be addressed.

Collectively, a program was devised to better characterize the physical and geochemical behaviour of Anderson Lake and the tailings on the lake floor with the hope that the system could eventually be modelled. However, subsequent to the commencement of this program, it was recognized that the inputs of water, acid and metals were too complex to quantify and model. Nonetheless, the program continued with the idea of enhancing the existing database. Following are the details and results of that program.

2.0 Methods

The scope of additional work initiated within Anderson Lake can be broadly described as having three objectives: 1) defining the physical evolution of the Lake as determined by lake thermal data and meteorological data; 2) defining the compositional evolution of Anderson Lake in the absence of all inputs except the existing subaqueous tailings; and 3) determining the thermal evolution of the sediments and interstitial waters. Each of these objectives is outlined below.

2.1 Physical/Thermal Evolution

Weather stations were emplaced at the Southwest and North ends of Anderson Lake to quantify the meteorological forcing on lake hydrology (Figure G-1). In addition to the weather stations, two thermister arrays (eight thermisters each) were deployed in Anderson Lake, one in the water column and one across the sediment-water interface (Plates 2-5 and 2-6 of Anderson Lake report). The water column array was to aid in assessing the physical evolution of the Anderson Lake water column with particular reference to the characteristics of lake turn-over.

Thermal data were collected by deployment of an array of eight YSI 46033 high-precision thermisters through the water column near station 1, connected to a RBI XL-805, 8-channel data logger. Thermisters were situated at depths of 0.58, 0.83, 1.10, 1.17, 1.68, 2.78, 3.05 and 3.28 metres above the lake floor. During winter, the string was shortened by 20 cm between thermisters at 1.67 and 2.78 metres to allow for the formation of ice. The latter three thermisters during the winter resided at 2.58, 2.85 and 3.08 metres above the lake floor, respectively. Sampling resolution was variable from deployment in August 1993 through to July 1995.

At the same time, two weather stations emplaced adjacent to Anderson Lake were continually serviced by HBM&S (Figure G-1). The data from these installations was downloaded routinely and sent to Rescan for analysis. Data included temperature, wind speed and direction, precipitation, relative humidity and

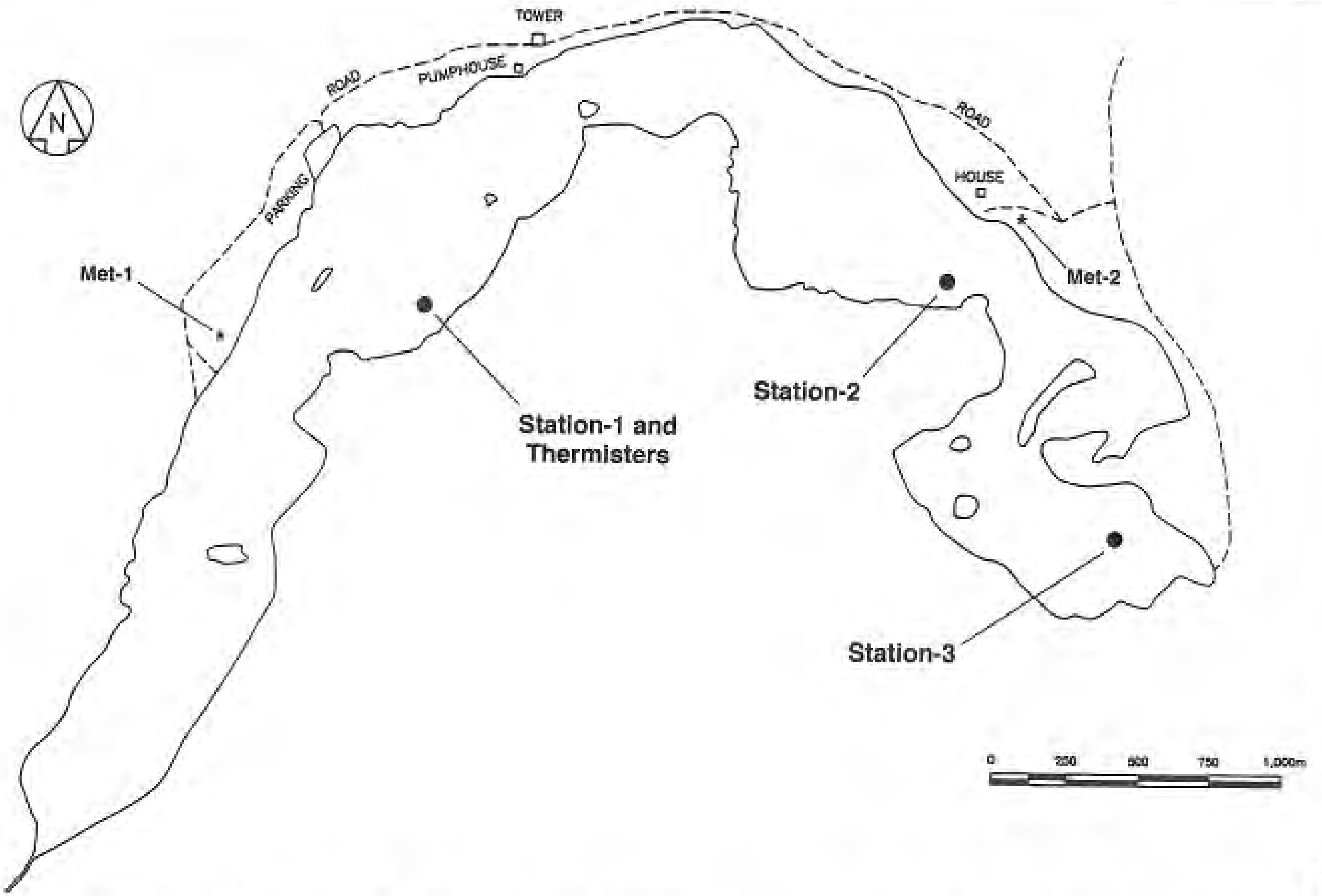

Figure G-1 Sampling Sites for the Anderson Lake Post Closure Study

Rescan

Fig 2-1

insolation. However, because of the limited scope of this project, only temperature, precipitation, wind speed and direction data are used.

2.2 Geochemical Evolution

One complication inherent in all of the Anderson Lake work to date has arisen through an inability to delineate all sources of trace metals and acid to the system. While the access road and adjacent areas were suspected to contribute metal loading to Anderson Lake, they were never targeted for investigation. A companion document (also appended to the Anderson Lake report) addresses some of these issues. In early 1994, tailings deposition into Anderson Lake ceased. Reclamation of the acid-generating road way and adjacent areas was also undertaken, spanning two to three years. The removal of acid generating material from the vicinity of Anderson Lake seemed to provided an opportunity to observe the chemical evolution of the lake waters in the absence of these unquantified contaminant sources. Discussions by the MEND steering committee during the meetings on June 5, 1995 identified the utility of acquiring such information and sanctioned this phase of the study.

The program as described at those meetings was designed to assess the relative influence of those unquantified metal sources by observing the compositional evolution of Anderson Lake in their absence. Following is a brief description of the sampling program.

Samples were collected from two depths at each of three stations within Anderson Lake. Collection began June 20, 1995 occurring twice weekly for a duration of six weeks. Stations were located at the two existing sites (Stations 1 and Stations 2) with a third site (Station 3) situated near the lake outflow (Figure G-1). A level of QA/QC similar to that of MEND Project 2.11 was adopted whereby replicate samples were collected from one station on each sampling interval. The sample replicates were rotated through the stations so that each site received equal sampling intensity throughout the program; sampler replicates and blanks accounted for approximately 25% of the analytical effort.

The recommencement of tailings deposition into Anderson Lake in mid-August 1995, afforded an opportunity to assess the relative influence of all sources on lake water quality (*i.e.*, the subaqueous tailings, the roadway and the tailings slurry).

Consequently, Anderson Lake sampling continued at a lower frequency (two stations twice monthly) until October to assess the impact that the tailings solids and supernatant water have on Anderson Lake water quality. All samples were analyzed for dissolved metals, nutrients and physical parameters.

2.3 Thermal Evolution of the Tailings

The interfacial thermister array was deployed to assess the thermal evolution of the interfacial sediments specifically with regard to the potential for thermally-induced advection of porewater.

Eight YSI 46033 high-precision thermisters connected to a RBI XL-805, 8-channel data-logger were mounted to a PVC rod such that they extended laterally away from the rod at intervals ranging from one to five centimetres. The array was inserted by diver into the tailings at Station 1 until the sediment-water interface eclipsed the zone between thermisters two and three. This resulted in a depth distribution of +4.5, +0.5, -0.5, -1.5, -2.5, -3.5, -8.5 and -13.5 centimetres relative to the sediment-water interface (negative values into the deposit). The array was programmed to download data with the same sampling resolution and duration as the water column.

3.0 Results

Tailings deposition ceased in Anderson Lake in early 1994. Little activity occurred in the area with the exception of the continued removal of the pre-existing sub-areal mine waste that existed proximal to the northern and western shores of the lake. Additional acid-generating areas to the west of Anderson Lake were also being removed.

Following is an assessment of the data generated by this campaign including water quality, meteorology, and lake and sediment thermal evolution. However, given the magnitude of the data set and limited scope of the project, only select portions of data are presented to illustrate specific influences.

3.1 Water Column Composition

Of the suite of parameters analyzed from the Anderson Lake water column, only major ions, nitrate and Zn displayed easily measurable change with time. Each component is presented in turn.

The major ion content and conductivity of Anderson Lake showed little variation with depth suggesting that the lake was well mixed at all three stations throughout the period of the study. Conductivity ranged from 1,450 to 1,530 µmhos/cm until early August after which it decreased at all three sites simultaneously to values as low as 1,350 µmhos/cm, suggesting a lake-wide addition of low-conductivity water. Calcium followed a similar pattern decreasing from 290 to 240 mg/L. In general, the major ion parameters track each other well between stations with the exception of periodic excursions.

Of the suite of trace metals analyzed, dissolved Zn, and to a lesser degree Cu, were the only metals to display marked changes in concentration with time through the course of the sampling program. By the beginning of the study, dissolved Zn had decreased from >200 µg/L during the August 1993 study to concentrations ranging from 100 to 150 µg/L (Figure G-3). However, by late July or early August, 1995, dissolved Zn began to increase steadily reaching values as high as 350 µg/L by study completion (October 2, 1995). Dissolved Cu had decreased from a concentration in August 1993 of ~30 µg/L by an order of magnitude to concentrations between 2 and 4 µg/L at the beginning of this study. After the August 8, 1995 sampling, dissolved Cu increased in a similar fashion to ~8 µg/L (Figure G-3). The implication from all parameters is the existence of a localized source of low conductivity water enriched in Zn and perhaps Cu.

3.2 Thermal Variations, Meteorology and Lake Mixing

An extensive thermal and meteorological data set exists for Anderson Lake for the period from 1993 to 1995. The limited scope of this project does not allow interpretation of the entire period. Consequently, select portions of the data are used to illustrate the salient features of lake dynamics.

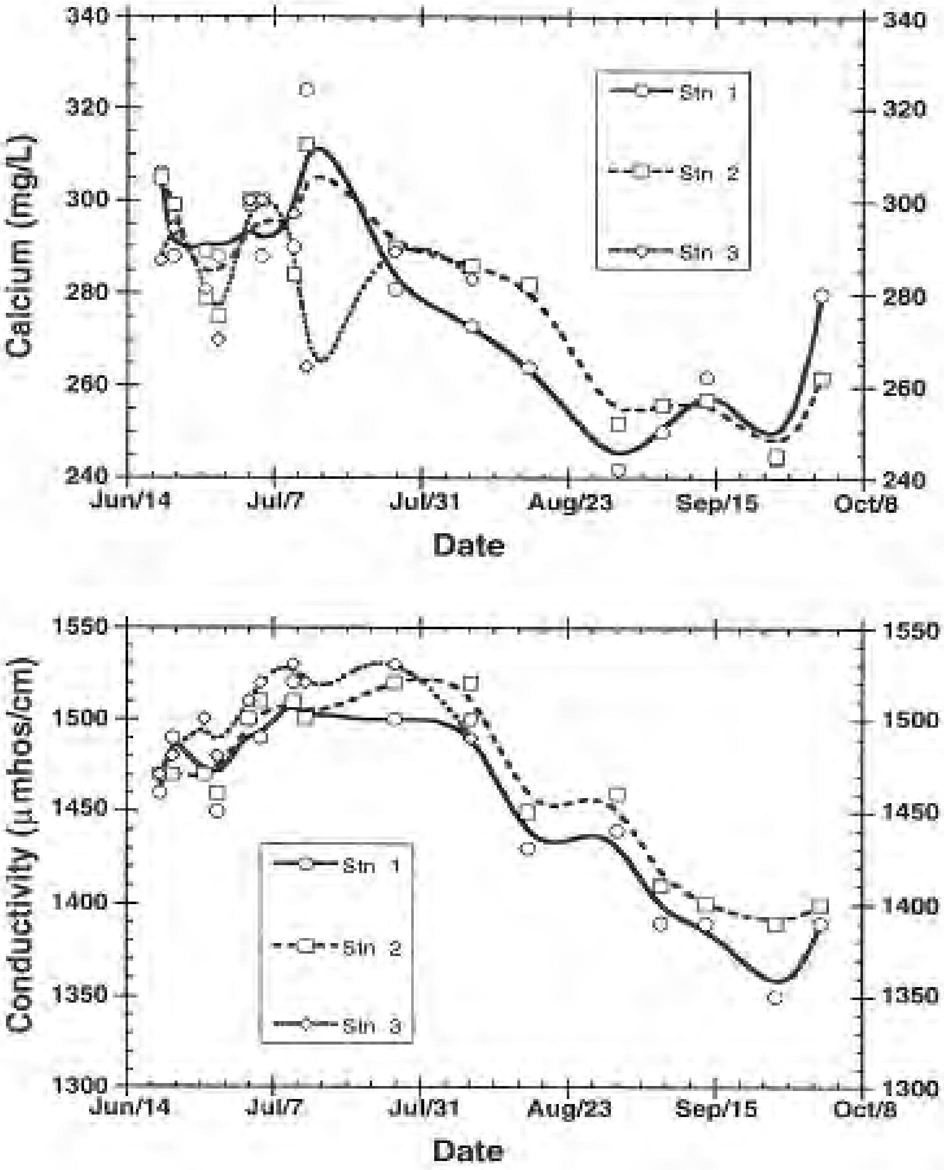

Figure G-2 Dissolved Ca and conductivity in Anderson Lake at all three stations.

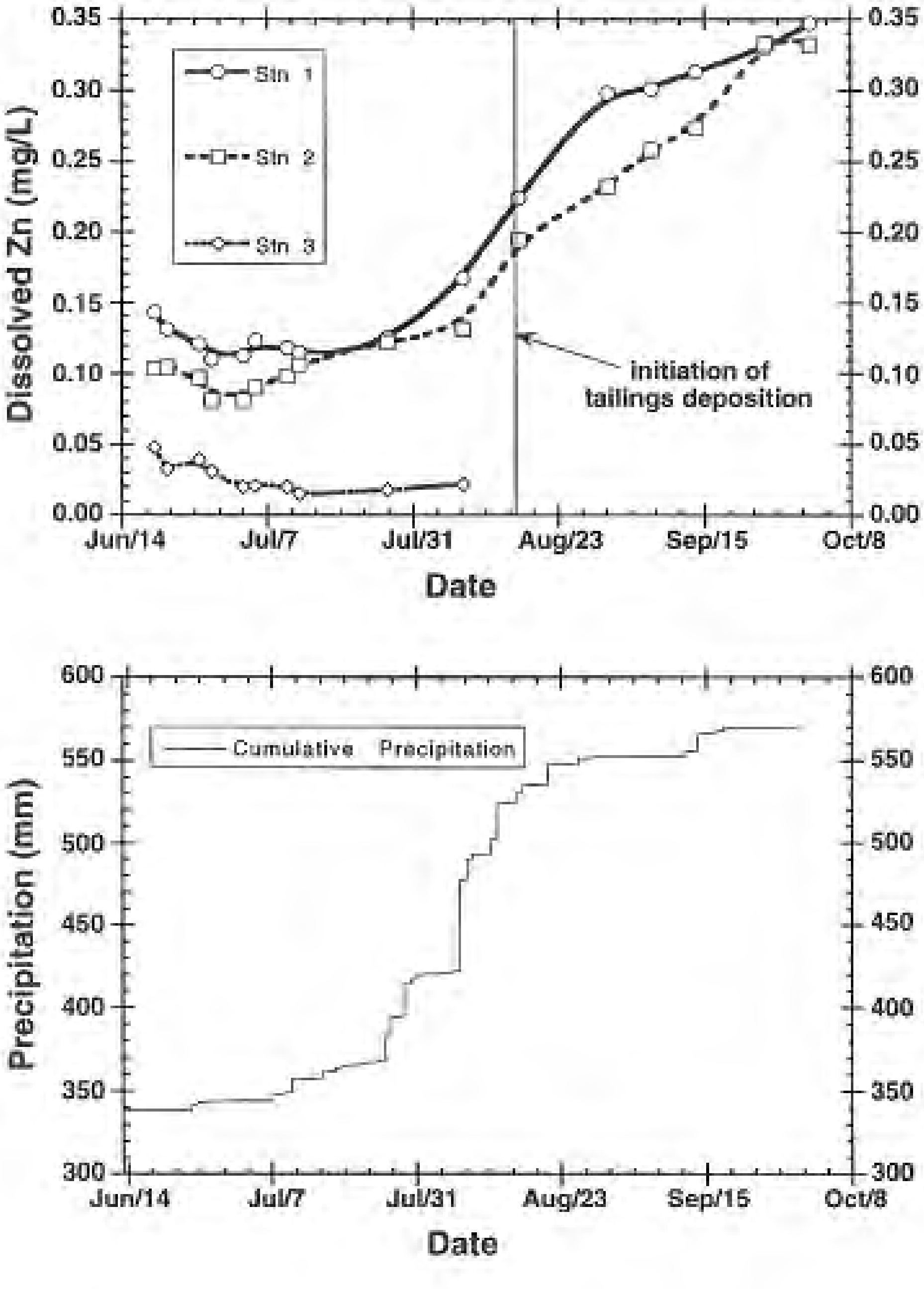

Figure G-3 The temporal concentration of dissolved Zn in Anderson Lake and the cummulative rainfall over the same interval.

Watercolumn

Annual water column temperatures range from approximately 2° to 22°C (Figure G-4). The thermal evolution is markedly seasonal with the highest and lowest temperatures generally occurring in August and November, respectively. During the two under-ice deployments, the lowest temperatures were recorded immediately after ice-cover after which the temperature was observed to rise slowly until spring melt.

Diurnal fluctuations can be seen during the cooling period from August to November, 1993 (Figure G-5) whereby the entire water column cools simultaneously (as evinced by the coalescence of the temperatures at various depths). However, during the day, when surface waters warm, brief periods of stratification develop (seen as a divergence of temperatures; Figure G-5). This process is also illustrated in the water column and meteorologic data from June to July, 1994 (Figure G-6) which show periodic stratification except when wind speed (hence mixing) is elevated.

Sediments

Sediment heating and cooling characteristics are best viewed in two plots which illustrate the influence of short and long-term temperature variations on the thermal structure of the sediments (Figure G-7). Where short-term temperature fluctuations occur (*i.e.* on the order of a few days), sediment cooling at depth appears to precede that of the water column and near-surface sediments (Figure G-7). In this example, bottom waters cool from 19°C to 16.5°C in two days. Sediment facies at depth (13.5 cm) respond simultaneously decreasing from 17.5 to 16°C. However, when lake water temperature changes persist for more than a few days, the deep sediments become a source of thermal energy rather than a sink; the deep sediments become warmer than the shallower. It is in the latter example that thermal pore water advection becomes possible.

4.0 Discussions

Following are discussions of the compositional and thermal evolution of the Anderson Lake water column.

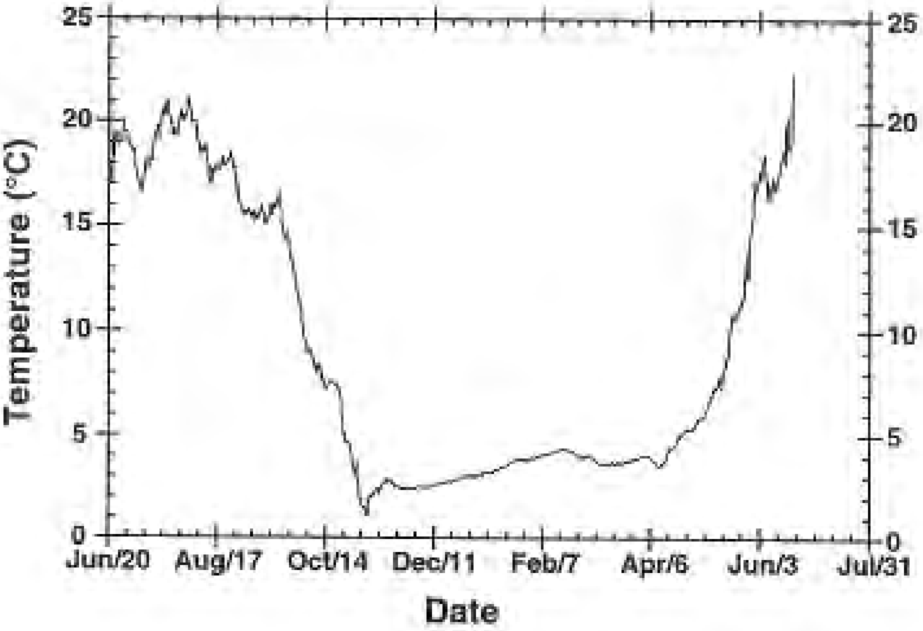

Figure G-4 Temporal evolution of bottom water temperature in Anderson Lake, Station 1.

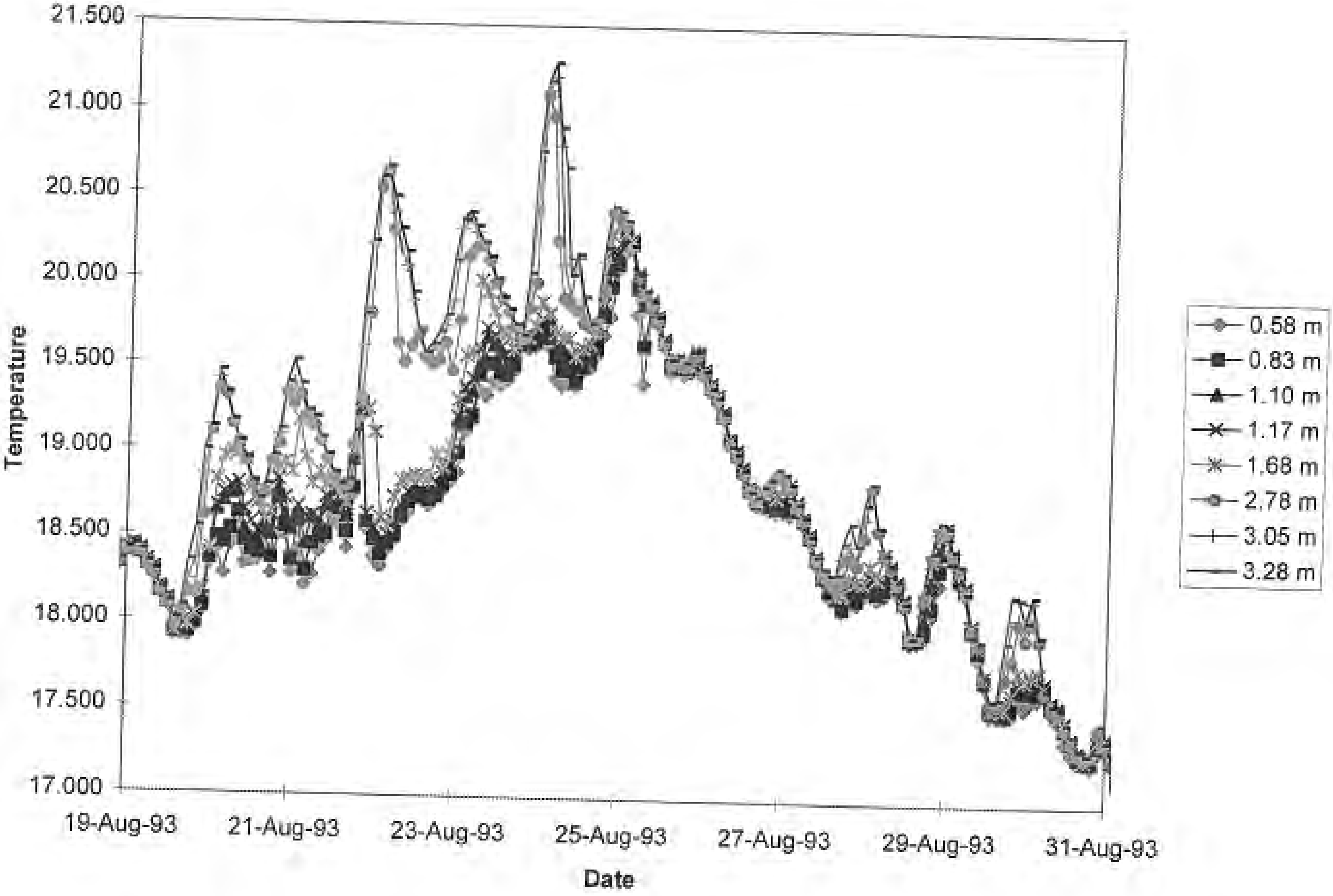

Figure G-5 Diurnal fluctuations of temperature within Anderson Lake at Station 1.

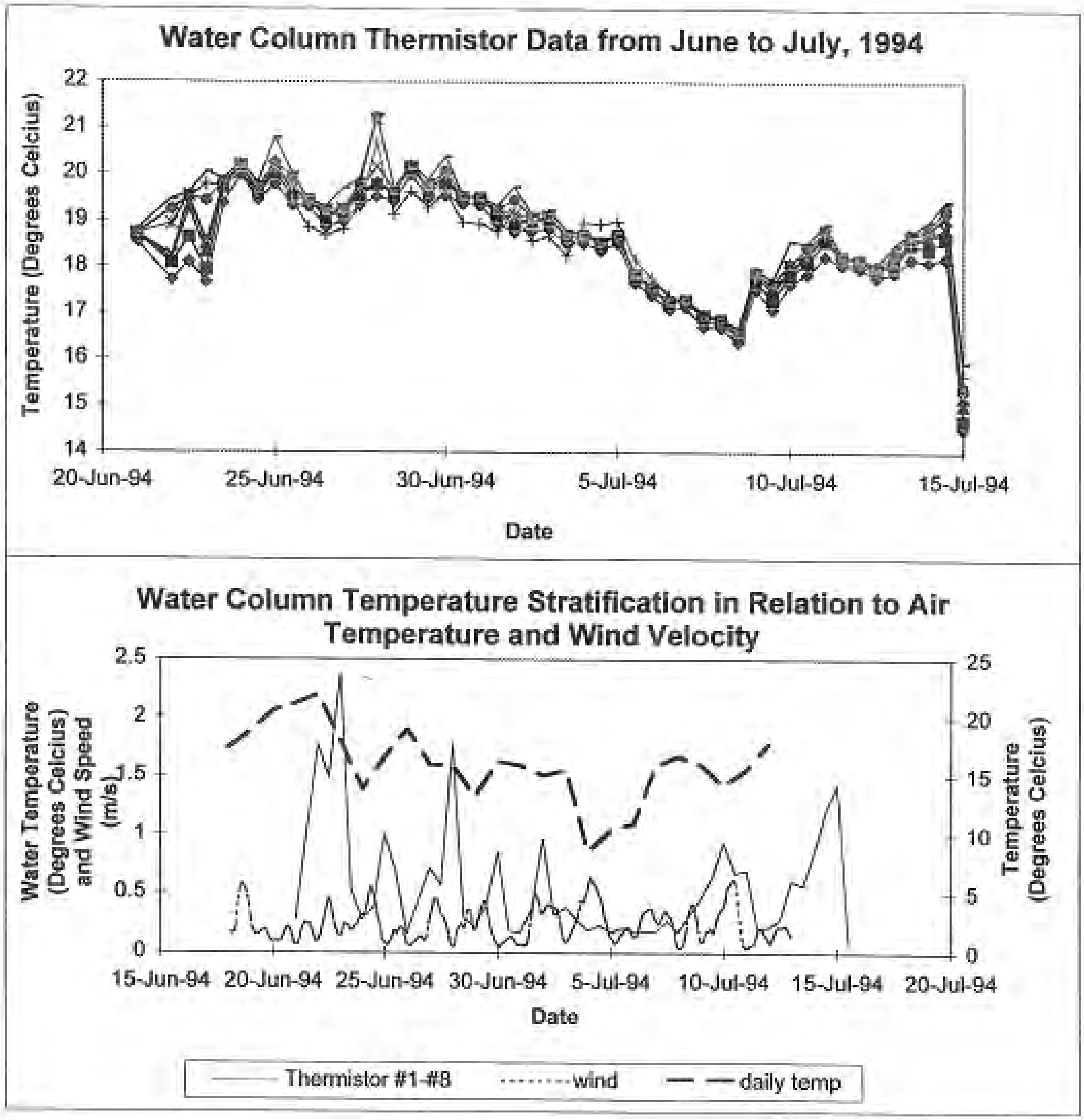

Figure G-6 The influence of temperature and wind-speed on lake stratification.

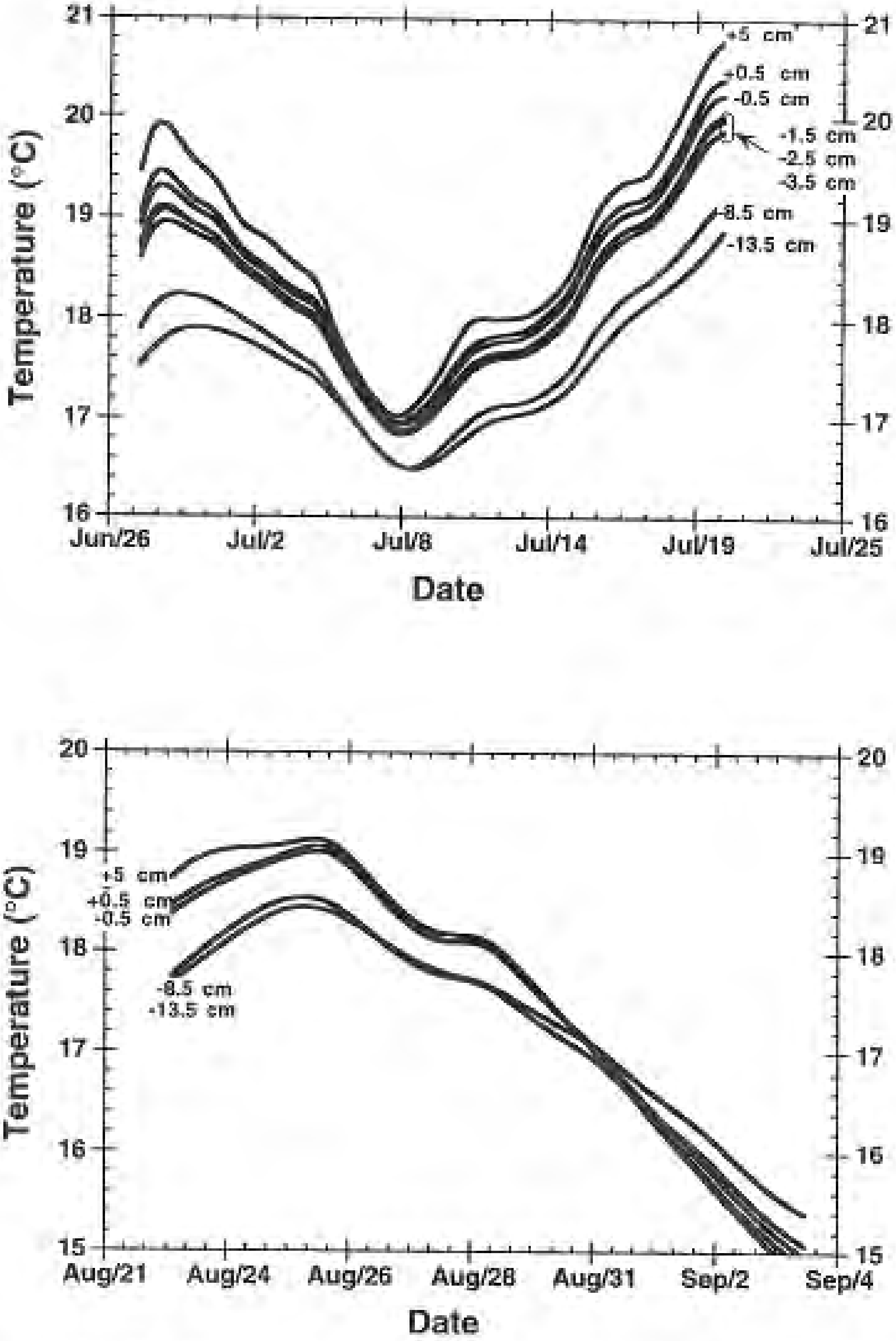

Figure G-7 Sediment Thermister Data from Anderson Lake for the Period from (a) June 26, 1994 to July 25, 1994 and (b) from August 21, 1993 to September 4, 1993. Depths are relative to the sediment-water interface, negative values are deeper in the deposit.

4.1 Water Column

Dissolved constituents in the water column at each station were uniform with depth for the duration of the post-closure study suggesting that the lake was vertically well mixed. Water quality improved markedly between the last study in August, 1993 and the beginning of this study, dissolved Zn in particular decreased from approximately 0.3 to 0.1 mg/L. This observation by itself suggests that the subaqueous tailings are not responsible for the majority of historical contamination in Anderson Lake. A large fraction of the contaminant metals must have come from external sources; presumably either the acid-generating road way and adjacent areas or the tailings supernatant.

It is unknown from these data in isolation as to whether the subaqueous tailings contributed a fraction to the lake water quality as there was likely insufficient time for the lake to flush completely. However, in the context of previous work, the diffusive flux of Zn (and other metals) was into the sediments. As pore water concentrations were below detection limits, it is impossible for tailings oxidation to alter water quality to the extent observed.

When tailings deposition recommenced, dissolved Zn began to increase steadily, on face value suggesting that tailings supernatant may have contributed to elevated dissolved metals (it is doubtful whether a tailings solid could dissolve rapidly enough to impact water quality to the observed degree particularly in light of the pore water gradients observed in the past). However, the initial increase in dissolved Zn (late July or early August) preceded the introduction of tailings to the lake (August 15, 1995). Furthermore, simple mass balance calculations (outlined below) using supernatant composition demonstrate that supernatant could not be solely responsible for the alteration of Anderson Lake water quality (Table G-1); dissolved Zn is too low to account for alteration in Anderson Lake water quality.

Table G-1
Anderson Lake Tailings Supernatant Water Quality

Date	Zn (mg/L)
Feb. 05, 1996	0.04
Feb. 12, 1996	0.29
Feb. 26, 1996	0.18

Assuming a conservative lake volume of 6 x 10^6 m^3 (approximately half of the actual volume; Rescan 1990) and an increase from 0.1 to 0.3 mg/L Zn over 90 days translates to an additional loading of ~600 kg Zn. The tailings discharge ran 50% of the time for the duration of the study at a flow rate of 7,273 m^3/day (S. West pers. comm.) for a total volume of 327 x 10^6 L over 90 days. Assuming a conservative slurry composition of 0% solids (*i.e.*, the entire flow as Zn-laden water), the concentration of dissolved Zn would by necessity have to be approximately 1.7 mg/L to result in the observed increase. This concentration is ten times larger than that presently found in the supernatant (Table G-1). Rather, the rapid increase in Zn (and lowering of conductivity) corresponds well with a marked increase in precipitation initiating at the same time (Figure G-3). The removal of the existing road-way (and other acid generating areas) likely disturbed residual soluble oxidation products. The relatively dry summer followed by the pronounced increase in precipitation may have been sufficient to introduce a pulse of metals to the Anderson Lake system. This premise is supported by the decrease in conductivity and major ion concentrations coincident with increases in Zn suggesting that the metals were associated with low conductivity runoff. The decrease in lake conductivity can be accounted for by as little as 10 to 15 cm of rainfall on the surface area of the lake which did indeed occur through the same period (Figure G-3). If terrestrial zones containing residual oxidation products existed, an increase in precipitation would result in elevated trace metals and diminished conductivity.

The lateral distribution of dissolved Zn between stations (Station 3 was the most pristine) suggests that the source of metals resides in the western and/or northern reaches of lake adjacent to the tailings outfall, roadway and sub-aqueous deposits.

4.2 Sediments

The temperature of the near-surface tailings is influenced by both the water column and the tailings below. In other word, the primary influence of heating or cooling is from above, when surface sediments cool during the fall, the deeper sediments (13.5 cm) cool concurrently as the heat flux from above is lowered; they are influenced by the cooler sediments deeper. Deep sediments do not become warmer than surface sediments until the cooling trend has persisted for several days at which point, the deeper sediments provide a source of residual thermal energy.

That the temperature lines of Figure G-7 are approximately symmetric around the temperature minimum on July 8, 1995 suggests that pore water advection is not responsible for a substantial fraction of heat transport. Rather, heat transfer must arise through conduction. However, the effect on pore water advection cannot be ruled out, nor can it be easily quantified from these data. Thus, the question is distilled to: "Can the maximum observed temperature gradient of ~2°C over depth scales of ~10 cm invoke pore water convection?" If it does, this influence is limited to a three month window from August to November in Anderson Lake; for the remainder of the year, thermal advection of interstitial waters cannot occur.

5.0 Conclusions

Are the mine tailings releasing metals to the water column? The answer is a qualified no. Dissolved Zn did indeed decrease from the last study (August, 1993) to the present study. However, given that removal of the acid generating roadway and adjacent areas spanned several years, residual oxidation by-products likely continued to flush into Anderson Lake, specifically during storm events. Because 1995 was a dry summer, a minimal quantity of fresh water was introduced to Anderson Lake; water was not released from the lake through the same period. Consequently, there was effectively no flushing or replacement of the system with fresh water nor were there any substantive metal inputs. However, it cannot be stated unequivocally that the stabilization of dissolved Zn in the water column from June to late July did not in part result from a tailings source. The absence of significant precipitation and discharge from Anderson Lake disfavours this possibility.

The elevation in dissolved Zn and decrease in conductivity occurring prior to recommencement of discharge of tailings into Anderson Lake corresponds to storm events which introduced substantial quantities of rainwater (and runoff) to the lake. As there is insufficient Zn in the tailings supernatant, it seems likely that the elevated metal (beginning in late July) reflects the rinsing of solids containing residual oxidation products on the lake shore. Periodic precipitation events wash this Zn into Anderson Lake. Thus, the water quality in Anderson Lake is likely a function of the rate input of oxidation by-products (dependent in part on meteorology), balanced by precipitate mechanisms in the water column. In this sense, Anderson Lake water composition has likely been variable with time and will continue to behave in this fashion until the flushing of oxidation products is complete.

Stn.1 - Sfc.	20-Jun-95	22-Jun-95	27-Jun-95	29-Jun-95	4-Jul-95	6-Jul-95	11-Jul-95	13-Jul-95
Cond.(umhos/cm)	1460	1490	1470	1450	1500	1490	1520	1500
Hardness CaCO3	830	779	782	780	865	779	786	878
pH	7.44	7.28	7.08	6.96	7.05	6.77	6.74	7.01
TSS (mg/L)	4	2	7	5	3	2	3	3
Alk. (mg/L)	20.9	21.2	20.8	21.5	21	21.5	19.8	20.7
Chloride	58	57.6	56.4	58.5	57.7	57.4	58.6	57.7
Sulphate	709	777	754	736	714	733	791	727
Ammonia	0.015	0.047	0.071	0.08	0.051	0.061	0.079	0.067
Nitrate	0.345	0.29	0.229	0.194	0.185	0.178	0.144	0.14
Total P	0.01	0.01	0.009	0.011	0.014	0.01	0.01	0.009
As(d)	0.0005	0.0006	0.0006	0.001	0.0009	0.0003	0.0009	0.0009
Cd(d)	0.0005	0.0003	<0.0002	0.0003	<0.0002	<0.0002	<0.0002	<0.0002
Ca(d)	306	288	289	288	299	288	290	324
Cu(d)	0.012	0.004	0.004	0.004	0.003	0.004	0.003	0.002
Fe(d)	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030
Pb(d)	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001
Mg(d)	15.8	14.8	14.9	14.6	16.5	14.6	15.1	16.7
Mn(d)	0.006	0.008	0.027	0.045	0.071	0.062	0.065	0.069
Hg(d)	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
K(d)	12.4	11.8	12.3	12.6	14.5	12.1	12.8	13.7
Na(d)	39.2	37	37.3	37.3	41.6	37.1	39.5	42.2
Zn(d)	0.143	0.131	0.121	0.11	0.112	0.123	0.118	0.115

All units are mg/L unless otherwise noted

Stn.1 - Sfc.	27-Jul-95	8-Aug-95	17-Aug-95	31-Aug-95	7-Sep-95	14-Sep-95	25-Sep-95	2-Oct-95
Cond.(umhos/cm)	1500	1500	1430	1440	1390	1390	1350	1390
Hardness CaCO3	762	740	720	662	684	714	670	766
pH	6.93	7.05	7	6.96	6.82	6.88	7.02	7.18
TSS (mg/L)	4	2	4	3	3	5	4	3
Alk. (mg/L)	21.9	19.4	18.9	18.2	18.8	18.2	17.2	17.4
Chloride	57.1	47.9	54	54.3	53.4	53.2	55	55.3
Sulphate	771	717	704	714	653	679	664	719
Ammonia	0.081	0.067	0.081	0.038	0.031	0.015	<0.005	0.017
Nitrate	0.082	0.065	0.064	0.059	0.05	0.052	0.057	0.056
Total P	0.009	0.008	0.008	0.007	0.012	0.008	0.01	0.009
As(d)	0.001	0.0009	0.0007	0.0008	0.0008	0.0007	0.0008	0.0006
Cd(d)	0.0002	0.0002	0.0004	<0.0002	0.0004	0.0006	0.0007	0.0006
Ca(d)	281	273	264	242	250	262	244	280
Cu(d)	0.003	0.002	0.007	<0.001	0.006	0.008	0.008	0.008
Fe(d)	<0.030	<0.030	<0.030	<0.030	0.034	<0.030	<0.030	<0.030
Pb(d)	<0.001	<0.001	<0.001	0.007	0.003	0.001	<0.001	0.001
Mg(d)	14.9	14.3	14.5	13.8	14.3	14.6	14.6	16.4
Mn(d)	0.05	0.039	0.053	0.075	0.079	0.08	0.076	0.087
Hg(d)	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
K(d)	12	11	11	11.7	10.4	11.6	11.8	13
Na(d)	38.2	36	34.4	33.2	32.4	33.8	39.5	40.3
Zn(d)	0.125	0.167	0.224	0.298	0.301	0.313	0.33	0.347

All units are mg/L unless otherwise noted

Stn.1 - Deep	20-Jun-95	22-Jun-95	27-Jun-95	29-Jun-95	4-Jul-95	6-Jul-95	11-Jul-95	13-Jul-95
Cond. (umhos/cm)	1470	1470	1470	1470	1490	1500	1500	1490
Hardness CaCO3	827	797	792	752	863	767	793	880
pH	7.4	7.23	7	7.01	7.15	6.79	7.04	7.06
TSS (mg/L)	5	3	161	5	4	3	<1	3
Alkalinity (mg/L)	20.9	21.3	20.6	21	21	21.3	20.3	20.8
Chloride	57.8	58.2	57.4	59.5	58	57.6	58.6	57.8
Sulphate	717	802	730	707	730	711	782	710
Ammonia	0.016	0.054	0.069	0.085	0.053	0.067	0.079	0.057
Nitrate	0.35	0.284	0.246	0.192	0.184	0.172	0.136	0.137
Total P	0.011	0.011	0.008	0.009	0.008	0.014	0.013	0.01
As(d)	0.0005	0.0006	0.0006	0.001	0.0009	0.0003	0.0009	0.0009
Cd(d)	0.0003	0.0002	0.0002	<0.0002	<0.0002	<0.0002	<0.0002	0.0002
Ca(d)	305	294	292	278	298	283	293	325
Cu(d)	0.003	0.004	0.003	0.004	0.003	0.003	0.004	0.003
Fe(d)	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030
Pb(d)	<0.001	<0.001	0.001	0.001	0.001	0.002	<0.001	0.001
Mg(d)	15.7	15.1	15.2	14.2	16.4	14.4	15.1	16.7
Mn(d)	<0.005	0.005	0.027	0.045	0.071	0.063	0.066	0.07
Hg(d)	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
K(d)	12.5	12.6	12.6	12.1	14.1	11.5	12.9	13.6
Na(d)	39.3	37.3	37.8	36.3	41.7	36.4	39.1	42.2
Zn(d)	0.125	0.13	0.119	0.105	0.11	0.122	0.117	0.115

All units are mg/L unless otherwise noted

Stn.1 - Deep	27-Jul-95	8-Aug-95	17-Aug-95	31-Aug-95	7-Sep-95	14-Sep-95	25-Sep-95	2-Oct-95
Cond. (umhos/cm)	1490	1500	1440	1420	1400	1390	1350	1400
Hardness CaCO3	812	763	739	687	686	704	678	754
pH	6.95	7.1	7.07	6.93	6.9	6.89	7.05	7.13
TSS (mg/L)	5	<1	3	3	<1	3	3	5
Alkalinity (mg/L)	21.4	19.4	18	18.3	18.4	18.7	16.8	17.5
Chloride	57.5	58.7	53.4	54.2	53.4	52.8	55.2	55.8
Sulphate	756	756	722	698	649	708	678	713
Ammonia	0.08	0.072	0.076	0.039	0.033	0.013	<0.005	0.014
Nitrate	0.081	0.038	0.068	0.056	0.053	0.053	0.057	0.063
Total P	0.01	0.009	0.008	0.009	0.004	0.009	0.01	0.009
As(d)	0.0009	0.001	0.0007	0.0007	0.0008	0.0007	0.0008	0.0006
Cd(d)	0.0002	0.0002	0.0003	<0.0002	0.0004	0.0006	0.0006	0.0006
Ca(d)	299	281	272	252	251	258	247	276
Cu(d)	0.002	0.003	0.006	<0.001	0.007	0.006	0.008	0.008
Fe(d)	<0.030	<0.030	<0.030	<0.030	0.034	<0.030	<0.030	<0.030
Pb(d)	<0.001	<0.001	<0.001	0.006	0.003	0.002	<0.001	<0.001
Mg(d)	15.8	14.7	14.7	14.2	14.3	14.4	14.8	16.1
Mn(d)	0.053	0.041	0.056	0.078	0.079	0.08	0.076	0.086
Hg(d)	<0.00005	<0.00005	<0.00005	<0.00005	0.00005	<0.00005	<0.00005	<0.00005
K(d)	13.1	11.9	11.5	11.6	10.3	11.5	11.1	12.7
Na(d)	40.6	37.1	35.1	34.3	32.4	33.4	40.3	39.3
Zn(d)	0.135	0.165	0.225	0.295	0.3	0.316	0.327	0.331

All units are mg/L unless otherwise noted

Stn.2 - Sfc.	20-Jun-95	22-Jun-95	27-Jun-95	29-Jun-95	4-Jul-95	6-Jul-95	11-Jul-95	13-Jul-95
Cond.(umhos/cm)	1470	1470	1470	1460	1500	1510	1510	1500
Hardness CaCO3	828	810	757	745	858	814	768	845
pH	7.49	7.17	6.96	6.94	7.06	6.77	6.73	6.93
TSS (mg/L)	4	3	16	1	3	1	6	1
Alk. (mg/L)	21.9	21.8	20.9	21.6	20.4	20.4	19.1	19.4
Chloride	56.5	58.7	57.8	59.6	58.6	58.5	59.2	58.7
Sulphate	726	785	727	741	735	728	813	723
Ammonia	0.007	0.04	0.063	0.07	0.059	0.041	0.049	0.045
Nitrate	0.304	0.22	0.185	0.159	0.144	0.122	0.091	0.093
Total P	0.013	0.017	0.009	0.013	0.01	0.011	0.005	0.009
As(d)	0.0004	0.0007	0.0011	0.0013	0.0011	0.0004	0.001	0.0011
Cd(d)	0.0002	0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Ca(d)	305	299	279	275	300	300	284	312
Cu(d)	0.004	0.003	0.003	0.002	0.001	0.004	0.002	0.002
Fe(d)	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030
Pb(d)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mg(d)	15.8	15.3	14.5	14.1	16.3	15.5	14.4	16
Mn(d)	<0.005	0.015	0.038	0.045	0.055	0.048	0.047	0.06
Hg(d)	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
K(d)	12.7	12.2	11.6	12.6	14	12.3	11.9	13
Na(d)	39.3	38	36.4	36	40.3	37.3	37.4	40.4
Zn(d)	0.103	0.104	0.097	0.081	0.081	0.09	0.098	0.106

All units are in mg/L unless otherwise noted

Stn.2 - Sfc.	27-Jul-95	8-Aug-95	17-Aug-95	31-Aug-95	7-Sep-95	14-Sep-95	25-Sep-95	2-Oct-95
Cond.(umhos/cm)	1520	1520	1450	1460	1410	1400	1390	1400
Hardness CaCO3	788	776	766	688	699	701	673	716
pH	6.94	7.08	7.05	6.9	6.75	7.01	7.04	7.08
TSS (mg/L)	4	3	6	1	4	1	1	3
Alk. (mg/L)	20.5	19.2	18	18.5	18.7	18.4	16.5	17.3
Chloride	58.2	58.9	55.9	56	53	53.5	56.7	55.8
Sulphate	764	744	726	716	661	715	667	739
Ammonia	0.072	0.048	0.046	0.029	0.022	0.006	<0.005	0.011
Nitrate	0.065	0.059	0.062	0.061	0.053	0.053	0.052	0.051
Total P	0.009	0.011	0.009	0.012	0.01	0.011	0.009	0.009
As(d)	0.0009	0.0008	0.0007	0.0007	0.0007	0.0006	0.0008	0.0006
Cd(d)	0.0002	0.0002	0.0004	<0.0002	0.0002	0.0006	0.0007	0.0006
Ca(d)	290	286	282	252	256	257	245	262
Cu(d)	0.003	0.002	0.005	<0.001	0.005	0.005	0.004	0.005
Fe(d)	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030
Pb(d)	<0.001	<0.001	<0.001	0.001	0.001	<0.001	<0.001	<0.001
Mg(d)	15.4	14.9	15.2	14	14.6	14.4	14.7	15.3
Mn(d)	0.05	0.049	0.059	0.071	0.075	0.074	0.069	0.075
Hg(d)	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
K(d)	12.7	11.5	12.2	11.8	9.9	11.2	11.7	11.8
Na(d)	40	37.8	36.8	34.3	33.5	33.2	39.9	37.2
Zn(d)	0.122	0.131	0.194	0.232	0.258	0.274	0.333	0.332

All units are in mg/L unless otherwise noted

Stn.2 - Deep	20-Jun-95	22-Jun-95	27-Jun-95	29-Jun-95	4-Jul-95	6-Jul-95	11-Jul-95	13-Jul-95
Cond.(umhos/cm)	1470	1490	1480	1460	1510	1500	1520	1500
Hardness CaCO3	822	780	749	729	845	842	806	786
pH	7.48	7.09	6.96	6.98	7.06	6.75	6.74	6.89
TSS (mg/L)	3	3	3	3	2	2	4	3
Alk. (mg/L)	21.3	21.7	21.3	21.5	20.1	19.9	20	19.1
Chloride	59	58.6	57.3	59	57.8	58.2	58.8	58.8
Sulphate	732	768	741	727	712	742	811	707
Ammonia	0.006	0.038	0.063	0.069	0.071	0.041	0.047	0.052
Nitrate	0.295	0.216	0.183	0.159	0.14	0.116	0.095	0.092
Total P	0.011	0.014	0.01	0.013	0.012	0.011	0.011	0.01
As(d)	0.0004	0.0006	0.0009	0.0013	0.0011	0.0006	0.001	0.0011
Cd(d)	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Ca(d)	304	288	276	269	298	311	297	290
Cu(d)	0.005	0.004	0.002	0.002	0.002	0.002	0.002	0.002
Fe(d)	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030
Pb(d)	<0.001	<0.001	<0.001	0.001	<0.001	0.001	<0.001	<0.001
Mg(d)	15.6	15	14.3	13.9	16.1	15.9	15.3	15.1
Mn(d)	0.005	0.015	0.038	0.044	0.054	0.052	0.05	0.056
Hg(d)	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
K(d)	12.6	11.8	11.8	11.7	13	12.2	12.9	12.1
Na(d)	38.8	37.5	36.1	35.4	39.1	38.2	40.2	38
Zn(d)	0.099	0.107	0.093	0.081	0.08	0.092	0.095	0.105

All units are in mg/L unless otherwise noted

Stn.2 - Deep	27-Jul-95	8-Aug-95	17-Aug-95	31-Aug-95	7-Sep-95	14-Sep-95	25-Sep-95	2-Oct-95
Cond.(umhos/cm)	1520	1490	1460	1470	1410	1400	1380	1410
Hardness CaCO3	767	768	720	719	674	651	677	648
pH	6.98	6.85	7.07	7	6.95	7.02	7.03	7.09
TSS (mg/L)	3	1	3	3	2	4	2	4
Alk. (mg/L)	20.3	18.9	18	18.9	18.8	18.4	16.7	17.5
Chloride	58.6	58.5	55.7	55.2	54.1	53.4	56.2	54.2
Sulphate	787	750	735	708	670	729	666	714
Ammonia	0.073	0.048	0.045	0.024	0.021	<0.005	<0.005	0.007
Nitrate	0.067	0.059	0.063	0.047	0.051	0.051	0.051	0.052
Total P	0.011	0.011	0.008	0.015	0.012	0.01	0.009	0.013
As(d)	0.0009	0.0009	0.0007	0.0007	0.0007	0.0006	0.0008	0.0006
Cd(d)	<0.0002	0.0002	0.0003	<0.0002	0.0002	0.0005	0.0006	0.0006
Ca(d)	282	283	264	264	247	239	247	236
Cu(d)	0.003	0.002	0.004	<0.001	0.005	0.005	0.004	0.004
Fe(d)	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030
Pb(d)	<0.001	<0.001	0.005	<0.001	0.001	<0.001	<0.001	<0.001
Mg(d)	15.1	14.9	14.5	14.6	14.1	13.4	14.7	14.1
Mn(d)	0.049	0.049	0.056	0.069	0.07	0.068	0.07	0.068
Hg(d)	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
K(d)	12.5	11.8	11.5	12.5	10.7	10.2	11.5	10.6
Na(d)	39	37.4	34.9	36.2	32.1	31	39.8	34.3
Zn(d)	0.116	0.132	0.186	0.194	0.251	0.27	0.332	0.336

All units are in mg/L unless otherwise noted

Stn.3 - Sfc.	20-Jun-95	22-Jun-95	27-Jun-95	29-Jun-95	4-Jul-95	6-Jul-95	11-Jul-95	13-Jul-95
Cond.(umhos/cm)	1470	1480	1500	1480	1510	1520	1530	1520
Hardness CaCO3	777	797	763	731	811	814	803	715
pH	7.59	7.19	7.09	7.09	7.42	7.1	7.42	7.52
TSS (mg/L)	3	1	4	3	1	2	1	<1
Alk. (mg/L)	22.7	23.3	23	23	22.9	22.2	23.1	22.9
Chloride	58.8	58.6	57.9	60.3	59.1	59.5	59.5	59.3
Sulphate	723	793	750	731	660	746	702	715
Ammonia	0.017	0.061	0.057	0.061	0.087	0.031	0.041	0.016
Nitrate	0.148	0.122	0.085	0.071	0.05	0.038	0.019	0.011
Total P	0.016	0.011	0.015	0.017	0.017	0.015	0.01	0.02
As(d)	0.0004	0.0004	0.0004	0.0006	0.0005	<0.0001	0.0004	0.0005
Cd(d)	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Ca(d)	287	294	281	270	300	300	297	264
Cu(d)	0.004	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Fe(d)	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030	0.033	0.042
Pb(d)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mg(d)	14.6	15.2	14.6	13.9	15.4	15.6	15.1	13.8
Mn(d)	0.007	0.016	0.024	0.033	0.038	0.038	0.037	0.035
Hg(d)	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
K(d)	11.6	12.2	11.7	11.5	12.3	12.3	12.6	11.2
Na(d)	37.2	37.6	36.9	35.4	38.6	38.2	39.3	34.7
Zn(d)	0.048	0.033	0.039	0.031	0.02	0.021	0.02	0.015

All units are in mg.L unless otherwise noted

Stn.3 - Sfc.	27-Jul-95	8-Aug-95	17-Aug-95	31-Aug-95	7-Sep-95	14-Sep-95	25-Sep-95	2-Oct-95
Cond.(umhos/cm)	1530	1490						
Hardness CaCO3	785	767						
pH	7.18	6.97						
TSS (mg/L)	3	3						
Alk. (mg/L)	24.2	21.2						
Chloride	59.9	59.3						
Sulphate	790	722						
Ammonia	0.029	0.011						
Nitrate	<0.005	<0.005						
Total P	0.02	0.01						
As(d)	0.0005	0.0006						
Cd(d)	<0.0002	<0.0002						
Ca(d)	289	283						
Cu(d)	0.002	0.001						
Fe(d)	<0.030	<0.030						
Pb(d)	<0.001	0.001						
Mg(d)	15.4	14.7						
Mn(d)	0.028	0.027						
Hg(d)	<0.00005	<0.00005						
K(d)	13	12						
Na(d)	40.4	37.3						
Zn(d)	0.018	0.022						

All units are in mg.L unless otherwise noted

Stn.3 - Deep	20-Jun-95	22-Jun-95	27-Jun-95	29-Jun-95	4-Jul-95	6-Jul-95	11-Jul-95	13-Jul-95
Cond.(umhos/cm)	1470	1490	1490	1470	1520	1520	1520	1500
Hardness CaCO3	759	766	676	697	776	814	783	744
pH	7.56	7.16	7.12	7.09	7.37	7.29	7.41	7.62
TSS (mg/L)	3	1	2	2	2	3	5	<1
Alk. (mg/L)	22.8	22.9	22.9	23.6	22.4	22.5	23.1	22.9
Chloride	59	59.1	57.6	60.3	59.3	59.6	58.6	59.4
Sulphate	721	786	763	734	757	743	751	704
Ammonia	0.014	0.055	0.056	0.054	0.087	0.031	0.04	0.023
Nitrate	0.147	0.12	0.088	0.069	0.05	0.04	0.019	0.011
Total P	0.017	0.016	0.015	0.015	0.012	0.014	0.013	0.015
As(d)	0.0004	0.0004	0.0004	0.0005	0.0005	<0.0001	0.0004	0.0005
Cd(d)	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Ca(d)	280	282	279	257	286	300	289	274
Cu(d)	0.003	0.002	0.002	0.001	0.001	0.002	0.002	0.002
Fe(d)	<0.030	<0.030	<0.030	<0.030	0.032	0.032	0.034	0.04
Pb(d)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mg(d)	14.4	14.7	14.1	13.3	14.7	15.6	14.7	14.3
Mn(d)	0.008	0.015	0.023	0.031	0.036	0.038	0.036	0.036
Hg(d)	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
K(d)	11.4	11.4	11.6	11.1	12.1	12	12	11.5
Na(d)	36.7	36.4	35.5	33.5	36.8	37.9	38.3	36.3
Zn(d)	0.05	0.032	0.039	0.032	0.022	0.024	0.019	0.016

All units are in mg.L unless otherwise noted

Stn.3 - Deep	27-Jul-95	8-Aug-95	17-Aug-95	31-Aug-95	7-Sep-95	14-Sep-95	25-Sep-95	2-Oct-95
Cond.(umhos/cm)	1530	1500						
Hardness CaCO3	782	727						
pH	7.21	7.02						
TSS (mg/L)	3	3						
Alk. (mg/L)	18.3	21.2						
Chloride	59.9	59.1						
Sulphate	764	729						
Ammonia	0.029	0.009						
Nitrate	<0.005	<0.005						
Total P	0.021	0.013						
As(d)	0.0005	0.0006						
Cd(d)	<0.0002	<0.0002						
Ca(d)	288	268						
Cu(d)	0.002	0.002						
Fe(d)	<0.030	<0.030						
Pb(d)	<0.001	<0.001						
Mg(d)	15.2	13.9						
Mn(d)	0.027	0.027						
Hg(d)	<0.00005	<0.00005						
K(d)	12.3	11						
Na(d)	39.9	35.4						
Zn(d)	0.023	0.024						

All units are in mg.L unless otherwise noted

Appendix H
Historical Assessment of the Mine-Related Inputs to Anderson Lake, Manitoba

Historical Assessment of the Mine-Related Inputs to Anderson Lake, Manitoba

Prepared for:

Hudson Bay Mining and Smelting Co., Ltd.
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July, 1995

ABSTRACT

An assessment of the mine-related inputs to Anderson Lake, Manitoba, was carried out to determine as much as possible the extent of relationships between the various discharges and observed historical changes in lake chemistry. All available records of lake water quality, lake sediment composition, tailings discharges, mill effluents, mine discharge waters, mine site drainages, and caustic soda additions were collected and interpreted over the 25 year period when the lake received mine-related inputs. Data for Cu, Zn and sulphate and pH provided the most useful diagnostic parameters due to their frequent measurement and high concentrations in mine-related discharge waters. Severe alterations of lake chemistry have occurred over the mining history. The lake has hosted high inventories of Cu, Zn, sulphate and chloride and has experienced periods of depressed pH. The most significant changes occurred immediately subsequent to tailings deposition.

Basic mass balance calculations, using limited volume and concentration data, were performed to determine the respective loadings from various sources. Available evidence suggests the primary controls on metal and acidity enrichments stem from unbuffered underground mine discharges and acidic minesite drainages. Several reasons are offered in support of this: 1.) Estimates of total loadings of dissolved Cu, Zn and acidity indicate that unbuffered underground discharges present the biggest potential contributor of heavy metal discharges to Anderson Lake. Measurements made on the particulate fractions and the pH of tailings discharges suggest that dissolved loadings from the tails were minimal; 2.) Similar calculations clearly identified the acidic drainages originating from the Anderson minesite and mine discharges as the primary sources of acidic loadings; 3.) Water quality data for Cu, Zn and pH plotted overtime with respect to five lake zones indicate that those areas adjacent to the mine site (i.e., not proximal to the tailings discharge), were characterized by higher metal and acidity loadings during lake wide occurrences of pH depression; and 4.) Post-depositional releases of contaminants were considered to be minimal as theoretical considerations and studies of the early diagenesis of submerged mine-tailings deposits suggest that under certain conditions, tailings may not release significant levels of contaminants. A recent study of the porewaters and associated solid phases in Anderson Lake demonstrated that Zn, Cu, Pb and Cd were being sequestered to the sediments where they are presumably precipitated as sulphide phases at shallow depths. Diffusive influx estimates of dissolved Zn and Cu to the lake sediments calculated in this report, however, cannot account for the imbalance between the estimated inputs of these dissolved metals and the outputs at the Anderson Dam.

SOMMAIRE

Une évaluation des apports d'origine minière dans le lac Anderson (Manitoba) a été effectuée afin de déterminer, dans la mesure du possible, la relation entre les déversements et les changements chronologiques observés sur le plan des caractéristiques chimiques du lac. Tous les relevés disponibles relatifs à la qualité des eaux du lac, à sa composition en sédiments, au rejet de résidus, aux effluents, aux eaux de la mine souterraine, au drainage du site minier et aux apports d'hydroxyde de sodium ont été recueillis et interprétés pour la période de 25 ans durant laquelle le lac a reçu des apports d'origine minière. Les données relatives de Cu, de Zn et de sulfate, ainsi que le pH, se sont révélées être les paramètres les plus utiles sur le plan diagnostique, en raison de leurs mesures fréquentes et aux concentrations élevées dans les eaux d'origine minière. Au cours de l'histoire de la mine, les caractéristiques chimiques du lac ont subi de graves perturbations. Le lac a renfermé des concentrations élevées de Cu, de Zn, de sulfate et de chlorure et a connu des épisodes donc le pH à chuté. Les changements les plus significatifs se sont produits immédiatement après le dépôt des résidus.

On a effectué des calculs de bilan massique de base, à l'aide de données limitées sur les volumes et les concentrations, afin de déterminer les apports respectifs de différentes sources. D'après les renseignements dont on dispose, l'enrichissement en métaux et l'acidification auraient pour principale origine le drainage acide du site minier et les eaux de la mine souterraine non tamponnés. Plusieurs raisons sont proposées pour corroborer cette hypothèse : 1) les estimations des apports totaux de Cu et de Zn dissous et de l'acidité indiquent que les eaux de la mine souterraine non tamponnés présentent le plus grand potentiel de métaux lourds dans le lac Anderson. D'après les mesures effectuées sur les fractions particulaires et sur le pH des résidus, les apports passés en solution de ces résidus seraient minimes; 2) des calculs similaires indiquent clairement que les drainages acides du site minier de la mine Anderson et les eaux de la mine souterraine constituent la principale source d'apports acides; 3) la représentation graphique des données sur la qualité de l'eau pour le Cu, le Zn et le pH en fonction du temps pour cinq zones du lac indique que les régions adjacentes aux sites d'exploitation de la mine (c.-à-d. éloignées du point de décharge des résidus) sont caractérisées par des apports plus élevés en métaux et en substances acides durant les épisodes de chute du pH à l'échelle du lac; 4) les rejets de contaminants après dépôt sont jugés minimes, et tant les considérations d'ordre théorique et les études portant sur la diagenèse précoce des dépôts de résidus submergés semblent indiquer que, dans certaines conditions, les résidus peuvent ne pas libérer de concentrations significatives de contaminants. Une étude récente portant sur les eaux interstitielles et les phases solides associées dans le lac Anderson a mis en évidence une séquestration des composés Zn, Cu, Pb et Cd par les sédiments, où ils se trouvent vraisemblablement sous forme de précipités en phases sulfurées à de faibles profondeurs. Toutefois, les estimations des apports de Zn et de Cu dissous dans les sédiments du lac calculées dans le présent rapport ne permettent pas d'expliquer le déséquilibre entre les apports estimés de ces métaux dissous et les concentrations observées au déversoir de la digue du parc à résidus Anderson.

ACKNOWLEDGMENTS

We are very grateful to Wayne Fraser and Wayne Fong of Hudson Bay Mining and Smelting Co. Ltd. (HBMS) for the hospitality and assistance extended while in Flin Flon and Snow Lake. Particular thanks go to Steve West (HBMS) for the time and effort taken to provide the information required for this project.

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1.0 INTRODUCTION

This report examines Anderson Lake, Manitoba, in an attempt to relate the history of mine-related loadings of heavy metals, sulphate and acidity to changes in lake chemistry. The fundamental objective of the study is to assess the extent to which inputs, other than the tailings fraction, have historically provided the principal chemical control on the lake. Particular attention is given to acidic drainages from the Anderson mine site and unbuffered mine discharges as potential sources of acidity and heavy metals. Operations of the Hudson Bay Mining and Smelting Co. Ltd. (HBMS) have supplied the water body with various mine-related inputs since the commencement of the Anderson Mine operation in 1970, and as result, the lake hosts high metal and sulphate inventories. The lake has also experienced periods of depressed pH.

Sources of information for this study included published scientific literature, consultants reports, internal reports and memoranda, and verbal communications with HBMS personnel. All available information was canvassed. Furthermore, the first author visited the Anderson Lake area, the moribund Snow Lake Mill, and the HBMS offices in Flin Flon during the period August 22 to 26, 1994.

1.1 Historical Background

Since 1970, Anderson Lake has served as the repository for several mine-related discharges including tailings and mill effluents, mine process waters, pumped waters from abandoned shafts, mine site drainages, local inputs of acid rock drainage, and caustic soda additions. Prior to subaqueous tailings disposal in 1979, Anderson Lake provided the water supply for the Anderson Mine located adjacent to the lake (Fig. 1). From 1970 to 1979, minewaters pumped from the underground workings represented the sole mining-related discharge to the lake. The minewater effluents have at times been quite acidic, being accompanied by enrichments of metals and sulphate. Discharges from the Anderson Mine continued until its closure in 1988. The discharge of sulphide-rich tailings from the Snow Lake Mill commenced in 1979, and until shutdown in March of 1994, approximately 8 million tons (dry wt.) of material had been delivered to Anderson Lake. The mill received various copper-lead-zinc ores from several mines in the surrounding area. Underground discharges from the nearby Stall (1979-1994) and Rod (1981-1990) mines were also introduced to the lake via the tailings line. Limited water quality data indicate that these mine discharges were highly acidic and hosted large concentrations of metals and sulphate. When the mill was operating, the Stall and Rod mine discharges were transported in conjunction with the well-buffered tailings stream. However, during days of mill shutdown, these effluents were delivered unbuffered to Anderson Lake.

In addition to those discharges introduced directly to the lake from mining operations, the lake has been impacted by acidic drainages originating from the Anderson Lake minesite. Between 1975 and 1976 large volumes of backfill from the Flin Flon mill were stockpiled adjacent to Anderson Lake, and subsequently, in 1978, substantial quantities of this material were used for the buildup of a roadway, and as a bed for the tailings line and areas of the Anderson minesite. A study of the sulphide-rich Flin Flon tails in 1972 suggested an acid-generating capacity in excess of 900 pounds of sulphuric acid per ton (HBMS, 1972). A water quality survey on minesite drainages conducted in 1985 investigated these waters as potential contributors to depressed lake pH levels. The two main run-off streams were determined to be very acidic (2.9-3.5 pH units), and exhibited high levels of sulphates, thiosalts and leached heavy metals. The extent of their influence on Anderson Lake, however, was not determined. Clean-up procedures of the minesite, which transpired from the spring to September, 1994, have since removed this material, estimated to total 115,000 m^3.

2.0 STUDY AREA

Anderson Lake is a small, shallow Precambrian Shield waterbody lying in a volcanic-rock depression approximately 2 km south of Snow Lake, Manitoba (Fig. 1). The lake has served as a polishing pond for the adjacent mining operations, in which mining wastes are diluted and allowed to settle and degrade before their final discharge to the environment. A recent bathymetric survey (Rescan, 1990) determined a number of morphometric parameters including lake area, volume, length, mean breadth, mean depth, maximum depth and shoreline length (Appendix I). Historically, the lake has received minimal input from surface runoff, swamp drainage and precipitation (Bridges, 1977). Lake outflows via Anderson Creek are currently controlled by a dam constructed in 1979. Anderson Lake is naturally productive and was originally floored by organic-rich sediments; both features are typical of many Precambrian Shield lakes. Available productivity data suggest that the lake is currently mesotrophic and is approaching eutrophic status. Physical profiling of temperature and dissolved oxygen indicate that

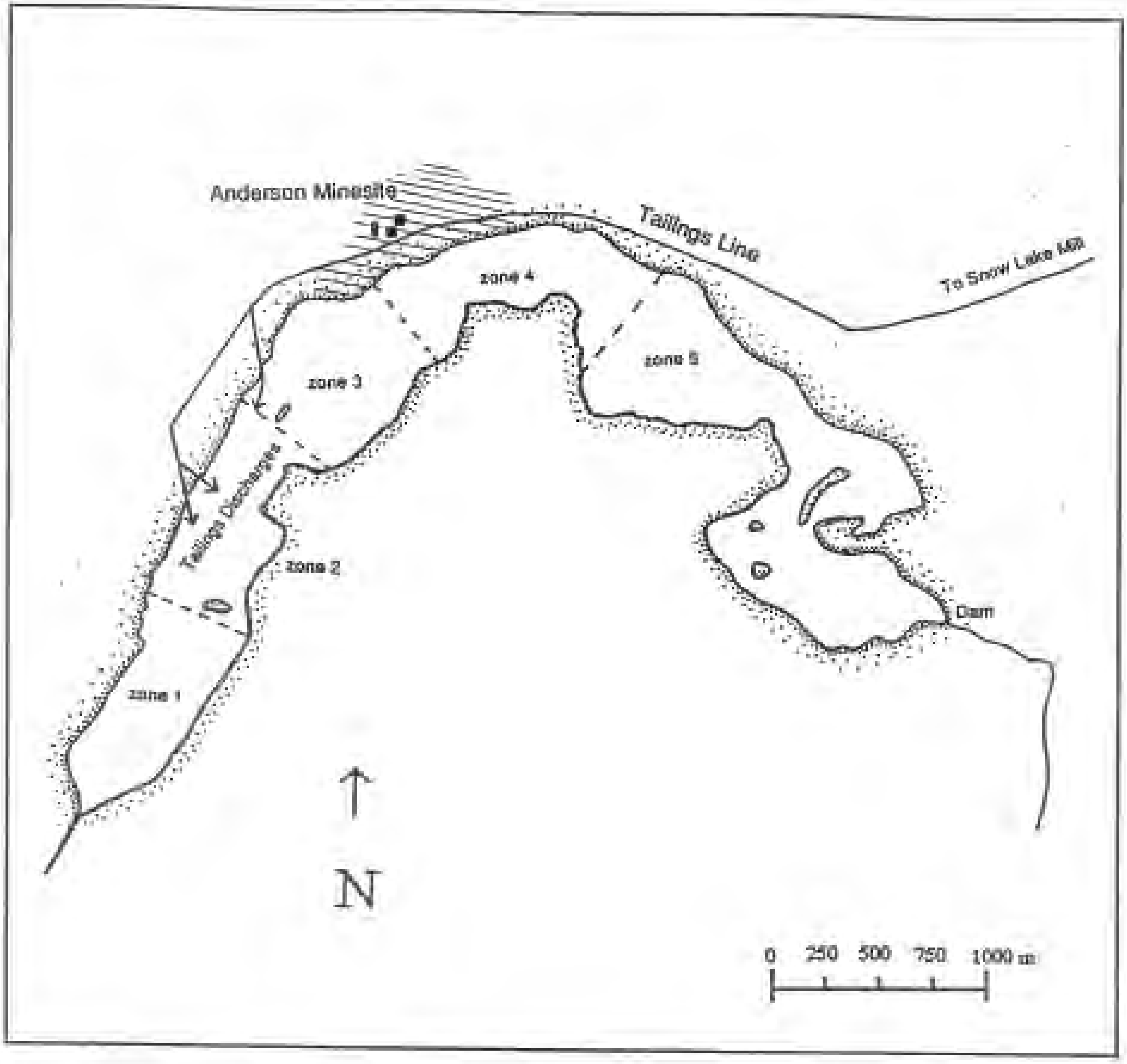

Fig. 1. Schematic of Anderson Lake, Manitoba, indicating area of Anderson minesite (dashed region), areas of tailings discharges and lake zones 1-5.

characteristic oxygen depletion in Anderson lake bottom waters (< 2 mg L^{-1}) reflects a high benthic oxygen demand. The lake supports minimal recreational use and has historically contained few fish.

3.0 APPROACH

Available data for the mine-related inputs to Anderson Lake, lake chemistry, and lake discharges were collected and compiled from various sources, of which unpublished reports from the Hudson Bay Mining and Smelting Company (HBMS) were of primary importance. Invaluable information was additionally gathered from reports prepared for the HBMS by consultants, published literature and verbal communications. As a result of infrequent analyses and/or missing records, a lack of data exists for several diagnostic parameters. Although the incompleteness of the respective data sets constrains rigorous scrutiny, averages estimated from existing values appear to represent adequately those missing, and consequently are sufficient to permit general conclusions to be drawn. The concentrations of Cu, Zn, sulphate, chloride and pH were most frequently measured, and due to their large signal in discharge waters, were most effective as tracers of mine-related inputs . Wherever possible, concentration and volume data were used to calculate basic mass loadings to and from Anderson Lake. Sections 3.1-3.5 below outline the data sources for the respective mine-related discharges.

Note that this report does not include a full acid-base accounting for the lake as this is impossible to perform with the available information. The acid-generating roadway along the north shore of the lake intermittently released acid and metals to the lake between 1979 and August 1994, and such inputs are impossible to quantify. Furthermore, exisiting pore water data (Rescan, 1994; Pedersen et al., 1993; Rescan, 1990) show that the tailings both consume (via sulphate reduction) and release sulphate (as an apparent result of gypsum dissolution). The relative balance between supply and demand associated with these processes cannot be determined. Thus, sulphate data from the lake waters cannot be used as an independent indicator of ARD inputs from the acidic roadway.

3.1 Lake Chemistry

Prior to the start-up of the Snow Lake Mill in 1979, three surveys of varying degrees of detail had been conducted on Anderson Lake (Allard, 1965; Bridges, 1977; Munro, 1977). As part of an assessment for the possible introduction of exotic game fish, Allard (1965) primarily sampled for fish and benthic invertebrates, limiting the water quality analyses to pH, dissolved oxygen, bicarbonate alkalinity and Secchi disk transparency. The HBMS carried out a more detailed limnological survey of Anderson Lake as part of a baseline assessment prior to tailings deposition (Bridges, 1977). In addition to extensive physical and chemical analyses (pH, dissolved oxygen, conductivity, turbidity, Secchi depth, chloride, sulphate and thiosalts), six water column and four sediment stations were sampled for a suite of heavy metals. The Environmental Protection Service (EPS) undertook an additional survey in June of 1977 as part of a federal government baseline study of potential impacts of lacustrine tailings disposal (Munro and Ruggles, 1977). A full complement of physical and chemical analyses was conducted at four stations along the lake, and included water column and sediment heavy metal measurements.

Following the start up of the Snow Lake mill in 1979, the HBMS conducted regular water quality surveys of Anderson Lake. These surveys were performed two or more times per year between 1979 and 1985 for various selected parameters which regularly included pH, suspended solids, turbidity, sulphate, copper and zinc. Other parameters measured less frequently included thiosalts, acidity/alkalinity, dissolved oxygen, Secchi depth, chloride, total lead, nickel and cadmium, conductivity, hydrogen sulphide and sediment chemistry. Other than periodic sampling by the HBMS for metals, pH and suspended solids, additional lake chemistry data have been supplied from various unpublished and published reports (Rescan, 1990a; Rescan, 1990b; Rescan, 1994; Pedersen et al., 1993)

Spatial and temporal distributions of various parameters in both the water column and sediments were collected from records outlined above. Where available data allowed, average monthly lake values of Cu, Zn, pH, sulphate and chloride were calculated (Appendix II). In addition, these monthly averages were plotted over time with respect to five lake zones (see Fig. 1) outlined in previous reports by the HBMS in order to determine the origins of differential loadings along the length of the lake. Available sediment chemistry data were treated in the same manner.

As a result of severe historical depressions in lake pH, HBMS episodically released significant quantities of 50 % caustic soda since 1985 in order to mitigate acidic conditions. Localized inputs via the Anderson minesite drainage ditch contributed over 440 barrels to Anderson Lake prior to 1994. In addition, a lake-wide addition from the service barge was employed in 1991 (Appendix III).

3.2 Anderson Lake Discharge

The Anderson Dam was initially constructed downstream of the Anderson Creek outflow and was designed both to control lake discharges and increase holding capacity. Since its installation in 1978, lake area has increased from 2.41 to 2.74 x 10^6 m^2. Records of dates of discharge, discharge volumes and water quality (pH, Cu, Zn, As, Pb, Ni and sulphate) were collected regularly since discharge commenced in 1981. From these, yearly average discharge values were calculated and used to estimate annual unloadings of the various heavy metals, acidity and sulphate (Appendix IV).

3.3 Underground Mine Discharges

Underground mine discharges to Anderson Lake originated from two sources: an influent stream from Anderson Mine which entered the lake via a culvert on the west side of the mine site (Fig. 1), and those discharges from Stall and Rod mines which were delivered to the lake via injection into the tailings pipeline at the Snow Lake Mill. Total yearly discharges for all three mines were obtained from the annual water balance reports for Anderson Lake and the Stall Lake Mill. Yearly loadings of acidity, heavy metals and sulphate from the Anderson and Stall mines were estimated from the sparse water quality data available (Appendices V and VI, respectively). Due to the complete absence of water quality for the Rod Mine discharge, estimates of the respective loadings were based on average values observed for Stall (Appendix VII). As noted earlier, during days of mill operation, the highly acidic metal-laden discharges from both Stall and Rod mines were delivered in the well buffered tailings stream (pH 8.5 - 11.3). Measurements of water quality at the tailings outfall indicate that particulate zinc accounted for over 99.9 % of the total Zn in the discharge stream. Due to the precipitation of metal hydroxides at high pH levels, we assume that during days of mill operation, the aqueous effluents from Stall and Rod mines were deposited with the tailings as particulate material; if so, dissolved loadings would have persisted only during days of mill shutdown. The Snow Lake mill operated on a 2 day/week shutdown schedule for the majority of its history, but for periods in 1986 and from 1992 onwards, a three-day shutdown was in effect.

Previously-documented underground drainage reports from Anderson Mine demonstrated that acidic effluents originated from the underground sump system. These discharges were, however, diluted to a degree at the main discharge box by the addition of compressor cooling water before their final discharge to the environment. The highly variable water quality data available (Appendix V) seem to represent sampling periods when compressor water was both absent and present.

3.4 Anderson Mine Site Drainage

As a result of the wide distribution of significant quantities of acid generating sulphide-rich backfill material, run-off from the Anderson minesite has been highly acidic and metal enriched. Approximate averages for pH, sulphate and metal concentrations were calculated from scarce data sets (Appendix VIII). Yearly records of average precipitation and minesite runoff (Appendix IX) were used to estimate annual loadings of acidity, heavy metals and sulphate (Appendix VIII). In addition, a drainage survey of the Anderson minesite conducted in 1985 provided volume discharge estimates and water quality of the two main influent streams (Appendix IX).

3.5 Snow Lake Mill

Metallurgical balances and records of tailings productions obtained for the Snow Lake Mill were used to estimate particulate metal loadings to Anderson Lake (Appendix X). From the tonnage of tails available, the percentage amounts designated for filtered and hydraulic backfill were subtracted from the total to obtain the residual waste fraction for lacustrine disposal. The percentages of Cu, Zn and Pb obtained from metallurgical reports were then used to estimate yearly mass loadings of these solid-phase metals. Records of lime additions were also used to monitor potential variations in the buffering capacity of the lake (Appendix XI).

4.0 RESULTS AND DISCUSSION

4.1 Lake Chemistry

Anderson Lake has experienced significant chemical changes over the course of the mining history in the area. Monthly lake averages indicate obvious periodic enrichments with respect to dissolved Zn, Cu, sulphate and chloride. The pH, while quite variable, generally decreased in the lake after the mid 1970's (Fig. 2). All pH values indicated were measured directly in the lake except for those from January 1991 to April 1994 which were taken from the reclaim water tank. This tank receives water pumped directly from the lake for its eventual use in ore processing. Significant impacts on lake chemistry from acidic drainages and mine discharges from the Anderson Mine site are not clearly evident from 1970 to 1979. During these periods, levels of the respective parameters generally fall within those ranges observed prior to the startup of the Anderson Mine in 1970. Acidic drainages do not seem to have been significant due to the initial location and distribution of the stockpiles of Flin Flon backfill. However, widespread emplacement of this material near the lake shore during construction in 1978 most likely created the conditions necessary to generate acidic drainages. Only slight increases in the concentrations of dissolved of Zn and Cu are evident between 1974 and 1978. Unfortunately, few water quality records date back to the pre-mining history, and due to differences in analytical techniques and detection limits, comparisons with the pre-mining period are limited.

The commencement of tailings and minewater discharges in 1979 appears to have had a significant effect on dissolved loadings. During the periods of tailings deposition, levels of Cu and Zn fluctuated similarly around respective elevated means of 0.04 and 0.2 mg/l (Fig. 3). Gradual decreases are observed after 1989. The gradual decline in pH follows an almost linear decrease from a pH of 8 in 1977 to a minimum of approximately pH 5 in 1984 and 1985 (Fig. 2). Assuming an accurate representation of lake chemistry, this linearity represents an exponential increase in the amount of acid added to Anderson Lake over the indicated period. Distinct spikes apparent for both Cu and Zn in 1985 coincide with a pH minimum (Figs. 4 and 5). Elevations in chloride and sulphate concentrations are also evident over the initial period of tailings discharge (Fig. 6). Underground surveys of Stall and Anderson Mines demonstrated that chloride enrichments were derived from underground pump waters . Since an additional period of depressed pH in 1992-93, the water quality in Anderson Lake has improved considerably.

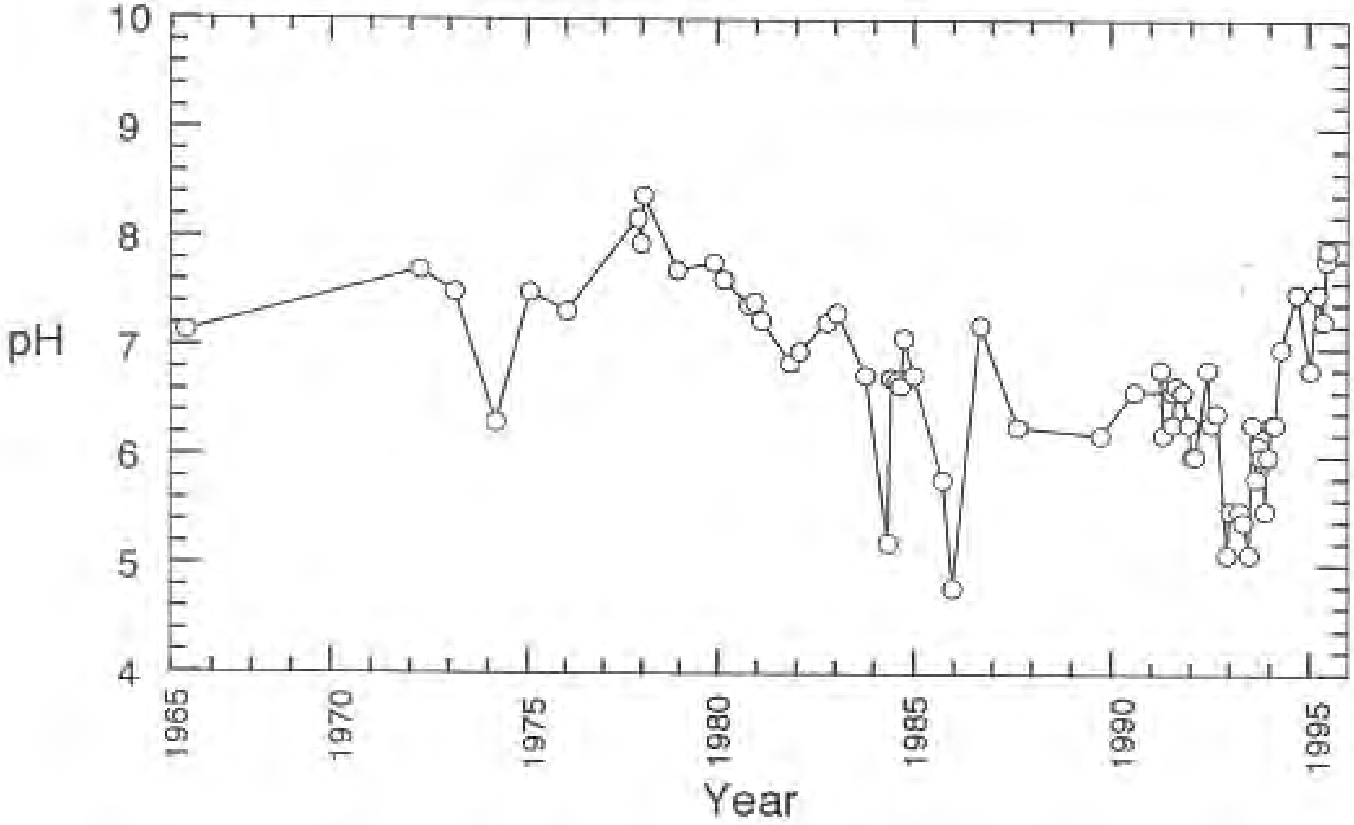

Fig. 2. Monthly averages of pH, Anderson Lake, Manitoba. Values indicated were measured directly in the lake except for those from January 1991 to April 1994 which were taken from the reclaim water tank.

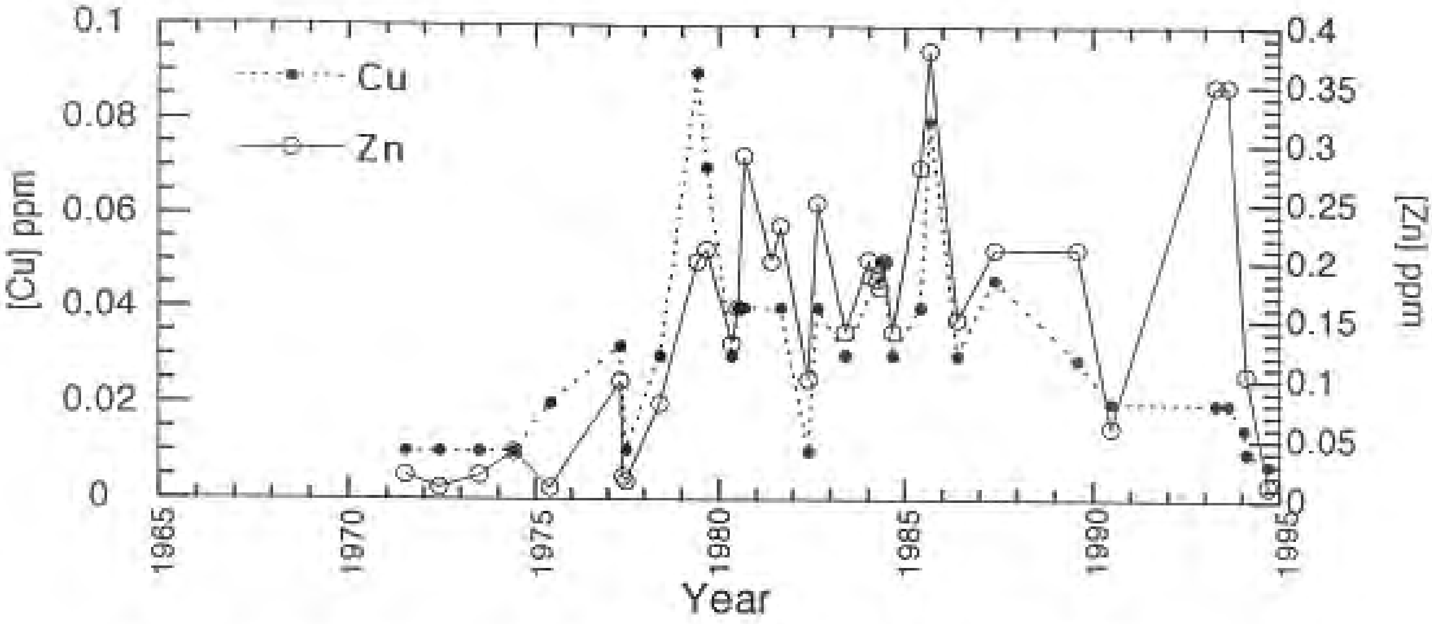

Fig. 3. Monthly averages of dissolved Cu and Zn, Anderson Lake, Manitoba.

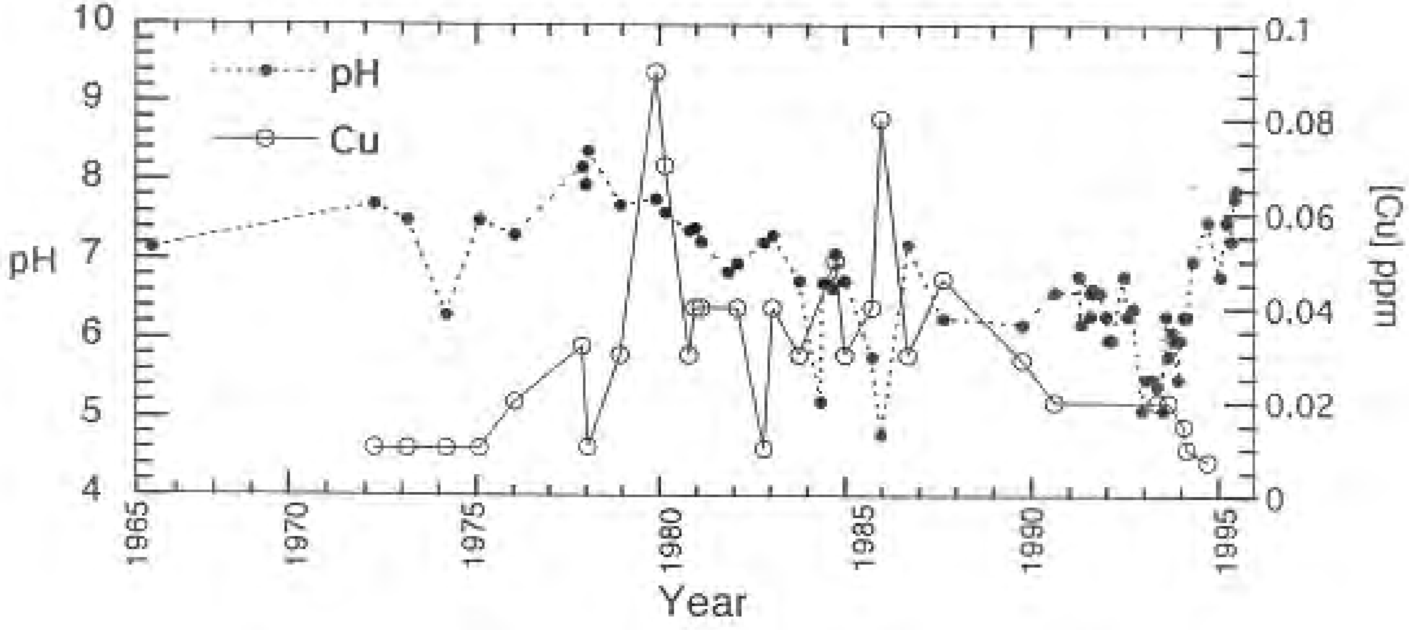

Fig. 4. Monthly averages of dissolved Cu and pH, Anderson Lake, Manitoba.

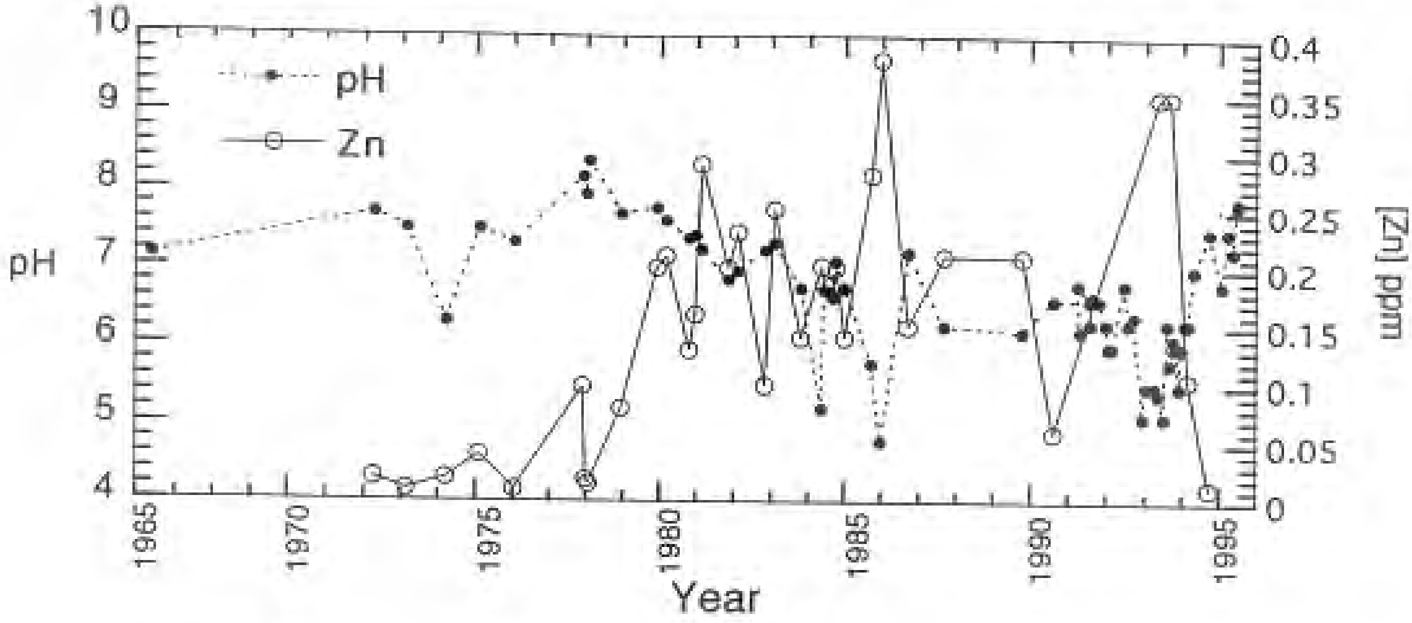

Fig. 5. Monthly averages of dissolved Zn and pH, Anderson Lake, Manitoba.

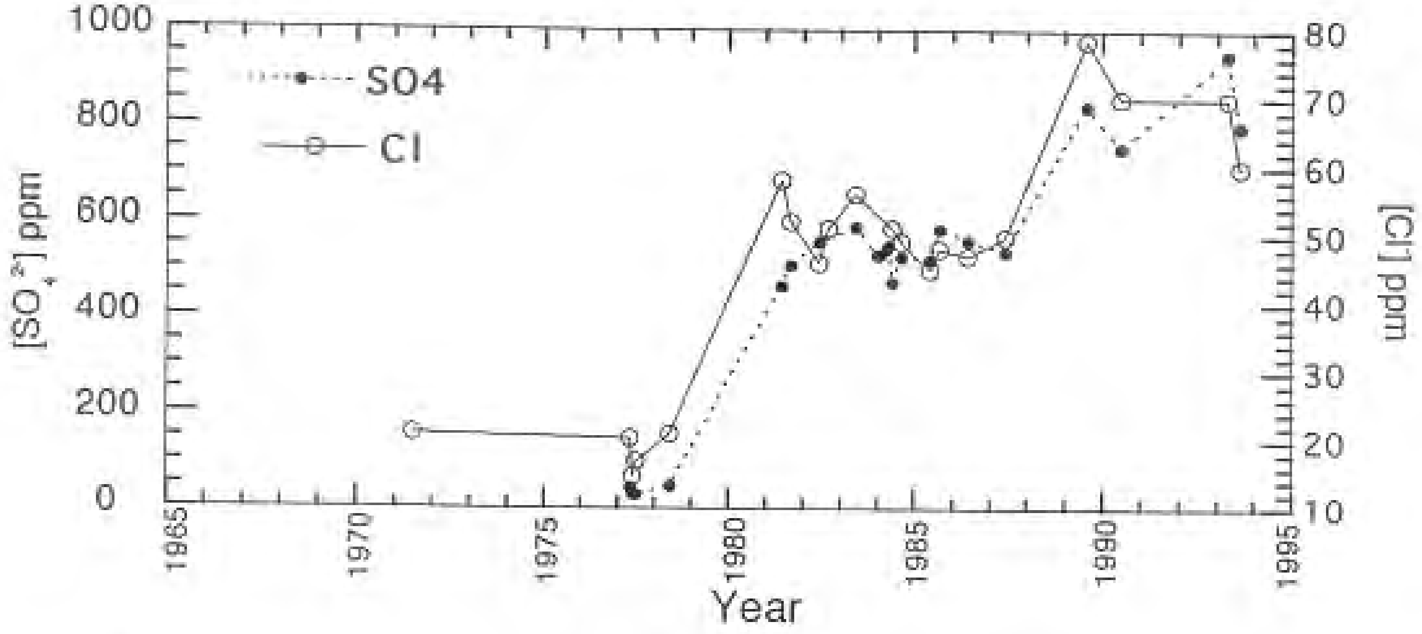

Fig. 6. Monthly averages of sulphate and chloride, Anderson Lake, Manitoba.

Surveys conducted episodically by HBMS between August 1994 and June 1995 after the acid-generating roadway was removed and all acidic pumped underground discharges ceased indicates that the pH has varied from near neutral to slightly basic (~6.9 to ~8.2). Measurements made on June 20, 22, 27 and 29, 1995 at three widely-separated stations within the lake fell within the range 7.3 -8.3 (24 separate measurements). The higher pH values observed during the last year appear to be associated with declining dissolved metal levels in the lake, although the data are currently too sparse to determine this with certainty. This paucity should be rectified by detailed biweekly water quality measurements during the summer of 1995, prior to resumption of tailings discharge in August 1995.

To assess the relative loadings of acidity, heavy metals and sulphate from the respective sources, total dissolved inputs and outputs to and from Anderson Lake were calculated (Table 1). Due to the extreme uncertainty in these estimates, an accurate annual acid/base budget analysis was obviated and caution should be employed in their application. Due to the high pH of the tailings discharges (8.5-11.3), loadings of dissolved metals from this source were considered to be negligible during days of mill operation. Thermodynamic considerations favour the precipitation of Cu and Zn as their respective hydroxides at such alkaline pH levels. The potential for dissolved loadings from the submerged tailings after deposition is discussed in section 4.3.

Dissolved contributions from Stall and Rod mines were based on days of mill shutdown during which underground pump waters were transported unbuffered to Anderson Lake because no limed tailings were flowing through the pipeline on such days. A standard two day shutdown schedule in effect most years switched to a three day shutdown operation in 1986 and from 1992 to closure. Inspection of the total dissolved metal inputs suggest that those discharges originating from the Stall, Rod and Anderson mines exert the primary control on metal distributions in Anderson Lake (Table 1). Basic mass calculations using estimates of yearly loadings and lake volume suggest that the above trio of inputs can more than account for the increase in dissolved metal burdens seen in the lake. Inspections of acidity additions suggest that runoff from the Anderson minesite (including both pumped underground discharges and minesite drainages) and the discharges from Stall and Rod mines exerted the chief influence on lake pH (Table 1). Calculated acidity additions required to depress lake pH values to observed minima fall within estimates of annual loadings from these sources.

Table 1. Estimates of total inputs and outputs of dissolved Cu, Zn, Pb, Ni, sulphate and acidity discharged to, and released from Anderson Lake, Manitoba, from 1979-1994.

	Total Outputs (1979-1994)	Total Dissolved Loadings-Inputs (1979-1994)				Stall +Rod Inputs	@Total Inputs (1979-1994)
Parameter	Anderson Dam	*Stall Mine	*Rod Mine	#And mine site	Tailings discharge		
moles H+	6,400	113,495	42,884	180,200		156,379	336,600
kg Cu	820	9,348	2,506	19,235		11,854	31,100
kg Zn	5,600	32,669	8,757	67,600		41,426	109,000
kg Pb	400	167	45	575		212	787
kg Ni	360	417	112	573		529	1102
kg SO4	20,420,474	3,675,258	985,162	9,716,000	6,418,415	4,660,420	20,795,000

*Estimates for Stall and Rod Mines are based on days of mill shutdown.

#Encompasses both acidic run-off and pumped underground discharges from the Anderson Mine. Calculations of acid run-off are based on a 15 year loading.

@ Includes discharges from Snow Lake Mill, Stall Mine, Rod Mine and Anderson minesite.

To understand more fully the origin of contamination, monthly averages of lake quality were plotted with respect to five lake zones (Fig. 1). Zone 1 represents the westernmost section of Anderson Lake while zone 2 lies in the region of tailings disposal. Zones 3 and 4 encompass those areas adjacent to the Anderson Lake minesite while zone 5 lies in the eastern sector. Lake-zone comparisons were plotted for Zn, Cu, pH and sulphate. Zonal distributions for each parameter correlate consistently over time. Sulphate distributions exhibit minimal zonal variation (Fig. 7). Concentrations of dissolved Zn and Cu, however, do vary temporally from zone to zone. During pH minima in 1984 and 1985, for example, values for zones 3 and 4 are considerably more depressed (0.8 pH units) than other areas of the lake (Fig. 8). Zones 3 and 4 also exhibit greater enrichments of both Cu and Zn during the 1985 pH minimum (Figs. 9 and 10). Higher zinc concentrations also accompany the pH minimum in 1984; copper data were not available

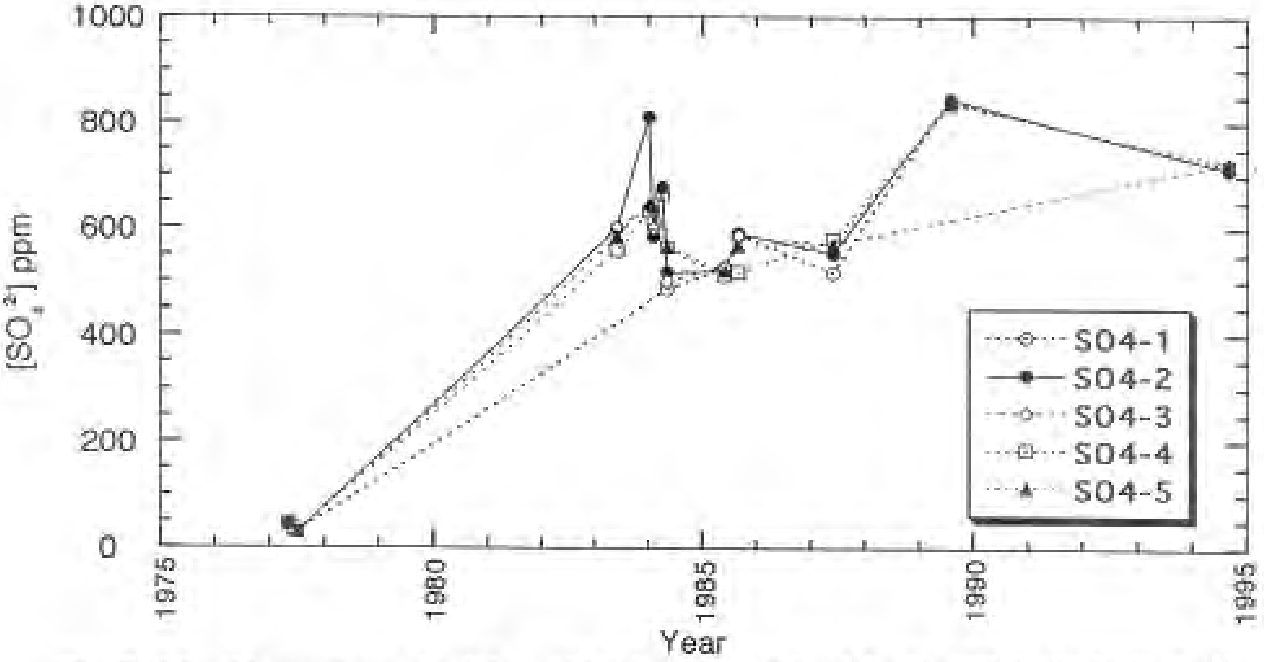

Fig. 7. Monthly averages of sulphate plotted with respect to lake zones 1-5, Anderson Lake, Manitoba.

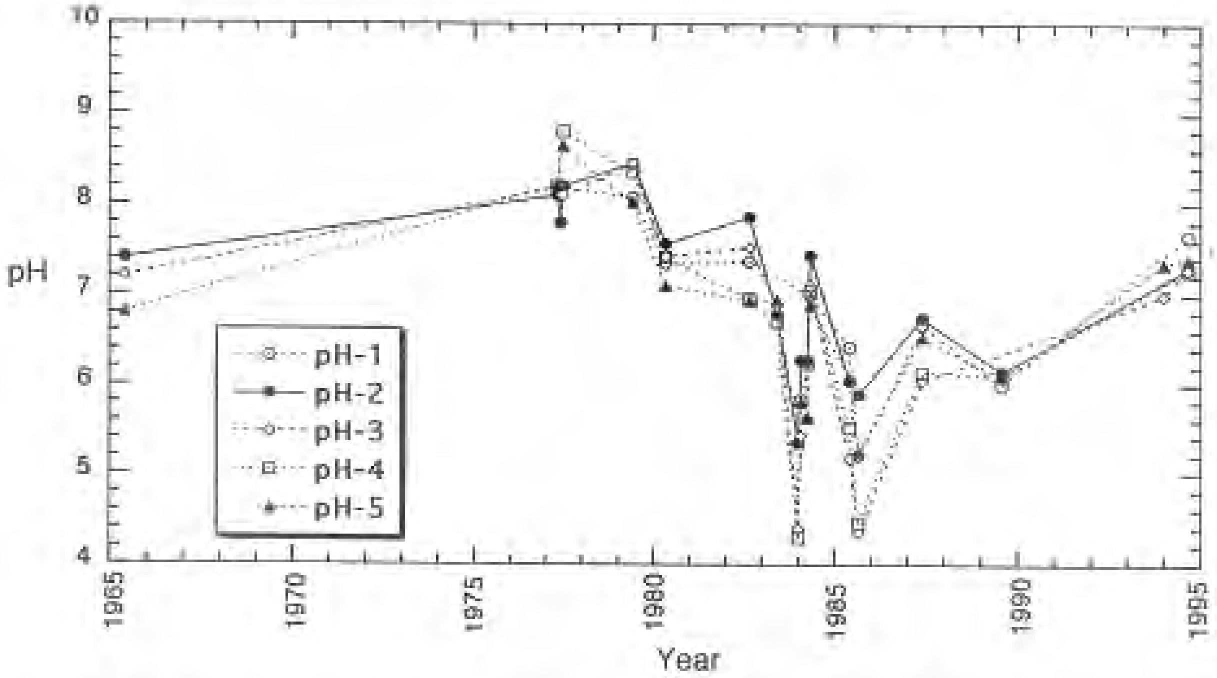

Fig. 8. Monthly averages of pH plotted with respect to lake zones 1-5, Anderson Lake, Manitoba. Note that the data from January 1991 to April 1994 are missing because no zonal distributions were available.

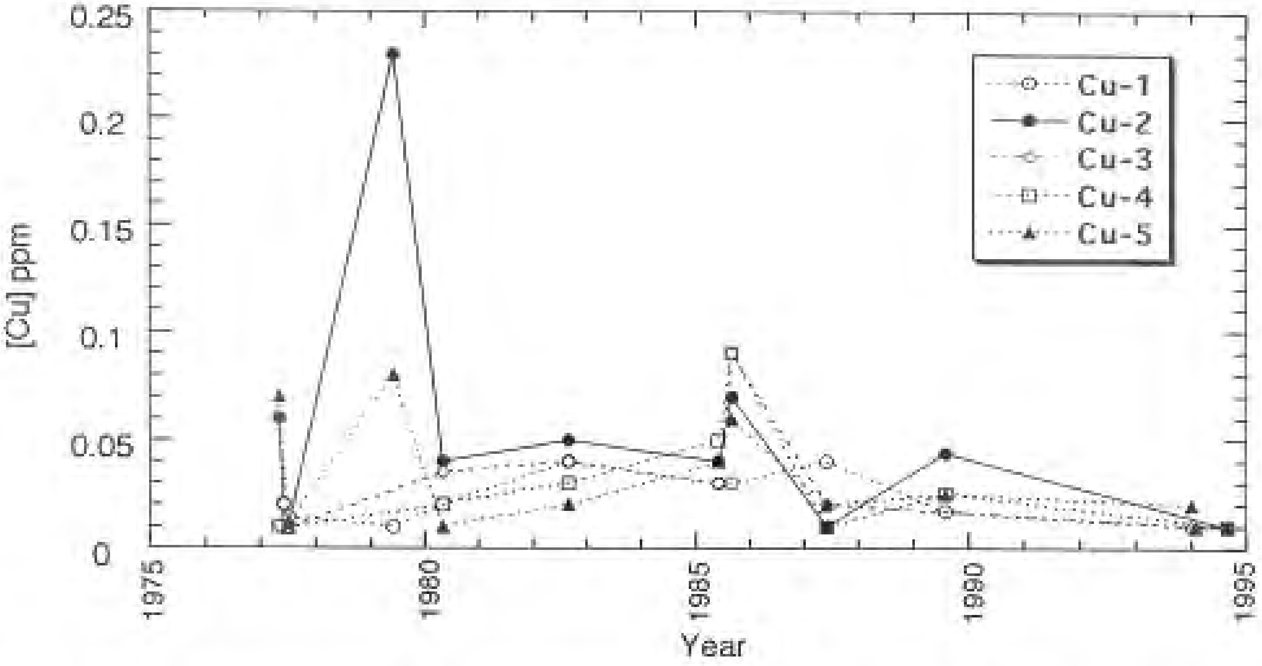

Fig. 9. Monthly averages of dissolved Cu plotted with respect to lake zones 1-5, Anderson Lake, Manitoba.

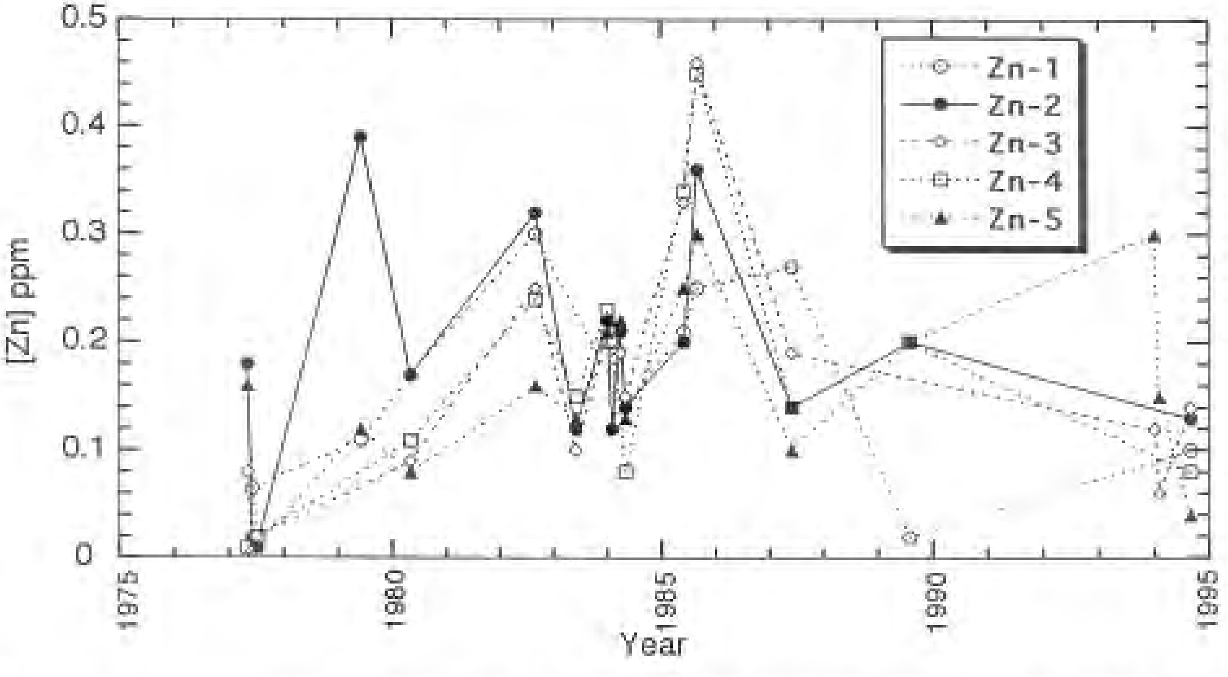

Fig. 10. Monthly averages of dissolved Zn plotted with respect to lake zones 1-5, Anderson Lake, Manitoba.

during this period for comparison. While both pumped mine discharges and minesite runoff contribute to lower pH values, it appears that the impact of acidic runoff is most keenly felt in lake areas adjacent to the mine site.

Available data suggest that although metal inputs are primarily derived from underground mine-discharges, total metal inventories may be significantly affected by the *in situ* leaching of heavy metals from deposited submerged tailings induced by the acidic drainages of the Anderson Mine site. In addition, transitions from 2 to 3 day mill shutdown periods imply that the relatively constant Stall and Rod mine discharge volumes were transported unbuffered to Anderson Lake 3 days per week. Furthermore, it implies that the lake was receiving 20% less buffered inputs due to decreased discharges of limed tailings. A lake-wide depression in pH was observed following the 2 to 3 day shutdown in 1992 (Steve West, verbal communication). The important implication of these observations is that the tailings stream acted as a major source of base to the lake when the Snow Lake Mill was operating. Given the acidity of other inputs to the lake, the tailings stream was therefore (and perversely) beneficial to mean water quality in the basin.

4.2 Diffusive Metal Fluxes

Comparisons of the inputs and outputs of total dissolved loads to the lake (Table 1) indicate an imbalance; inputs far exceed outputs, suggesting that there has been a significant net deposition of Cu and Zn within the lake. Metal scavenging by Anderson Lake sediments presents one plausible explanation for this discrepancy. To assess this, estimates of diffusive fluxes of Cu and Zn to Anderson Lake sediments were calculated from porewater gradients measured in a recent study (Rescan 1994). From Fick's first law,

$$J = -\phi \frac{D}{F} \frac{\partial C}{\partial Z}$$

the diffusive flux (J) was estimated from sediment porosity (ϕ), the respective diffusion coefficients (D_b) (from Li and Gregory, 1974), formation factor (F) (index of tortuosity) and estimated diffusion gradients (Rescan 1994). Integrated influxes over the entire lake area for dissolved Cu and Zn were calculated to range from 45-90 kg/yr and 610-1220 kg/yr respectively (Table 2). These ranges result from the spectrum of formation factors used (1 to 2). The calculated diffusive influxes of Cu and Zn to the sediments can account for no more than 5% of the difference between dissolved Cu inputs to the lake and outputs at the dam. Similarly, only up to ~17% of the "missing" Zn can be attributed to sequestration of dissolved Zn by the sediments (Table 2).

Table 2. Estimated diffusive fluxes of dissolved Cu and Zn to Anderson Lake Sediments. Ranges of yearly and total fluxes are based on a formation factor range of 1 to 2.

	Cu		Zn	
ϕ	0.9		0.9	
D	5×10^{-6} cm^2/s		5×10^{-6} cm^2/s	
$\partial C/\partial Z$	23 μg/L/cm		312 μg/L/cm	
F	1	2	1	2
Yearly flux	90 kg/yr	45 kg/yr	1220 kg/yr	610 kg/yr
Total flux	1350 kg (1979-1994)	675 kg (1979-1994)	18,200 kg (1979-1994)	9,100 kg (1979-1994)

These crude estimates suggest that authigenesis in the sediments, as possibly represented by precipitation of ZnS and CuS, cannot be invoked as a principal explanation for the difference between the estimated inputs of these dissolved metals to the lake and the outputs at the Anderson Dam. One other possible sink is impossible to quantify. Apparently, Anderson Lake "deep" waters become anoxic in many winters (Rescan, 1994). This could lead to large-scale "stripping" of metals from the water column if sulphate reduction produces sufficient sulphide to saturate the waters with respect to metal sulphide phases. The smell of H_2S has been recorded occasionally in the winter outflow at the dam, indicating that sulphate reduction does occur seasonally within the water column. However, the available data are insufficient to permit quantification of possibly associated metal precipitates; as a result, we can draw no conclusions as to the contribution of such phenomenon to the metal balance in the lake.

We are forced to conclude that the overall lack of closure in the mass balance may reflect the very spotty nature of the data sets on which the loading estimates were based, rather that an unidentified sink within the lake.

4.3 Lime and Caustic Soda Additions

During the operation of the Snow Lake Mill, lime consumption remained fairly constant and appears to have maintained pH levels at the tailings stream outlet between 8.5 and 11.3. Considering the steady decline in lake pH from 1979-1986, it appears that the buffered mill discharges had insufficient neutralizing capacity. Any potential hydroxyl additions derived from excess lime (i.e., lime not consumed in the mill) via

$$CaO + H_2O \Rightarrow Ca^{2+} + 2OH^-$$

must have been quickly depleted by reaction with protons. Lake pH recoveries were not evident until the employment of caustic soda additions which began in 1985. Approximately 1.75×10^5 moles of OH^- per year were added to Anderson Lake since 1985. These additions were primarily released to the lake via the Anderson minesite effluent stream. The excess concentrations of H^+ contributing to the depressed pH levels in 1984 , 1985 and 1992 have since been neutralized by these base additions.

4.4 Tailings Deposition and Sediment Chemistry

From 1979 to the spring of 1994, large volumes of sulphide rich mine tailings were deposited through a movable, floating Sclair pipe (30 cm diameter) over significant areas of Anderson Lake. Dramatic sediment enrichments of several heavy metals have occurred since tailings deposition. For example, Pb (Fig. 11) and Fe (Fig. 12) concentrations have both increased ten-fold since 1977 while Zn (Fig. 13) and Cu (Fig. 14) concentrations have exhibited 50-fold increases. It is evident from the zonal plots that enrichments are greatest in those areas closest to the tailings discharge.

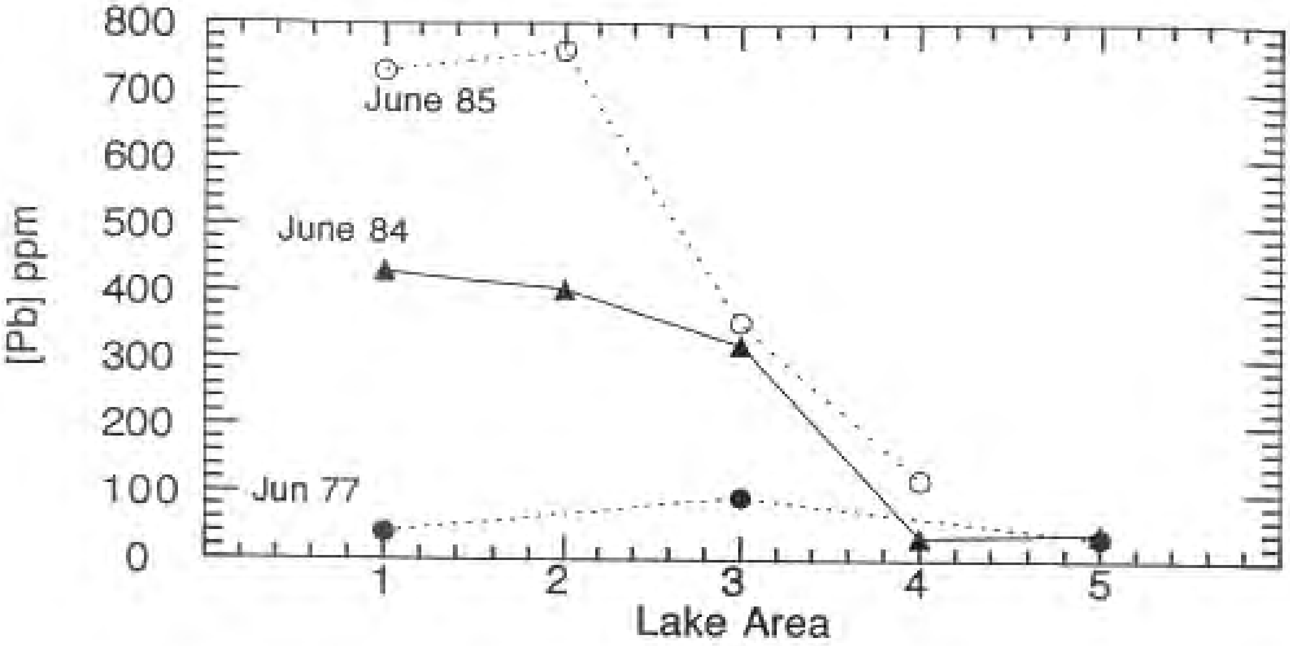

Fig. 11. Solid phase Pb concentrations for various years plotted with respect to lake zones 1-5, Anderson Lake, Manitoba.

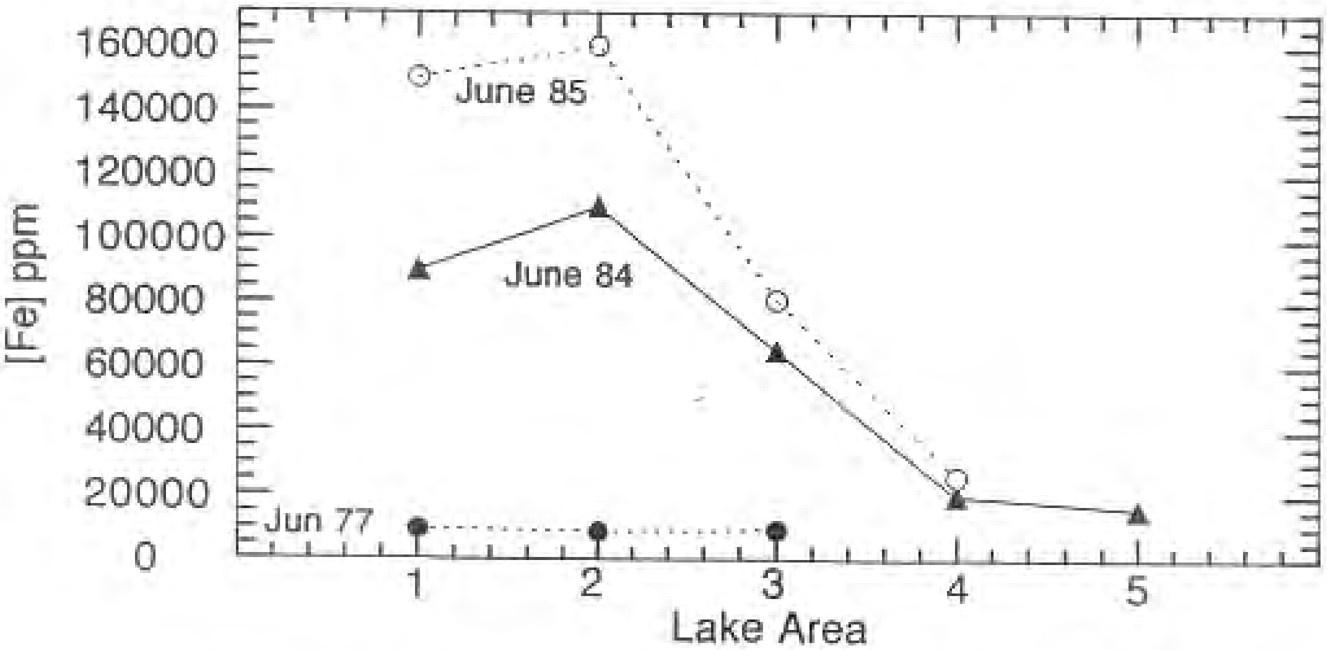

Fig. 12. Solid phase Fe concentrations for various years plotted with respect to lake zones 1-5, Anderson Lake, Manitoba.

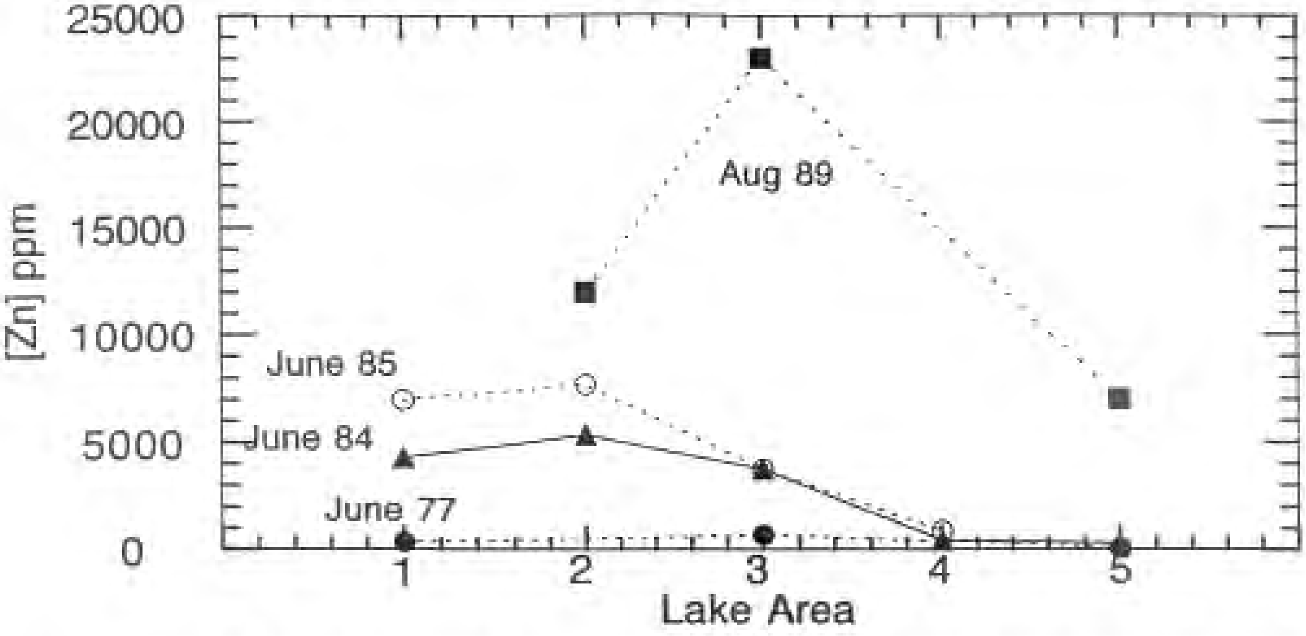

Fig. 13. Solid phase Zn concentrations for various years plotted with respect to lake zones 1-5, Anderson Lake, Manitoba.

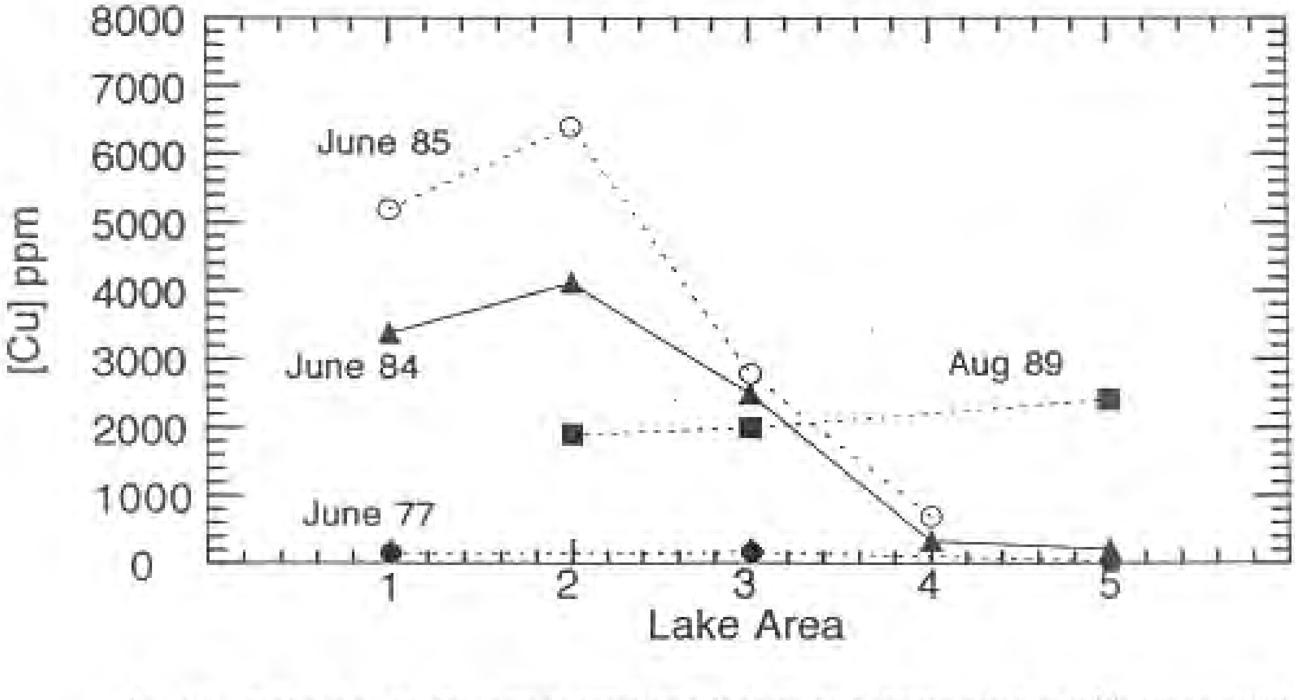

Fig. 14. Solid phase Cu concentrations for various years plotted with respect to lake zones 1-5, Anderson Lake, Manitoba

Concerns over the post-depositional reactivity of such submerged deposits with respect to their possible oxidation and leaching of heavy metals were acknowledged prior to discharge. Theoretical considerations and field studies indicate that both biologically catalyzed and abiotic oxidation of submerged tailings material and associated leaching of heavy metals and generation of acid are minimized underwater due to the relatively low ambient oxygen concentrations found in natural waters and sedimentary porewaters. Several studies in British Columbian coastal and lake waters support this rationale (Drysdale, 1990; Pedersen, 1984; Pedersen, 1985; Pedersen and Losher, 1988). Results of a study conducted in Anderson Lake in 1992 (Pedersen et al., 1993) strongly implied that the tailings on the lake floor were not releasing metals to the overlying waters and demonstrated that both natural sediments and tailings were acting as sinks for heavy metals. A recent report based on fieldwork carried out in 1993 offers the same conclusion (Rescan, 1994).

5. CONCLUSIONS

Although hindered by incomplete data sets, available information from the mine-related inputs to Anderson Lake suggests that acidic drainages from the Anderson minesite and mine discharges from Stall and Rod mines have presented the primary controls on dissolved metal inventories and pH. Dissolved heavy metal contributions originating from the buffered tailings stream were considered to be insignificant. The excess of dissolved Cu and Zn inputs relative to estimated outputs can only be partially attributed to diffusive influxes to Anderson Lake sediments. Current pH levels suggest that caustic soda additions added to combat depressed levels have since consumed any excess acidity. The cessation of discharges of acid mine effluents and the removal of all acid-generating material from the minesite should ensure that the pH of the lake remains near neutral in the future. Indeed, the pH of Anderson Lake water was neutral or slightly basic from the end of August 1994, the date by which all acid-generating material was removed from the northern shore of the lake, until the time of submission of this report (end of June, 1995).

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APPENDIX I

Anderson Lake Morphometry

Mean Breadth	436 m
Length	6,270 m
Maximum Depth	6,7 m
Mean Depth	2.1 m
Area	2.74 x 10^6 m^2
Volume	5.69 x 10^6 m^3
Shoreline Length	15,400 m

APPENDIX II

Anderson Lake Water Quality: monthly averages compiled from all available data measured directly from lake samples. Dates denoted by a (*) represent those samples measured from the reclaim water tank.

	pH	Cu mg/l	Zn mg/l	Pb mg/l	SO_4 mg/l	Cl mg/l
Jun-65	7.1					
Jul-71	7.7	<0.01	.020	<0.01		21
Jun-72	7.5	<0.01	<0.01	<0.01		
Jul-73	6.3	<0.01	.020	<0.01		
Jun-74	7.5	.010	.040	<0.01		
Jun-75	7.3	.020	.010	<0.01		
May-77	8.2	.032	.099	.020	43	20
Jun-77	8.0		.019	.004	30	15
Jul-77	8.4	.010	.015		30	17
Jun-78	7.7	.030	.080	.050	47	21
Jun-79	7.8	.090	.200			
Sep-79	7.6	.070	.210			
May-80	7.4	.030	.130			
Jul-80	7.4	.040	.160			
Sep-80	7.2	.040	.290			
Jun-81	6.9		.200		465	58
Sep-81	7.0	.040	.230	.010	508	52
Jun-82	7.2	.010	.100	.020	558	46
Sep-82	7.3	.040	.250	.010		51
Jun-83	6.7	.030	.140	.010	588	56
Jan-84	5.2		.202		530	
Feb-84	6.7		.187		530	
Apr-84	6.7		.185		543	
May-84	6.6		.177		550	
Jun-84	7.1	.050	.200	.010	473	51
Sep-84	6.7	.030	.140	.010	526	49
Jun-85	5.8	.040	.280	.010	521	45
Sep-85	4.8	.080	.380	.010	584	48
Jun-86	7.2	.030	.150		560	47
Jun-87	6.3	.046	.210		538	50
Aug-89	6.1	.028	.155	.047	841	81
Jun-90	6.6	0.02	0.06		755	70
*Jan-91	6.6					
*Feb-91	6.8					
*Mar-91	6.2					
*Jun-91	6.3					
*Jul-91	6.65					

*Sep-91	6.6					
*Nov-91	6.3					
*Dec-91	6					
*Jan-92	6					
*May-92	6.8					
*Jun-92	6.3					
*Aug-92	6.4					
*Nov-92	5.1					
*Dec-92	5.5					
*Mar-93	5.5					
Apr-93	5.4	0.02	0.35		950	70
*Jun-93	5.1					
*Jul-93	6.3					
Aug-93	5.8	0.02	0.35		800	60
*Sep-93	6.1					
*Oct-93	6					
*Nov-93	5.5					
*Dec-93	6					
Jan-94	6.3	0.015		0.04		
Feb-94	6.3	0.01	0.105			
*Apr-94	7					
Jul-94	6.8					
Aug-94	7.0					
Sep-94	7.4	0.007	0.013	0.04		
Jan-95	6.87					
Mar-95	7.5					
May-95	7.25					
Jun-95	7.8					
Jul-95	7.8					

APPENDIX III

Caustic Soda Additions

	Number of 45 gallon barrels of 50% caustic solution	
Year	To minesite drainage	To Lake
1979		
1980		
1981		
1982		
1983		
1984		
1985	48	
1986	42	
1987	46	
1988	47	
1989	60	
1990		
1991	40	50
1992	62	
1993	100	
1994		

APPENDIX IV

ANDERSON DAM DISCHARGE

A. Annual discharge volumes and annually-averaged water quality, compiled from periodic measurements from 1981-1993.

YEAR	DAYS OPENED	VOLUME m^3	pH	Cu mg/l	Zn mg/l	Pb mg/l	Ni mg/l	SO_4 mg/l
1979	0	0						
1980	0	0						
1981		850,000	6.99	0.034	0.141	0.013	0.011	435
1982	107	1,743,500	7.07	0.028	0.119	0.010	0.010	467
1983	175	4,091,000	6.72	0.020	0.134	0.010	0.010	562
1984	90	2,790,000	7.32	0.050	0.157	0.008	0.007	551
1985	90	3,600,000	6.63	0.039	0.160	0.010	0.009	520
1986	131	5,089,200	6.75	0.023	0.112	0.010	0.009	537
1987	147	2,150,000	6.95	0.013	0.088	0.010	0.012	577
1988	94	1,960,000	7.10	0.019	0.248	0.009	0.009	641
1989	34	1,075,000	7.49	0.024	0.174	0.010	0.010	771
1990	75	1,444,200	6.55	0.013	0.105	0.010	0.010	788
1991	110	3,096,300	7.03	0.020	0.150	0.010	0.010	639
1992	90	2,736,200	6.41	0.020	0.180	0.010	0.020	639
1993	56	3,598,800	6.45	0.010	0.330	0.030	0.010	724

B. Anderson dam discharge yearly unloadings, calculated from values in Table A.

YEAR	VOLUME m3	moles H+	Cu kg	Pb kg	Ni kg	Zn kg	Cd kg	SO_4 kg
1979	0		0.0	0.0	0.0	0.0	0.0	0
1980	0		0.0	0.0	0.0	0.0	0.0	0
1981	850,000	87	28.9	11.3	9.4	119.9	15.9	370,000
1982	1,743,500	148	48.4	17.4	17.4	208.3	17.4	813,800
1983	4,091,000	781	83.3	40.9	40.9	549.4	40.9	2,298,900
1984	2,790,000	134	139.5	22.5	19.3	437.8	21.5	1,537,500
1985	3,600,000	842	141.0	37.3	34.1	576.0	41.7	1,873,200
1986	5,089,200	906	116.6	48.9	46.3	571.8	50.0	2,734,600
1987	2,150,000	241	28.3	20.4	24.9	189.0	21.0	1,240,200
1988	1,960,000	155	38.0	18.4	18.2	485.5	19.1	1,255,400
1989	1,075,000	34	25.8	10.4	10.6	187.1	11.0	828,600
1990	1,444,200	407	18.8	13.8	14.4	151.6	14.3	1,137,600
1991	3,096,300	288	61.9	31.0	31.0	464.4	31.0	1,978,200
1992	2,736,200	1,064	54.7	27.4	54.7	492.5	27.4	1,748,200
1993	3,598,900	1,278	36.0	108.0	36.0	1187.6	36.0	2,604,400
Totals	34,224,100	6,400	821	408	357	5621	347	20,420,500

APPENDIX V

Anderson Mine Discharge

A. Water Quality: values represent data collected at various times during the year indicated.

year	pH	Cu mg/l	Zn mg/l	Pb mg/l	Ni mg/l	SO_4 mg/l
1978	6.92	0.43	4.4	0.12	0.09	1373
	6.72	0.03	2.6	0.15	0.15	1437
	6.92	0.04	2.4	0.2	0.08	1488
	7.00	0.74	2.2	0.09	0.47	1275
	6.12	1.26	5.5	0.2	0.1	1396
	5.38	0.63	4.9	0.08	0.06	1422
1981	6.23	5.5	8.2	0.37	0.27	905.1
	4.28	11.4	14.4	0.1	0.05	1808
	3.78	0.7	4	0.1	0.04	1940
	3.00	2.1	7.2	0.06	0.06	2041
	2.8	1.75	6.7	0.09	0.1	
	5.23	3.3	9.6	0.01	0.01	
	4.41	7.1	12.9	0.01	0.01	
	3.55	1.03	25.6	0.1	0.01	
1982	4.00	4.4	10.7	0.01	0.01	
	4.29	15.2	27.5	0.01	0.11	
	4.45	0.24	4.6	0.05		
	5.40	0.1	2	0.19		
	6.65	0.49	3.7	0.01		
	7.40	4.6	3.6	0.08		
	6.50	1.27	22.6			
	5.35	1.49	7.5			
	4.45					
	6.07					
	4.33					
Averages	5.25	2.9	8.76	0.102	0.101	1509

B. Anderson Mine Annual Discharge Volumes and Annually-Averaged Water Quality.

YEAR	VOLUME m3	pH	Cu mg/l	Zn mg/l	Pb mg/l	Ni mg/l	SO_4 mg/l
1970	297,967	5.25	2.9	8.76	0.102	0.101	1,509
1971	297,967	5.25	2.9	8.76	0.102	0.101	1,509
1972	297,967	5.25	2.9	8.76	0.102	0.101	1,509
1973	297,967	5.25	2.9	8.76	0.102	0.101	1,509
1974	297,967	5.25	2.9	8.76	0.102	0.101	1,509
1975	297,967	5.25	2.9	8.76	0.102	0.101	1,509
1976	297,967	5.25	2.9	8.76	0.102	0.101	1,509
1977	297,967	5.25	2.9	8.76	0.102	0.101	1,509
1978	297,967	5.25	2.9	8.76	0.102	0.101	1,509
1979	247,500	5.25	2.9	8.76	0.102	0.101	1,509
1980	320,858	5.25	2.9	8.76	0.102	0.101	1,509
1981	249,984	5.25	2.9	8.76	0.102	0.101	1,509
1982	297,419	5.25	2.9	8.76	0.102	0.101	1,509
1983	296,420	5.25	2.9	8.76	0.102	0.101	1,509
1984	342,216	5.25	2.9	8.76	0.102	0.101	1,509
1985	334,013	5.25	2.9	8.76	0.102	0.101	1,509
1986	336,157	5.25	2.9	8.76	0.102	0.101	1,509
1987	322,317	5.25	2.9	8.76	0.102	0.101	1,509
1988	232,786	5.25	2.9	8.76	0.102	0.101	1,509

Note: Volumes for the years 1970-1978 were based on average discharges from 1979-1988. Heavy metal, pH and sulphate values were estimated from a few yearly averages from 1978, 1981 and 1982, which represent the only data available. Their constancy is thus an artificial construct and reflects the meagre data base.

C. Anderson Mine Discharge: Estimated yearly and total loadings, based on the data in Table B.

YEAR	VOLUME m3	MOLES H+	Cu kg	Zn kg	Pb kg	Ni kg	As kg	SO_4 kg
1970	297,967	1,679	864	2,611	30.2	30.2	2.6	449,500
1971	297,967	1,679	864	2,611	30.2	30.2	2.6	449,500
1972	297,967	1,679	864	2,611	30.2	30.2	2.6	449,500
1973	297,967	1,679	864	2,611	30.2	30.2	2.6	449,500
1974	297,967	1,679	864	2,611	30.2	30.2	2.6	449,500
1975	297,967	1,679	864	2,611	30.2	30.2	2.6	449,500
1976	297,967	1,679	864	2,611	30.2	30.2	2.6	449,500
1977	297,967	1,679	864	2,611	30.2	30.2	2.6	449,500
1978	297,967	1,679	864	2,611	30.2	30.2	2.6	449,500
1979	247,500	1,395	718	2,169	25.1	25.1	2.1	373,400
1980	320,858	1,808	930	2,812	32.6	32.5	2.7	484,000
1981	249,984	1,409	725	2,191	25.4	25.3	2.1	377,100
1982	297,419	1,676	863	2,606	30.2	30.1	2.5	448,700
1983	296,420	1,671	860	2,598	30.1	30.0	2.5	447,200
1984	342,216	1,929	992	2,999	34.7	34.6	2.9	516,200
1985	334,013	1,882	969	2,927	33.9	33.8	2.9	503,900
1986	336,157	1,895	975	2,946	34.1	34.0	2.9	507,100
1987	322,317	1,817	935	2,825	32.7	32.6	2.8	486,200
1988	232,786	1,312	675	2,040	23.6	23.6	2.0	351,200
TOTALS	5,661,400	31,900	16,400	49,600	575	573	48	8,540,200

APPENDIX VI

Stall Mine Discharge

A. Water Quality: **values represent data collected at various times during the year indicated.**

year	pH	Cu mg/l	Zn mg/l	Pb mg/l	Ni mg/l	SO4
1978	3.99	19.8	26.7	0.3	1.09	1514
	5.07	1.7	6.9	0.3	0.19	746
	3.39	13.3	18	0.07		1534
	3.8	2.4	10	0.3		2062
	2.79	5.3	11.7	0.16		1273
1981	3.49	9.5	25.7	0.07	0.76	1661
	3.2	3.2	26.6	0.07	0.02	2834
	3.78	3.7	34	0.02	0.07	3193
	3.9	8.7	28.9	0.1	0.04	1848
	5.5	1.3	7.2	0.04	0.06	
	4.3	0.97	11.7	0.02	0.22	
	5.00	4	2.6	0.05	0.23	
	3.60	1.44	12	0.01	0.06	
1982	4.00	2.6	17.8	0.01	0.11	
	4.25	4.2	15.9	0.13	0.13	
	4.15	1.9	12.3	0.01	0.13	
	5.20	1.29	11.6	0.03	0.01	
	3.80	10.7	21	0.02	0.23	
	4.65	1.04	9.3	0.01	0.19	
	3.75	0.79	6.8	0.02	0.07	
	3.80	0.1	16.7	0.01	0.18	
1993	3.80	2.28	13	0.07	0.15	1583
		4.3	15.4			
		5.9	27.5			
		5.63				
Averages	4.06	4.646	16.26	0.083	0.207	1825.0

B. Stall Mine Annual Discharge Volumes and Annually-Averaged Water Quality.

YEAR	VOLUME M3	pH	Cu mg/l	Zn mg/l	Pb mg/l	Ni mg/l	SO_4 mg/l
1979	312,958	4.06	4.64	16.22	0.083	0.207	1,825
1980	417,278	4.06	4.64	16.22	0.083	0.207	1,825
1981	436,480	4.06	4.64	16.22	0.083	0.207	1,825
1982	418,547	4.06	4.64	16.22	0.083	0.207	1,825
1983	435,679	4.06	4.64	16.22	0.083	0.207	1,825
1984	389,967	4.06	4.64	16.22	0.083	0.207	1,825
1985	407,798	4.06	4.64	16.22	0.083	0.207	1,825
1986	449,536	4.06	4.64	16.22	0.083	0.207	1,825
1987	431,730	4.06	4.64	16.22	0.083	0.207	1,825
1988	372,059	4.06	4.64	16.22	0.083	0.207	1,825
1989	417,278	4.06	4.64	16.22	0.083	0.207	1,825
1990	417,278	4.06	4.64	16.22	0.083	0.207	1,825
1991	449,604	4.06	4.64	16.22	0.083	0.207	1,825
1992	400,965	4.06	4.64	16.22	0.083	0.207	1,825
1993	397,690	4.06	4.64	16.22	0.083	0.207	1,825
1994	139.093	4.06	4.64	16.22	0.083	0.207	1,825

Note: Volumes for the years 1979,1980, 1989,1990 and 1994 were based on average discharges from 1979-1993. Heavy metal, pH and sulphate values were estimated from a few yearly averages from 1978, 1981, 1982 and 1993 (see Table A).

C. Stall Mine Discharge: Estimated yearly and total loadings, based on the data in Table B.

VOLUME m3	moles H+	Cu kg	Zn kg	Pb kg	Ni kg	As kg	SO_4 kg
312,958	27,259	1,453	5,076	26	65	2	571,086
417,278	36,345	1,937	6,769	35	87	3	761,448
436,480	38,017	2,026	7,080	36	91	3	796,489
418,547	36,455	1,943	6,789	35	87	3	763,765
435,679	37,948	2,022	7,067	36	90	3	795,027
389,967	33,966	1,810	6,326	32	81	3	711,612
407,798	35,519	1,893	6,615	34	85	3	744,150
449,536	39,155	2,087	7,292	37	93	3	820,313
431,730	37,604	2,004	7,003	36	90	3	787,821
372,059	32,406	1,727	6,035	31	77	2	678,933
417,278	36,345	1,937	6,769	35	87	3	761,448
417,278	36,345	1,937	6,769	35	87	3	761,448
449,604	39,161	2,087	7,293	37	93	3	820,437
400,965	34,924	1,861	6,504	33	83	3	731,681
397,690	34,639	1,846	6,451	33	82	3	725,705
139,093	12,115	646	2,256	12	29	1	253,816
4,072,000	354,700	29,200	102,100	520	1,300	41	11,485,200

APPENDIX VII

ROD MINE DISCHARGE

A. Annual Discharge Volumes and Annually-Averaged Water Quality.

YEAR	VOLUME m^3	pH	Cu mg/l	Zn mg/l	Pb mg/l	Ni mg/l	SO$_4$ mg/l
1981	148,800	4.1	4.6	16.2	0.08	0.21	1,825
1982	159,170	4.1	4.6	16.2	0.08	0.21	1,825
1983	159,152	4.1	4.6	16.2	0.08	0.21	1,825
1984	79,585	4.1	4.6	16.2	0.08	0.21	1,825
1985	132,541	4.1	4.6	16.2	0.08	0.21	1,825
1986	212,833	4.1	4.6	16.2	0.08	0.21	1,825
1987	224,820	4.1	4.6	16.2	0.08	0.21	1,825
1988	232,785	4.1	4.6	16.2	0.08	0.21	1,825
1989	168,711	4.1	4.6	16.2	0.08	0.21	1,825
1990	168,711	4.1	4.6	16.2	0.08	0.21	1,825

Note: Water quality averages based on those values measured for Stall Mine discharge, as no specific data for Rod Mine were available.

B. Rod Mine Discharge: estimated annual and total loadings, based on data in Table A.

YEAR	VOLUME m3	moles H+	Cu kg	Zn kg	Pb kg	Ni kg	As kg	SO4 kg
1981	148,800	11,820	691	2,414	12.3	30.9	1.0	271,530
1982	159,170	12,643	739	2,582	13.2	33.0	1.0	290,453
1983	159,152	12,642	739	2,582	13.2	33.0	1.0	290,421
1984	79,585	6,322	369	1,291	6.6	16.5	0.5	145,227
1985	132,541	10,528	615	2,150	11.0	27.5	0.9	241,861
1986	212,833	16,906	988	3,452	17.6	44.1	1.4	388,378
1987	224,820	17,858	1,044	3,647	18.6	46.6	1.5	410,252
1988	232,785	18,491	1,080	3,776	19.3	48.3	1.5	424,786
1989	168,711	13,401	783	2,737	14.0	35.0	1.1	307,863
1990	168,711	13,401	783	2,737	14.0	35.0	1.1	307,863
Totals	1,687,108	134,012	7,831	27,366	139.6	349.85	10.97	3,078,634

APPENDIX VIII

ANDERSON MINE SITE DRAINAGE

A. Water Quality: values based on samples collected from the east and west minesite drainage streams.

DATE	pH mg/l	Cu mg/l	Zn mg/l	Ni mg/l	Fe mg/l	SO4 mg/l	Cl mg/l
Jun-77	7		0.184		0.18	106	149
Apr-84	3.06		27.3			1138.4	
Sep-85	3.35	0.49	4.6		63	823	
Sep-85	3.05	1.99	61		470	3344	
Jun-86	3.69		4.3				96.3
Jun-86	5		5.5			714	96.3
Jul-93	3.01	6.37	18.73				
Jul-93	3.03	4.36	20				
Apr-94	4.16	1.43	14.2	0.07	28.3	751	
May-94	3.06	1.94	20				
avg	3.8	2.8	17.6	0.1	140	1146	114

B. Estimated Loadings: values based on minesite run-off estimates in Appendix IX.

	Volume (m3)	H^+ moles	Cu kg	Zn kg	Ni kg	Fe kg	SO_4 kg	Cl kg
yearly runoff	68,400							
yearly loading	68,400	9887	189	1,203	5	9,600	78,400	7,800
10 year loading	684,000	98,870	1,890	12,026	48	96,000	783,900	77,900
15 year loading	1,026,000	148,305	2,835	18,039	72	144,000	1,175,900	116,800
20 year loading	1,368,000	197,740	3,780	24,051	96	192,000	1,567,800	155,800

APPENDIX IX

ANDERSON LAKE MINE SITE ANNUAL RUNOFF

MINE SITE AREA = 120.7 ACRES

MONTH	AVERAGE PRECIPITATION	AVERAGE RUNOFF	AREA RUFOFF	AREA RUNOFF
	INCHES	INCHES	Imp. Gal.	m3
JAN	0.78	0.21	574,140	2,610
FEB	0.72	0.18	492,120	2,237
MAR	0.88	0.16	437,440	1,989
APR	0.76	0.31	847,540	3,853
MAY	1.55	0.98	2,679,320	12,180
JUN	2.63	0.82	2,241,880	10,192
JUL	2.81	0.62	1,695,080	7,706
AUG	2.46	0.47	1,284,980	5,842
SEP	2.13	0.51	1,394,340	6,339
OCT	1.18	0.56	1,531,040	6,960
NOV	0.95	0.41	1,120,940	5,096
DEC	0.92	0.28	765,520	3,480
TOTALS	17.77	5.51	15,064,300	68,400

AREA DRAINAGE SURVEY- OCTOBER1985

Drainage	Flow Imp. Gal./min	Flow m^3/day	Discharge over 5 months, m^3
West Influent Stream	100	654.6	98190
East Influent Stream	8.5	38.6	5790

APPENDIX X

Snow Lake Mill Tailings Discharge: values obtained from annual metallurgical balances.

YEAR	TONS TAILS	Cu kg	Zn kg	Pb kg	SO4 kg
1979	302,400	469,000	1,335,500	126,300	251,200
1980	515,700	1,057,200	2,469,900	332,100	428,300
1981	558,800	922,600	2,392,700	263,600	464,100
1982	507,700	759,900	2,063,300	234,900	421,700
1983	451,100	654,800	1,338,100	143,200	374,700
1984	516,800	782,900	1,828,300	159,400	429,200
1985	461,900	636,900	1,835,200	129,900	383,600
1986	366,900	735,600	2,206,800	96,500	304,700
1987	515,500	874,500	2,361,700	140,300	428,200
1988	531,400	901,400	2,569,200	178,400	441,300
1989	505,000	888,700	2,867,700	256,500	419,400
1990	506,500	744,300	2,504,000	271,100	420,700
1991	638,900	799,900	2,625,600	278,200	530,700
1992	569,960	723,900	2,404,300	237,900	473,400
1993	511,300	519,500	1,957,400	306,100	424,700
1994	267,300	414,500	1,180,500	111,700	222,000
TOTALS	7,727,100	11,885,800	33,941,100	3,266,300	6,418,400

APPENDIX XI

Snow Lake Mill Lime Consumption: values obtained from internal reports.

Year	Tons milled	lbs. lime per ton	total lbs	kg lime
1979			2,546,961	1,156,320
1980	833,658	4.38	3,648,665	1,656,494
1981	850,143	3.06	2,603,416	1,181,951
1982	757,921	3.58	2,715,385	1,232,785
1983	740,151	3.17	2,343,332	1,063,873
1984	757,695	3.02	2,289,174	1,039,285
1985	735,968	3.43	2,523,530	1,145,683
1986	681,280	3.36	2,286,969	1,038,284
1987	876,451	3.51	3,080,399	1,398,501
1988	803,873	3.24	2,604,220	1,182,316
1989	847,157	3.04	2,577,005	1,169,960
1990	860,077	2.9	2,493,508	1,132,053
1991	915,841			
1992	867,458	3.73	3,231,958	1,467,309
1993	634,553	2.63	1,669,214	757,823
1994	314,520	2.63	827,188	375,543
totals	11,476,800		34,894,000	15,842,000

Note: lime consumption data for 1991 were included in the totals for the 1990 and 1992 reports.