

**GEOCHEMICAL ASSESSMENT OF  
SUBAQUEOUS TAILINGS  
DISPOSAL IN BUTTLE LAKE,  
BRITISH COLUMBIA  
1993 STUDY PROGRAM**

**MEND Project 2.11.4a**

This work was done on behalf of MEND and sponsored by:  
Placer Dome Canada Ltd.; Environment Canada, as well as  
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The Canada/British Columbia Mineral Development Agreement.

**May 1995**

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# ***Geochemical Assessment of Subaqueous Tailings Disposal in Buttle Lake, British Columbia***

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## **1993 STUDY PROGRAM**

Prepared for and funded by:

**Hudson Bay Mining and Smelting Co., Ltd.**

**Placer Dome Inc.**

**National Water Research Institute, Environment Canada**

Prepared by:

**Rescan Environmental Services Ltd.**

Vancouver, British Columbia

May 1995



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## **PREAMBLE**

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### *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 found 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 minimised 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 for 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 utilised 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)).

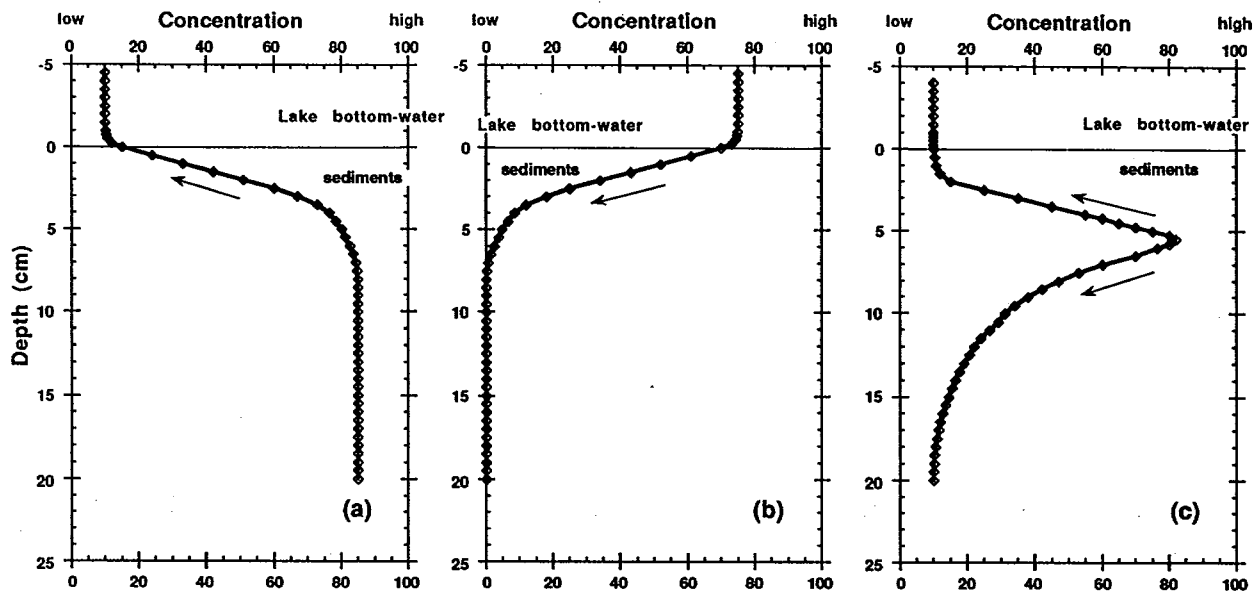


Figure 1 Three hypothetical concentration profiles for dissolved metals in the porewaters of tailings or natural sediments: (a) release of metal to pore solution. The arrow shows the gradient in concentration (from high to low) and the consequent direction of migration of dissolved metal ions; (b) consumption 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 metal 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 localised 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 continuous 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. 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 effective final control system.

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## EXECUTIVE SUMMARY

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The dissolved metal concentrations within Buttle Lake are among the lowest observed in the last 20 years of observations despite continued inputs of several trace metals (most notably Zn) from acid drainage in the Myra Creek watershed. The tailings are restricted to the South Basin and are now buried by several centimetres of oxic, natural sediments admixed with a small component of tailings bioturbated upward from below. The natural site indicates diffusive influxes of dissolved Cd and Zn into the sediments while Cu and Pb show no indication of reactivity. At both of the tailings sites, near surface pore waters indicate remobilization of Cd, Cu, Pb and Zn (and Hg at the distal site) likely associated with oxide dissolution. However, the impact of the upward flux toward the water column is likely attenuated by reprecipitation of Mn and Fe oxides which scavenge trace metals. Arsenic distributions follow Mn and Fe cycling but show no evidence of efflux. Simple flux-based diffusion calculations suggest that effluxes of Cu, Pb and Zn to the South Basin bottom waters are small and have limited impact on water quality; very little, if any, oxidation of sulphide particles can be accommodated by the near-surface pore water data.

These observations are consistent with those of previous studies of Buttle and other lakes.

A preamble entitled, "An Overview of the Reactivity of Subaqueous Mine Tailings Deposits" precedes the report to provide an appropriate foundation upon which the data may be viewed.

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## SOMMAIRE

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Les concentrations de métal dissous contenues dans la lac Buttle sont parmi les moins élevées observées au cours des 20 dernières années malgré l'apport continu de plusieurs métaux traces (notamment le Zn) provenant du drainage acide du bassin hydrographique de Myra Creek. Les résidus étaient limités au Bassin sud et sont maintenant enfouis sous plusieurs centimètres de particules oxiques, sédiments naturels auxquels se mélange une petite composante de résidus bioturbés du bas vers le haut. Le site naturel démontre que des flux entrants diffusent du Cd et du Zn dissous dans les sédiments tandis que le Cu et le Pb n'indiquent aucune réactivité. Dans les deux sites d'accumulations de résidus, de l'eau interstitielle au voisinage de la surface indique la remobilisation de Cd, Cu, Pb et Zn (et Hg sur le site le plus éloigné) qui semble associée à la dissolution de l'oxyde. Toutefois, l'impact de l'écoulement ascendant vers la colonne d'eau est, selon toute vraisemblance, atténué par la précipitation des oxydes de Mn et Fe qui capturent les métaux traces. Les distributions d'arsenic suivent la succession des cycles de Mn et Fe mais ne donnent pas de signe d'écoulement. De simples calculs basés sur la diffusion par le flux suggèrent que les écoulements de Cu, Pb et Zn dans les eaux de fond du Bassin sud sont minimales et ont un impact limité sur la qualité de l'eau; très peu, s'il en est, de données sur l'oxydation des particules sulfurées peuvent être incluses avec les données relatives aux eaux interstitielles au voisinage de la surface. Ces observations sont compatibles avec celles qui ont été faites dans des études précédentes du lac Buttle et d'autres lacs.

Un aperçu intitulé, "Aperçu de la réactivité des dépôts de résidus miniers submergés" précède le rapport afin de fournir l'information appropriée pour mieux comprendre les données.

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# 1.0 Introduction

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## 1.0 INTRODUCTION

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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 economic benefits (for which it has transpired historically) but rather because recent research suggests that such a mode of deposition results in greater long-term chemical stability of potentially reactive sulphide tailings (Pedersen 1983; Rescan 1990; Pedersen *et al.* 1993).

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 to help dispel misconceptions regarding subaqueous disposal by 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 over-looked. 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 geochemical survey performed in Buttle Lake, British Columbia, during October 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 survey performed in Buttle Lake involved sampling of the water column as well as sampling of the sediments and associated porewaters. The latter was accomplished utilizing two techniques: core extrusion and centrifugation, and membrane dialysis arrays (peepers) to address diffusive trace metal fluxes across the sediment-water interface with reasonably high resolution. Additionally, the National Water Research Institute (NWRI) collaborated on the survey by 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

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## 2.0 STUDY AREA AND METHODS

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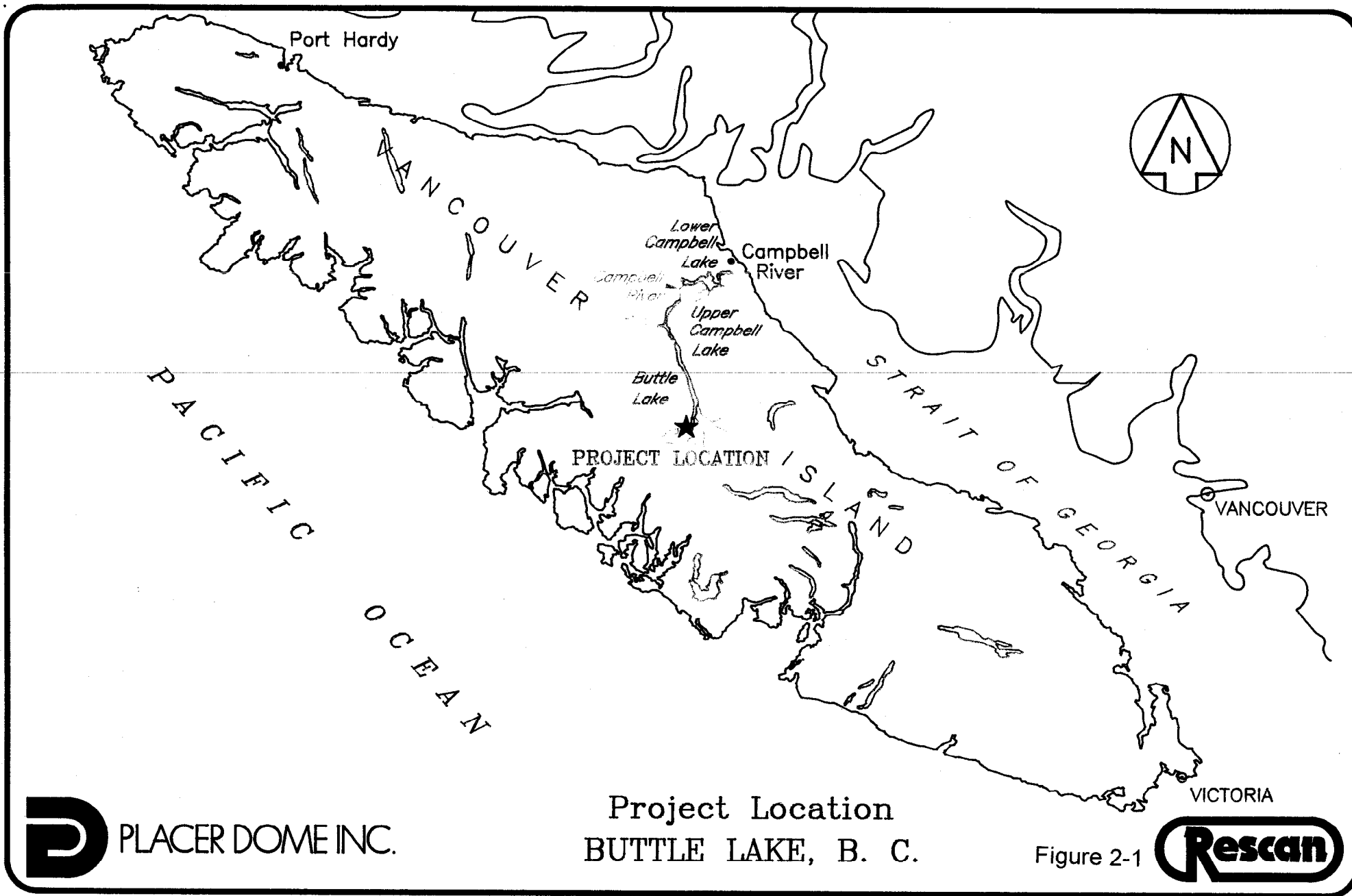
### 2.1 Study Area

Westmin Resources Ltd. (Westmin) operates a copper-zinc mine at Myra Falls located in Strathcona Provincial Park on central Vancouver Island, approximately 30 km southwest of the city of Campbell River (Figure 2-1). The climate at the site is considered moderate, with an average maximum temperature of 31.5°C in July, and an average minimum temperature of -12.0°C in January. The mean annual precipitation is 292 cm.

Being located in a provincial park, the mining operation is situated amidst important wildlife habitat and recreational areas. Buttle Lake, Upper and Lower Campbell Lakes, and Campbell River are located downstream of the mine sites. These water systems support recreational and commercial fisheries that could be adversely affected by aquatic degradation resulting from mining activity. Conversely, mining activity in the area has allowed for the development of trails and access to hiking areas that might not have otherwise been available.

Buttle Lake is large (35 km long x 1 km wide x 80 m deep), occupying a U-shaped valley in an area of high relief in central Vancouver Island. Like many neighbouring lakes, Buttle Lake has low nutrient levels and is generally considered oligotrophic. The lake drains northeastward into Georgia Strait via Campbell Lake and the Campbell River, a major spawning channel for salmon.

Presumably due to its size and location, Buttle Lake is monomictic, turning over in mid winter (Dec/Jan); winter temperatures are insufficiently low to induce winter stratification. Despite its monomictic nature, Buttle Lake is able to maintain a significant inventory of dissolved oxygen throughout the water-column year-round (typically >5 mg/L). This is likely a function of a relatively low oxygen demand instilled by the oligotrophic nature of the lake. Buttle Lake water contains low concentrations of major anions; for example, sulphate concentrations are typically ~10 mg/L.



**D** PLACER DOME INC.

Project Location  
 BUTTLE LAKE, B. C.

Figure 2-1



Cad No. C0584 1 P1 1:1,800,000 Job No. 425-1 02/14/1995- 12:07pm RES\_AV



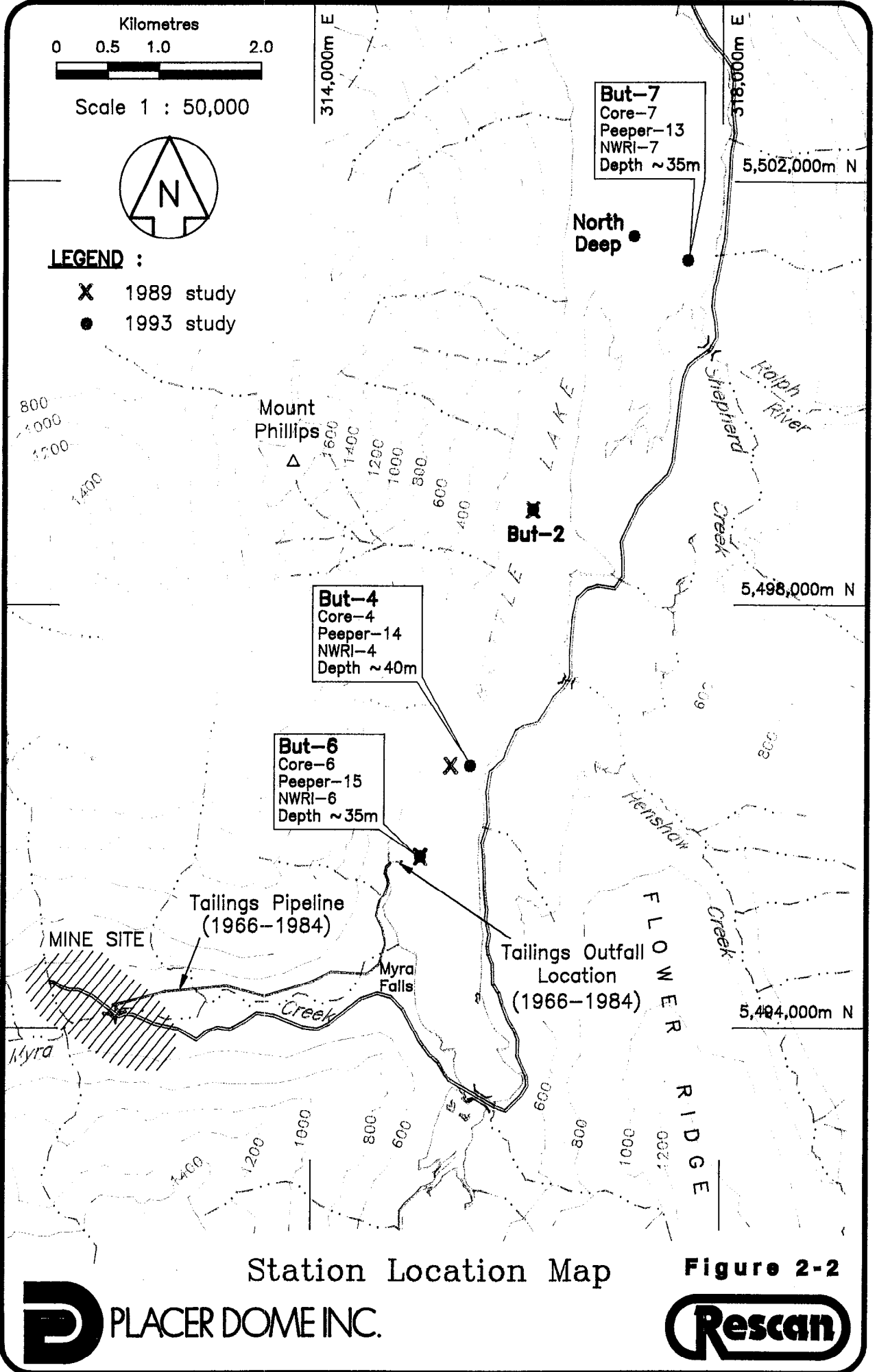
### **2.1.1 Historical Overview**

Mining activity at the south end of Buttle Lake commenced in the early 1900's. Claims were first staked in 1918 in the Myra Falls area and exploration was carried out sporadically until the properties were acquired by Western Mines Ltd. in 1961. In 1966, Westmin Resources commenced operation of the Lynx mine, located adjacent to Myra Creek, 6 km west of the south basin of Buttle Lake (Figure 2-2). The south basin is about 7 km long, and reaches a maximum depth of 87 m roughly 4 km north of the former tailings discharge point (Figure 2-2). Some  $5.5 \times 10^6$  tons of tailings were discharged to this basin via a submerged outfall between 1966 and 1984, when the disposal strategy switched to tailing ponds on land. A relatively shallow sill about 5 km north of the outfall effectively confined physical dispersion of the tailings to the south basin of Buttle Lake.

Westmin's current and past operations in the Myra Creek valley (summarized by Rescan, 1990) include the H-W, Lynx, Myra and Price mines from which Cu, Pb, Zn, Au, Ag, and Cd have been recovered. Open pit and underground mining of the Lynx deposit began in 1966 with a mill capacity of 750 tpd. Mill capacity has been increased several times; current output is about 4,400 tpd. The mill process uses conventional crushing and grinding followed by differential flotation to produce separate copper, lead and zinc concentrates.

After concentrator startup in late 1966, tailings were discharged to a small nearby pond. Direct discharge into Buttle Lake commenced shortly thereafter. The sand-sized material from the tailings underflow was removed by cycloning and used as backfill in the underground mine, while the cyclone slime overflow was routed from the minesite down a pipeline through seven drop boxes to a raft about 100 m offshore. The tails were discharged below the thermocline via a submerged outfall and polyacrylamide flocculants were used to assist settling of the solids. Cessation of subaqueous discharge occurred in July 1984.

Buttle Lake boasts a wealth of historical hydrographic and weather-station data, dating back to the mid 1970's (WMB-SEAM water quality and climate data as well as several water quality reports by B.C. Research). Additionally, data from previous sedimentary geochemical surveys (Pedersen 1982; Pedersen 1983a; Pedersen 1983b; Rescan 1990) add to the knowledge inventory. Utilizing this information, a series of surveys were organized and implemented to address the



Station Location Map

Figure 2-2



concerns expressed by the Rawson Academy Peer Review and advisors of the MEND Project 2.11.

### **2.1.2 Station Locations**

In late October of 1993, three stations were sampled for lake waters, sediment solids and interstitial waters: the first proximal to the location of the tailings raft (Station But-6, depth ~35 m), the second located in the central basin (adjacent to But-4, depth ~ 40 m) and a control station in the southern-most portion of the northern basin (But-7, depth ~ 35 m) where tailings do not exist (Figure 2-2). The locations of But-4 and But-6 in this survey are identical to those occupied in 1989. These three stations represent a satisfactory cross-section of sedimentary geochemical conditions, having experienced varying degrees of influence from tailings deposition. But-6 was a station dominated by tailings accumulation. Previous cores from this area had shown that a thin veneer (1 to 2 cm thick) of natural sediments admixed with tailings capped the pure tailings deposit. Station But-4 was presumed to consist of natural sediments overlain by 10 to 20 cm of tailings in turn overlain by a few cm of natural sediments admixed with tailings. Finally, Station But-7 was expected to consist of only pristine, natural sediments.

## **2.2 Methods**

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

### **2.2.1 Water-column Sampling**

Discrete samples from the water-column were collected using acid-washed Go-Flo bottles, while conductivity, temperature, percent light transmission, and dissolved oxygen were measured by remote profiling.

#### *2.2.1.1 Discrete Water-column Sampling*

High-resolution water-column sampling was not deemed necessary in Buttle Lake, given its depth and size. Previous work did not suggest any strong chemical or physical gradients (Pedersen 1982; Pedersen 1983a; Pedersen 1983b; Rescan 1990). At the sediment-water interface, where gradients are potentially the strongest, water-column sampling was better accomplished by the exposed portions

of the peepers (see Section 2.3.3). For the water-column above this critical zone, duplicate profiles were collected at all three stations over 15 depths.

The water-column was sampled at 5 m intervals from the surface down using 1 L acid-washed Go-Flo bottles. Several 1 L Go-Flo bottles were rigorously cleaned and acid-washed prior to field use. Bottles were first cleaned thoroughly by washing with a mild detergent followed by several rinses with distilled water. The interior of the bottles were then exposed to low strength (1% v/v) ultrapure Seastar HCl followed by several rinses with dilute (0.1% v/v) HCl, separated by many rinses with copious amounts of distilled, deionized water (DDW). Go-Flo bottles were stored in clean plastic within storage boxes until deployment.

Immediately prior to sampling, Go-Flo bottles were rinsed with dilute (0.1% v/v) ultrapure HCl followed by several rinses with DDW. Sampling involved attaching a clean Go-Flo bottle to a stainless steel hydrowire weighted by resin-coated ballast. Once lowered to the appropriate depth, the bottles were tripped by a teflon-coated messenger.

Because the entire Buttle Lake water-column is oxic, sub-sampling of water did not need to be conducted under a nitrogen atmosphere to avoid oxidative artifacts. However, care was taken to collect uncontaminated trace-metal subsamples, using acid-washed tubing to draw samples in concert with the implementation of general trace-metal protocols (*i.e.*, Nriagu *et al.* 1993).

Sub-samples of unfiltered water were collected for total metals, physical parameters and total organic carbon (TOC), and stored in acid-washed polyethylene bottles except for TOC which was stored in 60 mL glass ampoules. Later, filtered water samples (filtered within a few hours of collection at the minesite laboratory with acid-washed Nuclepore 0.45  $\mu\text{m}$  Syrifil filters) were apportioned to three fractions:

1. dissolved metals - preserved acidified (pH 2.0) with ultra-pure  $\text{HNO}_3$ ;
2. nutrients ( $\text{NO}_3^-$ ,  $\text{PO}_4^{3-}$  as well as  $\text{SO}_4^{2-}$ ) and pH, preserved frozen;
3. dissolved organic carbon (DOC), preserved refrigerated in glass bottles.

Eh and pH were measured discretely from sub-samples of the water bottles. Thus, Go-Flo bottles were sub-sampled in the following manner:

1. Teflon tube attached to Go-Flo bottle outflow, trace metal sample drawn, sub-sampled for nutrients and physical parameters;
2. Samples tested for pH, followed by connection of the outflow to the flow-through Eh-cell designed for routine measurements of Eh. The sample was slowly gravity fed through the cell until a stable reading was achieved.

### 2.2.1.2 *Water-column Profiling*

Dissolved oxygen (DO) profiles were collected at each station (But-4, -6 and -7) with a YSI Model 58 dissolved oxygen meter and probe. The probe was lowered to the appropriate depth and the electrode allowed to equilibrate before recording the reading and lowering the probe to the next depth. Oxygen profiles were performed synchronously with water-column sampling in order to temporally match the data. In all cases, the oxygen electrode was calibrated in the field.

Finally, the hydrographic picture was completed through high resolution profiling of the water-column at all three stations plus But-2 and North Deep utilizing an Applied Microsystems CTD Profiler. Conductivity, temperature and percent light transmission data were downloaded directly into a portable computer. Of these data, the temperature profiles were most reliable while conductivity was more accurately reflected in the water quality sampling and interpretations of the latter relied solely on lab conductivity measurements.

### 2.2.2 **Peepers**

Dialysis-membrane array-samplers (peepers) were utilized to sample waters at high resolution both within the sediments and across the sediment-water interface. A tandem peeper consists of two vertical banks of sample wells machined into an acrylic plate. In principle, a semi-permeable membrane traps de-oxygenated, distilled, deionized water within the peeper cavities, while allowing diffusion of dissolved species across its surface. When in contact with sediments, the entrapped peeper water comes into chemical equilibrium with adjacent interstitial water such that, after approximately two weeks, they are chemically indistinguishable.

Each peeper is approximately 1 m in length and has two vertical columns of 61 wells (70 mm x 8 mm x 14 mm deep) machined into its surface; sample wells are located

every 10 mm. The spatial resolution in the central section of the peeper is 5 mm which is obtained by offsetting a series of smaller wells (32 mm x 8 mm x 14 mm).

### 2.2.2.1 *Peeper Preparation*

Rescan peepers were assembled for deployment under clean-room conditions at the University of British Columbia (UBC), prior to shipment to Buttle Lake. Preparation involved immersion in a tank of de-oxygenated, distilled, deionized water (DDDW), where bubbles were dislodged; peeper assembly then took place under water. A sheet of 0.45  $\mu\text{m}$  polysulfone, Gelman depth filter covered all wells. An acrylic face plate, attached with several nylon screws, served to hold the filter in place. All peeper components were cleaned with a mild detergent and rinsed with copious amounts of distilled water prior to acid-washing. Components were then acid washed in dilute ultrapure  $\text{HNO}_3$  (0.1% v/v) followed by several 24 hour soaks in DDW to remove any residual acid. The assembled peepers were stored in sealed acrylic boxes containing DDDW bubbled with nitrogen until deployment by diver insertion.

NWRI peeper preparation differed slightly from that of Rescan. Peepers were first acid-washed by soaking in 1 M  $\text{HNO}_3$  followed by several rinses with DDW. Peepers were assembled in the field lab by submergence in a plastic tank of oxygen-free DDW. All adhering bubbles were first dislodged from the peeper body after which a 0.45  $\mu\text{m}$  Gelman filter was lain over the submerged wells. An acrylic face-plate, secured with stainless steel screws, served to hold the filter membrane in place. Peepers were stored in oxygen-free DDW until installation by divers.

Carignan *et al.* (1994) have recently shown that plexiglass, from which the Rescan and NWRI peepers were manufactured, absorbs (in air) 1.6% vol/vol of  $\text{O}_2$ , which is lost slowly (half-time 5.7  $\text{d}^{-1}$ ) once the material is exposed to an anoxic environment. The presence of such traces of oxygen could introduce an artifact by reacting with  $\text{Fe}^{2+}$  which diffuses into the peeper cells after deployment, precipitating  $\text{Fe}(\text{OH})_3$  *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 in this 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 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<sub>2</sub> content of the plexiglass to an insignificant level.

### 2.2.2.2 *Peeper Deployment*

As part of the QA/QC component of the study, one tandem and one single peeper were deployed at each of Stations But-4, But-6 and But-7: one tandem by Rescan and the single peeper by NWRI (National Water Research Institute). The role of the NWRI peeper was to serve as an independently-processed control to assess more accurately the variability of the metal fluxes both from small scale inhomogeneities and methodological differences.

Because station depths in Buttle Lake ranged from 40 to 60 metres, it was necessary to use commercial diving techniques to install and retrieve the peepers. Moorings anchored by 30 kg weights and surface floats marked the station locations.

At each station, peepers were pushed vertically into the sediment by commercial divers; the tailings were soft enough to allow the divers to insert the peepers unaided by additional weight. The tandem peepers were moored within a benthic lander frame while the single peepers were allowed to free-stand. The single peeper was attached via a slack line to the lander which was in turn attached to a mooring marked by a buoy. The peepers were pushed slowly into the lake sediments until the sediment-water interface eclipsed the high-resolution portion of the sample wells. At this time, each peeper was videotaped and photographed and the location of the sediment-water interface, relative to the peeper, was recorded. Each peeper was attached to the central mooring via a slack line and left to equilibrate for 14 days.

This deployment configuration allows for high resolution sampling in the upper 60 cm of interstitial waters, and across the sediment-water interface, extending approximately 30 cm into the bottom waters, thereby integrating interstitial waters and water-column samples.

### 2.2.2.3 *Peeper Retrieval and Subsampling*

Peeper removal was accomplished by diver-retrieval and was accompanied (within 24 hours) by collection of cores at the same sites; these were processed for both solid phase and interstitial waters (Section 2.2.3). The peepers were brought to just below the surface, agitated to remove adhering particulate matter, taken out of the lake and immediately inserted in their nitrogen-flushed storage boxes for transport to the field lab where they were transferred to a N<sub>2</sub>-filled glove-bag. Processing started by careful removal of the nylon screws and frit. Two small holes were made in the Gelman filter through which samples were withdrawn using an Eppendorf pipette and acid-washed pipette tips.

NWRI processing involved retrieval of the peepers from the sediments, followed by agitation in the lake water to remove any adhering sediment particles. Peeper sub-sampling was accomplished immediately by rapidly withdrawing interstitial water with disposable syringes (within the first three to four minutes) in the field. The rapid sub-sampling, although conducted in air, is thought to yield samples free of oxidation artifacts. The samples were transferred to pre-acidified, acid-washed polyethylene vials.

All peeper samples were apportioned for measurements of trace metals (As, Cd, Cu, Fe, Hg, Mn, Pb and Zn, preserved in solution by acidification to pH 2 with Seastar™ nitric acid), nutrients (NO<sub>3</sub><sup>-</sup>, PO<sub>4</sub><sup>3-</sup> and SO<sub>4</sub><sup>2-</sup>, preserved frozen) and ΣH<sub>2</sub>S (preserved with Zn-acetate), where the volume permitted. All analyses were performed by UBC and ASL (see Section 2.2.4).

## 2.2.3 **Coring**

Two cores were collected for extraction of their interstitial waters at each of the three stations. A standard reconnaissance coring technique was employed, whereby a retrieved core was assessed for an undisturbed interface. If disturbance was observed, additional cores were collected until a satisfactory core was retrieved.

### 2.2.3.1 *Collection*

Cores were collected using the light-weight Pedersen Gravity Corer (Pedersen *et al.* 1985) with an 8 cm I.D., catcher-free, butyrate core barrel. The corer was lowered to the lake floor and allowed to penetrate the sediments slowly (< 10 cm/s). After



returning to the surface, the bottom of the core barrel was quickly capped by insertion of an O-ring-fitted piston. The barrel was removed from the corer, sealed completely with plastic core-caps and electrician's tape and transported hand-held to the lab for processing.

### 2.2.3.2 Processing

Four of the six cores collected were processed: both cores from station But-4, and one from each of station But-6 and But-7. The two cores that were not processed were sub-sampled and the sediments stored frozen for potential future analysis, if deemed necessary.

In the laboratory, all cores were processed identically. Cores were first logged (Appendix C) and then firmly attached to the underside of an extrusion table fitted with an N<sub>2</sub>-filled glove bag. 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 Buttle Lake. Processing commenced within two hours of collection.

In order to obtain the high resolution profiles necessary to define diagenetic reactivity in the upper few centimetres of sediment, 5 mm sample intervals were sectioned for the top two cm. The next four cm consisted of one cm thick slices followed by two cm intervals beyond the top decimetre. Sub-sampling was accomplished by jacking the piston up slowly, extruding the core into the inert atmosphere of the glove bag. Initially the supernatant water was sub-sampled in duplicate, the remaining supernatant water was syringed off carefully until the sediment-water interface was exposed. Core sectioning then commenced.

Prior to each horizontal sampling, a small aliquot of wet sediment was collected and preserved frozen, to determine water content by weight loss upon drying. Samples were then sequentially sliced from the core, placed into 250 mL N<sub>2</sub>-filled centrifuge bottles, sealed, removed from the glove bag, and centrifuged for 20 minutes at approximately 1,200 RFC (relative centrifugal force). The supernatant water in each bottle was decanted into a polypropylene syringe barrel and expressed through acid-washed Nuclepore™ 0.45 and 0.1 μm mixed cellulose-acetate filters in another N<sub>2</sub>-filled glove bag. The filtrate was collected in rigorously acid-washed high-density

polyethylene containers and preserved by acidification to pH 2 with Ultrapure Seastar™ concentrated HNO<sub>3</sub> to keep the metals in solution. Prior to 0.1 μm filtration, 0.45 μm filtered sub-samples were collected and frozen for NO<sub>3</sub><sup>-</sup>, PO<sub>4</sub><sup>3-</sup> and SO<sub>4</sub><sup>2-</sup> analysis at UBC. Where sample volume permitted, sub-samples for ΣH<sub>2</sub>S (preserved with Zn-acetate) were collected.

All plasticware and filters were rigorously acid-washed in a class 100 laminar flow bench prior to collecting the cores. All plasticware was:

1. wiped outside and rinsed inside with reagent grade acetone to remove grease and soluble organic residues;
2. soaked at least 1 day in hot (40°C) 20% reagent grade HNO<sub>3</sub>;
3. rinsed twice with DDW (distilled, deionized water);
4. soaked at least one day in 0.1% Seastar HNO<sub>3</sub>;
5. rinsed once in DDW;
6. repeat 4) and 5);
7. soaked for 1 day in DDW; and
8. dried covered in a drying oven.

Filters were cleaned by expressing 10 mL (v/v) of 0.1% ultrapure HCl through the filter, followed by 30 mL of DDW. Clean filters were stored in acid-washed, polypropylene containers.

### 2.2.4 Analytical Methods

The analytical work performed on the samples acquired from Buttle Lake is briefly addressed below. For a rigorous description, the reader is referred to the appropriate appendices compiled by Analytical Services Laboratories (ASL) and the University of British Columbia (Appendix D).

Samples were collected for water-column, sediments and interstitial waters. Analyses were performed exclusively by ASL and the UBC geochemistry group. Analyses were divided between the two labs according to sample type and 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 analyzed 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 and Discussion

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## 3.0 RESULTS AND DISCUSSION

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### 3.1 Water Column

Water column profiles of dissolved O<sub>2</sub> and temperature are shown in [Figure 3-1](#). Both sets of data at all three sites show that the water column was moderately stratified and reasonably well oxygenated (~5 to 10 mg/L O<sub>2</sub>) during the sampling period.

Conductivity, pH, nutrient and major and minor ion concentration data are listed in Appendix B. Few variations with depth are seen at the three sites. Conductivity and hardness are both slightly lower than measured in the water column in 1989 (Rescan 1990), averaging about 60  $\mu$ mhos/cm, and 33 mg/L (as CaCO<sub>3</sub>), respectively. These levels are commensurate with the relatively low concentrations of major ions (Mg<sup>2+</sup>, Na<sup>+</sup>, Ca<sup>2+</sup>, K<sup>+</sup>, Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup>) measured in general throughout the water column; such soft waters are characteristic of British Columbia coastal lakes. For comparison, the waters in Anderson Lake, Manitoba, which also hosts submerged sulphide-rich tailings, have major ion concentrations typically 40- to 50-fold higher and 100-fold higher in the case of sulphate (Rescan 1994).

Buttle Lake waters are near neutral, with pH values ranging from extremes of ~7.1 to ~8.6. The highest pH values are observed in surface or near-surface samples, which may reflect CO<sub>2</sub> consumption by phytoplankton; the lowest pH levels are generally seen in the deep waters and probably result from addition of carbon dioxide from oxidative degradation of sinking organic detritus. This suggestion is supported by the nitrate-N levels at 30 or 35 m depth which are some three- to four-fold higher than concentrations in near-surface waters ([Table 3-1](#)).

The concentrations of dissolved metals measured in the October, 1993 sample set are amongst the lowest seen in Buttle Lake in the last 20 years. Zinc levels range from minima of ~5  $\mu$ g/L in surface or near-surface waters to maxima of ~24  $\mu$ g/L in the deepest samples at 35 m depth ([Figure 3-2](#)). In the 1990 survey, maximum zinc concentrations were twice as high, reaching 52  $\mu$ g/L in deep waters (88 m depth) near the bottom in the central part of the South Basin (But-2). At intermediate depths (18-22 m) dissolved Zn values in 1990 ranged from 29 to

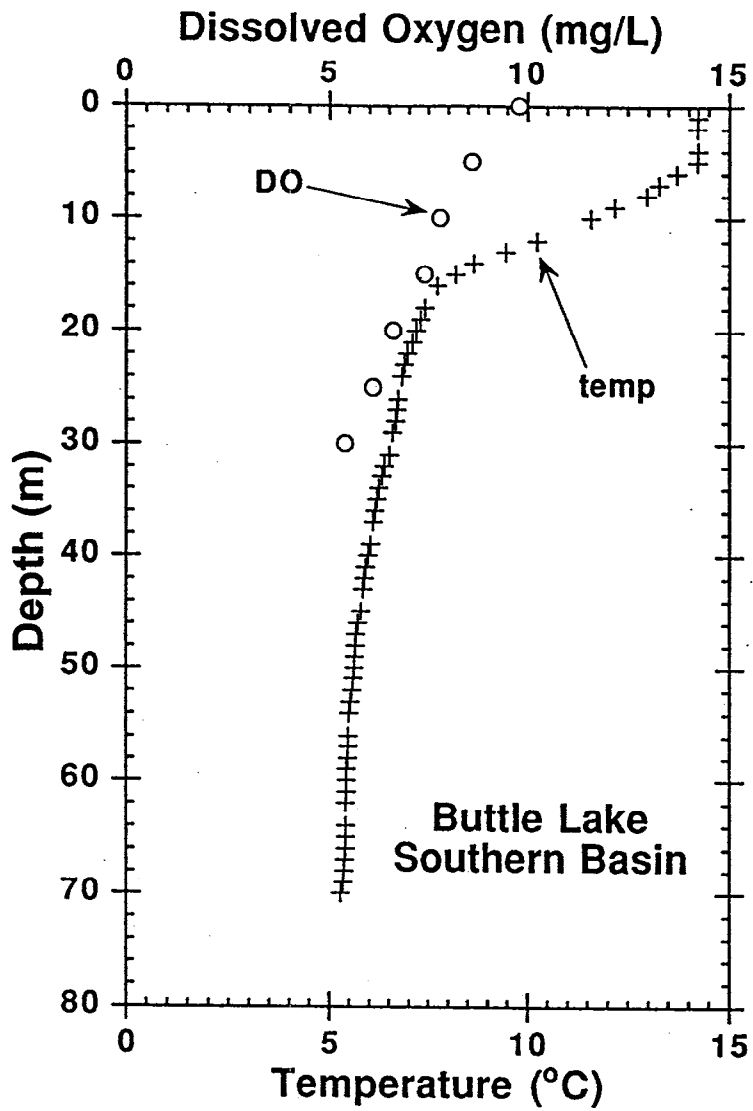
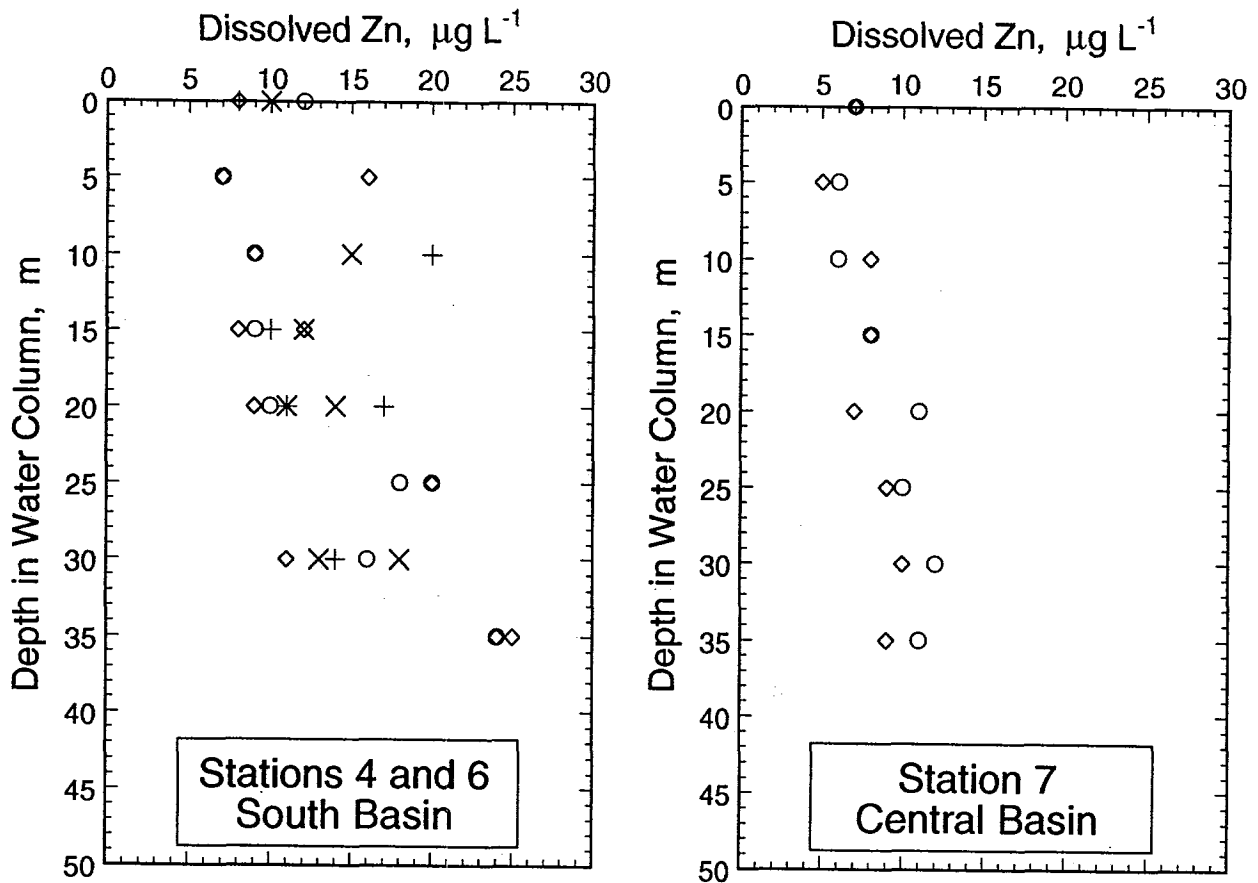


Figure 3-1: Temperature and dissolved oxygen in the South Basin of Butte Lake.





**Figure 3-2: Dissolved zinc distributions in the Buttle Lake water column, October, 1993. Circles and diamonds represent duplicate samples sets collected at But-4 and 7; X symbols and crosses represent casts 6A and 6B at But-6.**



Table 3-1

## Nitrate-N in the Buttle Lake Water Column

Depth (m)	Nitrate Concentration (mg/L)		
	But-4	But-6	But-7
Surface	0.019	0.016	0.007
5	0.025	0.020	0.013
10	0.024	0.026	0.008
15	0.041	0.016	0.031
20	0.045	0.039	0.022
25	0.053	0.049	0.040
30	0.046	0.059	0.043
35	0.066	-	0.054

40  $\mu\text{g/L}$  in the southern half of the South Basin. Copper concentrations are 2  $\mu\text{g/L}$  or less, and show little variation with depth. Dissolved lead, cadmium and mercury were not detected anywhere in the water column; respective concentrations were <0.5, <0.2 and <0.01  $\mu\text{g/L}$ . Arsenic levels are similarly low, ranging from undetectable (<0.1  $\mu\text{g/L}$ ) to a maximum, seen in only one sample at But-7, of 0.3  $\mu\text{g/L}$ .

The slightly higher dissolved zinc concentrations seen in the deeper water at the three locations may be the result of one or more of three phenomena. First, Myra Creek continues to contribute dissolved metals to the lake at levels higher than would be expected in a pristine watershed. Because Myra Creek water is often very cold and therefore relatively dense, it usually sinks and spreads laterally at a considerable depth in the South Basin. The effect of this input is to raise the dissolved Zn concentration in the deeper waters. Water quality monitoring results from Myra Creek in 1993 support this suggestion (Table 3-2). Elevated dissolved zinc levels were observed in several months of the year and it is interesting to note that the highest was observed in October just prior to the commencement of this



Table 3-2

## 1993 Dissolved Zinc Levels in Myra Creek

Date	Dissolved Zinc (mg/L)	Temperature (°C)
01/13/93	0.219	1.0
02/25/93	0.129	4.0
03/15/93	0.126	3.8
04/26/93	0.128	4.2
05/25/93	0.041	5.8
06/30/93	0.061	9.5
07/06/93	0.062	10.2
08/25/93	0.074	11.0
09/27/93	0.216	9.2
10/14/93	0.254	9.5
11/23/93	0.086	1.3
12/21/93	0.152	3.6

study. Second, zinc is an essential element for phytoplankton growth and is actively sequestered by cells in the euphotic zone and released at depth or to sedimentary pore waters when the cells are subsequently degraded (Reynolds and Hamilton-Taylor 1992). However, Buttle Lake is oligotrophic, and its waters have a relatively short residence time, so such biological vectoring is unlikely to have more than a minor influence on the Zn distribution in the water column. Third, benthic recycling at or just below the sediment surface, for example via the reductive dissolution of oxide phases, could theoretically support an efflux of dissolved zinc that might augment the concentration of the metal in bottom waters, despite the short residence time. This possibility will be discussed further later in this chapter.

### 3.2 Sediments

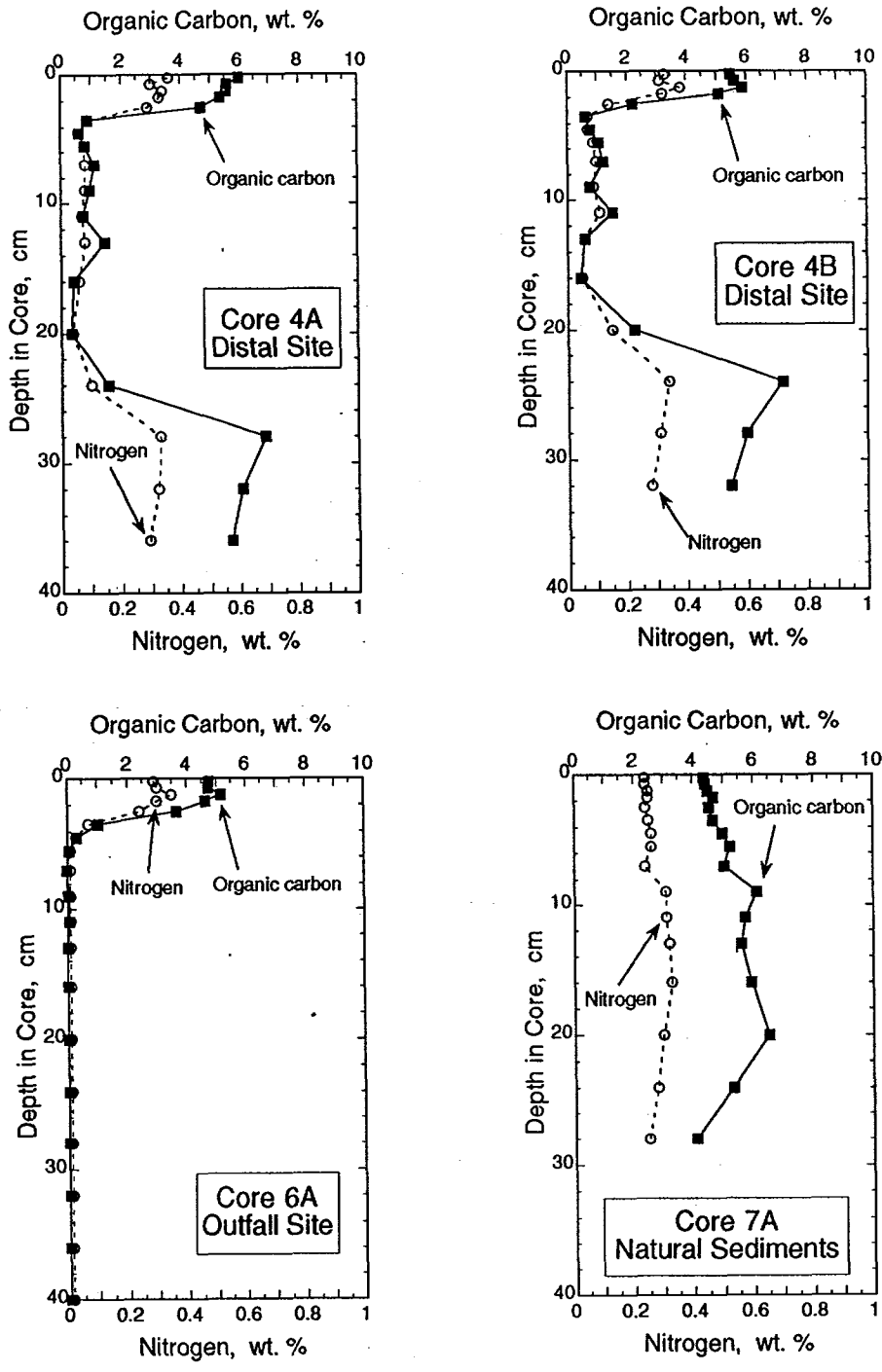
Two cores were collected at each site using the open-barrelled, catcher-free lightweight stainless-steel gravity corer described by Pedersen *et al.* (1985). The general quality of the cores was good to excellent, and interstitial waters were

extracted from both cores at But-4, and from one core from each pair raised at But-6 and But-7. Detailed core logs are presented in Appendix C.

The natural sediments collected from But-7 on the southeastern margin of the deep central basin of the lake consist of relatively organic rich detritus, as noted in Appendix C. Organic carbon ( $C_{org}$ ) concentrations range from ~4.5 wt. % in surface deposits to a maximum of ~7% at 20 cm depth (Figure 3-3). The  $C_{org}:N$  weight ratio averages about 19, indicating that the organic matter at But-7 contains a high proportion of protein-depleted terrestrial material. The significance of this is that vascular plant debris is less reactive during diagenesis than algal detritus. Thus, the sedimentary oxidant demand at But-7 should be somewhat curtailed despite the relative organic richness of the deposits.

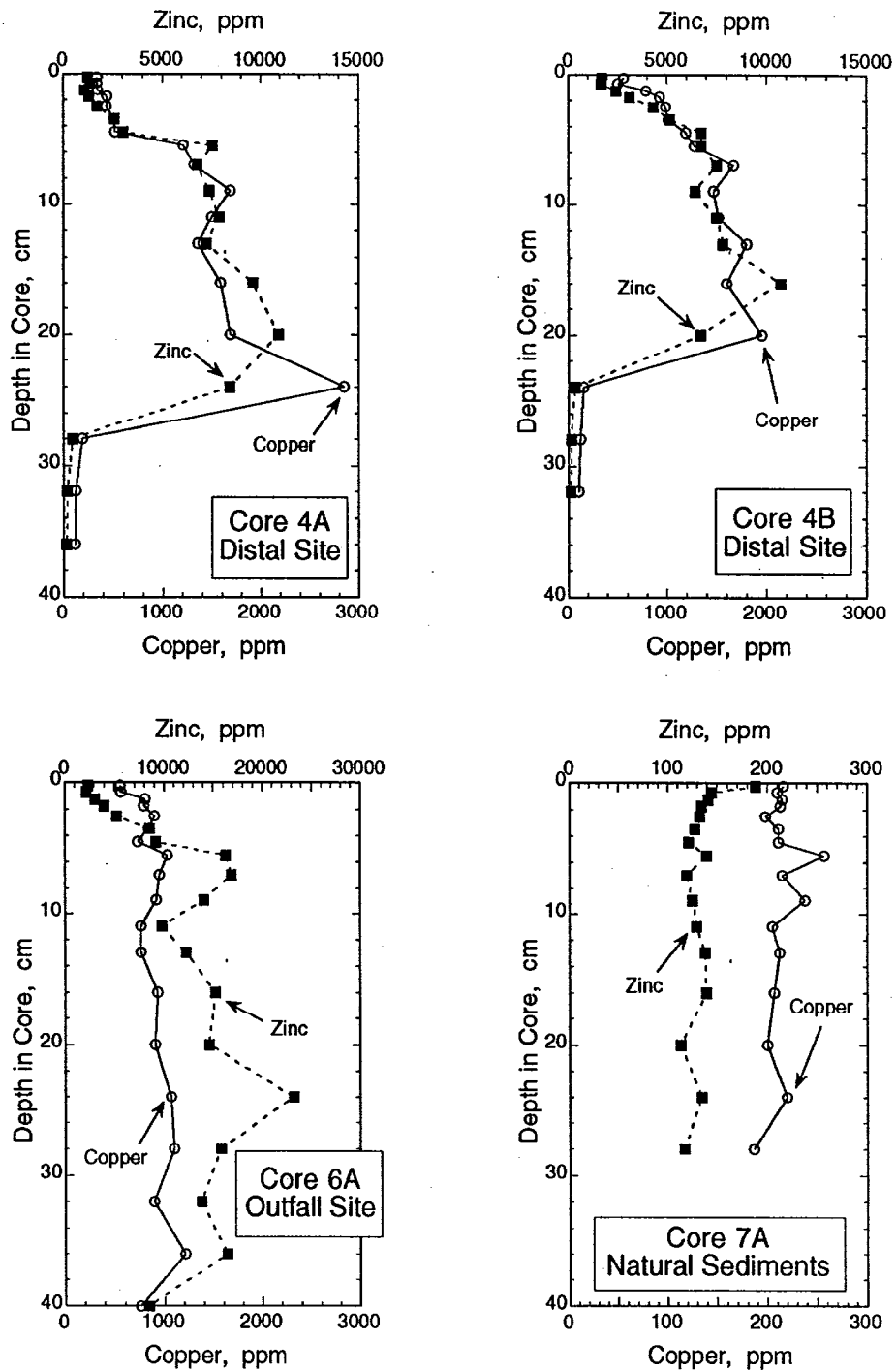
Solid-phase zinc, copper, lead, cadmium, and sulphur profiles in Core-7A suggest that there has been insignificant accumulation of tailings at this site, with the possible exception of the upper two centimetres, where the data are equivocal (Figures 3-4 to 3-6), indicating slight enrichments of Zn and Pb, but not Cu, Cd or S. Fe/Al and Mn/Al weight ratio distributions in the core (Figure 3-7) indicate that near-surface oxide enrichments, which are commonly observed in sediment profiles in lakes (Davison 1993) are essentially absent at But-7. Because iron occurs as a major element in a variety of mineral phases, mineralogic variation in the lithogenic fraction could obscure a minor authigenic Fe-oxide component in the surface deposits, but the same is not true for Mn. Lattice-bound manganese is a minor component in lithogenous detritus, and the presence or absence of Mn oxides is therefore sensitively illustrated by the Mn/Al weight ratio. Profiles from the four cores (Figure 3-7) show that Mn oxide is relatively abundant in the surface sediments at But-4 and But-6, but is scarce at the top of Core-7A.

The deposits collected from But-6 very near the site of the historical tailings outfall in the south basin consist of about 4 cm of organic-rich mostly natural sediments overlying homogeneous and organic-poor tailings. Organic carbon ( $C_{org}$ ) concentrations range from ~5 wt. % in surface deposits to barely detectable in the “pure” tailings below 5 cm (Figure 3-3). The  $C_{org}:N$  weight ratio in the upper few cm ranges from 15-16, implying that a quarter to a third of the organic matter accumulating at this location consists of algal material (assuming a C:N wt. ratio in plankton of 7-8). On this basis, and assuming comparable rates of



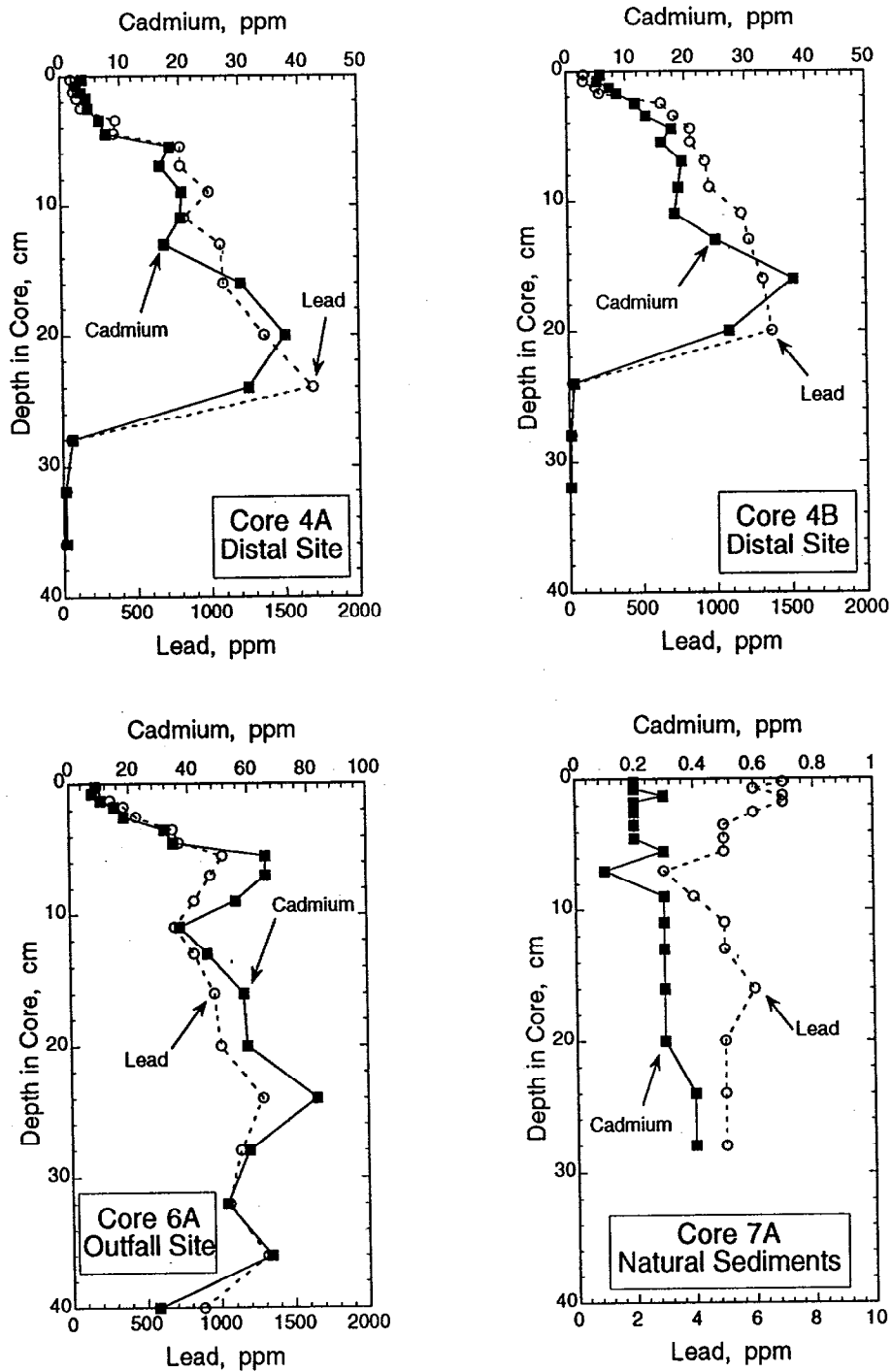
**Figure 3-3: Solid-phase organic carbon and nitrogen profiles in the four cores discussed in this report.**





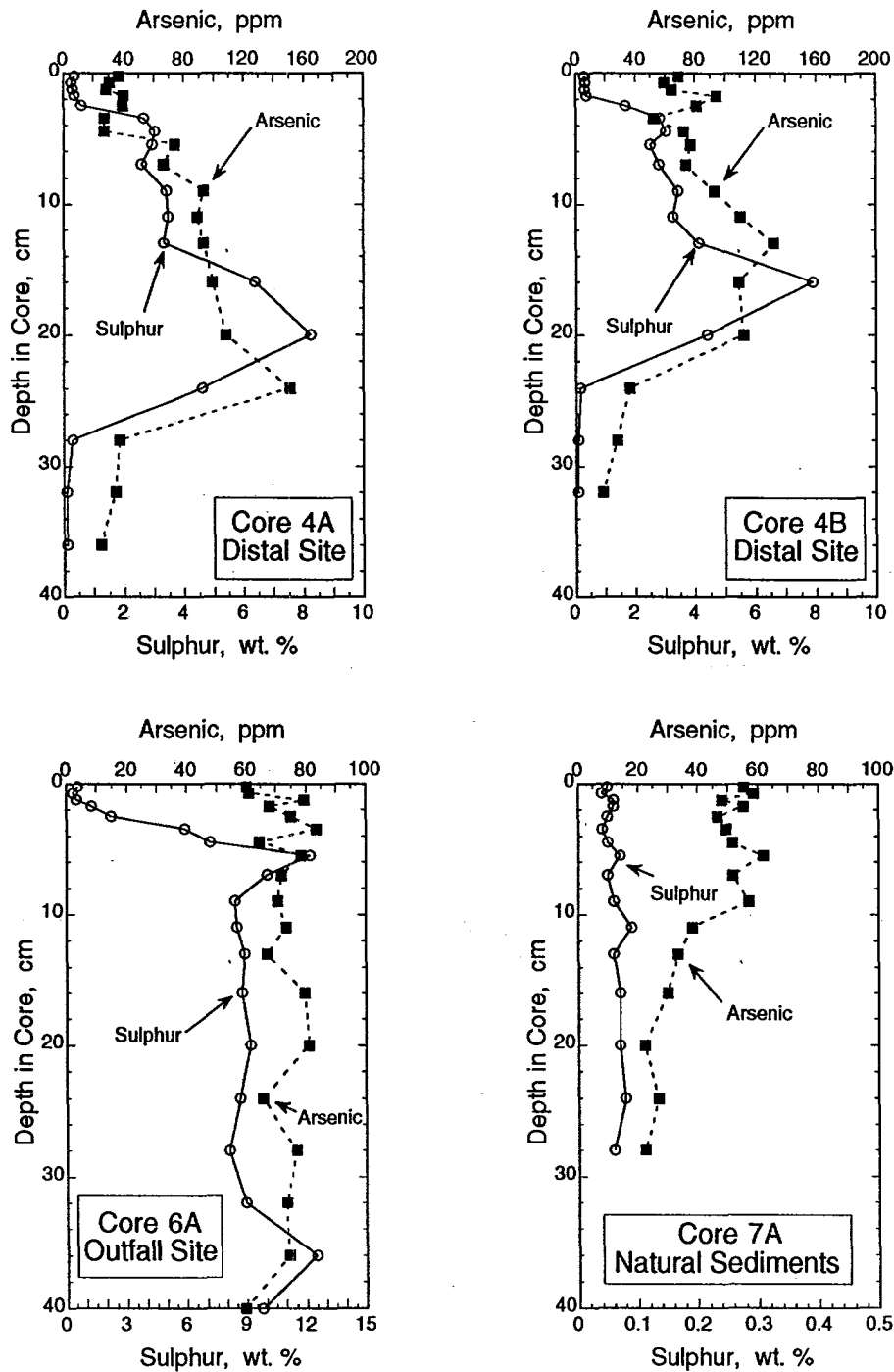
**Figure 3-4: Solid-phase zinc and copper profiles in the four cores discussed in this report.**



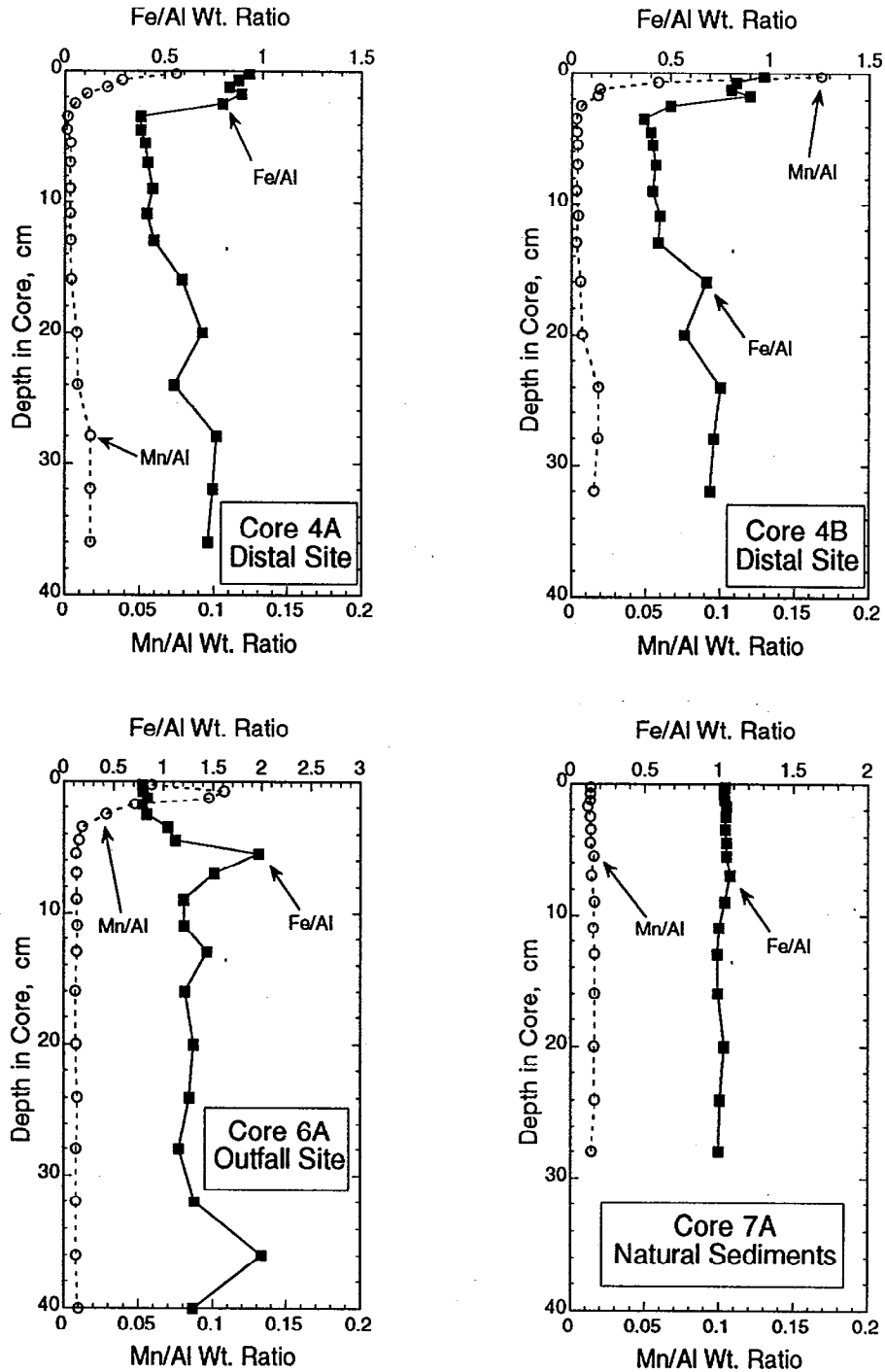


**Figure 3-5: Solid-phase cadmium and lead profiles in the four cores discussed in this report.**





**Figure 3-6: Solid-phase arsenic and sulphur profiles in the four cores discussed in this report.**



**Figure 3-7: Fe/Al and Mn/Al weight ratio distributions in the four cores discussed in this report.**

sedimentation, the sedimentary oxidant demand at But-6 should be somewhat higher than that seen at But-7.

Solid-phase zinc, copper, lead, cadmium, and sulphur profiles in Core-6A (Figures 3-4 to 3-6) chemically define the metal-sulphide rich tailings below 5 cm depth where, for example, Zn concentrations exceed 10,000  $\mu\text{g/g}$  (1 wt. %) and sulphur contents are on the order of 10 wt. %. These levels are very similar to those measured in previous surveys (Pedersen 1983a; Rescan 1990). High Fe/Al ratios below 5 cm depth (Figure 3-7) mark the high pyrite content that is characteristic of the tailings. In contrast, high relative Mn contents occur only in the upper 3 cm (Figure 3-7) of the core, where concentrations reach nearly 1 wt. %. Such high values are attributed to the diagenetic accumulation of Mn oxides in the aerobic zone just below the sediment-water interface, as discussed later in this chapter. Profiles of dissolved iron in interstitial waters indicate that there must be also be an enrichment of Fe oxides in the upper few centimetres, but the high Fe content attributable to other phases, particularly pyrite, makes the oxide fraction difficult to distinguish with the existing data. Visual observations listed in Appendix C, in concert with the Zn, Cu, Pb and Cd data indicate that the surface sediments at this site still contain as much as 15% tailings by weight (somewhat less by volume) which may reflect ongoing bioturbation.

The deposits collected from But-4 about 1 km northeast of the old outfall (Figure 2-2) consist of about 4 cm of organic-rich mostly natural sediments overlying about 20 cm of relatively homogeneous and organic-poor tailings which were deposited onto pre-existing organic-rich sediments. Organic carbon ( $C_{\text{org}}$ ) concentrations range from ~6-7 wt. % at the surface and in the underlying natural sediments in the lower portion of the core, to 0.5-1.0% in the intervening tailings between ~5 and 20 cm depth (Figure 3-3). The  $C_{\text{org}}:\text{N}$  weight ratio in the upper few cm ranges from 16-19, implying that as much as a quarter of the organic matter accumulating at this location consists of algal material. On this basis, and assuming comparable rates of sedimentation, the sedimentary oxidant demand at But-4 should be intermediate between But-7 and But-6.

Solid-phase zinc, copper, lead, cadmium, and sulphur profiles in Core-4A and -4B (Figures 3-4 to 3-6) define the tailings chemically between 5 and 20 cm depth. Zn concentrations in the tailings at this “distal” site reach as high as 1 wt. % and sulphur contents as high as 8 wt. %, substantially higher than in the natural deposits. Despite



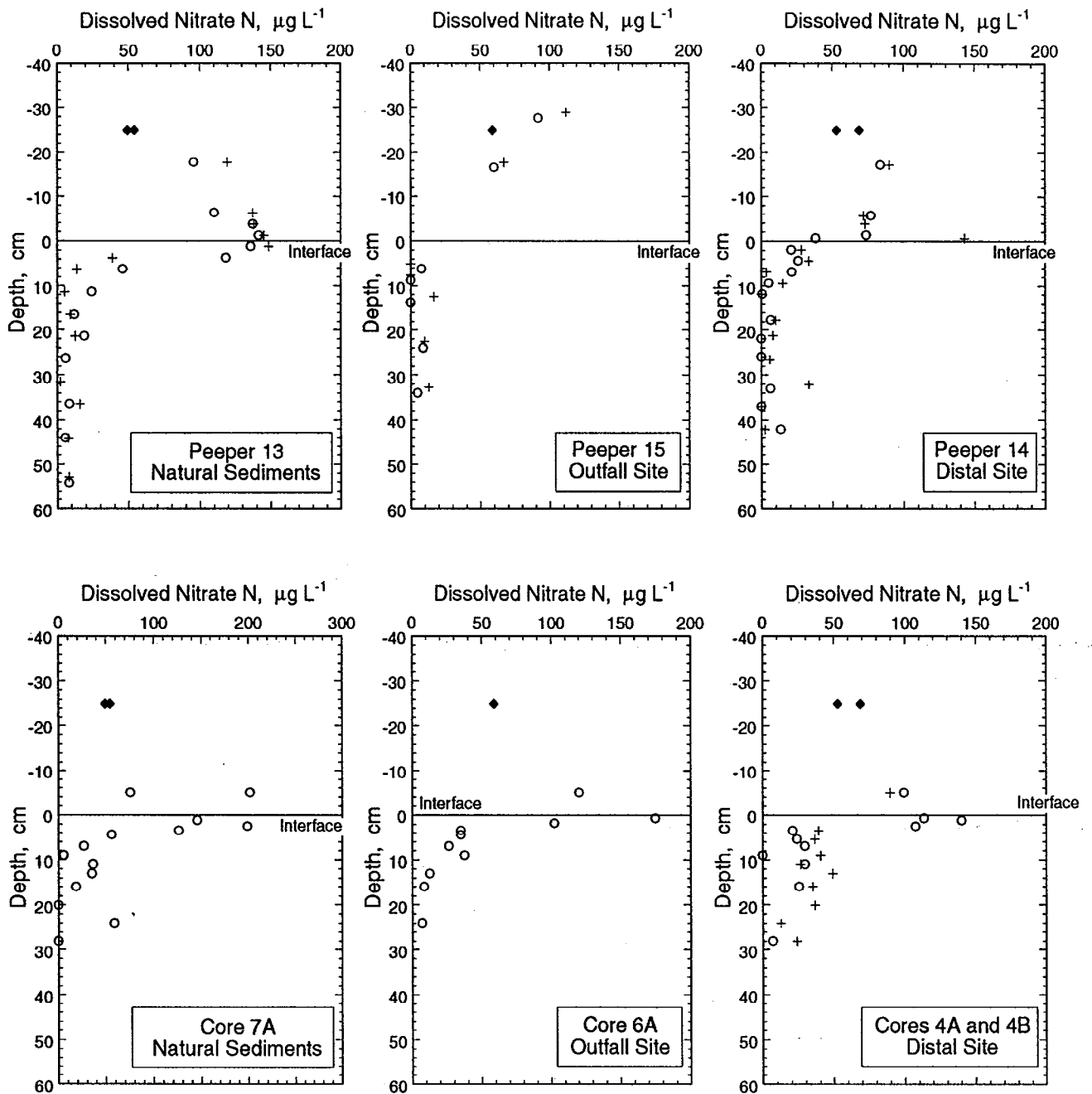
the presence of abundant pyrite in the tailings at this location, the Fe/Al ratio profiles in the two cores show lower values in the tailings stratum than in the natural deposits that sandwich it (Figure 3-7), indicating either that Fe oxides are abundant both above and below the buried tailings, or that the natural sediments contain a relatively high concentration of iron-bearing detrital minerals. As discussed below, pore water iron distributions suggest that the former explanation is the most likely. Manganese concentrations in the near-surface sediments from both cores are very high, ranging up to 1.3 wt. % in the upper 5 mm of Core-4B. These high values are matched by high Mn/Al ratios (Figure 3-7), and indicate that manganese oxides are abundant in the deposits now accumulating on top of the tailings at this site. Slight increases in the Mn/Al ratio and higher absolute Mn levels below the tailings, *i.e.* below ~20 cm (Figure 3-7) suggest that a residual manganese oxide phase is present in these buried natural deposits. Arsenic is enriched in both the tailings and the near-surface oxide-rich deposits at the outfall and distal sites (Figure 3-6). At the natural sediments location, slightly lower As concentrations are observed in the upper 10 cm. These levels (~50-60  $\mu\text{g/g}$ ) are relatively high compared to pristine lake sediments elsewhere (*e.g.* Azcue 1993).

### **3.3 Interstitial Waters**

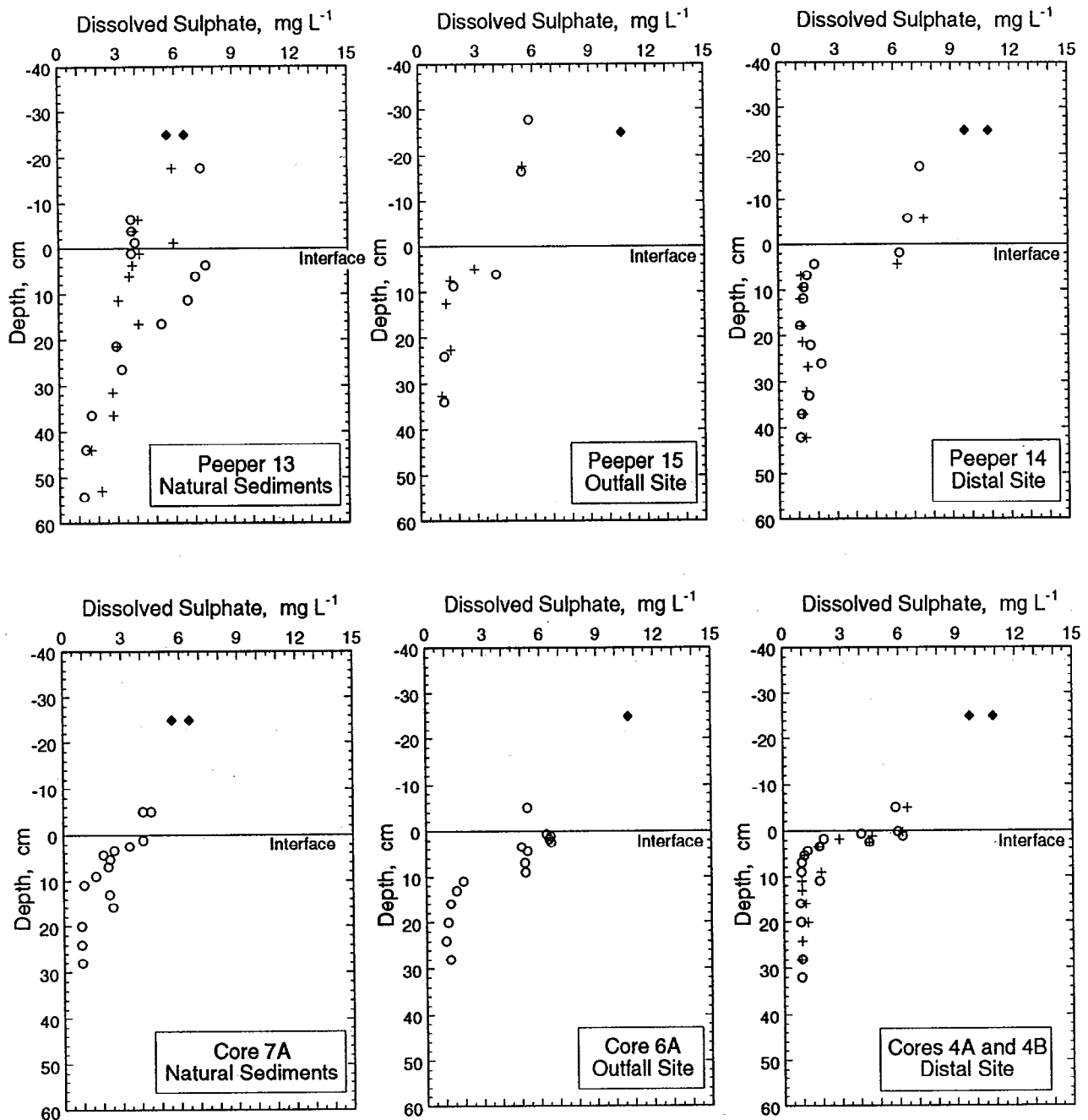
Pore water samples from the three cores from the natural sediments and the tailings sites, and dialysis-array samples from sets of peepers emplaced at all three sampling locations were analyzed for sulphate, nitrate,  $\Sigma\text{H}_2\text{S}$  and a suite of dissolved metals, including Fe, Mn, Zn, 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. pH measurements were also made on a number of the samples. The methods employed for all pore water analytical work are described in Section 2.2, and all results are listed in Appendix B.

#### *Nitrate, Sulphate and Sulphide Distributions*

Dissolved  $\text{NO}_3^-$  and  $\text{SO}_4^{2-}$  profiles from the Rescan peepers emplaced at each site and from the quartet of cores are shown in Figures 3-8 and 3-9. The nitrate data show some scatter, which primarily reflects imprecision inherent in analyzing relatively low concentrations in small samples. Nevertheless, a clear pattern is



**Figure 3-8: Dissolved nitrate in interstitial waters at the three sites sampled in this study. Left and right columns of cells in the tandem peepers (upper panels) are represented respectively by circles and crosses. Circles and crosses respectively delineate Core-4A and -4B. The filled diamonds in each panel represent the  $\text{NO}_3^-$  concentration measured in the deepest samples collected from the water column at the three locations.**



**Figure 3-9: Dissolved sulphate in interstitial waters at the three sites sampled in this study. Left and right columns of cells in the tandem peepers (upper panels) are represented respectively by circles and crosses. Circles and crosses respectively delineate Core-4A and -4B. The filled diamonds in each panel represent the  $\text{SO}_4^{2-}$  concentration measured in the deepest samples collected from the water column at the three locations.**

evident in the data. At all three sites, nitrate contents in the peeper pore waters decrease rapidly below the interface (Figure 3-8) and reach zero or near-zero levels at depths ranging from ~10-20 cm in the natural sediments (But-7), ~5-10 cm at the outfall site (But-6), and roughly 10 cm at the distal site (But-4). Reproducibility of the profiles at each site is very good, based on the similarity of the results from the two columns of cells in each peeper. Samples collected from the emerged peeper cells (*i.e.*, those above the interface) yield values generally comparable to those measured in Go-Flo bottle samples collected below the thermocline. The profiles obtained using the pore waters centrifuged from core subsamples are similar to the peeper results, in that nitrate contents exhibit the same general decline with sub-bottom depth. The data from duplicate cores 4A and 4B also agree reasonably well.

Nitrate is used by denitrifying bacteria as an electron acceptor during the degradation of organic matter in sediments, once aerobes have consumed most of the oxygen. The rapid sub-bottom decline in  $\text{NO}_3^-$  seen at the three sites in this study thus implies that the aerobic zone is confined to the upper 2 to 4 cm (or possibly less). Aerobic degradation of organic matter (thus, the presence of molecular  $\text{O}_2$ ) at or just below the interface is indicated by the nitrate enrichments seen in the upper 1 or 2 cm at the natural sediments and outfall sites (Figure 3-8). Furthermore, the data suggest that oxygen from bottom water does not penetrate more than about 3 cm into the deposits.

The dissolved sulphate profiles confirm the interpretation of the nitrate data. Steep subsurface declines are witnessed at the south basin sites, in particular at But-4 (Peeper-14 and Core-4A and -4B; Figure 3-9). The peeper data indicate that sulphate is being used as an oxidant below about 3 cm depth at the distal site, below ~5 cm depth at the outfall site, and below roughly 15 cm at the natural sediments site north of the narrows. These distributions imply that the benthic oxidant demand at the natural sediments site is less than that at either of the locations sampled in the south basin. Presumably, this reflects a lower rate of accumulation of reactive (particularly algal) organic matter at But-7, which is consistent with the solid-phase Fe and Mn data discussed earlier.

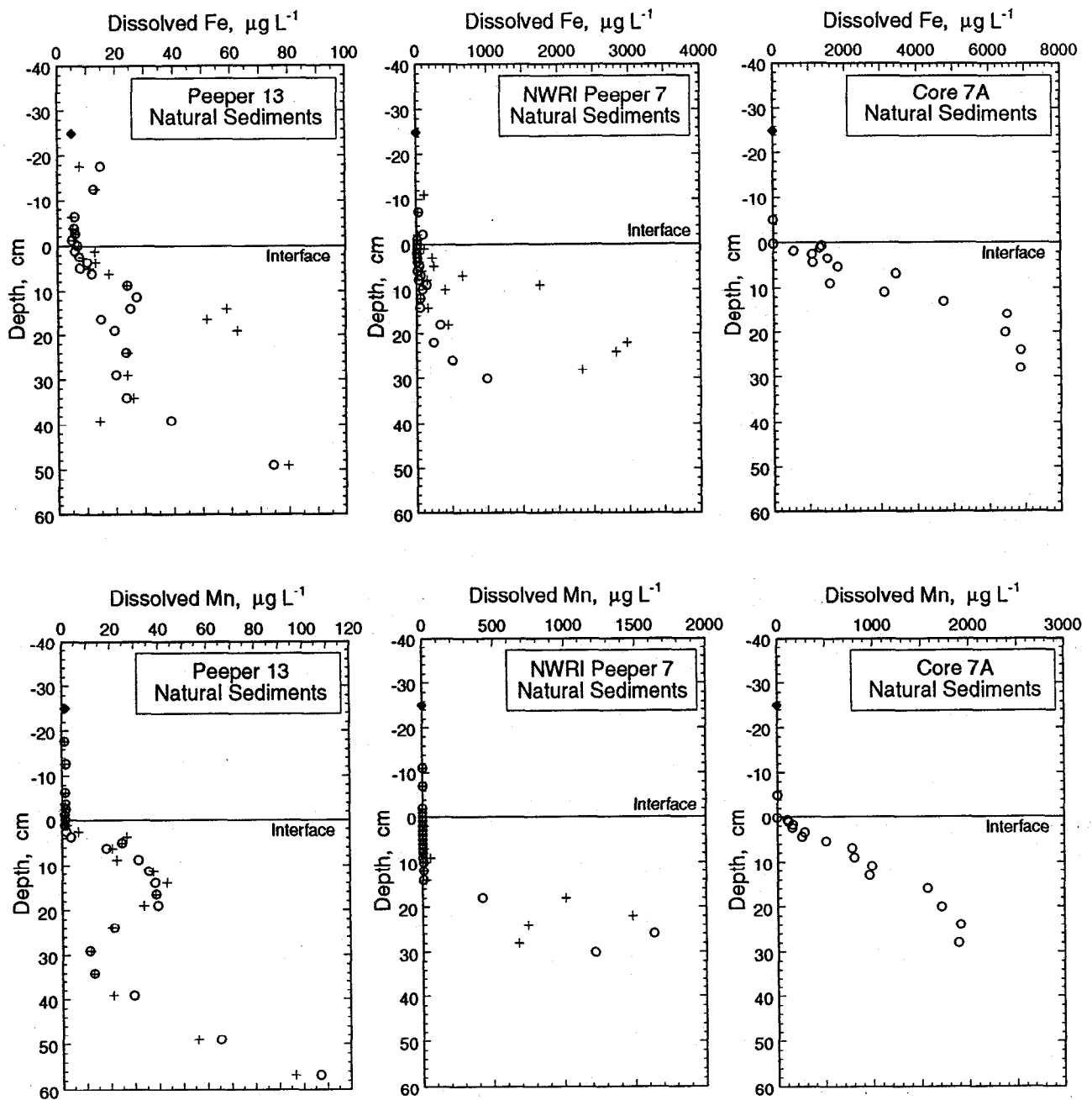
Dissolved sulphide species were universally undetectable ( $<40 \mu\text{g/L}$ ) in the peeper and core samples analyzed, which reflects ongoing precipitation of authigenic solid-phase sulphide species, presumably FeS and  $\text{FeS}_2$ . As will become evident below,

lack of dissolved iron is not limiting precipitation of sulphide minerals in Buttle Lake sediments, but the relative lack of sulphate almost certainly is.

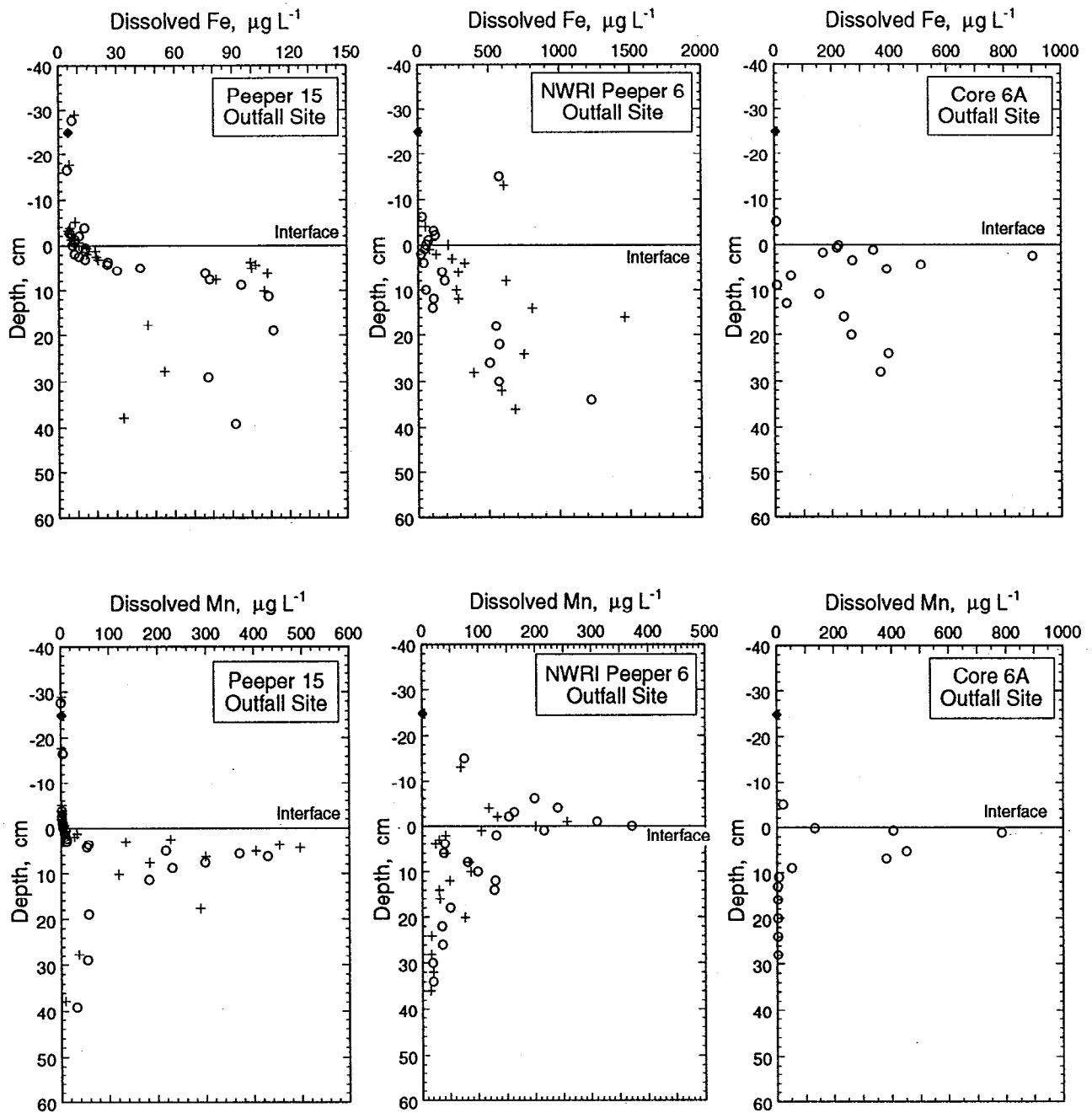
### *Dissolved Iron and Manganese Distributions*

#### *Sampling Problems*

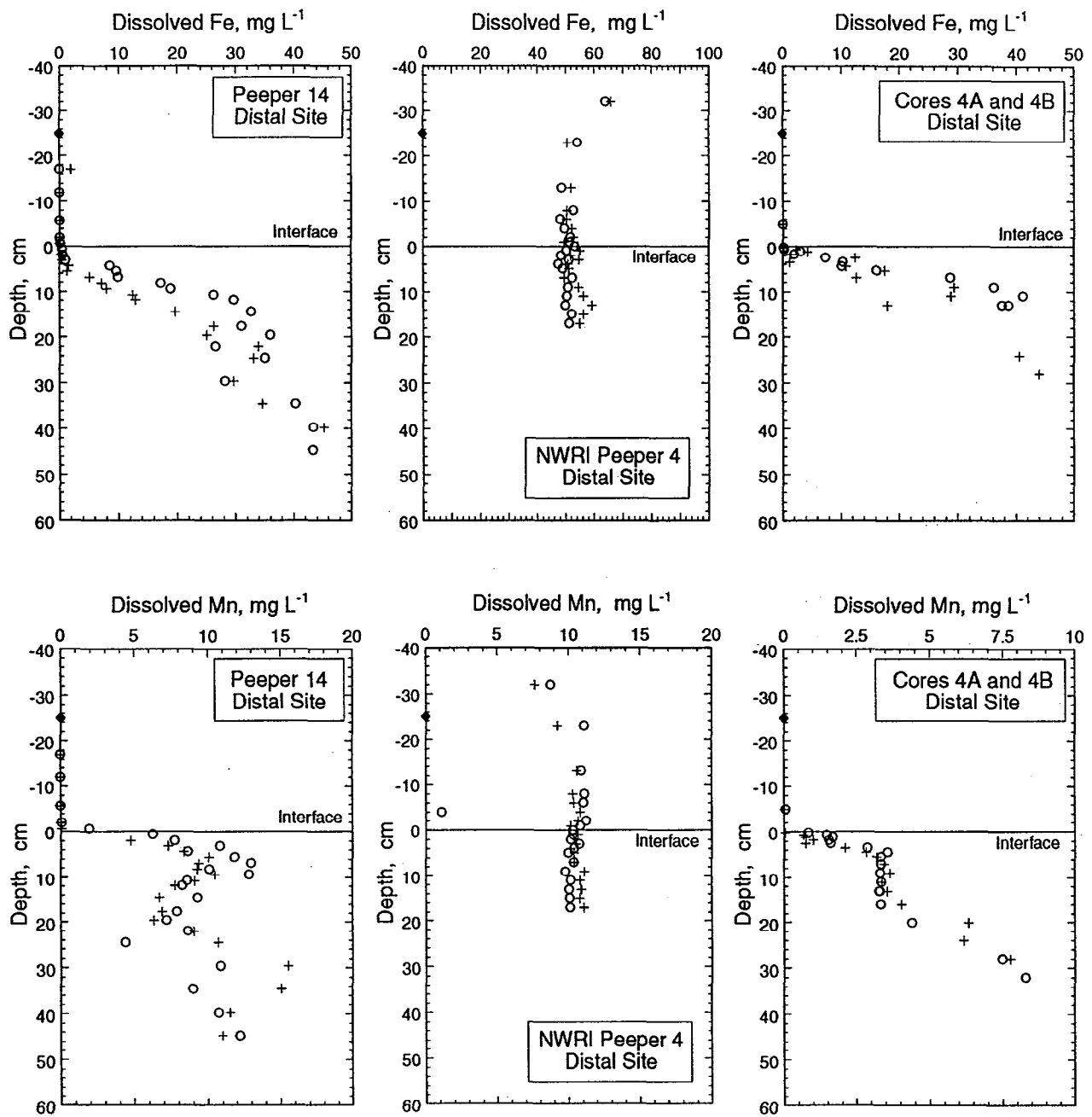
Although Fe and Mn profiles obtained from parallel columns of cells in the tandem Rescan peepers agree well at all sites, agreement with the data retrieved from the cores varies from being comparable at the distal tailings site to poor at the outfall station and negligible at the natural sediments site (Figures 3-10 to 3-12). Agreement between the Rescan and NWRI peeper profiles is similarly poor. There may be a number of reasons for these contrasts, including lateral heterogeneity in the deposits, problems with peeper emplacement, and compression effects induced by coring. The profound contrasts between the Rescan peeper Fe and Mn data and the core profiles from But-7 extends to other element distributions, as discussed below. There are two possible explanations for these differences which are not seen in the dissolved metals data from the other sites. The first (and we believe the most likely) is that the Rescan peeper and the core sampled different sedimentary facies. Dissolved Fe and Mn levels in the profile from Core-7A reach ~7,000  $\mu\text{g/L}$  and 2,000  $\mu\text{g/L}$ , respectively, one to two orders of magnitude higher than the maxima seen in the duplicate profiles from Peeper-13 (Figure 3-10). The very high levels in the core suggest that these deposits contained a significant proportion of Fe (and Mn) oxides which were (and are continuing to be) solubilized during burial, adding high concentrations of the metals to the pore waters. Solubilization at depth is also indicated by the profiles from Peeper-13, but the levels observed are very low, implying a paucity of oxides in the sediments penetrated by the array. The topography of the slope in the area of But-7 is uneven, and as the sites were located by visual triangulation rather than rigorous surveying, it is possible that the core was raised from a slightly different sedimentary facies. A second explanation, which we believe is much less likely than the first, is that the centrifugation and 0.2  $\mu\text{m}$  filtering procedure used to extract pore waters from Core-7A failed to remove some colloidal Fe and Mn from the samples. Although a 0.2  $\mu\text{m}$  pore diameter is normally sufficient to retain colloids during filtration of lacustrine pore waters (Carignan *et al.* 1985), it may be that some Fe and Mn-bearing colloids passed the 0.2  $\mu\text{m}$  filters used in this study.



**Figure 3-10: Dissolved iron and manganese profiles in interstitial waters at the natural sediments site. Left and right columns of cells in the tandem peepers (upper panels) are represented respectively by circles and crosses. The filled diamonds in each panel represent the concentrations measured in the deepest samples collected from the water column at this locations. Note the different scales on the abscissae.**



**Figure 3-11: Dissolved iron and manganese profiles in interstitial waters at the outfall site (But-6) in the South Basin. Left and right columns of cells in the tandem peepers (upper panels) are represented respectively by circles and crosses. The filled diamonds in each panel represent the concentrations measured in the deepest samples collected from the water column at this locations. Note the different scales on the abscissae.**



**Figure 3-12: Dissolved iron and manganese profiles in interstitial waters at the distal sediments site (But-4) in the South Basin. Left and right columns of cells in the tandem peepers (upper panels), and Core-4A and -4B (lower right) are represented respectively by circles and crosses. The filled diamonds in each panel represent the concentrations measured in the deepest samples collected from the water column at this locations. Note the different scales on the abscissae.**



Dissolved iron concentrations at the outfall site are also higher in the core pore waters than in the corresponding Rescan peeper (Figure 3-11) although the difference is smaller than that seen in the natural sediments. At the distal site, the levels observed in both are similar, as well as being very high. However, the Fe profiles obtained from the core at But-4 (Figure 3-12) are steeper than those from the Rescan peeper, and this may reflect some core compression or shortening. Shortening can occur during gravity coring (Lebel *et al.* 1982; Crusius and Anderson 1991), but the extent is very sensitive to the diameter of the core barrel used and the type of corer employed. The 8 cm I.D. core barrel and the open-valved corer used in this study should have resulted in minimal or no compression (perhaps 5-10 cm in a 60 cm core), as predicted by the Hvorslev criteria (Hvorslev 1949), yet the steepness of the Fe and Mn core profiles compared to the Rescan peeper results shown in Figure 3-12 imply that some compression might have occurred. The Hvorslev criteria assume homogeneous sediments, and it is possible that the alternation between natural sediments and much denser tailings at But-4 confounded the minimal compression behaviour expected with the 8 cm I.D. barrels. Indeed, core shortening has been reported to increase when more compact sediment is encountered during penetration, giving rise to what has been determined “lateral thinning” (Blomqvist 1991; Cumming *et al.* 1993).

The Fe and Mn profiles from the NWRI peepers differ from those in both the cores and the Rescan tandem peepers at three sites. There is no obvious explanation for this at But-7, but lateral inhomogeneity might have contributed to the contrast, as suggested above. Any traces of oxygen present in the plexiglass of the NWRI peepers at the time of emplacement could also have augmented the true iron content, as noted by Carignan *et al.* (1994), and discussed in the methods section earlier (Section 2). The occurrence of relatively high dissolved Mn concentrations immediately above the indicated interface (*i.e.*, in the bottom water) in the NWRI peeper at But-6 is troubling (Figure 3-11), and implies that the interface was either mislocated or that the peeper emerged by about 10 cm shortly before retrieval. The results from the NWRI peeper emplaced at But-4 show exceptionally high dissolved Mn and Fe concentrations above the apparent interface, which is impossible. These data imply that the free-standing peeper may have “fallen over” during the two-week equilibration period. As a result of the apparent artifacts in the samples from NWRI Peeper-4 and -6, none of the data from either array will be considered further in this report. The deoxygenated Rescan peepers were held fixed on the bottom in

aluminum frames at all three sites, and since they are not subject to possible compression artifacts and are unlikely to have been affected by diffusion of colloids into the cells, they are believed to have yielded the most representative pore water data collected during the study. This assumption appears to be reasonable and, as noted below, it is generally supported by the spectrum of data collected from the companion cores, with the exception of the results from the natural sediments site (But-7). Most of the interpretative weight in the remainder of the report will be placed on the results from the Rescan peepers.

### *Iron and Manganese Diagenesis and the Redox State of the Sediments*

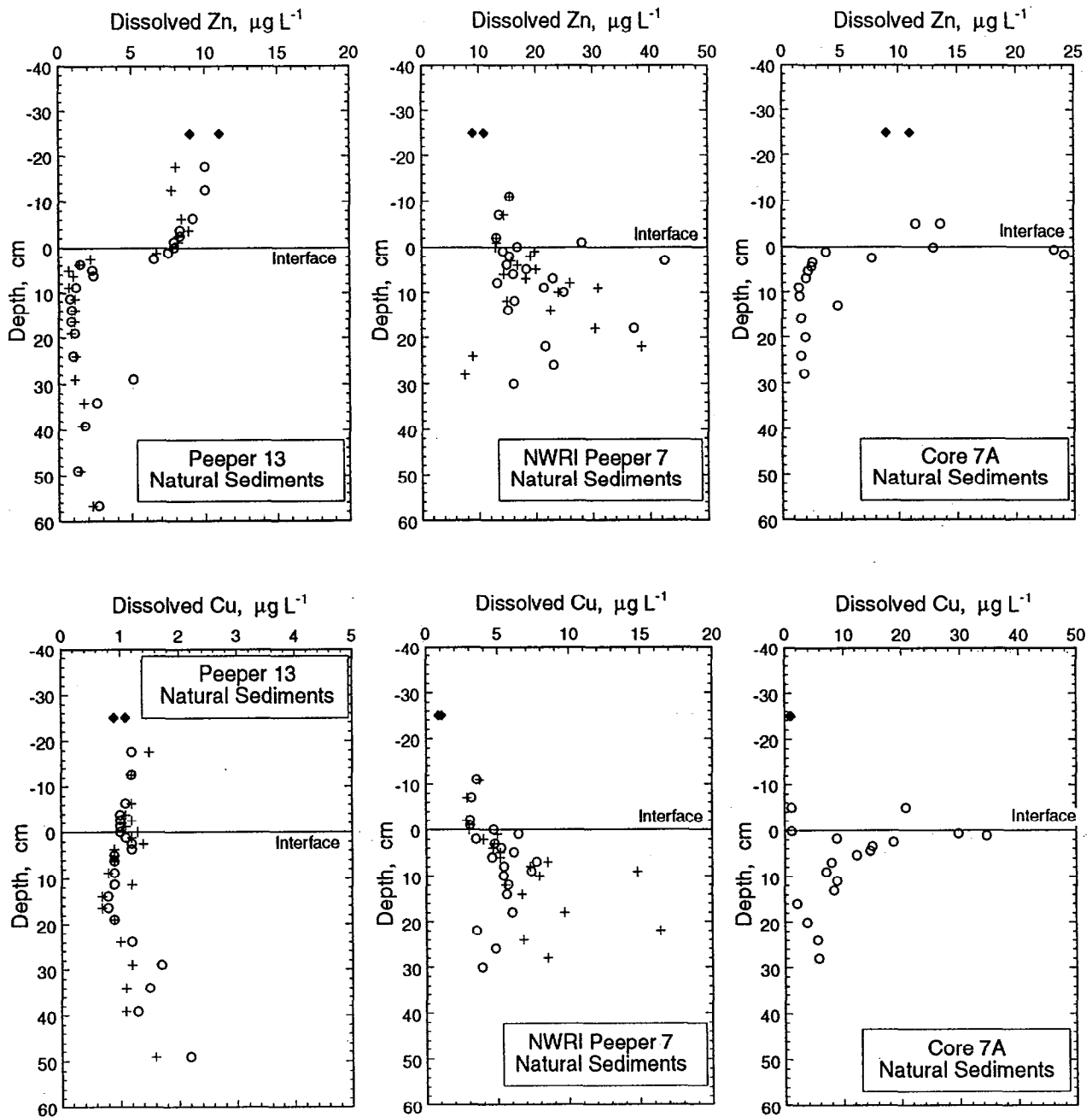
One of the principal objectives of this study was to assess the role of post-depositional cycling of the oxides in influencing the mobility of Zn, Cu, Cd, Pb, As and Hg. The Fe and Mn results from the Rescan peepers, in conjunction with the nitrate and sulphate data, show that the aerobic zone is thin at all three stations, and that accumulation of oxides must be confined to the upper 2 cm at both the outfall and the distal sites. During early diagenesis in sediments, manganese oxides are reduced at about the same redox potential as nitrate, but at a higher potential and thus a shallower depth than iron oxide phases (Froelich *et al.* 1979). This behaviour is illustrated by the slightly shallower manganese concentration maxima in the profiles, relative to dissolved iron, at both of the south basin sites (Figures 3-11 and 3-12). Similar results were seen in 1989 (Rescan 1990) and confirm that the south basin sediments are dysaerobic (essentially oxygen-free) below about 2 cm depth. Solid-phase oxides are actively cycling in these deposits; solution during burial is clearly supporting upward diffusion of dissolved Mn and Fe, and upon encountering molecular O<sub>2</sub>, these species are reprecipitating near the sediment-water interface, as illustrated by the high solid-phase Mn/Al ratios in the upper 1-1.5 cm of the south basin cores (Figure 3-7). Although there is little indication in the Fe/Al and Mn/Al ratio solid-phase data that significant concentrations of oxides are accumulating in the surface deposits at the natural sediments site, visual observations (orange-brown colouration; Appendix C) suggest that an oxide fraction, albeit minor, is present in the upper few millimetres or so, and this is consistent with the cycling indicated by the pore water Fe and Mn profiles from Core-7A (Figure 3-10). As noted earlier, the results from Core-7A indicate substantial release of manganese and iron to pore solution below depths of 12 to 15 cm. If oxide dissolution deeper in the core is the source of these enrichments, then the profiles are inconsistent with steady-state

depositional conditions given that anoxic conditions prevail today at a very shallow depth. The implied upward fluxes should be supporting ingrowth of Fe and Mn oxide phases in the surface deposits, but these are not seen in the solid-phase ratio profiles (Figure 3-7). Given the limited nature of the available data, the source of these deep enrichments cannot be determined. One possibility that cannot be ruled out is that groundwater is supplying dissolved Fe and Mn to the sediment column from below at But-7, but we are unable to confirm this.

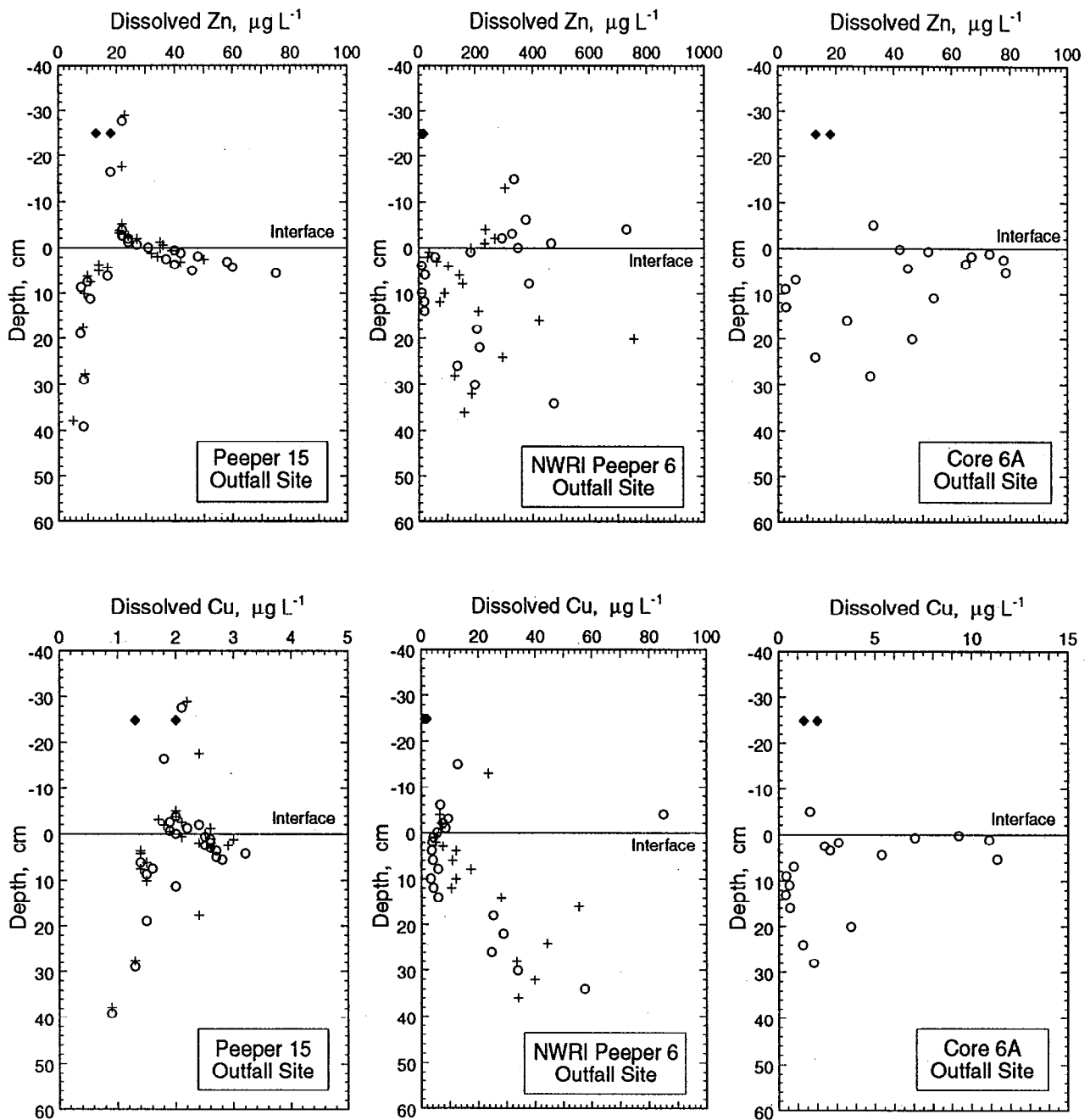
### *Behaviour of Dissolved Zinc*

The dissolved Zn concentration decreases sharply between 3 and 4 cm depth in the duplicate Rescan peeper profiles in the natural sediments (Figure 3-13), indicating that zinc is diffusing into these deposits from bottom water and being precipitated *in situ*, presumably as an authigenic sulphide. Such behaviour has been observed previously in Canadian Shield lakes (Carignan and Tessier 1985) and may be a common phenomenon. Scatter in the three near-surface samples between 0.5 and 2.0 cm depth in the core collected at the same site suggests that there may be a contamination problem, and the principle of “oceanographic consistency” is violated by the sharp single-point spikes at 0.75 and 1.75 cm depth which bracket a minimum at 1.25 cm (Figure 3-13, upper right). This scatter precludes confirmation of the influx indicated by the peeper data; below this interval, however, a sink is firmly suggested.

The results from the south basin sediments indicate that zinc is behaving in a significantly different way where oxide-rich deposits are accumulating on top of the tailings. The duplicate peeper profiles at the outfall site, and to a lesser degree the core data, show that zinc is being released to the interstitial waters between about 1 and 5 cm depth (Figure 3-14), and consumed in the immediately underlying tailings. The maxima in the left and right banks of peeper cells respectively occur at ~3 and ~5.5 cm and are spatially indistinguishable from the six- to ten-fold higher dissolved manganese maxima in the same cell banks (compare the upper left panel in Figure 3-14 with the lower left in Figure 3-11). Iron and zinc maxima are similar in absolute concentration but the iron peaks occur at slightly greater depths (Figure 3-11). The very close correspondence between the zinc and manganese distributions, which is also implied by the core pore water data, suggests that solubilization of Mn oxides during progressive



**Figure 3-13: Dissolved zinc and copper profiles in interstitial waters at the natural sediments site (But-7). Left and right columns of cells in the tandem peepers (upper panels) are represented respectively by circles and crosses. The filled diamonds in each panel represent the concentrations measured in the deepest samples collected from the water column at this location. Note the different scales on the abscissae.**

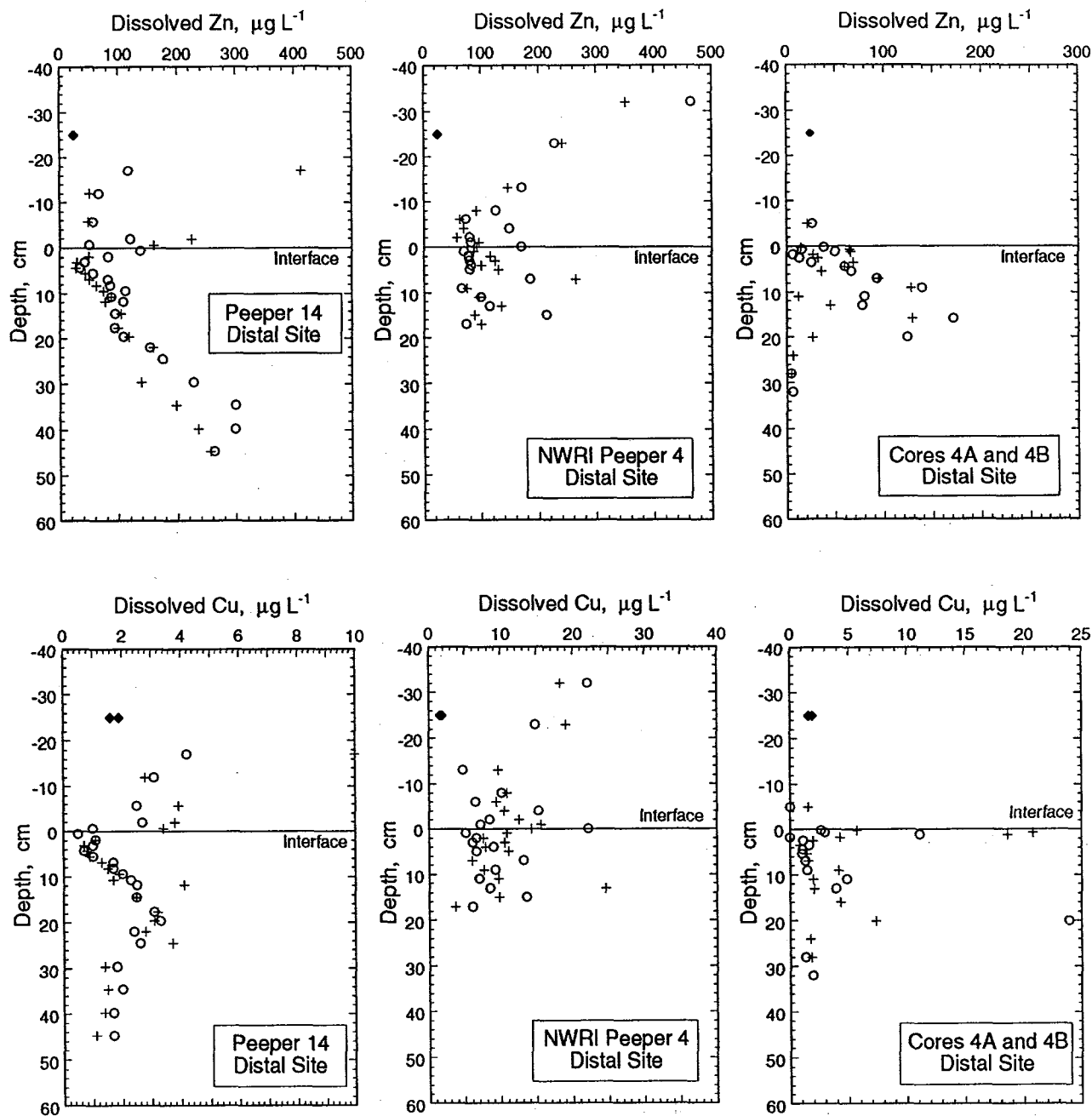


**Figure 3-14: Dissolved zinc and copper profiles in interstitial waters at the outfall site (But-6) in the South Basin. Left and right columns of cells in the tandem peepers (upper panels) are represented respectively by circles and crosses. The filled diamonds in each panel represent the concentrations measured in the deepest samples collected from the water column at this locations. Note the different scales on the abscissae.**

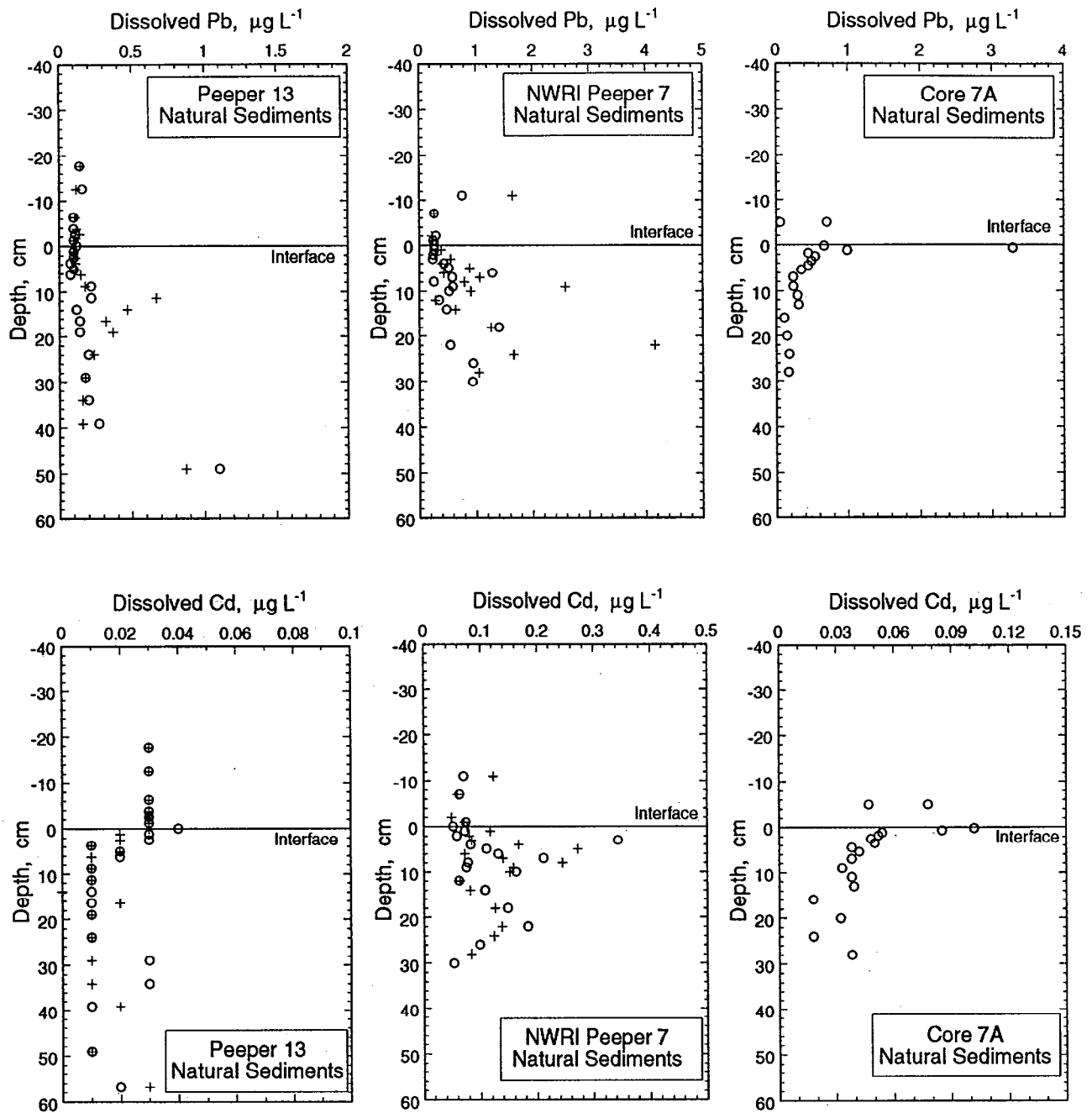
burial exerts a principal control on the post-depositional behaviour of zinc at the outfall site. Iron oxides appear to be less important. Zinc is presumably being precipitated at depths greater than ~8-10 cm at this location as an authigenic sulphide, which is consistent with the sulphate profile. The nature of the sink indicated for manganese at depth is unknown.

Dissolved zinc profiles from the distal site (But-4) have a fundamentally different character (Figure 3-15); concentrations in Peeper-14 increase generally with depth, reaching ~300  $\mu\text{g/L}$  below ~30 cm, several fold higher than the maxima seen at the outfall station. Unlike the other two sites, some scatter is evident in the concentrations measured just above the interface. Similar scatter is seen in the Cu, Pb and Cd results, which may reflect slight contamination by particles introduced during sampling of the peeper cells. The scatter makes it difficult to define the near-interface behaviour of zinc. There is no clear evidence in the top 2 cm of an efflux, although this cannot be conclusively ruled out; nor is there evidence for consumption of Zn from pore water onto, for example, freshly precipitating oxides. However, Cu, Pb and Cd show small deficits in the pore waters in the top few cm at this site relative to bottom waters and/or slightly deeper pore waters (Figures 3-13 to 3-18), implying consumption from solution. By analogy to these three metals, the scatter in the zinc data near the interface in Peeper-14 may be disguising minor uptake.

Between 5 and 20 cm depth, the dissolved zinc concentration increases steadily in both the peeper and the cores (Figure 3-15) to values of about 150  $\mu\text{g/L}$ . Below this horizon, the concentration of the metal decreases markedly in the cores, but continues to rise in the peeper. The sharp decline in the core profiles occurs approximately at the tailings/natural sediment boundary, and can be attributed to precipitation of zinc in the basal organic-rich deposits (Figure 3-3). By contrast, there is no ready explanation for the high dissolved Zn levels seen below 20 cm in both the peeper profiles. If the peeper did not penetrate natural sediments, then the high Zn values might represent Zn release from the more deeply buried tailings. No such release is seen in the peeper profile in the rapidly deposited “pure tailings” at the outfall site, nor was such an addition to pore water seen in the rapidly accumulating tailings in either of the previous coring surveys (Pedersen 1983; Rescan 1990). However, release of zinc to pore solution in the slowly accumulating distal tailings facies remains a possibility. Alternatively, some of the



**Figure 3-15: Dissolved zinc and copper profiles in interstitial waters at the distal sediments site (But-4) in the South Basin. Left and right columns of cells in the tandem peepers (upper panels), and Core-4A and-4B (lower right) are represented respectively by circles and crosses. The filled diamonds in each panel represent the concentrations measured in the deepest samples collected from the water column at this locations. Note the different scales on the abscissae. A high copper concentration at 16 cm depth in Core-4A ( $52 \mu\text{g L}^{-1}$ ) is not shown.**



**Figure 3-16: Dissolved lead and cadmium profiles in interstitial waters at the natural sediments site (But-7). Left and right columns of cells in the tandem peepers (upper panels) are represented respectively by circles and crosses. The filled diamonds in each panel represent the concentrations measured in the deepest samples collected from the water column at this locations. Note the different scales on the abscissae. High lead concentrations at 57 cm depth in both cell banks in Peeper-13 (8 and 5 µg L<sup>-1</sup>) are not shown.**



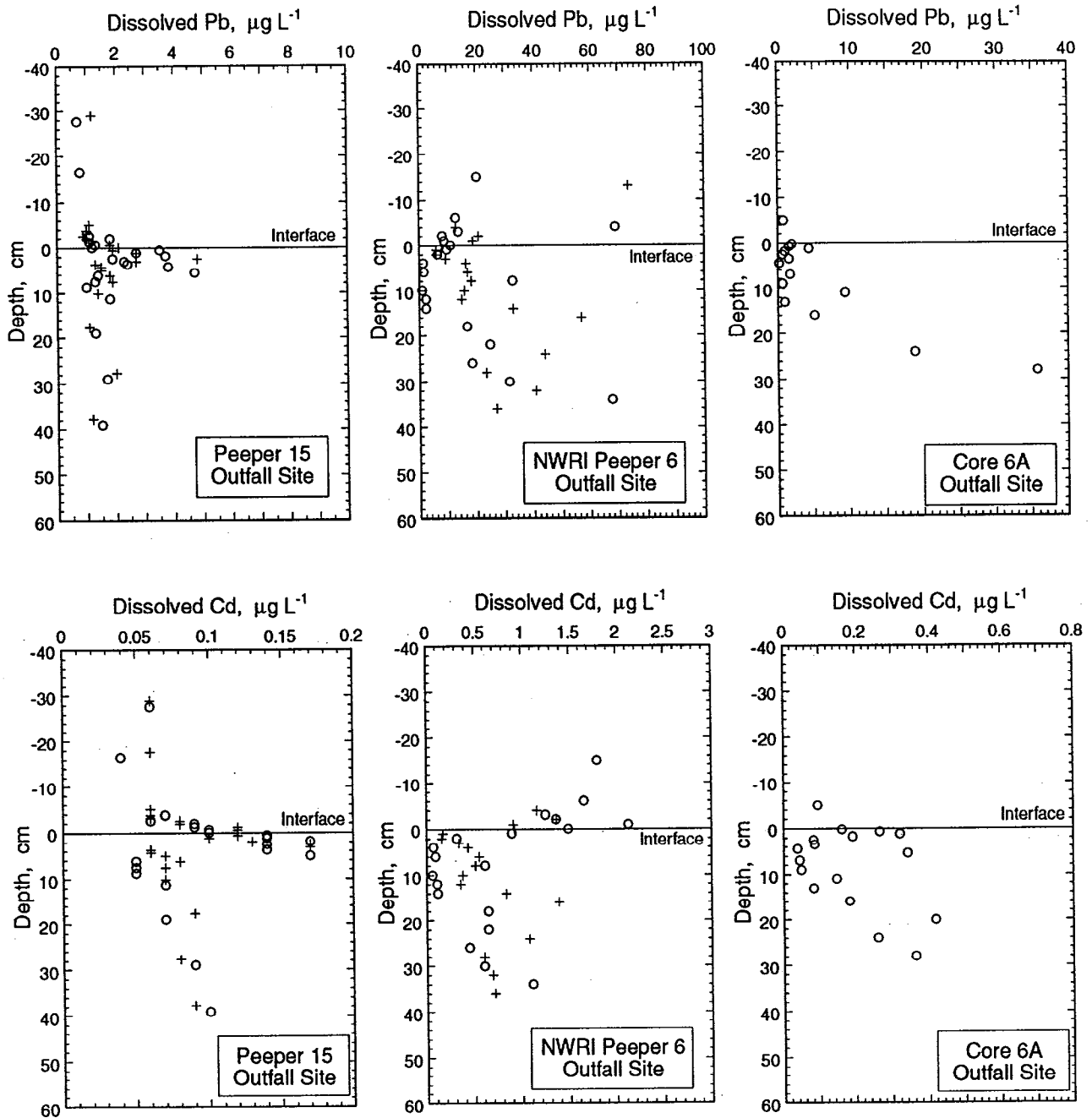
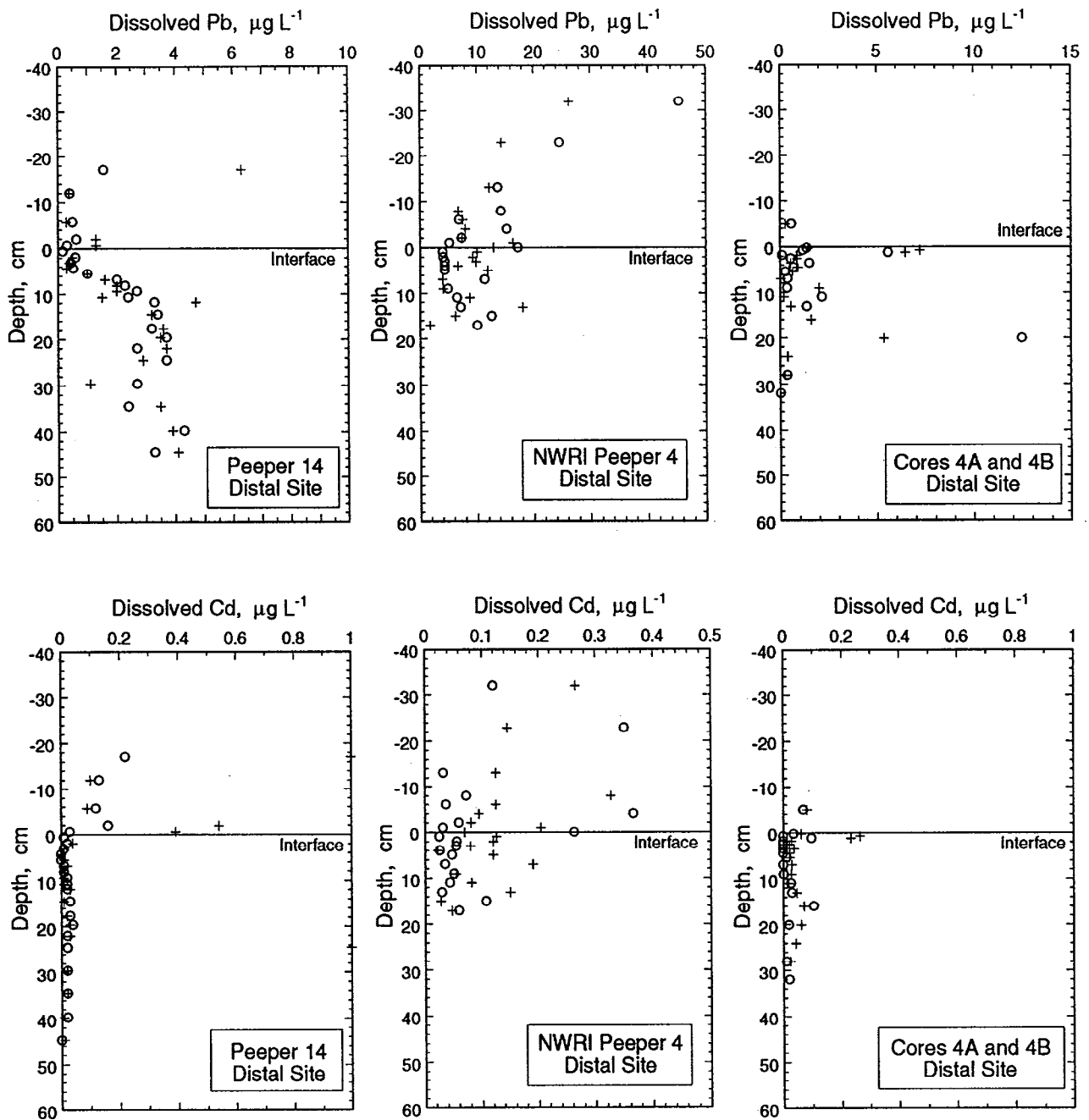


Figure 3-17: Dissolved lead and cadmium profiles in interstitial waters at the outfall site (But-6) in the South Basin. Left and right columns of cells in the tandem peepers (upper panels) are represented respectively by circles and crosses. Lead and cadmium were not detected ( $<0.5$  and  $<0.2$   $\mu\text{g L}^{-1}$  respectively) in the deepest samples collected from the water column at this location. Note the different scales on the abscissae. High lead concentrations at -3.8 and 5 cm depth (17 and 34  $\mu\text{g L}^{-1}$ ) in Peeper-15L, at -17.6 and 1.9 cm depth (117 and 44  $\mu\text{g L}^{-1}$ ) in Peeper-15R, and at 20 cm in Core-6A (41  $\mu\text{g L}^{-1}$ ) are not shown.



**Figure 3-18: Dissolved lead and cadmium profiles in interstitial waters at the distal site (But-6) in the South Basin. Left and right columns of cells in the tandem peepers (upper panels), and Core-4A and -4B are represented respectively by circles and crosses. Lead and cadmium were not detected ( $<0.5$  and  $<0.2 \mu\text{g L}^{-1}$  respectively) in the deepest samples collected from the water column at this location. Note the different scales on the abscissae.**

high concentrations could represent “relict” dissolved Zn that that was buried contemporaneously with the tailings in metal-rich lake water during the 1970’s and 80’s, and not removed by subsequent precipitation of authigenic ZnS. This is highly unlikely given that sulphate reduction (thus, sulphide production) is actively occurring in the deposits today (Figure 3-9). Interstitial waters extracted from the core collected at But-4 during the 1989 survey (Rescan 1990) revealed discrete zones of high dissolved zinc concentration at depths of 7 and 20 cm. Both cores collected from the same site in this campaign show similar structure, with dissolved Zn peaks at ~10 and 17 cm depth (Figure 3-15). The fact that the peaks appear at the same depths in both 1993 cores suggests that they cannot be attributed to random contamination, nor are they likely to be an artifact of sample processing. The origin of the peaks remains unclear. It is possible that these high levels, which are seen in specific intervals in the cores in 1989 and 1993 and at depth in the peeper in 1993, are being sustained by dissolution of an unknown alteration product that is thermodynamically unstable in anoxic conditions, but this is highly speculative. It is also dynamically unlikely, as noted in the section below. We conclude that, despite the occurrence of active sulphate reduction, there is a net release of Zn to pore solution at depth from the slowly-accumulated, and presumably very fine-grained, buried tailings on the margins of the submerged deposit in the South Basin. No such release is observed from the rapidly deposited, and presumably coarser, buried tails near the outfall.

The absolute concentrations in the Zn maxima in Core-4A and -4B are much lower than those seen at about the same depths four years earlier, and the values in the pore waters in the intervening horizons are lower by a factor of four to five (Figure 3-19). This disparity may have arisen as a result of methodological differences between this and the 1989 survey. In 1989, porewaters were filtered to 0.45  $\mu\text{m}$  only, not to 0.2  $\mu\text{m}$  as done in the present study. A fraction of dissolved Zn associated with colloidal Fe or organic matter could account for the observed differences. Implications of upward diffusion of the released zinc on the chemistry of the deep waters in the South Basin are discussed below in Section 3.4.

### *Behaviour of Dissolved Copper, Lead and Cadmium*

Concentrations of dissolved copper, lead and cadmium in the Rescan peepers from all three sites are low, typically <5  $\mu\text{g/L}$  in the case of Cu and Pb, and <0.2  $\mu\text{g/L}$  in the case of Cd (Figures 3-13 to 3-18). Two samples in each cell bank from

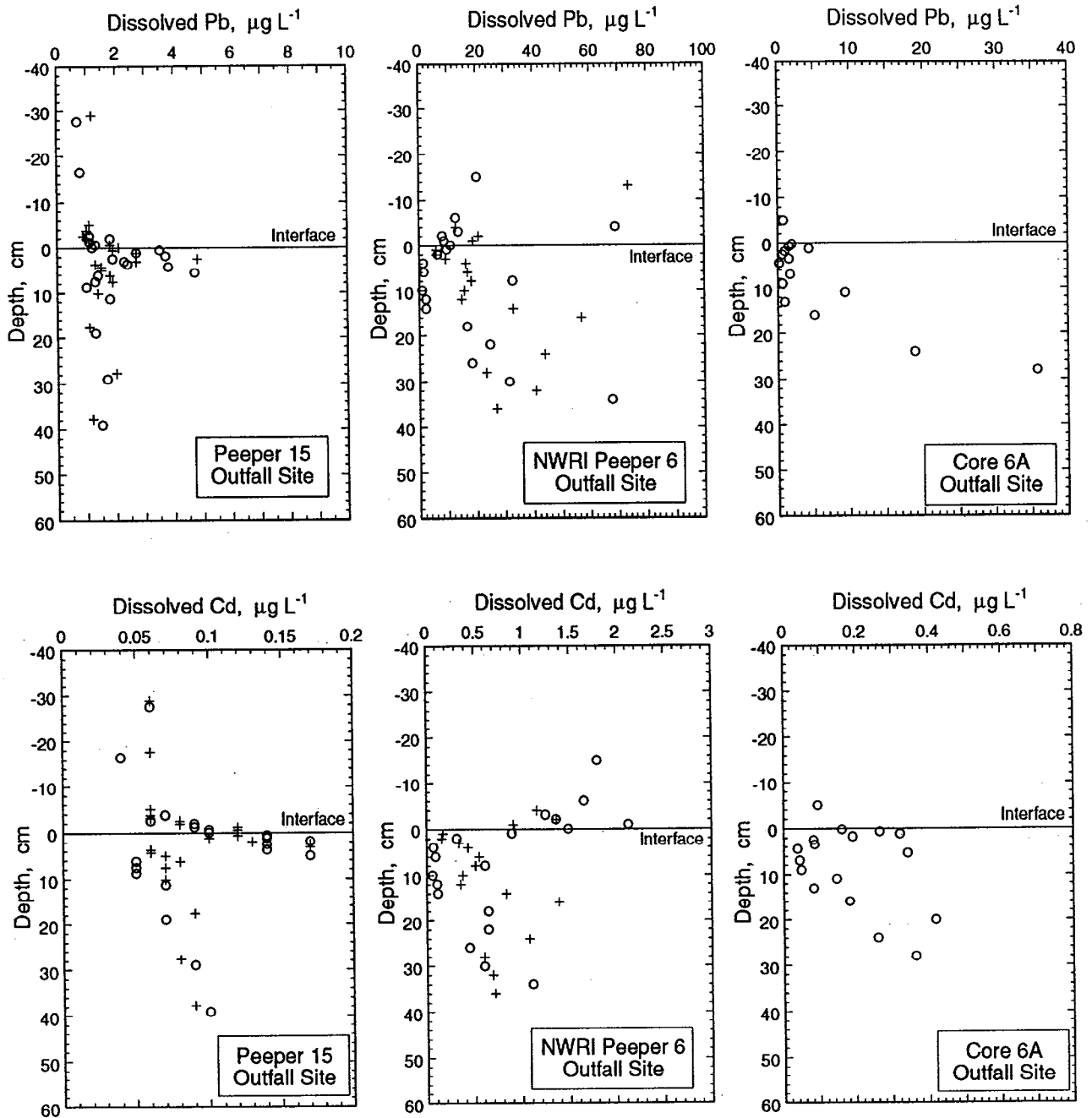
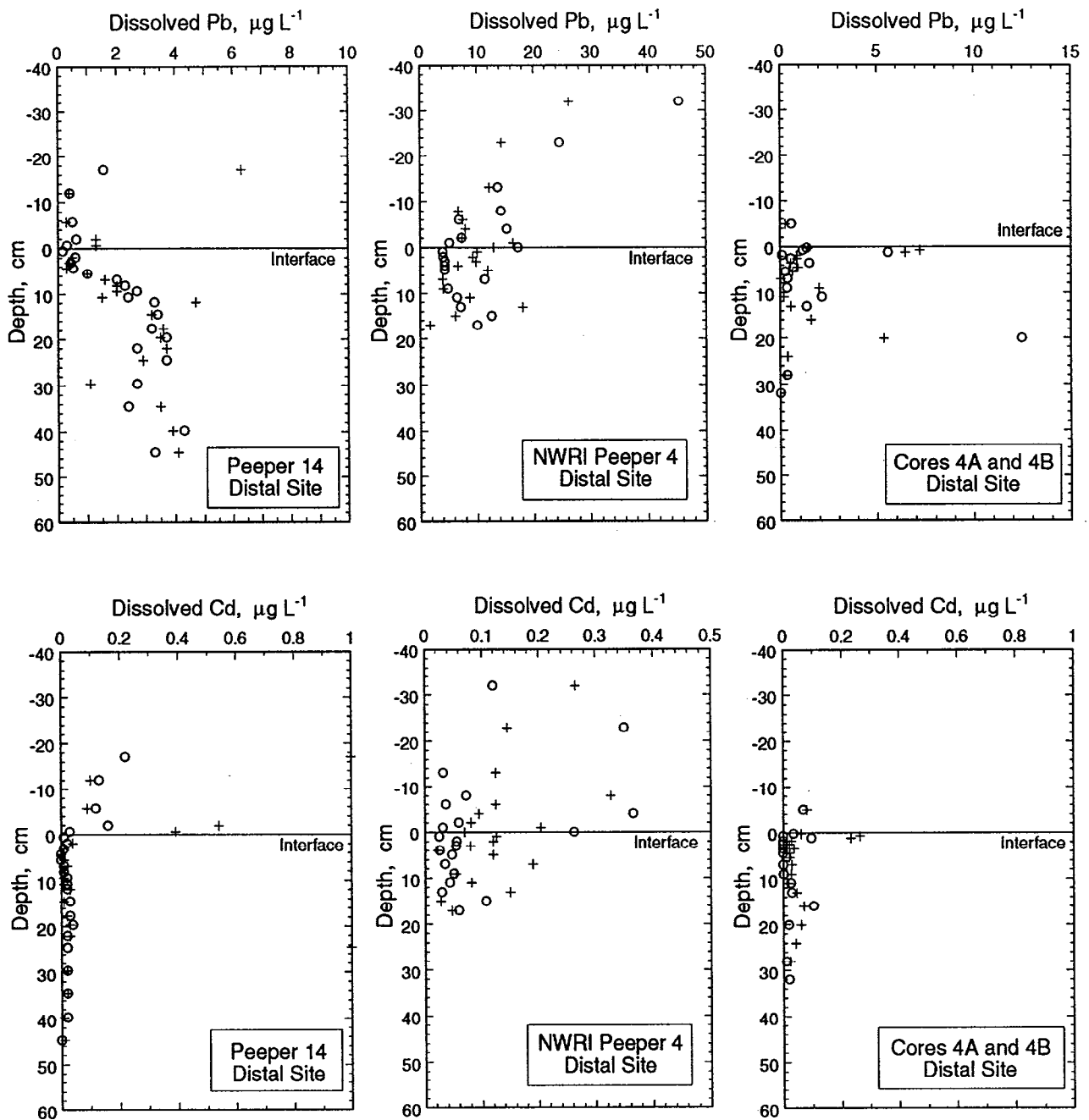


Figure 3-17: Dissolved lead and cadmium profiles in interstitial waters at the outfall site (But-6) in the South Basin. Left and right columns of cells in the tandem peepers (upper panels) are represented respectively by circles and crosses. Lead and cadmium were not detected ( $<0.5$  and  $<0.2 \mu\text{g L}^{-1}$  respectively) in the deepest samples collected from the water column at this location. Note the different scales on the abscissae. High lead concentrations at  $-3.8$  and  $5$  cm depth ( $17$  and  $34 \mu\text{g L}^{-1}$ ) in Peeper-15L, at  $-17.6$  and  $1.9$  cm depth ( $117$  and  $44 \mu\text{g L}^{-1}$ ) in Peeper-15R, and at  $20$  cm in Core-6A ( $41 \mu\text{g L}^{-1}$ ) are not shown.

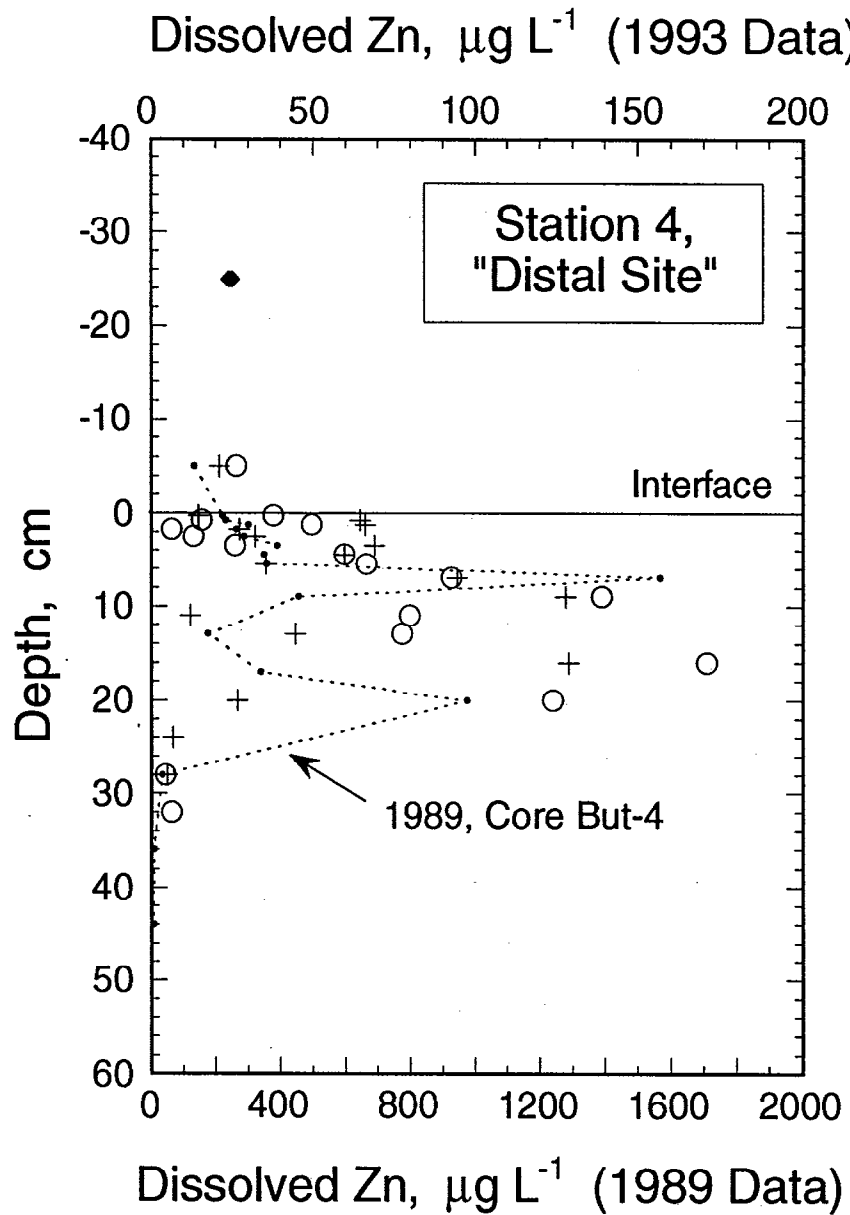


**Figure 3-18: Dissolved lead and cadmium profiles in interstitial waters at the distal site (But-6) in the South Basin. Left and right columns of cells in the tandem peepers (upper panels), and Core-4A and -4B are represented respectively by circles and crosses. Lead and cadmium were not detected ( $<0.5$  and  $<0.2 \mu\text{g L}^{-1}$  respectively) in the deepest samples collected from the water column at this location. Note the different scales on the abscissae.**

Peeper-15 (Samples 125, 139, 153 and 166; Appendix B) yielded very high Pb concentrations and are believed to have been contaminated; these are excluded from further discussion.

At the natural sediments site, little variation in Cu or Pb contents with depth is seen in the upper decimetre; there is no indication in the peeper profiles that either copper or lead are diffusing from bottom water into the deposits. However, cadmium, like zinc (its geochemical analogue), decreases with depth immediately below the interface, indicating that the deposits are acting as a sink for this metal. As for zinc, sharp increases in Cu, Pb and Cd concentrations immediately below the interface followed by depletion in the underlying deposits are seen in the pore waters collected from the core at this site (Figures 3-13 and 3-16). There is no obvious explanation for this near-interface cycling of the four metals. It may be that the trace metal releases are associated with the early diagenetic cycling of iron, given that significant concentrations of Fe are released to solution between 0.5 and 1.5 cm depth in the core (Figure 3-10). The depletions at depth presumably reflect sulphide precipitation. The contrast between the dissolved metals profiles in the core with those from the peeper is attributed to compositionally different sediments, as discussed above.

Copper, lead and cadmium distributions in the duplicate profiles from the Rescan peeper at the outfall site (But-6) are similar to zinc (compare Figures 3-14 and 3-17). Maxima for all four metals occur in the upper several centimetres, and consumption at depth is indicated by the general downward concavity seen below about 5 cm. Comparison with the dissolved Mn and Fe distributions (Figure 3-11) suggests that Cu, Pb and Cd are cycling with oxides during early diagenesis in the natural sediments that now overly the tailings at this location. The Cu, Pb, and Cd profiles correspond more closely to the dissolved manganese distribution than to iron, which suggests that solution of  $MnO_2$  below about 2 cm depth is releasing the adsorbed metals to the pore waters. Slight upward concavity in the profiles immediately below the interface implies that fractions of the metals are being re-adsorbed by manganese (or iron?) oxides that reprecipitate in the thin aerobic zone. The concentration gradients also extend into the waters immediately above the interface, suggesting that the re-adsorption is not quantitative, and that small effluxes into South Basin bottom water exist for all four elements. The profiles from the core raised from the outfall site are of the same concentration order and have



**Figure 3-19: Dissolved zinc distributions in cores collected at the distal site in 1989 and for this study. Core -4A and -4B are represented respectively by circles and crosses. The filled diamonds represent the concentrations measured in the deepest samples collected from the water column at this location.**

similar gross structure. Although these results show more scatter, they confirm the peeper data.

Dissolved copper and lead distributions in the Rescan peeper at the distal site (But-4) are similar in form and magnitude, with slight minima being evident immediately below the interface (Figures 3-15 and 3-18). These minor depletions imply scavenging of the metals from solution at about 3 cm depth, possibly by freshly-precipitated oxides. This is consistent with the dissolved iron profile (Figure 3-12) which indicates precipitation at that same horizon. The form of the cadmium profiles in Peeper-14 is similar to those of copper and lead below the interface, in that a concentration minimum is evident at about 4 cm depth. However, the overall Cd concentrations are much lower than those determined in the overlying near-bottom water (Figure 3-18). These data imply that there is no diffusive efflux of cadmium from the deposits sampled at this site by the Rescan peeper, as is the case for copper and lead.

The ranges in concentration of Cu, Pb and Cd measured in most of the pore water samples from both cores at But-4 are similar to those seen in the peeper profiles. However, the profiles from both cores exhibit discrete maxima for the three metals that are not seen in the peeper data, for reasons which are not clear. Cu and Pb concentration peaks occur at ~1, ~11 and ~18 cm in Core-4A and ~1, ~9 and ~18 cm in Core-4B. Although contamination cannot be ruled out as an explanation for these peaks, their occurrence at approximately the same depth range in *both* cores argues against this. As well, it is possible that the peaks represent a colloidal fraction(s) that passed the 0.2  $\mu\text{m}$  filter. The peaks centred at about 1 cm depth suggest that there is significant release of all three metals in the upper 1.5 cm, but the relatively low concentrations in the uppermost sample (0-0.5 cm) implies that there can be no significant diffusive efflux to the overlying bottom water.

Discrete peaks similar to those seen deeper in the cores were observed in the core collected from this station in 1989 (Rescan 1990), albeit with much higher maximum concentrations. For example, lead values of 140 and 153  $\mu\text{g/L}$  were recorded in Core-4 at respective depths of 7 and 20 cm. Precipitates were also observed in the acidified samples from these depths in the 1989 survey, and it was speculated at the time that these might be composed of humic acids. This was not confirmed, and no similar precipitates were observed in this study. If the observed

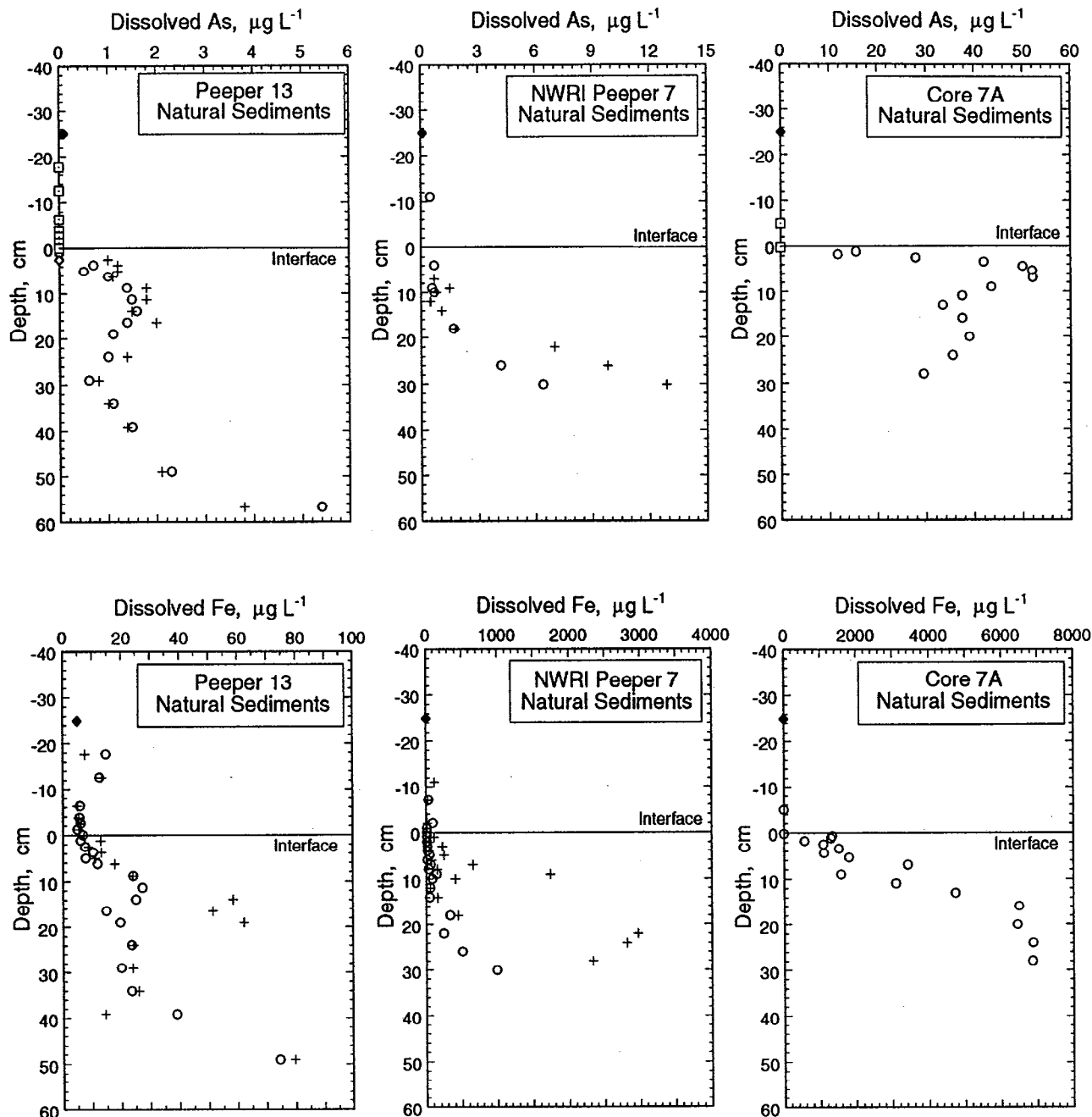


peaks are real, their origin remains enigmatic, as they would be very difficult to sustain dynamically for several years in the face of continuous diffusion.

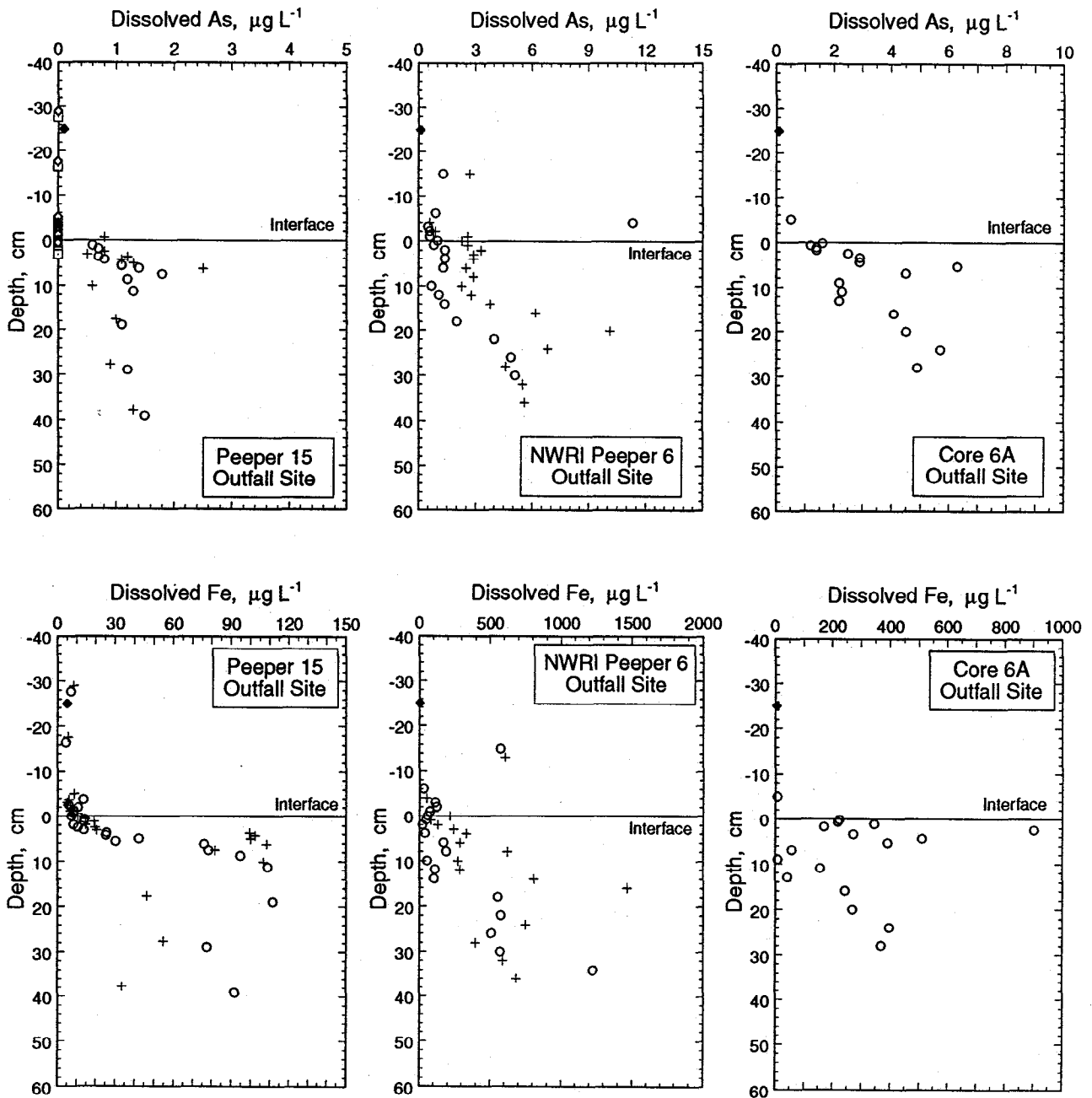
### *Behaviour of Dissolved Arsenic*

Most reports in the literature suggest that a strong chemisorptive affinity between Fe oxide and arsenate is more important in natural arsenic cycling during early diagenesis in lacustrine sediments than is any association between Mn oxides and As (*e.g.* Belzile and Tessier 1990; De Vitre *et al.*, 1991). However, recent measurements made at UBC on pore waters collected in shallow Balmer Lake, Ontario, show an exceptionally tight correlation between dissolved manganese and arsenic (Alan Martin, unpublished data). These data imply that both iron and manganese oxide phases can strongly influence As cycling, and this implication is consistent with the similar distributions of dissolved As, Fe and Mn seen with depth at the natural sediments site (compare [Figure 3-20](#) with [3-10](#)), as well as with the correlations between As and Fe and As and Mn ([Figure 3-23](#)). These profiles illustrate the natural diagenetic cycle for arsenic that is typical in lakes. Burial and reductive dissolution of oxides releases arsenate to solution whereupon it is reduced to arsenite and diffuses upward to be oxidized to arsenate and be readsorbed. At the natural sediments site, the very low (undetectable) concentrations in the upper 2 cm of the Rescan peeper pore waters suggests that such readsorption is quantitative. The dissolved As data from Core-7A ([Figure 3-20](#)) show much higher concentrations of arsenic in the pore waters than do the results from the peepers, as is the case for iron. Despite these contrasts, the depletion of dissolved As (*i.e.* <0.5  $\mu\text{g/L}$ ) from the 0-5 mm sample in the core supports the peeper results in implying that there can be little diffusive efflux of arsenic to the overlying bottom water at this site.

Furthermore, the data do not imply that As is diffusing into the bottom at this location. Therefore, the relative enrichment seen in the solid phase ([Figure 3-6](#)) apparently cannot be attributed to progressive diagenetic uptake from lake water. The high solid-phase values instead probably reflect deposition of As-rich particulate material of unknown provenance. At the outfall site (But-6), dissolved As concentrations are low and of the same order seen in the natural sediments ([Figure 3-21](#)). The arsenic distributions in the Rescan peeper correlate slightly better with iron than with manganese ([Figure 3-24](#)). Near-quantitative consumption of As from solution in the aerobic zone is again indicated by the



**Figure 3-20: Dissolved arsenic and iron profiles in interstitial waters at the natural sediments site. Left and right columns of cells in the tandem peepers (upper panels) are represented respectively by circles and crosses. The filled diamonds in each panel represent the concentrations measured in the deepest samples collected from the water column at this locations. Note the different scales on the abscissae.**



**Figure 3-21: Dissolved arsenic and iron profiles in interstitial waters at the outfall site (But-6) in the South Basin. Left and right columns of cells in the tandem peepers (upper panels) are represented respectively by circles and crosses. The filled diamonds in each panel represent the concentrations measured in the deepest samples collected from the water column at this locations. Note the different scales on the abscissae.**



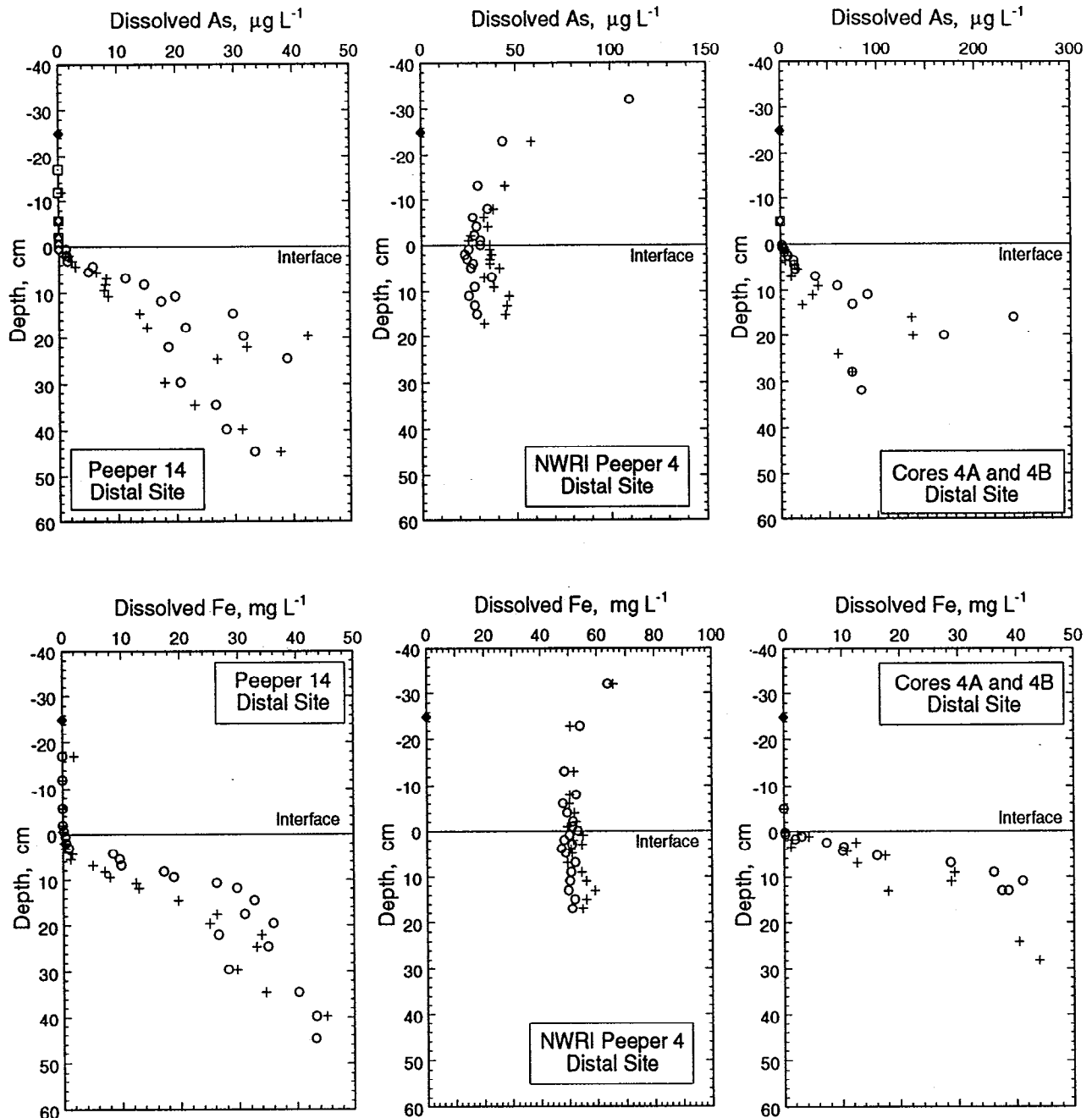
extremely low concentrations ( $<0.5 \mu\text{g/L}$ ) seen in the samples at or just below the interface. Arsenic is similarly depleted in the upper centimetre of the core profile, where concentrations are less than or equal to three times the detection limit.

At the distal site (But-4), where exceptionally high concentrations of both iron and manganese occur in the pore waters, As correlates well with Fe in the Rescan peeper profiles (Figure 3-22) but poorly with Mn (Figure 3-25). The profiles indicate a large upward flux of reduced iron, and almost quantitative oxidation at or just below the interface (Figure 3-12). This is consistent with the high concentrations of iron oxides in the surface sediments that are implied by the Fe/Al ratio data (Figure 3-7). Thus, intense Fe oxide cycling appears to be a major early diagenetic phenomenon in the distal facies in the south basin, and it dominates arsenic behaviour, as illustrated by the correlations in Figure 3-25. Both the Rescan peeper and the core pore water data from this site indicate that very little, if any, arsenic escapes to the overlying bottom water.

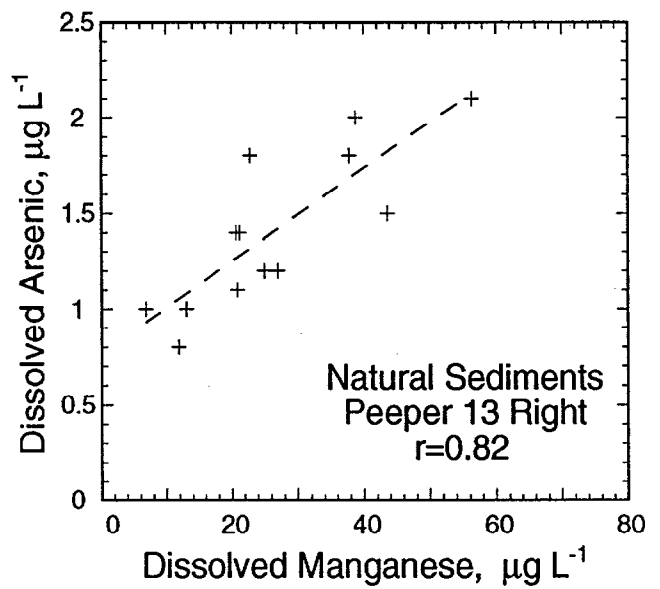
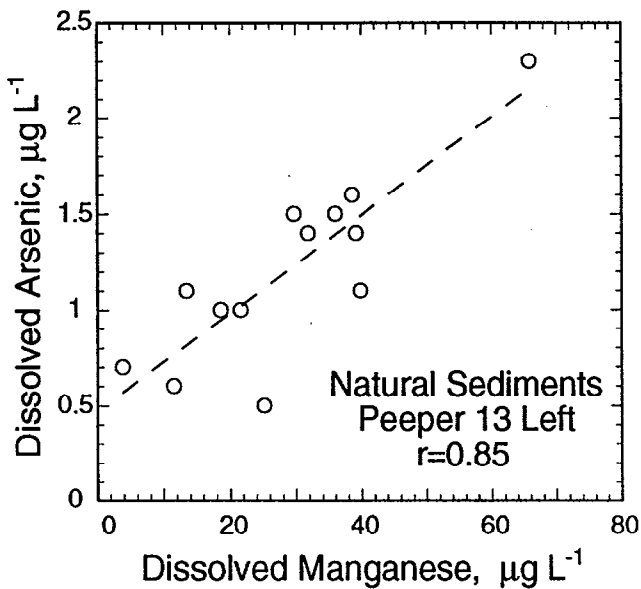
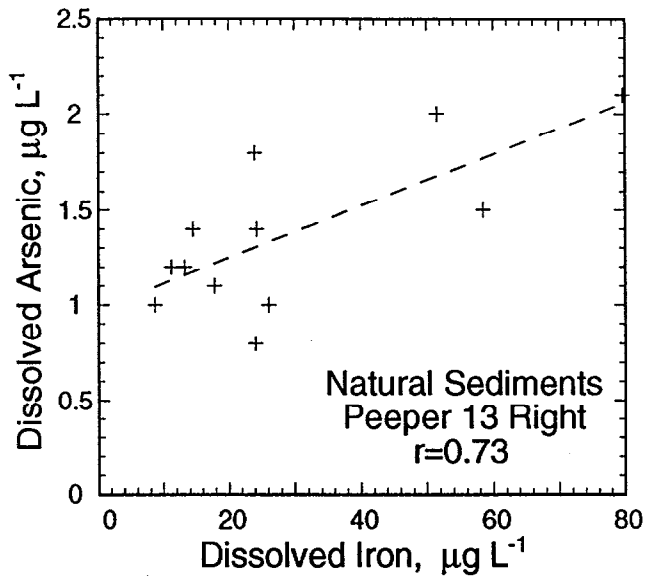
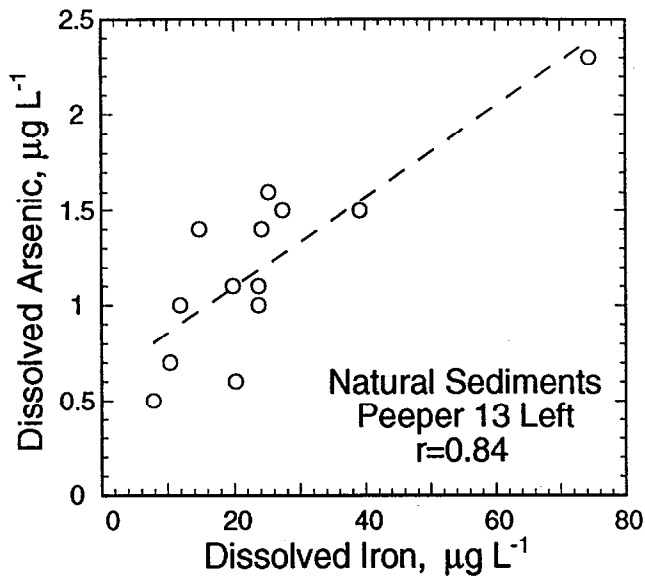
#### *Behaviour of Dissolved Mercury*

Mercury concentrations in the pore waters at all sites are low, never exceeding  $0.5 \mu\text{g/L}$ . The element was undetectable ( $<0.1 \mu\text{g/L}$ ) in all supernatant water aliquots from the cores and in all samples from the peeper sections that were exposed to bottom waters. In the natural sediments, all samples from the Rescan peeper similarly yielded Hg contents  $<0.1 \mu\text{g/L}$  (the detection limit). Equally low concentrations were observed in the pore waters from Core-7A, with the exception of the three deepest samples, which yielded contents of  $0.2 \mu\text{g/L}$  (Appendix B).

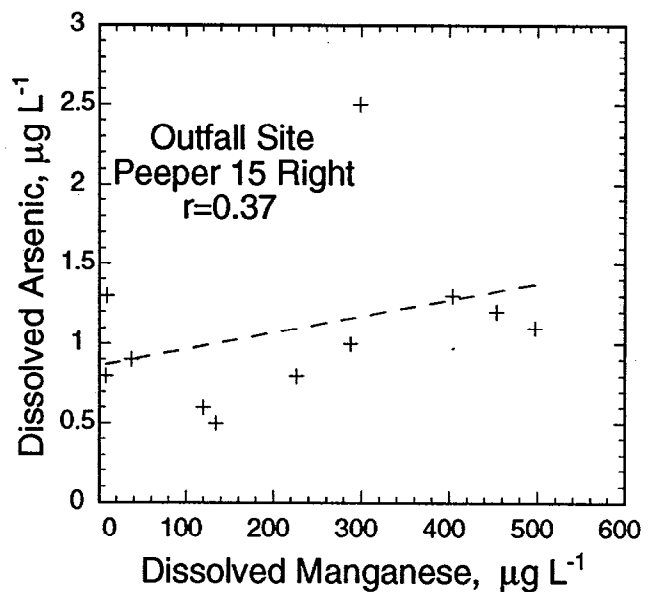
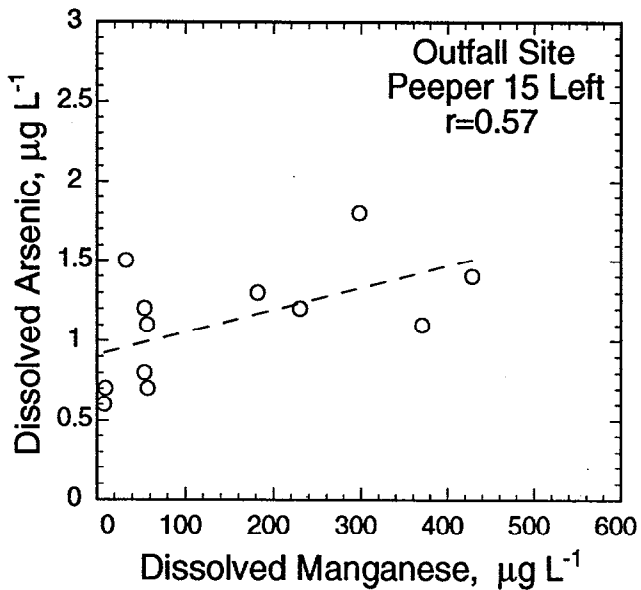
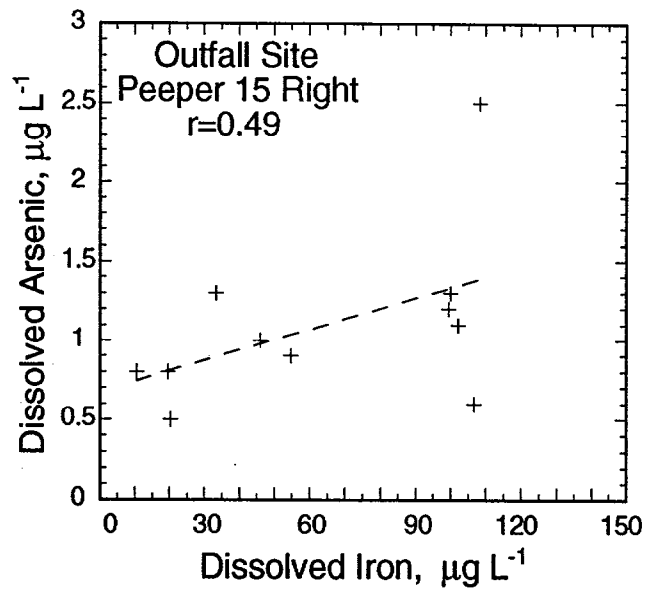
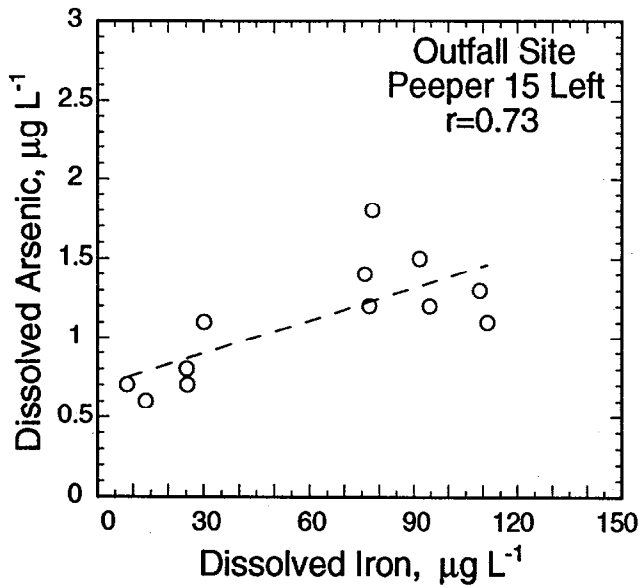
Mercury values were also at or below the detection limit in the right bank of cells in Peeper-15 (the outfall site), but three samples in the left column from the same array yielded marginally detectable values ( $0.2$ ,  $0.1$  and  $0.3 \mu\text{g/L}$  at  $0.63$ ,  $1.26$  and  $1.89$  cm sub-bottom depth, respectively). Pore waters extracted from the companion core at the outfall site (Core-6A) showed very slight but inconsistent enrichments just below the interface:  $0.3$ ,  $<0.1$ ,  $0.4$  and  $0.4 \mu\text{g/L}$  at  $0.25$ ,  $0.75$ ,  $1.25$  and  $1.75$  cm depth, respectively (Appendix B). Mercury was essentially undetectable throughout the rest of the core. The data from these two sites suggest that little early diagenetic remobilization of mercury is occurring at either location, and that there is no detectable diffusive flux of the element from the sediments to the bottom waters.



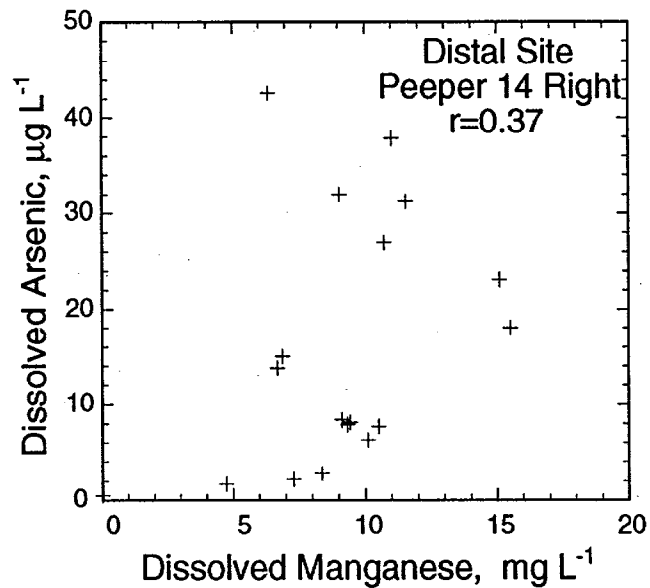
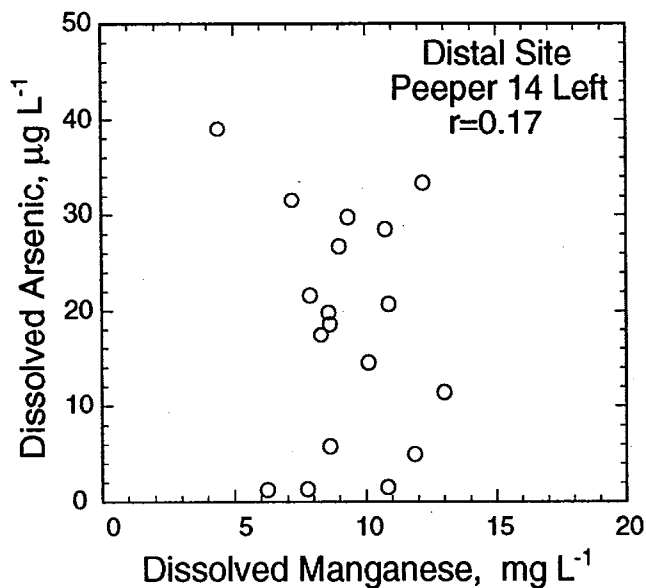
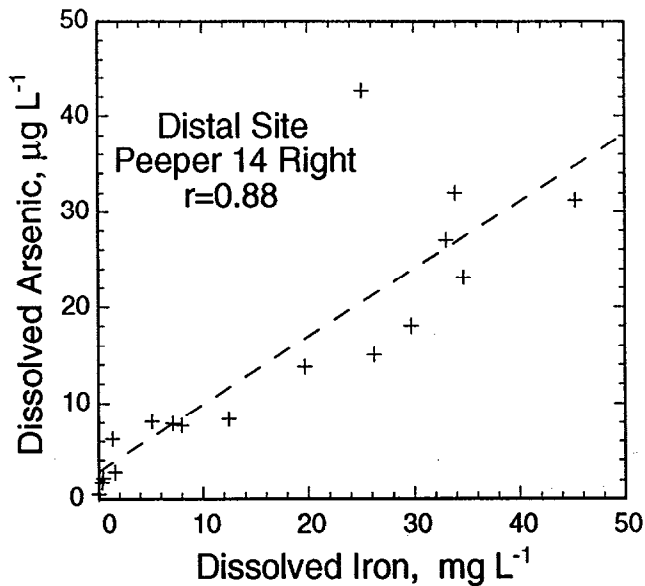
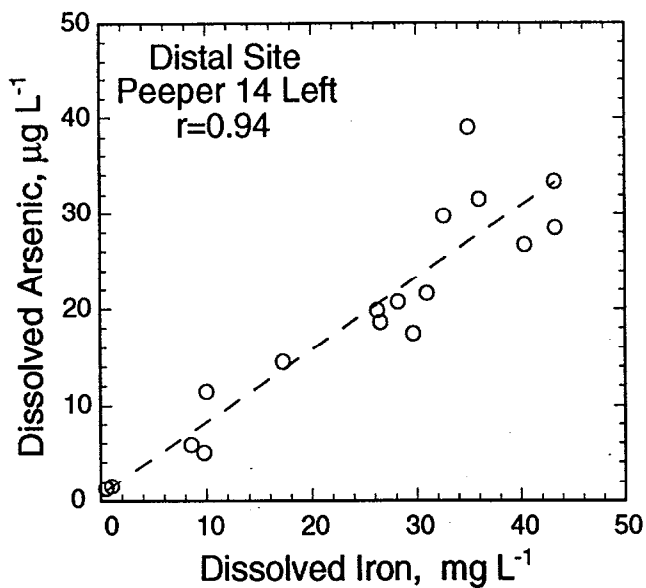
**Figure 3-22: Dissolved arsenic and iron profiles in interstitial waters at the distal site (But-4) in the South Basin. Left and right columns of cells in the tandem peepers (upper panels) are represented respectively by circles and crosses. The filled diamonds in each panel represent the concentrations measured in the deepest samples collected from the water column at this locations. Note the different scales on the abscissae.**



**Figure 3-23: Correlations between arsenic and iron and arsenic and manganese in pore waters from Peeper-13 at the natural sediments site (But-7).**



**Figure 3-24: Correlations between arsenic and iron and arsenic and manganese in pore waters from Peeper-15 at the outfall site (But-6).**



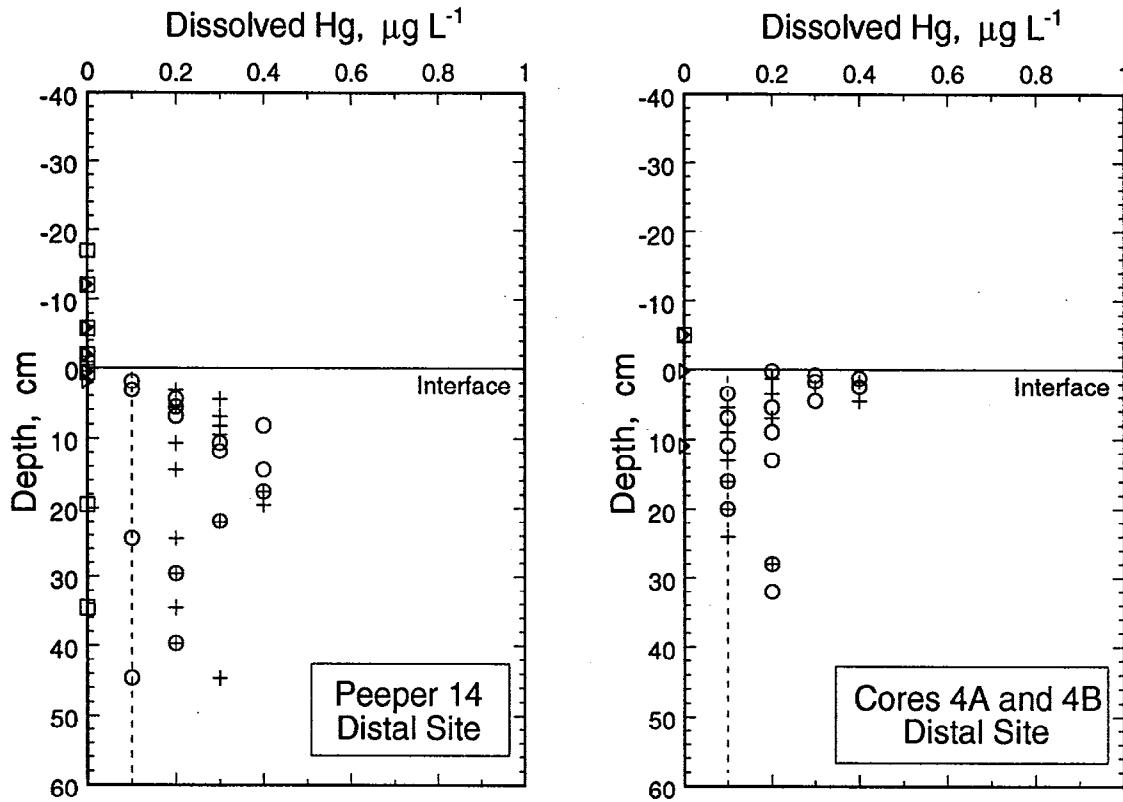
**Figure 3-25: Correlations between arsenic and iron and arsenic and manganese in pore waters from Peeper-14 at the distal site (But-4).**



At the distal site, dissolved mercury shows distinct, albeit very low, concentration maxima in the profiles from both the Rescan Peeper-14 and Core-4A and -4B (Figure 3-26). The maxima in the peeper occur between about 4 and 18 cm depth and are broader than those in the cores, where a single peak in each is observed between about 1.5 and 6 cm below the interface. Mercury is undetectable in the top centimetre of both peeper profiles and the upper 5 mm from Core-4B. These results indicate that there is no or very little diffusion of mercury from these deposits to bottom waters. The data also indicate that the element is cycled during early diagenesis, probably via sorption onto oxide phase(s) within the surface aerobic zone, and release during subsequent burial. The element is diffusing both upward and downward from concentration maxima, and is presumably rescavenged by oxides in the surface sediments, and is sequestered into sulphide phases at depth. The quality of the data is not sufficient to define the presumed oxide host with confidence, but the release of Hg to pore solution at very shallow depths implies that MnO<sub>2</sub> is the most likely candidate.

### **3.4 Implications of Diffusive Fluxes**

The data presented in this report confirm that dysaerobic or anoxic conditions universally prevail at shallow sub-bottom depths in all sedimentary facies sampled in Buttle Lake, and this is clearly a welcome condition for the storage in perpetuity of sulphide-bearing tailings. The natural sedimentation rate indicated by the current depth of the tailings-natural sediment boundary is about 4 mm/yr, which agrees very well with previous work (Pedersen 1983b; Rescan 1990). This implies that the tailings now buried just below the aerobic zone were exposed to molecular oxygen (at progressively decreasing concentrations) for seven or eight years following deposition, and that those tailings particles that have been mixed upward into the near-surface natural deposits will have a mean oxygen exposure time perhaps twice as long. Has this nearly decade-long exposure of sulphide-particle surfaces to dissolved oxygen promoted significant release of metals to Buttle Lake bottom waters? Although this question can be addressed from a quantitative standpoint by calculating diffusive fluxes, as done below, the magnitude of sulphide oxidation cannot be clearly determined with the data at hand. This is because Buttle Lake was contaminated with acid-rock drainage during and after the fifteen years of tailings discharge to the lake, so that the metal cycling seen in the pore water profiles is not just an indication of tailings reactivity. Instead, the



**Figure 3-26: Dissolved mercury profiles in interstitial waters at the distal site (But-4) in the South Basin. Left and right columns of cells in the Peeper-14 and in Core-4A and -4B are represented respectively by circles and crosses. The vertical dotted lines mark the detection limit; samples containing undetectable levels of Hg are plotted along the ordinate.**

profiles reflect the accumulated chemical history associated with scavenging by oxide phases of metals from the contaminated water column. Thus, some or all of the zinc that appears to be actively cycling in the upper few centimetres at the outfall site, for example, could be zinc that has been derived by progressive adsorption from the water column since ~1970 - it might not be related to tailings reactivity at all. Indeed, the actual buried "pure tailings" facies at this site is clearly consuming zinc rather than releasing it. The same reasoning applies to Cu, Pb, Cd and As at this location. However, to put this in perspective, Zn, Cu and Pb *are* being released to pore solution at depth in the "slowly-accumulating" tailings facies represented by the profiles collected at But-4. Although these data could be interpreted as representing post-depositional reactivity of slowly accumulating tailings, the very high Mn and Fe levels seen in the pore waters at the same location equally suggest that dissolving buried oxides might be supplying the metals to pore solution. Thus, we cannot conclude unequivocally that sulphide particles are undergoing or have undergone oxidative chemical alteration on the floor of Buttle Lake.

The potential impact on deep-water metals levels implied by the diffusive effluxes indicated at the outfall and distal sites is assessed using Fick's First Law of diffusion:

$$J = -\phi(K_c/F)(\partial C/\partial x)$$

where  $\phi$  is the porosity (assumed here to be 1; the true porosity is slightly less so fluxes will be slightly overestimated by the adoption of 100% porosity).  $K_c$  is the diffusion coefficient for each metal (from Li and Gregory 1974) corrected for estimated in situ temperature (6°C); the metals are presumed to occur largely as divalent ions - no allowance is made for complexation in the calculations. The coefficients are thus  $4 \times 10^{-6} \text{ cm}^2 \text{ sec}^{-1}$  for Zn, Cu and Cd, and  $5.5 \times 10^{-6} \text{ cm}^2 \text{ sec}^{-1}$  for Pb.  $\partial C/\partial x$  is the concentration gradient across the interface indicated by the pore water profiles.  $F$  is the formation factor (Manheim 1970) which takes into account the tortuous diffusion path of an ion in wet sediments. Given the high water content of the uppermost sediments at each core site, we estimate the formation factor to be only slightly greater than unity; thus  $F$  is taken to be 1.1. No corrections are applied here for the possible electrical coupling of the divalent metal ions to the fluxes of major ions (see Lasaga 1979), since the latter are unknown. In eastern Canadian lakes, Carignan and Tessier (1985) found that correcting for the coupling effect required a relatively small adjustment in the calculated flux for  $\text{Zn}^{2+}$  (about

+10% in one lake, and -7% in another). Since we have very limited major ion data, we have chosen to ignore this small potential effect on our calculated fluxes, all of which are listed in Table 3-3.

Table 3-3

Flux Calculations, Buttle Lake South Basin Sites

Site and Profile	Concentration Gradient ng cm <sup>-4</sup>	Diffusion Coefficient <i>in situ</i> cm <sup>2</sup> sec <sup>-1</sup>	Flux μg cm <sup>-2</sup> yr <sup>-1</sup>
Outfall, Zn/Peeper 15L	11.9	4 x 10 <sup>-6</sup>	1.4
Outfall, Zn/Peeper 15R	5.2	4 x 10 <sup>-6</sup>	0.6
Outfall, Zn/Core 6A	30.8	4 x 10 <sup>-6</sup>	3.5
Distal, Zn/Peeper 14L	69.8	4 x 10 <sup>-6</sup>	8.0
Distal, Zn/Peeper 14R	Insufficient data	4 x 10 <sup>-6</sup>	Not calculable
Distal Zn/Core 4A	Poor quality data	4 x 10 <sup>-6</sup>	Not calculable
Distal Zn/Core 4B	Poor quality data	4 x 10 <sup>-6</sup>	Not calculable
Outfall, Cu/Peeper 15L	0.5	4 x 10 <sup>-6</sup>	0.1
Outfall, Cu/Peeper 15R	0.4	4 x 10 <sup>-6</sup>	0.0
Outfall, Cu, Core 6A	18.6	4 x 10 <sup>-6</sup>	2.1
Distal, Cu/Peeper 14L	Influx	4 x 10 <sup>-6</sup>	Influx
Distal, Cu/Peeper 14 R	Influx	4 x 10 <sup>-6</sup>	Influx
Distal, Cu/Core 4A	5.4	4 x 10 <sup>-6</sup>	0.6
Distal, Cu/Core 4B	8.3	4 x 10 <sup>-6</sup>	1.0
Outfall, Pb/Peeper 15L	4.3	5.5 x 10 <sup>-6</sup>	0.7
Outfall Pb/Peeper 15R	1.5	5.5 x 10 <sup>-6</sup>	0.2
Outfall Pb/Core 6A	2.8	5.5 x 10 <sup>-6</sup>	0.4
Distal, Pb/Peeper 14L	Influx?	5.5 x 10 <sup>-6</sup>	No efflux
Distal, Pb/Peeper 14R	Influx?	5.5 x 10 <sup>-6</sup>	No efflux
Distal, Pb/Core 4A	3.9	5.5 x 10 <sup>-6</sup>	0.6
Distal, Pb/Core 4B	9.2	5.5 x 10 <sup>-6</sup>	1.4

Concentration gradients were calculated from the data listed in Appendix B, and represent steepest gradient (the worst case) calculable for each profile. All numeric fluxes are out of the bottom. Influxes, where evident in the pore water data, were not calculated.

The estimates shown in [Table 3-3](#) represent “worst case” diffusive effluxes. The near-surface deposits in the South Basin are finely laminated suggesting that bioturbation, although present, has not been extensive and is unlikely to have a major influence on dissolved metal fluxes. To put into perspective the potential impact of these fluxes on dissolved metal concentrations in Buttle Lake deep waters, we have integrated the maximum diffusive flux for each element indicated above over the entire area of the tailings deposit on the bottom of the South Basin, which we estimate to be 2 km<sup>2</sup> (4 km by 0.5 km). In one year (approximately the residence time of water in the South Basin), the total release of Zn, Cu and Pb to bottom waters would then be about 160, 42, and 28 kg, respectively. These are of the same order as the estimates computed in the previous survey in Buttle Lake (Rescan 1990). Adding these masses to the lower 50 m of South Basin water (a volume of about 0.3 x 10<sup>12</sup> L) would increase the dissolved Zn, Cu and Pb concentrations respectively by 0.5, 0.14 and 0.1 µg/L. These estimates are both very crude and probably an overestimate of any augmentation of the metal inventories in the lake deep waters due to upward diffusion from the sediments. We conclude, as we did in following the previous survey (Rescan 1990), that the diffusive effluxes of Zn, Cu and Pb implied by the pore water profiles at But-4 and But-6 have a very limited impact on water quality.

## 4.0 Conclusions

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## 4.0 CONCLUSIONS

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Concentrations of dissolved metals in the water column of Buttle Lake in October 1993 were amongst the lowest seen in nearly 20 years. Zinc concentrations, for example, were about 10% of the levels observed during the early 1980's when acid rock drainage evolving from the area near the original mine site was flowing into the lake via Myra Creek.

Relatively organic-rich natural sediments are now covering the tailings deposit in the South Basin of Buttle Lake at a rate of about 4 mm/yr. The natural veneer still hosts as much as 15% tailings by weight, which presumably reflects upward mixing by burrowing infauna. Tailings are essentially absent in the natural sediments sampled at But-7 in the basin immediately to the north.

Nitrate and sulphate concentrations decrease with depth in the pore waters at all sites. These data, in conjunction with dissolved and solid-phase Mn and Fe profiles, indicate that at all locations oxygen does not penetrate more than two to three cm into the deposits, and below this depth, dysaerobic or anoxic conditions prevail. The combination of this information and the sedimentation rate estimates imply that a minimum of seven to eight years elapsed before most of the last tailings to be discharged in 1984 were buried to a depth sufficient to ensure perpetual storage under anoxic conditions. Bioturbation, and possibly down-slope transport, will continue to expose an ever-diminishing fraction of tailings to aerobic conditions for about another decade.

Dissolved element profiles from the Rescan peepers vary in comparability to data obtained from cores collected at the two sites in the South Basin. However, in the natural sediments at But-7, contrasts in dissolved metal distributions between the Rescan peeper and the core are profound. The differences may be a result of emplacement of the peeper in sediments of different composition from that collected in the core.

Dissolved metals levels in pore waters in methane-bearing natural sediments underlying the tailings and at But-7 are extremely low, probably due to precipitation of authigenic sulphide minerals. At the natural sediments site, duplicate profiles from the Rescan peeper indicate that zinc and cadmium are diffusing into the

bottom; thus these deposits appear to be acting as a sink for these metals. Cu and Pb concentrations are very low and invariant between bottom water and pore water at this location implying lack of reactivity.

Remobilization to pore waters of dissolved Zn, Cu, Pb, and Cd is indicated in near-surface sediments at the site of the former tailings discharge. These metals must be diffusing both upward and downward from the shallow sub-surface maxima. Early diagenetic dissolution of buried manganese and iron oxides as dysaerobic conditions are established at depth is likely responsible for the metal releases. Precipitation of upward-diffusing Fe and Mn just below the sediment-water interface and scavenging onto the fresh oxide phases may be attenuating the upward fluxes of the other metals. At the distal site, where the tailings originally accumulated slowly, remobilization is more profound. Exceptionally high concentrations of Fe and Mn are observed in the pore waters at depth, and these are associated with relatively high dissolved zinc levels. The concentration profiles of Cu, Pb, Cd and Hg also appear to be tracking the distributions of Fe and Mn, although their concentrations are very low.

The release of these various metals to pore solution at depth at this site is not supporting diffusive effluxes to bottom water, at least for Cu, Pb and Cd (the data for zinc are equivocal). The dissolved iron data imply that oxidation of upward diffusing  $\text{Fe}^{2+}$  at about 2-3 cm depth may be producing oxides that effectively scavenge other metals from solution, thus inhibiting their release to bottom waters.

Arsenic concentrations in Buttle Lake pore waters are closely associated with the diagenetic cycling of iron, as seen in other lakes. There is no indication from the pore water data that arsenic is being released to bottom waters at any of the sampled sites.

Simple flux calculations based on conservative assumptions indicate that diffusive Zn, Cu and Pb effluxes to South Basin bottom waters implied by some of the pore water profiles are small and have a limited impact on water quality in the basin. This conclusion matches that reached in previous work.

The continuing presence of tailings in the aerobic zone, coupled with clear evidence for diagenetic cycling of oxide phases, makes it difficult to distinguish between active oxidation of sulphide-particle surfaces in the uppermost veneer (say, the



upper 1 or 2 mm) of the sediments and passive diagenetic remobilization. However, the near-interface dissolved metals measurements made on peeper samples for this report imply that active oxidation of particulate sulphides and concomitant release of metals in the aerobic zone is strongly inhibited; very little, if any, surface oxidation can be accommodated by the existing data. More detailed assessment of oxidation and desorption right at the sediment-water interface will require further study including application of microelectrode technology.

Finally, conclusions regarding seasonal effects cannot be drawn until time-series studies have been carried out.

## References

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## REFERENCES

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- Ambe, M. and K. Suwabe. 1977. The preparation of standard solutions of mercury at the p.p.b. level. *Anal. Chim. Acta*, 92, 55-60.
- Belzile, N. and A. Tessier. 1990. *Interactions Between Arsenic and Iron Oxyhydroxides in Lacustrine Sediments*. *Geochim. Cosmochim. Acta* 54, 103-109.
- Blomqvist, S. 1991. *Reliability of Core Sampling of Soft Bottom Sediment - An in situ Study*. *Sedimentology* 32, 843-846.
- Carignan, R. 1984. *Interstitial Water Sampling by Dialysis: Methodological Notes*. *Limnol. Oceanogr.* , 29, 667-670.
- Carignan, R. and A. Tessier. 1985. *Zinc Deposition in Acid Lakes: the Role of Diffusion*. *Science* 228, 1524-1526.
- Carignan, R., F. Rapin and A. Tessier. 1985. *Sediment Porewater Sampling for Metal Analysis: A Comparison of Techniques*. *Geochim. Cosmochim. Acta*, 49, 2493-2497.
- Carignan, R., S. St. Pierre and R. Gachter. 1994. *Use of Diffusion Samplers in Oligotrophic Lake Sediments: Effects of Free Oxygen in Sampler Material*. *Limnol. Oceanogr.* 39, 468-474.
- Carron, J. and H. Agemian. 1977. Preservation of sub-p.p.b. levels of mercury in distilled and natural fresh waters. *Anal. Chem. Acta.*, 92, 61-70.
- Crusius, J. and R.F. Anderson. 1991. *Core Compression and Surficial Sediment Loss of Lake Sediments of High Porosity Caused by Gravity Coring*. *Limnol. Oceanogr.* , 36, 1021-1031.
- Cumming, B.F., J.R. Glew, J.P. Smol and R.B. Davis. 1993. *Comment on "Core Compression and Surficial Sediment Loss of Lake Sediments of High Porosity Caused by Gravity Coring" (Crusius and Anderson)*. *Limnol. Oceanogr.* 38, 695-699.
- Davison, W. 1993. *Iron and Manganese in Lakes*. *Earth-Sci. Rev.* 34, 119-163.

- De Vitre, R., N. Belzile and A. Tessier. 1991. *Speciation and Adsorption of Arsenic on Diagenetic Iron Oxyhydroxides*. *Limnol. Oceanogr.* 36, 1480-1485.
- Deniseger, J., L.J. Erickson, A. Austin, M. Roch, and M. J.R. Clark. 1988. *The Effects of Decreasing Heavy Metal Concentrations on the Biota of Buttle Lake, Vancouver Island, British Columbia*. Unpublished manuscript, Waste Management Branch, Ministry of Environment and Parks, Province of British Columbia, 32 pp.
- Froelich, P.N., G.P. Klinkhammer, M.L. Bender, N.A. Luedtke, G.R. Heath, D. Cullen, P. Dauphin, D. Hammond, B. Hartman, and V. Maynard. 1979. *Early Oxidation of Organic Matter in Pelagic Sediments of the Eastern Equatorial Atlantic: Suboxic Diagenesis*. *Geochim. Cosmochim. Acta* 43, 1075-1090.
- Hamilton-Taylor, J. and W. Davison. In press. *Redox-driven Cycling of Trace Elements in Lakes*. In: *Lakes II* (eds. A. Lerman, J.R. Gat and D.M. Imboden), Springer-Verlag, Heidelberg,
- Hvorslev, M.J. 1949. *Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes*. U.S. Army Corps of Engineers, Waterways Experimental Station, Vicksburg, Mississippi, 521 pp.
- Lansens, P., C. Meuleman and W. Baeyens. 1990. Long-term stability of methylmercury standard solutions in distilled deionized water. *Anal. Chim. Acta*, 229, 281-285.
- Lasaga, A.C. 1979. *The Treatment of Multi-component Diffusion and Ion Pairs in Diagenetic Fluxes*. *Am. J. Sci.* 279, 324-346.
- Lebel, J., N. Silverberg and B. Sundby. 1982. *Gravity Core Shortening and Pore Water Chemical Gradients*. *Deep-Sea Res.*, 29, 1365-1372.
- Li, Y.-H. and S. Gregory. 1974. *Diffusion of Ions in Seawater and in Deep-sea Sediments*. *Geochim. Cosmochim. Acta* 38, 703-714.
- Louchouart, P., M. Lucotte, A. Mucci and P. Pichet. 1993. *Geochemistry of mercury in two hydroelectric reservoirs in Quebec, Canada*. *Can. Journ. Fish. Aquatic Sci.* 50:269-281.

- Manheim, F.T. 1970. *The Diffusion of Ions in Unconsolidated Sediments*. Earth. Planet. Sci. Lett. 9, 307-309.
- Pedersen, T.F. 1982. *Dissolved Interstitial Zn, Cd and Cu in Mine Tailing in Buttle Lake*. Unpublished report prepared for Westmin Resources Ltd. 17 pp.
- Pedersen, T.F. 1983a. *Dissolved Heavy Metals in a Lacustrine Mine Tailings Deposit - Buttle Lake, British Columbia*. Mar. Poll. Bull. 14, 249-254.
- Pedersen, T.F. 1983b. *Rate of Accumulation of Natural Sediments in the South Basin of Buttle Lake, B.C.* Unpublished report prepared for Westmin Resources Ltd. 25 pp.
- Pedersen, T.F., B. Mueller, J.J. McNee and C.A. Pelletier. 1993. *The Early Diagenesis of Submerged Sulphide-rich Tailings in Anderson Lake, Manitoba*. Canadian Journal of Earth Sciences 30: 1099-1109.
- Pedersen, T.F., S.J. Malcolm and E.R. Sholkovitz. 1985. *A Lightweight Gravity Corer for Undisturbed Sampling of Soft Sediments*. Canadian Journal of Earth Sciences, 22: 133-135.
- Rescan. 1990. *Geochemical Assessment of Subaqueous Tailings Disposal in Buttle Lake, British Columbia*. Unpublished Report to the Mine Environment Neutral Drainage Program.
- Rescan. 1994. *Geochemical Assessment of Subaqueous Tailings Disposal in Anderson Lake, Manitoba: 1993 Study Program*. Unpublished Report to the Mine Environment Neutral Drainage Program.
- Reynolds, G.L. and J. Hamilton-Taylor. 1992. *The role of Planktonic Algae in the Cycling of Zn and Cu in a Productive Soft-water Lake*. Limnol. Oceanogr. 37, 1759-1769.
- Stoeppler, M. and W. Matthes. 1978. Storage behaviour of inorganic mercury and methylmercury chloride in sea water. *Anal. Chim. Acta*, 98, 389-392.

# Appendix A - Quality Assurance - Quality Control

## Appendix A1 - ASL QA/QC

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**BUTTLE LAKE**

**QA/QC DATA**



**BUTTLE LAKE**

**WATER COLUMN**

**QA/QC DATA**

## **QUALITY ASSURANCE/QUALITY CONTROL (QA/QC) RESULTS AND DISCUSSION FOR WATER COLUMN SAMPLES**

### **Laboratory QA/QC**

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  $\pm 10\%$  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  $\pm 15\%$  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:

- 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 for one of the Method Blanks were slightly above the stated detection limit of 0.005 mg/L, but less than 5x this detection limit.
- Total Phosphorus results for two of the Method Blanks fell slightly above the stated detection limit of 0.001 mg/L, but less than 5x this detection limit.

The results on the Reference Materials 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.

- Manganese results for one of the seven NWRI TM-02 samples.
- Total Phosphorus results for all of the NWRI CM-ION-94 samples.
- Calcium results for one of the seven NWRI CM-ION-94 samples.

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  $\pm 15\%$  of a calculated mean, demonstrating good precision for all parameters tested.

All spike recoveries were within an acceptable range (74% - 120%).

### **Field QA/QC**

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

		Method Blank #1 Dec 01/93	Method Blank #2 Dec 01/93	Method Blank #3 Dec 01/93	Method Blank #4 Dec 01/93	Method Blank #5 Dec 01/93
<b>Physical Tests</b>						
Conductivity	umhos/cm	1.4	1.8	1.3	1.2	1.2
<b>Dissolved Anions</b>						
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
<b>Nutrients</b>						
Ammonia Nitrogen	N	<0.005	<0.005	<0.005	<0.005	<0.005
Nitrate Nitrogen	N	0.007	<0.005	<0.005	<0.005	<0.005
Total Phosphorus	P	0.001	<0.001	0.001	<0.001	<0.001
<b>Total Metals</b>						
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	<0.001	<0.001	<0.001	<0.001	<0.001
<b>Dissolved Metals</b>						
Arsenic	D-As	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cadmium	D-Cd	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Calcium	D-Ca	<0.050	<0.050	<0.050	<0.050	<0.050
Copper	D-Cu	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Iron	D-Fe	<0.003	<0.003	<0.003	<0.003	<0.003
Lead	D-Pb	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Magnesium	D-Mg	<0.010	<0.010	<0.010	<0.010	<0.010
Manganese	D-Mn	<0.001	<0.001	<0.001	<0.001	<0.001
Mercury	D-Hg	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Potassium	D-K	<0.010	<0.010	<0.010	<0.010	<0.010
Sodium	D-Na	<0.010	<0.010	<0.010	<0.010	<0.010
Zinc	D-Zn	<0.001	<0.001	<0.001	<0.001	<0.001
<b>Organic Parameters</b>						
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 for Conductivity (umhos/cm).  
 < = Less than the detection limit indicated.

	NWRI CM- ION-94 #1 Dec 01/93	NWRI CM- ION-94 #2 Dec 01/93	NWRI CM- ION-94 #3 Dec 01/93	NWRI CM- ION-94 #4 Dec 01/93	NWRI CM- ION-94 Certified	
<b>Physical Tests</b>						
Conductivity	umhos/cm	37.0	36.0	36.0	34.0	36.69 ± 3.37
Hardness	CaCO <sub>3</sub>	8.06	8.54	7.43	7.78	7.45 ± 1.23
pH		6.25	6.30	6.31	6.30	6.27 ± 0.39
<b>Dissolved Anions</b>						
Alkalinity - Total	CaCO <sub>3</sub>	3.5	4.1	3.2	3.4	3.39 ± 2.10
Chloride	Cl	5.6	5.7	5.6	5.6	5.11 ± 1.08
Sulphate	SO <sub>4</sub>	2.8	2.5	2.4	2.8	2.79 ± 0.88
<b>Nutrients</b>						
Ammonia Nitrogen	N	<0.005	<0.005	0.006	0.006	0.007 ± 0.007
Nitrate Nitrogen	N	0.051	0.044	0.044	0.041	0.036 ± 0.022
Total Phosphorus	P	0.003	0.003	0.003	0.003	0.007 ± 0.003
<b>Total Metals</b>						
Calcium	T-Ca	1.99	2.12	1.82	1.91	1.80 ± 0.20
Magnesium	T-Mg	0.753	0.785	0.701	0.734	0.680 ± 0.153
Potassium	T-K	0.31	0.32	0.30	0.31	0.289 ± 0.105
Sodium	T-Na	3.90	3.92	3.90	3.88	4.10 ± 0.56
<b>Organic Parameters</b>						
Dissolved Organic Carbon	C	8.80	9.00	9.10	9.85	11.4 ± 3.4

	NWRI CM- ION-94 #5 Dec 01/93	NWRI CM- ION-94 #6 Dec 01/93	NWRI CM- ION-94 #7 Dec 01/93	NWRI CM- ION-94 Certified	
<b>Physical Tests</b>					
Conductivity	umhos/cm	34.0	33.0	33.0	36.69 ± 3.37
Hardness	CaCO <sub>3</sub>	7.41	7.64	7.64	7.45 ± 1.23
pH		6.32	6.28	6.22	6.27 ± 0.39
<b>Dissolved Anions</b>					
Alkalinity - Total	CaCO <sub>3</sub>	4.8	3.9	4.6	3.39 ± 2.10
Chloride	Cl	6.0	5.3	5.5	5.11 ± 1.08
Sulphate	SO <sub>4</sub>	2.5	2.5	2.8	2.79 ± 0.88
<b>Nutrients</b>					
Ammonia Nitrogen	N	<0.005	<0.005	<0.005	0.007 ± 0.007
Nitrate Nitrogen	N	0.051	0.046	0.051	0.036 ± 0.022
Total Phosphorus	P	0.003	0.003	0.003	0.007 ± 0.003
<b>Total Metals</b>					
Calcium	T-Ca	1.84	1.89	1.87	1.80 ± 0.20
Magnesium	T-Mg	0.687	0.712	0.720	0.680 ± 0.153
Potassium	T-K	0.32	0.29	0.30	0.289 ± 0.105
Sodium	T-Na	3.91	3.90	3.90	4.10 ± 0.56
<b>Organic Parameters</b>					
Dissolved Organic Carbon	C	9.85	10.2	10.4	11.4 ± 3.4

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

NWRI CM-ION-94 is a Standard Reference Material from the National Water Research Institute certified for assorted parameters.

NWRI	NWRI	NWRI	NWRI	NWRI
TM-02	TM-02	TM-02	TM-02	TM-02
#1	#2	#3	#4	
Dec 01/93	Dec 01/93	Dec 01/93	Dec 01/93	Certified

**Total Metals**

Cadmium	T-Cd	0.0243	0.0211	0.0214	0.0215	0.0210	+ 0.0035
Copper	T-Cu	0.0522	0.0522	0.0522	0.0532	0.0541	+ 0.0098
Iron	T-Fe	0.050	0.051	0.054	0.052	0.050	+ 0.016
Lead	T-Pb	0.0270	0.0280	0.0290	0.0285	0.0259	+ 0.0052
Manganese	T-Mn	0.024	0.024	0.024	0.023	0.0215	+ 0.0040
Zinc	T-Zn	0.035	0.038	0.030	0.037	0.0344	+ 0.0094

NWRI	NWRI	NWRI	NWRI
TM-02	TM-02	TM-02	TM-02
#5	#6	#7	
Dec 01/93	Dec 01/93	Dec 01/93	Certified

**Total Metals**

Cadmium	T-Cd	0.0229	0.0222	0.0221	0.0210	+ 0.0035
Copper	T-Cu	0.0515	0.0530	0.0490	0.0541	+ 0.0098
Iron	T-Fe	0.053	0.055	0.053	0.050	+ 0.016
Lead	T-Pb	0.0285	0.0280	0.0280	0.0259	+ 0.0052
Manganese	T-Mn	0.022	0.025	0.026	0.0215	+ 0.0040
Zinc	T-Zn	0.037	0.039	0.030	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#11838 #1 Dec 01/93	APG Lot#11838 #2 Dec 01/93	APG Lot#11838 #3 Dec 01/93	APG Lot#11838 #4 Dec 01/93	APG Lot#11838 Certified
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<u>Total Metals</u>						
Arsenic	T-As	0.0164	0.0155	0.0164	0.0161	0.0187 + 0.0046
Mercury	T-Hg	0.00163	0.00154	0.00160	0.00163	0.00169 ± 0.00050

APG Lot#11838 #5 Dec 01/93	APG Lot#11838 #6 Dec 01/93	APG Lot#11838 #7 Dec 01/93	APG Lot#11838 Certified
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<u>Total Metals</u>						
Arsenic	T-As	0.0155	0.0149	0.0155	0.0187 + 0.0046	
Mercury	T-Hg	0.00168	0.00177	0.00168	0.00169 ± 0.00050	

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.



Parameter	Number of Spikes Carried Out (n)	Spike Level (mg/L)	Recovery (%)	
			Minimum	Maximum
<b>Metals</b>				
Arsenic	4	0.0020	95	105
Cadmium	6	0.0020	108	116
Copper	8	0.010	96	110
Iron	11	0.010	74	110
Lead	5	0.010	90	100
Manganese	8	0.010	104	120
Zinc	8	0.010	76	120

		Travel Blank #1 Dec01/93	Travel Blank #2 Dec01/93	Travel Blank #3 Dec01/93	Travel Blank #4 Dec01/93	Travel Blank #5 Dec01/93
<b>Physical Tests</b>						
Conductivity	umhos/cm	2.1	1.6	1.4	1.4	1.5
<b>Dissolved Anions</b>						
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
<b>Nutrients</b>						
Ammonia Nitrogen	N	<0.005	<0.005	<0.005	<0.005	<0.005
Nitrate Nitrogen	N	<0.005	0.012	0.008	<0.005	<0.005
Total Phosphorus	P	<0.001	<0.001	<0.001	<0.001	<0.001
<b>Total Metals</b>						
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	<0.001	<0.001	<0.001	<0.001	<0.001
<b>Organic Parameters</b>						
Total Organic Carbon	C	<0.50	<0.50	0.53	<0.50	<0.50

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

		Travel Blank #6 Dec01/93	Travel Blank #7 Dec01/93	Travel Blank #8 Dec01/93
<b>Physical Tests</b>				
Conductivity	umhos/cm	1.5	1.5	1.3
<b>Dissolved Anions</b>				
Alkalinity - Total	CaCO3	<1.0	<1.0	<1.0
Chloride	Cl	<0.5	<0.5	<0.5
Sulphate	SO4	<1.0	<1.0	<1.0
<b>Nutrients</b>				
Ammonia Nitrogen	N	<0.005	<0.005	<0.005
Nitrate Nitrogen	N	<0.005	<0.005	<0.005
Total Phosphorus	P	<0.001	<0.001	<0.001
<b>Total Metals</b>				
Arsenic	T-As	<0.0001	<0.0001	<0.0001
Cadmium	T-Cd	<0.0002	<0.0002	<0.0002
Calcium	T-Ca	<0.050	<0.050	<0.050
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
Magnesium	T-Mg	<0.010	<0.010	<0.010
Manganese	T-Mn	<0.001	<0.001	<0.001
Mercury	T-Hg	<0.00001	<0.00001	<0.00001
Potassium	T-K	<0.010	<0.010	<0.010
Sodium	T-Na	<0.010	<0.010	<0.010
Zinc	T-Zn	<0.001	<0.001	<0.001
<b>Organic Parameters</b>				
Total Organic Carbon	C	<0.50	1.60	1.00

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

**BUTTLE LAKE**

**PORE AND PEEPER WATER**

**QA/QC DATA**

## **QUALITY ASSURANCE/QUALITY CONTROL (QA/QC) RESULTS AND DISCUSSION FOR PORE AND PEEPER WATER**

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  $\pm 10\%$  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  $\pm 15\%$  of a calculated mean.
- Reference Material - 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.

None of the tested parameters were detected in any of the Method Blanks indicating good contamination control throughout this project.

The Reference Material results met the manufacturers/suppliers 95% acceptance criteria in all cases.

All spike recoveries were within an acceptable range (the range of recoveries were 71-135%).

**Section I**

**Batch #1 QA/QC Data**

		Method Blank #1	Method Blank #2	Method Blank #3
<b>Total Metals</b>				
Arsenic	T-As	<0.0005	<0.0005	<0.0005
Mercury	T-Hg	<0.000005	<0.000005	<0.000005

		APG Lot12455 #1	APG Lot12455 #2	APG Lot12455 #3	APG Lot12455 #4	APG Lot12455 Certified
<b>Total Metals</b>						
Arsenic	T-As	0.108	0.104	0.107	0.110	0.0961 ± 0.0163
Mercury	T-Hg	0.00104	0.00124	0.00122	0.00121	0.00124 ± 0.00057

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

APG Lot 12455 is a Standard Reference Material from the Analytical Products Group.



## RESULTS OF ANALYSIS - QA Data - Spikes

File No. D8042

ARSENIC

Sample Identification	Spike Concentration (mg/L)	Sample Concentration (mg/L)	Sample + Spike Concentration Found (mg/L)	% Recovery
Cell 1A #9	0.0040	0.0014	0.0049	88
Cell 1A #34	0.0040	0.0006	0.0037	77
Cell 1B #9	0.0040	0.0010	0.0048	95
Cell 1B #34	0.0040	0.0009	0.0037	71

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Results are expressed as milligrams per litre.

**Section II**

**Batch #2 QA/QC Data**

		Method Blank #1	Method Blank #2	Method Blank #3	Method Blank #4	Method Blank #5
<b>Total Metals</b>						
Arsenic	T-As	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Mercury	T-Hg	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
<hr/>						
		Method Blank #6	Method Blank #7			
<b>Total Metals</b>						
Arsenic	T-As	<0.0005	<0.0005			
Mercury	T-Hg	<0.00005	<0.00005			
<hr/>						
		APG Lot12455 #1	APG Lot12455 #2	APG Lot12455 #3	APG Lot12455 #4	APG Lot12455 Certified
<b>Total Metals</b>						
Arsenic	T-As	0.109	0.0930	0.0980	0.105	0.0961 ± 0.0163
Mercury	T-Hg	0.000920	0.000960	0.00120	0.00100	0.00124 ± 0.00057
<hr/>						
		APG Lot12455 #5	APG Lot12455 #6	APG Lot12455 #7	APG Lot12455 #8	APG Lot12455 Certified
<b>Total Metals</b>						
Arsenic	T-As	0.108	0.110	0.111	0.105	0.0961 ± 0.0163
Mercury	T-Hg	0.00118	0.00100	0.000920	0.00128	0.00124 ± 0.00057
<hr/>						
		APG Lot12455 #9	APG Lot12455 #10	APG Lot12455 Certified		
<b>Total Metals</b>						
Arsenic	T-As	0.0960	0.0970	0.0961 ± 0.0163		
Mercury	T-Hg	0.00131	0.00125	0.00124 ± 0.00057		

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

APG Lot 12455 is a Standard Reference Material from the Analytical Products Group.

ARSENIC

Sample Identification	Spike Concentration (mg/L)	Sample Concentration (mg/L)	Sample + Spike Concentration Found (mg/L)	% Recovery
M6	0.0040	<0.0005	0.0040	100
M14	0.0040	0.0014	0.0054	100
M22	0.0040	0.0006	0.0047	102
M32	0.0040	<0.0005	0.0032	80
M38	0.0040	<0.0005	0.0039	98
M50	0.0040	0.0014	0.0053	98
M60	0.0040	0.0038	0.0079	102
M68	0.0040	0.0012	0.0054	104

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

**Section III**

**Batch #3 QA/QC Data**

		Method Blank #1	Method Blank #2	Method Blank #3	Method Blank #4	Method Blank #5
<b>Total Metals</b>						
Arsenic	T-As	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Mercury	T-Hg	<0.000005	<0.000005	<0.000005	<0.000005	<0.000005
<hr/>						
		Method Blank #6	Method Blank #7			
<b>Total Metals</b>						
Arsenic	T-As	<0.0005	<0.0005			
Mercury	T-Hg	<0.000005	<0.000005			
<hr/>						
		APG Lot12455 #1	APG Lot12455 #2	APG Lot12455 #3	APG Lot12455 #4	APG Lot12455 Certified
<b>Total Metals</b>						
Arsenic	T-As	0.0920	0.0980	0.101	0.0870	0.0961 ± 0.0163
Mercury	T-Hg	0.00116	0.00113	0.00122	0.000970	0.00124 ± 0.00057
<hr/>						
		APG Lot12455 #5	APG Lot12455 #6	APG Lot12455 #7	APG Lot12455 #8	APG Lot12455 Certified
<b>Total Metals</b>						
Arsenic	T-As	0.0890	0.0960	0.108	0.103	0.0961 ± 0.0163
Mercury	T-Hg	0.000950	0.00125	0.00112	0.00122	0.00124 ± 0.00057
<hr/>						
		APG Lot12455 #9	APG Lot12455 #10	APG Lot12455 Certified		
<b>Total Metals</b>						
Arsenic	T-As	0.0990	0.101	0.0961 ± 0.0163		
Mercury	T-Hg	0.00118	0.00115	0.00124 ± 0.00057		

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

APG Lot 12455 is a Standard Reference Material from the Analytical Products Group.

ARSENIC

Sample Identification	Spike Concentration (mg/L)	Sample Concentration (mg/L)	Sample + Spike Concentration Found (mg/L)	% Recovery
M99	0.0040	0.0017	0.0071	135
M102	0.0040	0.0063	0.0108	112
M109	0.0040	0.0150	0.0079	128
M121	0.0040	<0.0005	0.0041	102
M130	0.0040	<0.0005	0.0034	85
M150	0.0040	0.0015	0.0054	97
M151	0.0040	<0.0005	0.0035	87
M162	0.0040	0.0008	0.0046	95
M167	0.0040	0.0008	0.0044	90
M180	0.0040	0.0013	0.0049	90

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

**Section IV**

**Batch #4 QA/QC Data**



RESULTS OF ANALYSIS - QA Data - Method Blanks/CRM's

File No. D8676

		Method Blank #1	Method Blank #2	Method Blank #3	Method Blank #4	Method Blank #5
<b>Total Metals</b>						
Arsenic	T-As	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Mercury	T-Hg	<0.000005	<0.000005	<0.000005	<0.000005	<0.000005
		Method Blank #6	Method Blank #7	Method Blank #8		
<b>Total Metals</b>						
Arsenic	T-As	<0.0005	<0.0005	<0.0005		
Mercury	T-Hg	<0.000005	<0.000005	<0.000005		
		APG Lot12455 #1	APG Lot12455 #2	APG Lot12455 #3	APG Lot12455 #4	APG Lot12455 Certified
<b>Total Metals</b>						
Arsenic	T-As	0.104	0.104	0.109	0.104	0.0961 ± 0.0163
Mercury	T-Hg	0.00117	0.00116	0.00115	0.00107	0.00124 ± 0.00057
		APG Lot12455 #5	APG Lot12455 #6	APG Lot12455 #7	APG Lot12455 #8	APG Lot12455 Certified
<b>Total Metals</b>						
Arsenic	T-As	0.0970	0.106	0.0960	0.103	0.0961 ± 0.0163
Mercury	T-Hg	0.00119	0.00123	0.00107	0.00130	0.00124 ± 0.00057
		APG Lot12455 #9	APG Lot12455 #10	APG Lot12455 #11	APG Lot12455 #12	APG Lot12455 Certified
<b>Total Metals</b>						
Arsenic	T-As	0.101	0.0900	0.0970	0.0930	0.0961 ± 0.0163
Mercury	T-Hg	0.00122	0.00132	0.00126	0.00112	0.00124 ± 0.00057

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

APG Lot 12455 is a Standard Reference Material from the Analytical Products Group.

## RESULTS OF ANALYSIS - QA Data - Spikes

File No. D8676

ARSENIC

Sample Identification	Spike Concentration (mg/L)	Sample Concentration (mg/L)	Sample + Spike Concentration Found (mg/L)	% Recovery
M3	0.010	<0.0005	0.0103	103
M11 FRep.	0.010	0.0435 <sup>1</sup>	0.0190	111
M12	0.010	0.0375 <sup>1</sup>	0.0184	112
M20	0.010	0.0016	0.0112	98
M25	0.010	0.0029	0.0120	94
M31	0.010	0.0022	0.0102	82
M36	0.010	<0.0005	0.0094	94
M53 FRep.	0.010	<0.0005	0.0090	90
M59	0.010	0.0053	0.0138	90

<sup>1</sup>These samples were diluted 5 times prior to spiking and analysis.  
Results are expressed as milligrams per litre.

< = Less than the detection limit indicated.

FRep. = Field Replicate.

**Section V**

**Batch #5 QA/QC Data**

		Method Blank #1	Method Blank #2	Method Blank #3	Method Blank #4		
<b>Total Metals</b>							
Arsenic	T-As	<0.0005	<0.0005	<0.0005	<0.0005		
Mercury	T-Hg	<0.00005	<0.00005	<0.00005	<0.00005		
		APG Lot12531 #1	APG Lot12531 #2	APG Lot12531 #3	APG Lot12531 Certified		
<b>Total Metals</b>							
Arsenic	T-As	0.208	0.200	0.200	0.189	± 0.053	
		APG Lot13072 #1	APG Lot13072 #2	APG Lot13072 #3	APG Lot13072 #4	APG Lot13072 Certified	
<b>Total Metals</b>							
Arsenic	T-As	0.014	0.013	0.013	0.012	0.0114 ± 0.00285	
		APG Lot12455 #1	APG Lot12455 #2	APG Lot12455 #3	APG Lot12455 #4	APG Lot12455 Certified	
<b>Total Metals</b>							
Mercury	T-Hg	0.00118	0.00120	0.00117	0.00119	0.00124 ± 0.00057	
		APG Lot12455 #5	APG Lot12455 #6	APG Lot12455 #7	APG Lot12455 Certified		
<b>Total Metals</b>							
Mercury	T-Hg	0.00118	0.00113	0.00114	0.00124	± 0.00057	

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

APG Lots 12531, 13072 and 12455 are Standard Reference Materials from the Analytical Products Group.

ARSENIC

Sample Identification	Spike Concentration (mg/L)	Sample Concentration (mg/L)	Sample + Spike Concentration Found (mg/L)	% Recovery
4a-10	0.0050	0.043	0.096	106
4a-16	0.0050	0.043	0.089	92
4a-24	0.0050	0.039	0.082	86
4a-37	0.0050	0.027	0.074	94
4a-49	0.0050	0.027	0.075	96

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Results are expressed as milligrams per litre.

**Section VI**

**Batch #6 QA/QC Data**

		Method Blank #1	Method Blank #2	Method Blank #3	Method Blank #4	
<b>Total Metals</b>						
Arsenic	T-As	<0.0005	<0.0005	<0.0005	<0.0005	
Mercury	T-Hg	<0.00005	<0.00005	<0.00005	<0.00005	
		APG Lot12531 #1	APG Lot12531 #2	APG Lot12531 #3	APG Lot12531 Certified	
<b>Total Metals</b>						
Arsenic	T-As	0.236	0.236	0.240	0.189	± 0.053
		APG Lot13072 #1	APG Lot13072 #2	APG Lot13072 #3	APG Lot13072 Certified	
<b>Total Metals</b>						
Arsenic	T-As	0.013	0.013	0.013	0.0114	± 0.00285
		APG Lot12455 #1	APG Lot12455 #2	APG Lot12455 #3	APG Lot12455 #4	APG Lot12455 Certified
<b>Total Metals</b>						
Mercury	T-Hg	0.00130	0.00131	0.00135	0.00130	0.00124 ± 0.00057
		APG Lot12455 #5	APG Lot12455 #6	APG Lot12455 Certified		
<b>Total Metals</b>						
Mercury	T-Hg	0.00134	0.00124	0.00124	0.00124	± 0.00057

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

APG Lots 12531, 13072 and 12455 are Standard Reference Materials from the Analytical Products Group.

ARSENIC

Sample Identification	Spike Concentration (mg/L)	Sample Concentration (mg/L)	Sample + Spike Concentration Found (mg/L)	% Recovery
4b-5	0.0050	0.102	0.139	74
4b-15	0.0050	0.050	0.097	94
4b-25	0.0050	0.038	0.077	78
4b-35	0.0050	0.037	0.098	122
4b-45	0.0050	0.040	0.101	122

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Results are expressed as milligrams per litre.



**Section VII**

**Batch #7 QA/QC Data**

		Method Blank #1	Method Blank #2	Method Blank #3	Method Blank #4		
<u>Total Metals</u>							
Arsenic	T-As	<0.0005	<0.0005	<0.0005	<0.0005		
Mercury	T-Hg	<0.00005	<0.00005	<0.00005	<0.00005		
		APG Lot12531 #1	APG Lot12531 #2	APG Lot12531 #3	APG Lot12531 Certified		
<u>Total Metals</u>							
Arsenic	T-As	0.216	0.206	0.214	0.189	± 0.053	
		APG Lot13072 #1	APG Lot13072 #2	APG Lot13072 #3	APG Lot13072 #4	APG Lot13072 Certified	
<u>Total Metals</u>							
Arsenic	T-As	0.012	0.012	0.012	0.012	0.0114 ± 0.00285	
		APG Lot12455 #1	APG Lot12455 #2	APG Lot12455 #3	APG Lot12455 #4	APG Lot12455 Certified	
<u>Total Metals</u>							
Mercury	T-Hg	0.00109	0.00117	0.00113	0.00119	0.00124 ± 0.00057	
		APG Lot12455 #5	APG Lot12455 #6	APG Lot12455 #7	APG Lot12455 Certified		
<u>Total Metals</u>							
Mercury	T-Hg	0.00110	0.00120	0.00114	0.00124	± 0.00057	

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

APG Lots 12531, 13072 and 12455 are Standard Reference Materials from the Analytical Products Group.

ARSENIC

Sample Identification	Spike Concentration (mg/L)	Sample Concentration (mg/L)	Sample + Spike Concentration Found (mg/L)	% Recovery
6a-9	0.0040	0.0009	0.0048	98
6a-10	0.0040	0.0006	0.0053	117
6a-25	0.0040	0.0011	0.0050	98
6a-35	0.0040	0.0043	0.0075	80
6a-44	0.0040	0.0068	0.0103	88

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Results are expressed as milligrams per litre.

**Section VIII**

**Batch #8 QA/QC Data**

RESULTS OF ANALYSIS - QA Data - Method Blanks/CRM's

File No. E2285

		Method Blank #1	Method Blank #2	Method Blank #3	Method Blank #4		
<b>Total Metals</b>							
Arsenic	T-As	<0.0005	<0.0005	<0.0005	<0.0005		
Mercury	T-Hg	<0.00005	<0.00005	<0.00005	<0.00005		
		<b>APG Lot12531 #1</b>	<b>APG Lot12531 #2</b>	<b>APG Lot12531 #3</b>	<b>APG Lot12531 Certified</b>		
<b>Total Metals</b>							
Arsenic	T-As	0.206	0.216	0.214	0.189	± 0.053	
		<b>APG Lot13072 #1</b>	<b>APG Lot13072 #2</b>	<b>APG Lot13072 #3</b>	<b>APG Lot13072 #4</b>	<b>APG Lot13072 Certified</b>	
<b>Total Metals</b>							
Arsenic	T-As	0.012	0.012	0.012	0.012	0.0114 ± 0.00285	
		<b>APG Lot12455 #1</b>	<b>APG Lot12455 #2</b>	<b>APG Lot12455 #3</b>	<b>APG Lot12455 #4</b>	<b>APG Lot12455 Certified</b>	
<b>Total Metals</b>							
Mercury	T-Hg	0.00114	0.00116	0.00112	0.00114	0.00124 ± 0.00057	
		<b>APG Lot12455 #5</b>	<b>APG Lot12455 #6</b>	<b>APG Lot12455 #7</b>	<b>APG Lot12455 Certified</b>		
<b>Total Metals</b>							
Mercury	T-Hg	0.00112	0.00109	0.00111	0.00124	± 0.00057	

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

APG Lots 12531, 13072 and 12455 are Standard Reference Materials from the Analytical Products Group.

ARSENIC

Sample Identification	Spike Concentration (mg/L)	Sample Concentration (mg/L)	Sample + Spike Concentration Found (mg/L)	% Recovery
6b-10	0.0040	0.0006	0.0054	120
6b-20	0.0040	0.0025	0.0062	93
6b-29	0.0040	0.0024	0.0064	100
6b-40	0.0040	0.0056	0.0091	88
6b-50	0.0040	0.0056	0.0088	80

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Results are expressed as milligrams per litre.

**Section IX**

**Batch #9 QA/QC Data**

		Method Blank #1	Method Blank #2	Method Blank #3	Method Blank #4		
<u>Total Metals</u>							
Arsenic	T-As	<0.0005	<0.0005	<0.0005	<0.0005		
Mercury	T-Hg	<0.00005	<0.00005	<0.00005	<0.00005		
		APG Lot12531 #1	APG Lot12531 #2	APG Lot12531 #3	APG Lot12531 Certified		
<u>Total Metals</u>							
Arsenic	T-As	0.206	0.190	0.198	0.189	± 0.053	
		APG Lot13072 #1	APG Lot13072 #2	APG Lot13072 #3	APG Lot13072 #4	APG Lot13072 Certified	
<u>Total Metals</u>							
Arsenic	T-As	0.012	0.012	0.012	0.012	0.0114 ± 0.00285	
		APG Lot12455 #1	APG Lot12455 #2	APG Lot12455 #3	APG Lot12455 #4	APG Lot12455 Certified	
<u>Total Metals</u>							
Mercury	T-Hg	0.00122	0.00119	0.00116	0.00119	0.00124 ± 0.00057	
		APG Lot12455 #5	APG Lot12455 #6	APG Lot12455 #7	APG Lot12455 Certified		
<u>Total Metals</u>							
Mercury	T-Hg	0.00120	0.00117	0.00115	0.00124	± 0.00057	

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

APG Lots 12531, 13072 and 12455 are Standard Reference Materials from the Analytical Products Group.



ARSENIC

Sample Identification	Spike Concentration (mg/L)	Sample Concentration (mg/L)	Sample + Spike Concentration Found (mg/L)	% Recovery
7a-9	0.0040	<0.0005	0.0045	113
7a-20	0.0040	<0.0005	0.0045	113
7a-29	0.0040	0.0013	0.0057	110
7a-40	0.0040	0.0051	0.0084	83
7a-50	0.0040	0.0123	0.0152	73

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

**Section X**

**Batch #10 QA/QC Data**

		Method Blank #1	Method Blank #2	Method Blank #3	Method Blank #4	
<b>Total Metals</b>						
Arsenic	T-As	<0.0005	<0.0005	<0.0005	<0.0005	
Mercury	T-Hg	<0.00005	<0.00005	<0.00005	<0.00005	
		APG Lot12531 #1	APG Lot12531 #2	APG Lot12531 #3	APG Lot12531 Certified	
<b>Total Metals</b>						
Arsenic	T-As	0.206	0.190	0.198	0.189	± 0.053
		APG Lot13072 #1	APG Lot13072 #2	APG Lot13072 #3	APG Lot13072 #4	APG Lot13072 Certified
<b>Total Metals</b>						
Arsenic	T-As	0.012	0.012	0.012	0.012	0.0114 ± 0.00285
		APG Lot12455 #1	APG Lot12455 #2	APG Lot12455 #3	APG Lot12455 #4	APG Lot12455 Certified
<b>Total Metals</b>						
Mercury	T-Hg	0.00117	0.00109	0.00113	0.00106	0.00124 ± 0.00057
		APG Lot12455 #5	APG Lot12455 #6	APG Lot12455 Certified		
<b>Total Metals</b>						
Mercury	T-Hg	0.00113	0.00105	0.00124 ± 0.00057		

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

APG Lots 12531, 13072 and 12455 are Standard Reference Materials from the Analytical Products Group.

ARSENIC

Sample Identification	Spike Concentration (mg/L)	Sample Concentration (mg/L)	Sample + Spike Concentration Found (mg/L)	% Recovery
7b-10	0.0040	<0.0005	0.0038	96
7b-20	0.0040	<0.0005	0.0040	100
7b-29	0.0040	0.0009	0.0046	93
7b-40	0.0040	0.0122	0.0152	73
7b-50	0.0040	0.0100	0.0133	83

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

**BUTTLE LAKE**

**SEDIMENT**

**QA/QC DATA**

## **QUALITY ASSURANCE/QUALITY CONTROL (QA/QC) RESULTS AND DISCUSSION FOR SEDIMENT SAMPLES**

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  $\pm 10\%$  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  $\pm 15\%$  of a calculated mean.
- Reference Material - 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.

None of the tested parameters were detected in any of the Method Blanks indicating good contamination control throughout this project. All replicate results agreed to within  $\pm 15\%$  of a calculated mean, demonstrating good precision for all parameters tested.

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

- Aluminum results for all of the NRC MESS-2 and three of the four NRC BCSS-1 samples.
- Arsenic results for two of the four NRC MESS-2 and two of the four NRC BCSS-1 samples.
- Cadmium results for one of the four NRC BCSS-1 samples.
- Chromium results for all of the NRC BCSS-1 and all of the NRC PACS-1 samples.
- Iron results for all of the NRC PACS-1 samples.
- Magnesium results for all of the NRC BCSS-1 samples.
- Nickel results for three of the four NRC MESS-2 samples and all of the NRC PACS-1 samples.
- Sodium results for one of the two NRC PACS-1 samples.
- Zinc results for one of the two NRC PACS-1 samples.

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.

		Method Blank #1 94 03 15	Method Blank #2 94 03 15	Method Blank #3 94 03 15	Method Blank #4 94 03 18
<b>Total Metals</b>					
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.



		Method Blank #5 94 03 18	Method Blank #6 94 03 18	Method Blank #7 94 03 18
<hr/>				
<b>Total Metals</b>				
Aluminum	T-Al	<50	<50	<50
Arsenic	T-As	<0.10	<0.10	<0.10
Cadmium	T-Cd	<0.10	<0.10	<0.10
Chromium	T-Cr	<2.0	<2.0	<2.0
Cobalt	T-Co	<2.0	<2.0	<2.0
Copper	T-Cu	<1.0	<1.0	<1.0
Iron	T-Fe	<50	<50	<50
Lead	T-Pb	<2.0	<2.0	<2.0
Magnesium	T-Mg	<50	<50	<50
Manganese	T-Mn	<0.10	<0.10	<0.10
Mercury	T-Hg	<0.005	<0.005	<0.005
Nickel	T-Ni	<2.0	<2.0	<2.0
Potassium	T-K	<250	<250	<250
Sodium	T-Na	<250	<250	<250
Zinc	T-Zn	<1.0	<1.0	<1.0

---

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

		NRC MESS-2 #1 94 03 15	NRC MESS-2 #2 94 03 15	NRC MESS-2 #3 94 03 15	NRC MESS-2 #4 94 03 24	NRC MESS-2 Certified
<b>Total Metals</b>						
Aluminum	T-Al	89500	89300	88900	89500	85700 ± 2590
Arsenic	T-As	19.5	19.6	19.6	21.5	20.7 ± 0.8
Cadmium	T-Cd	0.23	0.25	0.25	0.25	0.24 ± 0.01
Chromium	T-Cr	107	107	112	103	106 ± 8
Cobalt	T-Co	13.6	14.0	14.1	14.4	13.8 ± 1.4
Copper	T-Cu	38.2	40.6	37.3	39.4	39.3 ± 2.0
Iron	T-Fe	42200	42100	42300	41800	43500 ± 2170
Lead	T-Pb	21.0	20.8	21.3	20.8	21.9 ± 1.2
Manganese	T-Mn	368	355	346	366	365 ± 21
Mercury	T-Hg	0.086	0.100	0.089	0.091	0.092 ± 0.009
Nickel	T-Ni	47.3	46.8	47.1	50.7	49.3 ± 1.8
Zinc	T-Zn	172	163	159	173	172 ± 16

---

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 BCSS-1 #1 94 03 15	NRC BCSS-1 #2 94 03 15	NRC BCSS-1 #3 94 03 24	NRC BCSS-1 Certified
<b>Total Metals</b>					
Aluminum	T-Al	65900	65200	64400	65800 ± 2200
Arsenic	T-As	10.2	9.74	9.10	11.1 ± 1.4
Cadmium	T-Cd	0.23	0.23	0.23	0.25 ± 0.04
Chromium	T-Cr	103	107	102	123 ± 14
Cobalt	T-Co	12.6	13.0	11.4	11.4 ± 2.1
Copper	T-Cu	16.7	18.0	17.2	18.5 ± 2.7
Iron	T-Fe	33900	33100	33000	32900 ± 1000
Lead	T-Pb	22.5	22.5	22.5	22.7 ± 3.4
Magnesium	T-Mg	12800	12600	12800	14700 ± 1400
Manganese	T-Mn	232	224	221	229 ± 15
Nickel	T-Ni	56.7	54.5	55.1	55.3 ± 3.6
Potassium	T-K	18000	18200	18100	18000 ± 300
Sodium	T-Na	20200	19200	20000	20200 ± 1600
Zinc	T-Zn	117	120	126	119 ± 12

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 PACS-1 #1 94 03 15	NRC PACS-1 #2 94 03 24	NRC PACS-1 Certified
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**Total Metals**

Aluminum	T-Al	64900	65100	64700 ± 1160
Arsenic	T-As	233	205	211 ± 11
Cadmium	T-Cd	2.30	2.30	2.38 ± 0.20
Chromium	T-Cr	102	101	113 ± 8
Cobalt	T-Co	18.0	18.4	17.5 ± 1.1
Copper	T-Cu	468	414	452 ± 16
Iron	T-Fe	47600	47800	48700 ± 800
Lead	T-Pb	404	389	404 ± 20
Mercury	T-Hg	4.47	4.70	4.57 ± 0.16
Nickel	T-Ni	41.2	41.8	44.1 ± 2.0
Potassium	T-K	12300	11800	12500 ± 700
Sodium	T-Na	31900	31400	32600 ± 800
Zinc	T-Zn	859	831	824 ± 22

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Results for Total Metals are expressed as milligrams per dry kilogram.

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

## Appendix A2 - UBC QA/QC

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

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### 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<sub>3</sub>); 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 continuously 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).**

<b>Standard</b>	<b>Fe</b>	<b>Mn</b>	<b>Zn</b>	<b>Cu</b>	<b>Pb</b>	<b>Cd</b>
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 Appendix B. 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 reflect 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.

**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)**

<b>Metal</b>	<b>Detection Limit (ppb)</b>
Fe	1.8
Mn	1.6
Zn	0.5
Cu	0.12
Pb	0.03
Cd	0.024

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

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.



## **Appendix A3 - NWRI QA/QC Assessment**

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

**BUTTLE LAKE (FALL SURVEY) MEND PROJECT 2.11**

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

December 1994

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## 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 the 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), 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 results for **copper** were quite reasonable with no data flagged at either three or five standard deviations.
- The concentrations of **cadmium** were too low to be detected by ASL. The only sample (M112) with a sufficient concentration had very comparable data.
- For **zinc**, 6 of 19 results were flagged at three standard deviations and 3 of 19 results were flagged at five standard deviations.
- No data for **lead** were flagged. This appears quite satisfactory, although the graphical comparison of data (Appendix A) clearly reveals a slight bias. Either ASL data is biased high or the UBC is biased low.
- For **iron and manganese**, the data were quite scattered with extreme values reported by both laboratories. One half of all data were flagged at five standard deviations. The comparability is poor and a review is in order.
- For a visual snapshot on comparability, the reader should review the graphs in Appendix A.

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## **(1) INTRODUCTION**

This report has been prepared to respond to the question on the comparability of data from the two laboratories that created data for Buttle Lake on Vancouver Island. 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 five to fifteen percent of the samples received for the Buttle Lake project were analyzed by the two different laboratories. These samples, referred to as the exchange samples, were first analyzed by UBC and then sent to ASL as blind samples for reanalysis.

Only the total metals data are the focus of this report since only these data were provided by these two laboratories.

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

To assess whether two laboratories are comparable, the authors:

- transcribed the original exchange sample data into a simple tabular form, (see Table 2),
- prepared a graphical comparison of one laboratory's data against the other laboratory's data (see Appendix A) and
- and used the historical data from round robins to decide if each pair of exchange sample data were considered similar, (see Appendix B and 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 in 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 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. It is safe to say that no laboratory would normally report data that is highly inaccurate or biased.

### (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
Cadmium	PW	GFAAS	0.2	ICP - MS	Unknown
Zinc	PW	GFAAS	1.0	ICP - MS	Unknown
Lead	PW	GFAAS	0.5	ICP - MS	Unknown
Iron	PW	GFAAS	3.0	GFAAS	Unknown
Manganese	PW	GFAAS	1.0	GFAAS	Unknown

PW = pore or peeper water

#### 3.2 Results Reported for Exchange Samples

It is understood that UBC made the initial analysis of the pore water samples and on completion sent these to ASL for reanalysis. This process is referred as the exchange samples, the results for which are tabulated below in Table 2.

**TABLE 2: COMPARISON OF SPLIT SAMPLE DATA (PORE AND PEEPER WATERS)  
BUTTLE LAKE FALL SURVEY (Dissolved Metals)**

Sample I.D.		Metal Concentrations (as PPB)					
		Cu	Cd	Zn	Pb	Fe	Mn
M1	UBC	1.2	0.03	10	0.1	15.	<1.6
	ASL	1.	<0.2	9	<0.5	3.	2
M7	UBC	1.0	0.03	7.9	0.1	5/5	<1.6
	ASL	4.	<0.2	7.	<0.5	10.	1.
M9	UBC	1.1	0.03	7.5	0.1	6	<1.6
	ASL	2.	<0.2	7.	<0.5	20	2.
M30	UBC	20.0	<0.024	2.7	8.2	1640/1800	107.
	ASL	24	<0.2	2.	15.	2000	100.
M37	UBC	1.1	0.03	8.2	0.1	6	<1.6
	ASL	2	<0.2	7.	2.	46.	17.
M54	UBC	1.1	<0.024	1.7	0.2	26	13.
	ASL	2	<0.2	1.	<0.5	8	2.
M58	UBC	1.6/1.5	<0.024/<0.024	1.5/1.4	0.9/0.9	80	56
	ASL	3.	<0.2	5.	3.	180	60
M60	UBC	8.9	0.03	2.3	5.0	900/930	97
	ASL	13.	<0.2	2.	10.	1000	100
M69	UBC	1.1	<0.024	83	0.6	540	7,750
	ASL	1.	<0.2	<1	2.	10,000	10,000
M72	UBC	1.0	<0.024	57	1.0	9,730	11,850
	ASL	1.	<0.2	40	2.0	47,000	10,000
M73	UBC	1.7	<0.024	82	2.0	9,990	13,000
	ASL	2.	<0.2	70	4.	60	11,000
M88	UBC	1.7/1.7	<0.024/0.03	299/304	4.3/4.2	43,300	10,750
	ASL	1.	<0.2	100	6.	10,000	10,000
M90	UBC	1.7	<0.024	262	3.3	43,200	12,200
	ASL	1.	<0.2	100	5.	32,000	10,000
M98	UBC	2.3	0.2	121	0.8	61/65	1,220
	ASL	3.	<0.2	100	1.	400	4,000

continued/

		<b>Cu</b>	<b>Cd</b>	<b>Zn</b>	<b>Pb</b>	<b>Fe</b>	<b>Mn</b>
M99	UBC	1.1	0.04	50	0.5	325	4,750
	ASL	1.	<0.2	30	0.5	80	1,300
M112	UBC	3.7	1.	503	2.9	33,000	10,700
	ASL	3.	0.9	700	5.	46,000	7,000
M118	UBC	1.4/1.4	<0.024	235/234	3.9	45,300	11,600
	ASL	1.	<0.2	100	5.	300	60
M146	UBC	1.5	0.07	7.7	1.3	111	56/64
	ASL	1.	<0.2	7.	2.	45,000	11,000
M176	UBC	2.4	0.09	8.5	1.1	46.	288/275
	ASL	3.	<0.2	9.	1.	70	45.
M178	UBC	1.3/1.3	0.08/0.08	9.2/9.1	2.0/2.0	55	37
	ASL	2.	<0.2	9.	4	80	400



#### (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 process or the contaminants introduced in handling that contributed to the often large differences seen in the paired data.

The ICP-MS method is clearly the more sensitive instrument and can provide estimates on the low concentrations of Cd, Cu, Pb and Zn.

##### 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 is found in Table 2. 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 format in Appendix A is a more effective means of comparing the laboratory data. It is particularly evident that the data for iron and manganese are not comparable for over half of the samples.

The data for iron and manganese are graphed with two scales to visualize the low and the high ranges. Either way, the graphics illustrate a problem in the comparability.

The comparability of data for copper, cadmium, zinc and lead is quite reasonable.

Lead presents an interesting situation. There were no flags assigned. However, it is visusly clear that the data are slightly biased with either ASL biased high or UBC biased low.

### 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, which are based on large volume freshwater samples. The summary of the process is tabulated in Appendix C. The authors have chosen a conservative approach with 5 standard deviations in order to reflect the greater uncertainty normally seen in graphite atomic absorption spectroscopy compared to flame AAS.

If the difference for the data are greater than five standard deviations then the pair of data were considered as not comparable.

A summary of the flagged data is given below in Table 3. The results for iron and manganese clearly indicate that most of the data were not comparable.

**Table 3: Summary of Flagged or Non-Comparable Data**

METAL	NUMBER OF PAIRED RESULTS AVAILABLE **	NUMBER OF FLAGS ASSIGNED
Cu	20	0 flags
Cd	1 **	0 flags
Zn	19	3 flags (16%)
Pb	16	0 flags
Fe	20	10 flags (50%)
Mn	16	8 flags (50%)

**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. Refer to Appendix A for a visual comparison of data and Appendix C for the details on the calculations of non comparable data.

### **(5) SUMMARY OVERVIEW**

This report concludes that most of the trace metal data for the exchange samples analyzed by the two MEND laboratories (UBC and ASL) were 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 the 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), 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 results for **copper** were quite reasonable with no data flagged at either three or five standard deviations.
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- No data for **lead** were flagged. This appears quite satisfactory, although the graphical comparison of data (Appendix A) clearly reveals a slight bias. Either ASL data is biased high or the UBC is biased low.
- For **Iron and manganese**, the data were quite scattered with extreme values reported by both laboratories. One half of all data were flagged at five standard deviations. The comparability is poor and a review is in order.
- For a visual snapshot on comparability, the reader should review the graphs in Appendix A.

## (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.

- American Society for Testing and Materials. 1983. Intralaboratory Quality Control Procedures and a Discussion on Reporting Low Level Data. A Standard Practise. (ASTM-D19, D4210-83 Philadelphia, Pa.)
- Aspila, K.I., R.E. White and J. Clark. 1985. Quality Assurance Aspects of the International Joint Commission Great Lakes Monitoring Program. Am. Soc. Test. Mater. Spec. Tech. Publ. 867: 407-421.
- Brossman, M.W., T.J. Hoogbeem, and R.C. Splinter. 1982. Quality assurance project plans: a key to effective cooperative monitoring programs. Am. Soc. Test. Mater. Spec. Tech. Publ. 867: 53-61
- "Geochemical Assessment of Subaqueous Tailings Disposal in Anderson Lake, Manitoba - 1993 Study Program", prepared by Rescan Environmental Services Ltd., Vancouver, BC, July 1994.
- Hunter, J.S. 1980. National system of scientific measurement. Science 210: 869-874.

- King, D. 1985. Quality Management Plans. Laboratory Services Branch, Ontario Ministry of Environment and Energy, Rexdale, Ontario.
- King, D. 1986. Quality Assurance Policy and Guidelines. Laboratory Services Branch, Ontario Ministry of Environment and Energy, Rexdale, Ontario
- Lawrence, J., A.S.Y. Chau and K.I. Aspila. 1982. Analytical Quality Assurance: key to reliable environmental data. Can. Res. 15(7): 35-47.
- "Quality Assurance in Water Quality Monitoring", Ecosystem Sciences and Evaluation Directorate, Environment Canada. 1993. Canada Communications Group, Ottawa, Ontario, Catalogue No. EN40-448/1993E.
- Taylor, J.K. 1987 Quality Assurance of Chemical Measurements. Lewis Publishers, Chelsea, Mich.
- Youden, W.J. 1969. Ranking laboratories by round robin test. Natl. Bur. Stand. (U.S.) Spec. Publ. 300 (1): 165-9-159-13
- 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.**

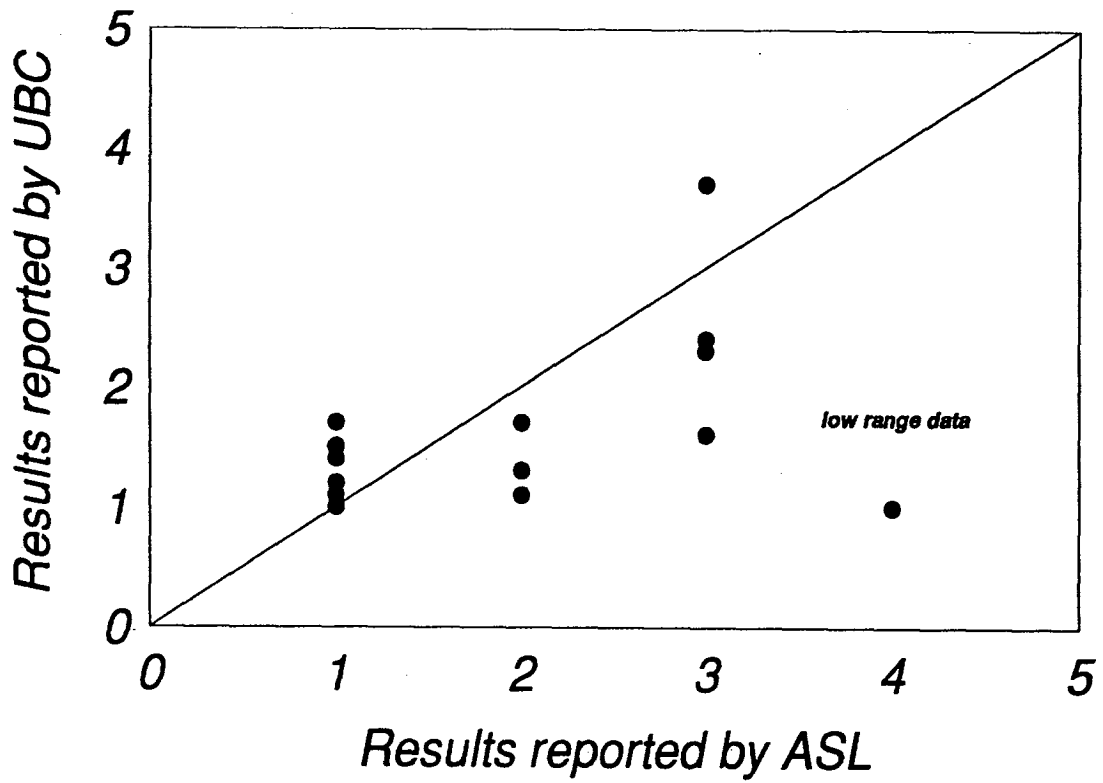
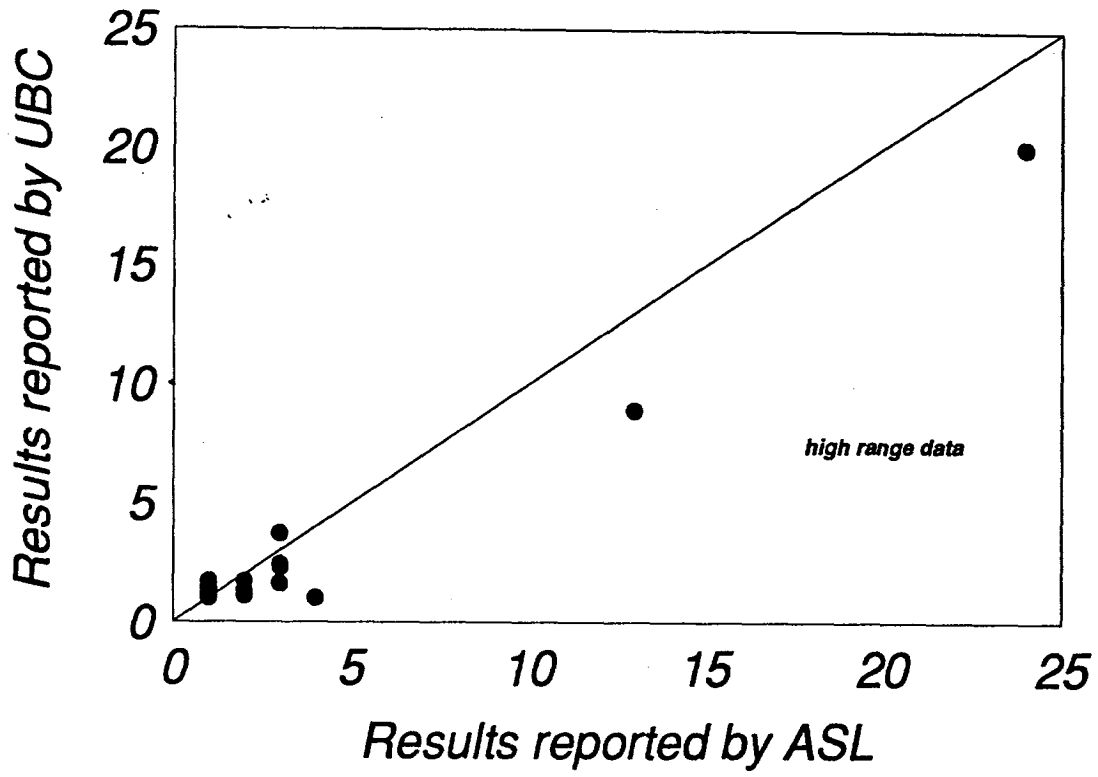
The following six Figures illustrate in a graphic format how the data reported by UBC relate to the data reported by ASL.

When one laboratory reports a "less than value", no point for that sample appears on the figure.

Note: All data in these figures have concentration units of ppb, with the exception of iron and manganese where the high range concentrations are expressed as thousands of ppb.

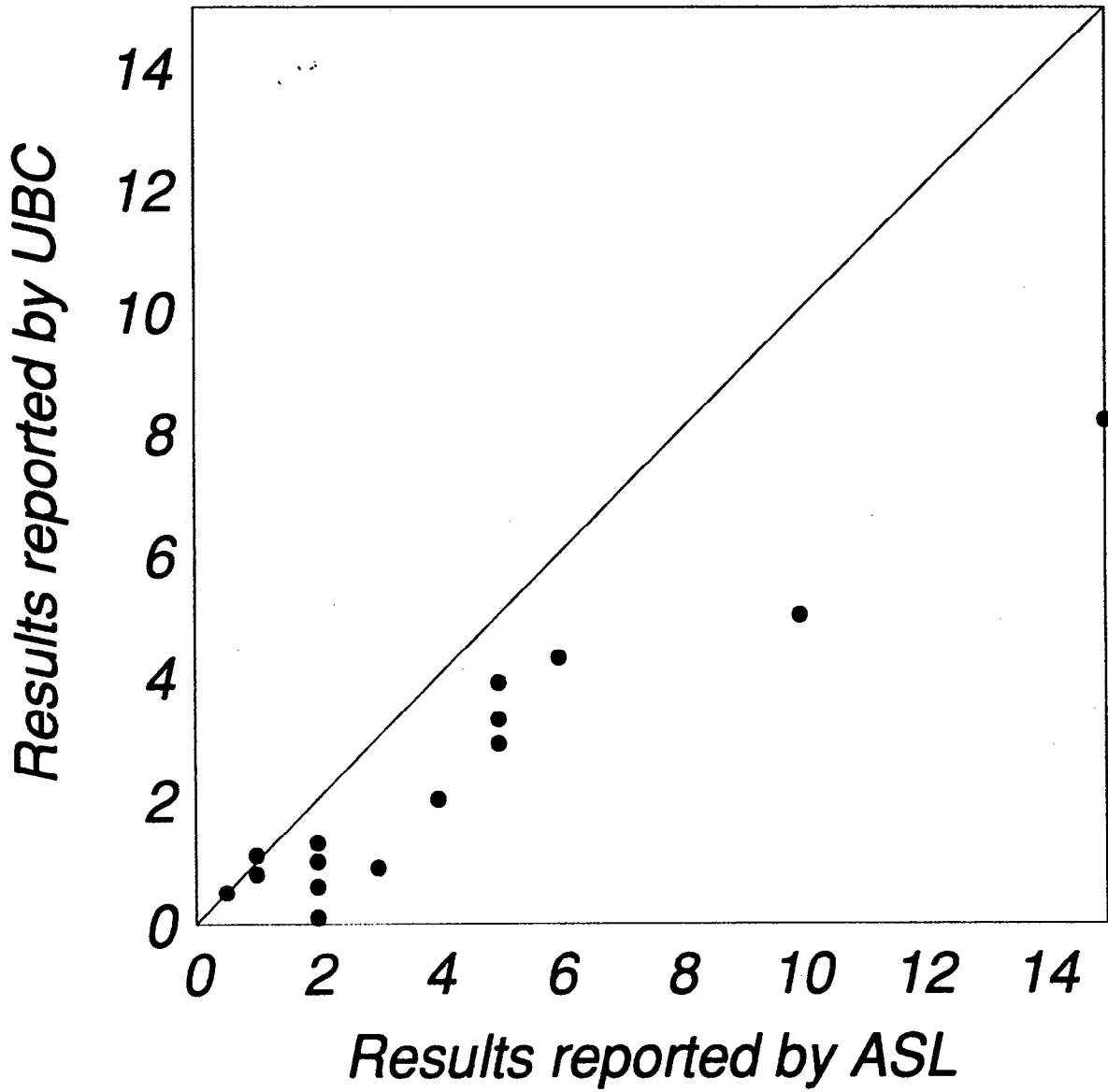
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*Pore & Peeper Waters*



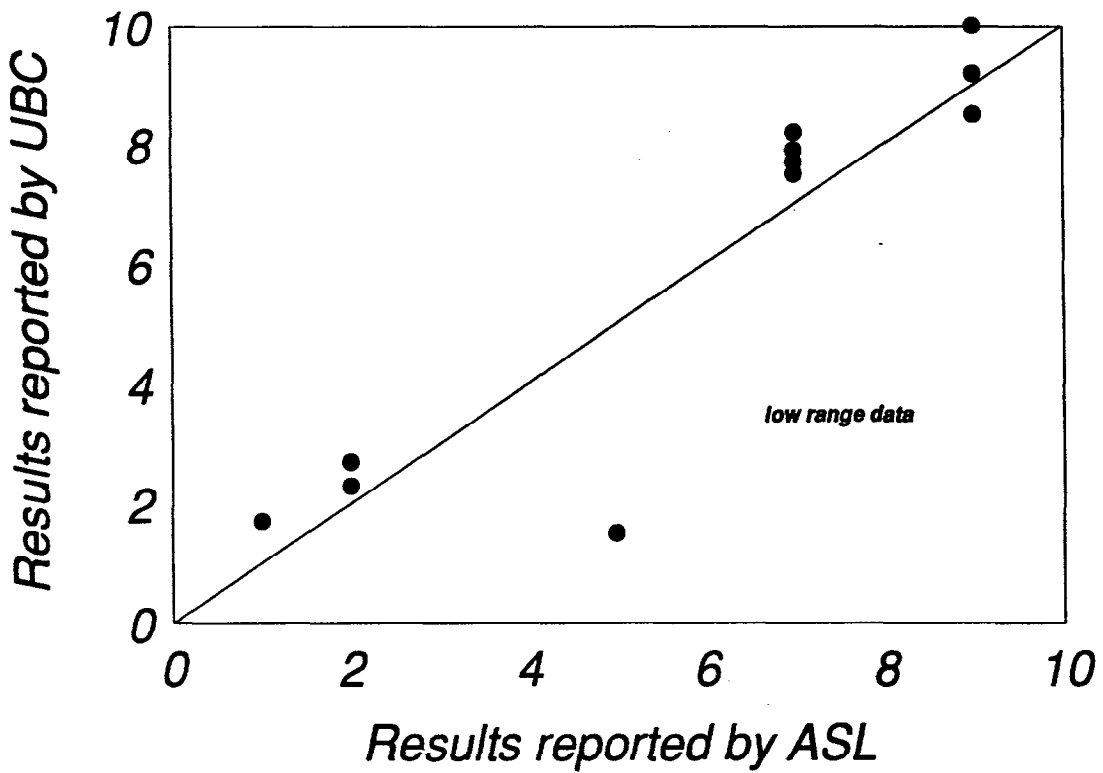
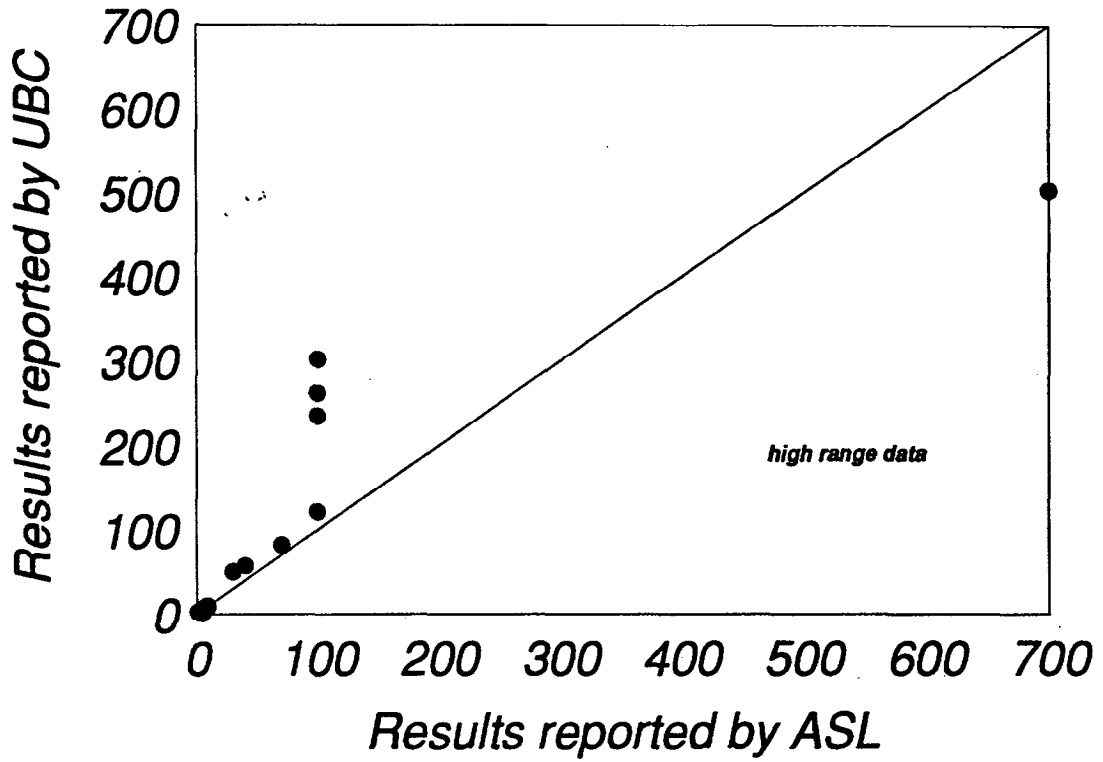
# LEAD

*Pore & Peeper Waters*



# ZINC

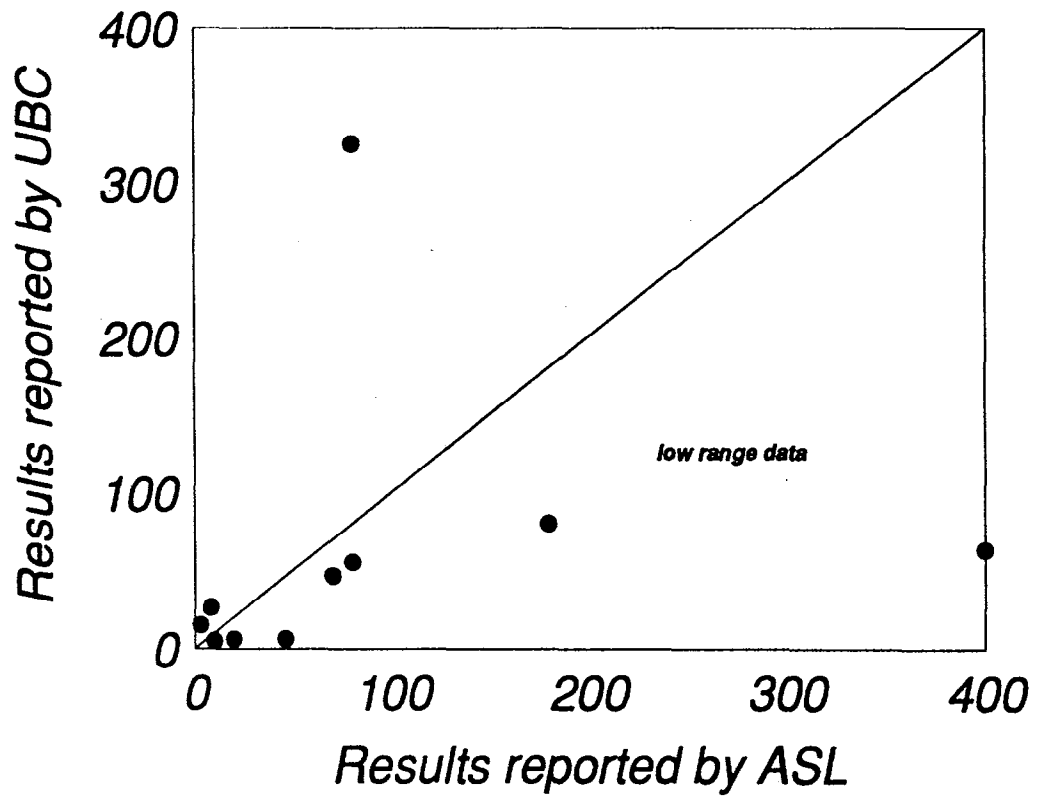
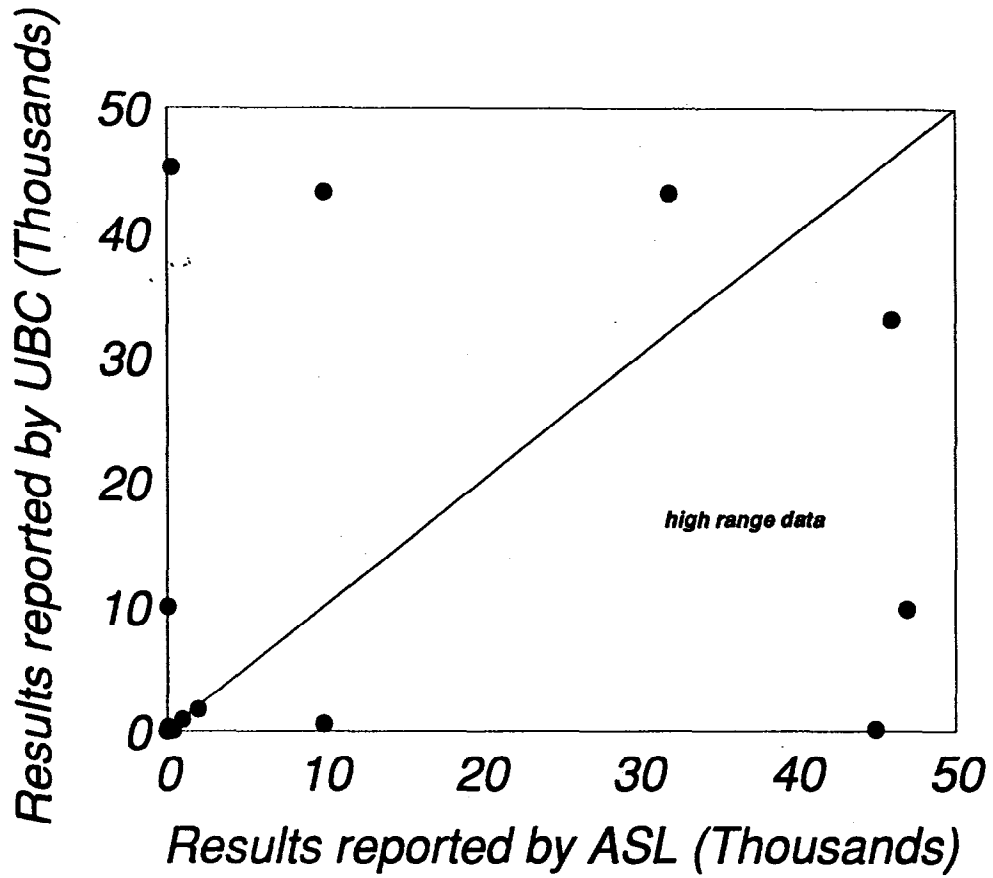
*Pore & Peeper Waters*





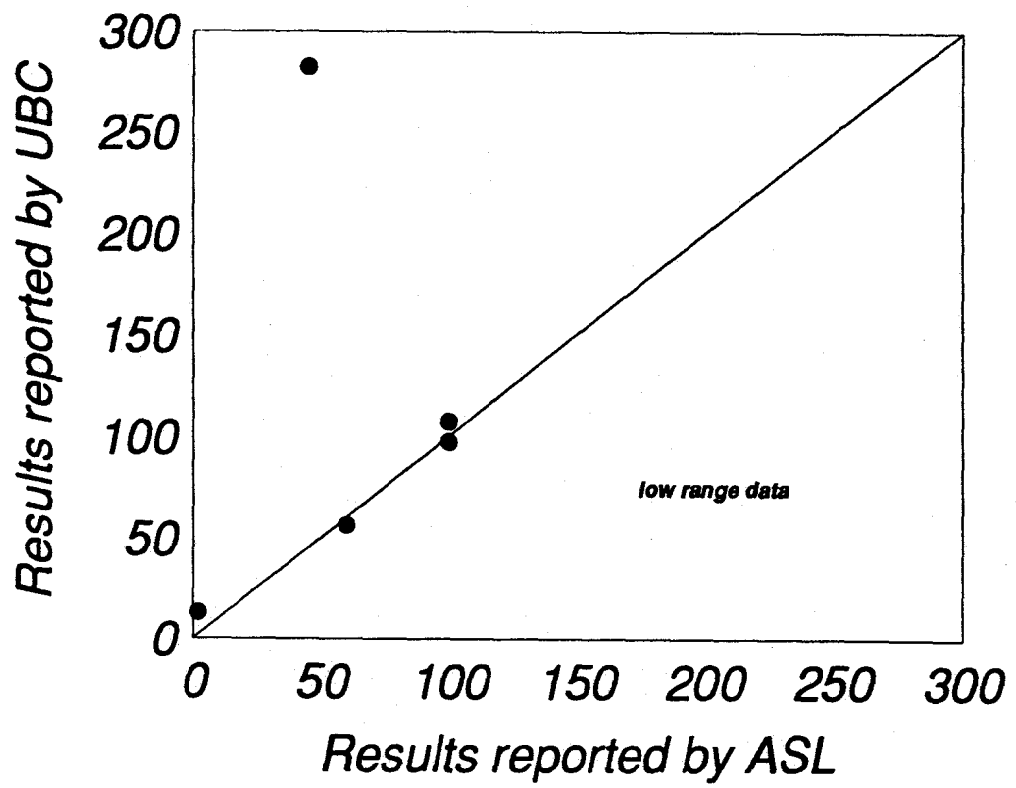
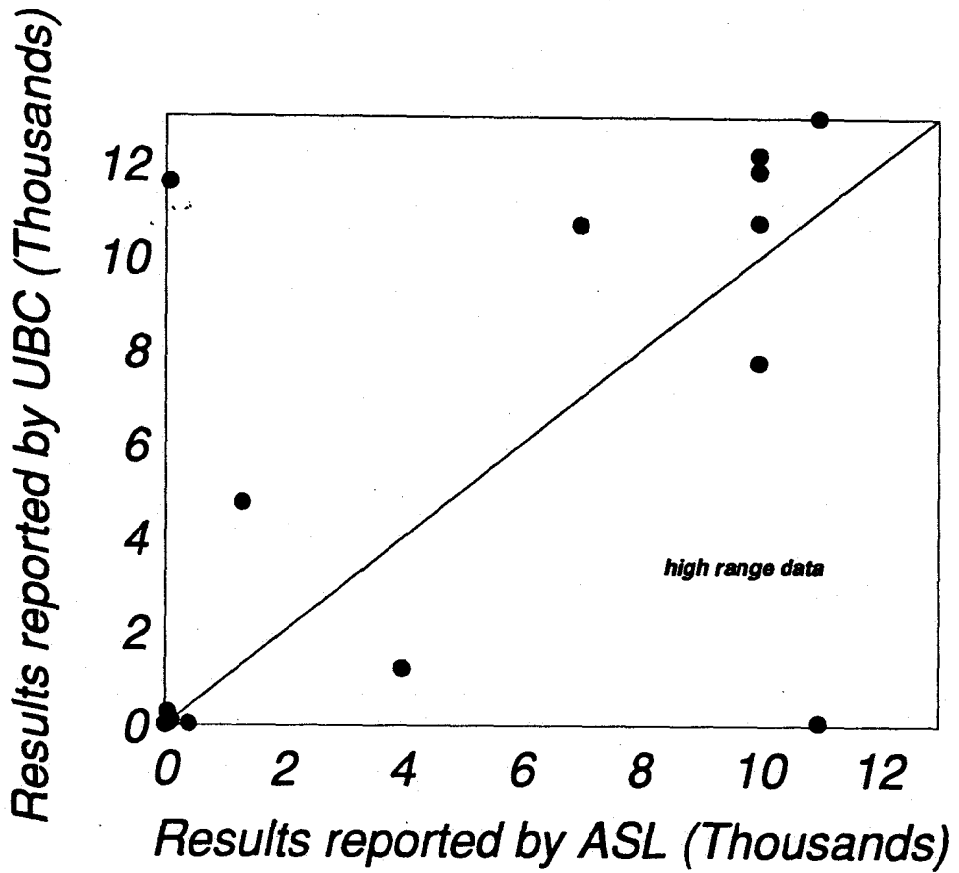
# IRON

*Pore & Peeper Waters*



# MANGANESE

*Pore & Peeper Waters*



**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 B: Precision Functions Derived from NWRI QA Studies for Some Metals in Water**

Metal	Group of Data	Equation of the Precision Function	Correlation Coefficient	Range (ppb)
		$y = mx + b$	"r"	
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.

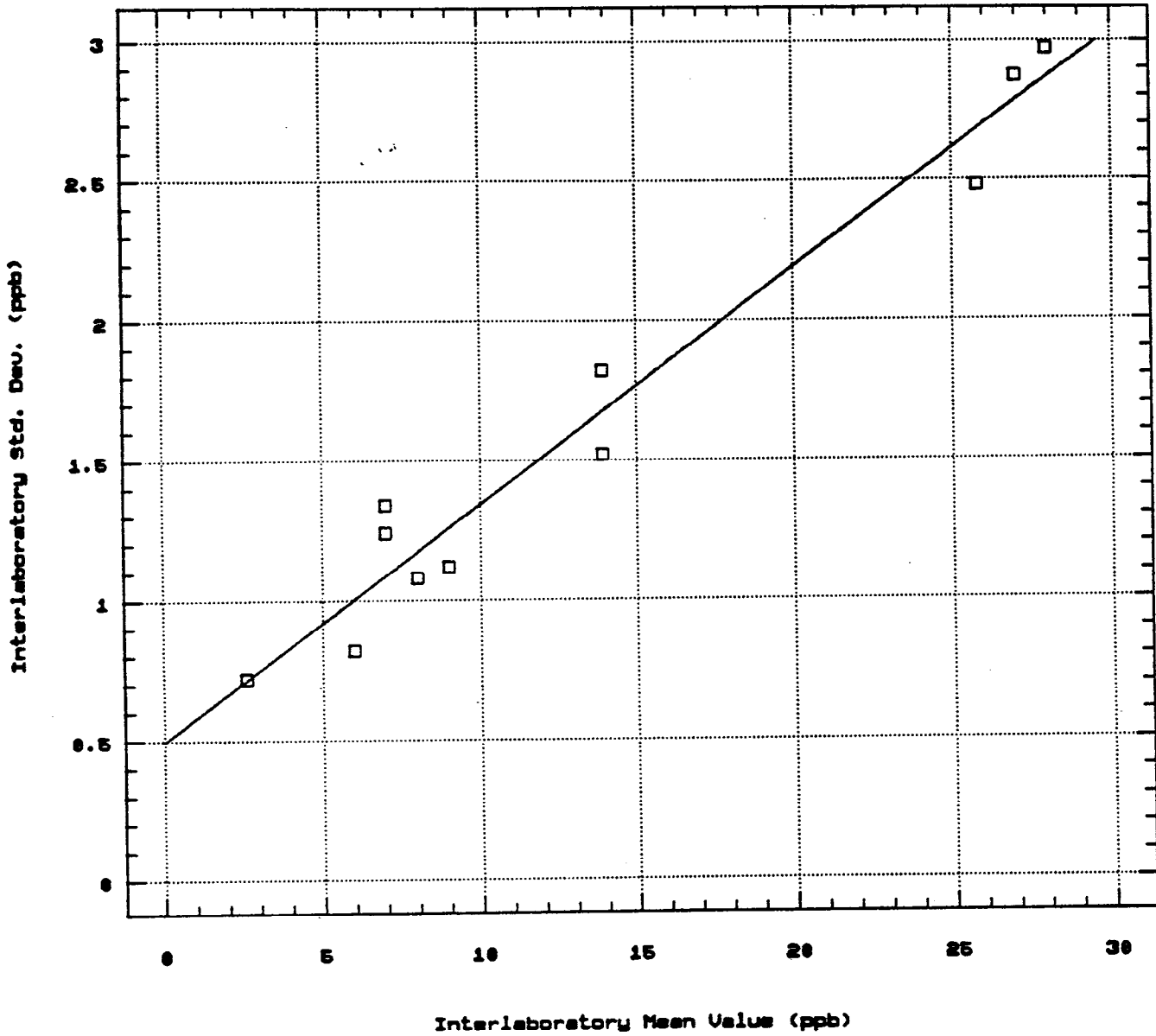
The above equations were derived from the same series of NWRI interlaboratory studies. (20 samples and about 30 different laboratories). Three files of data were selected in developing a criteria. These selections were:

**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.

# Copper In Water



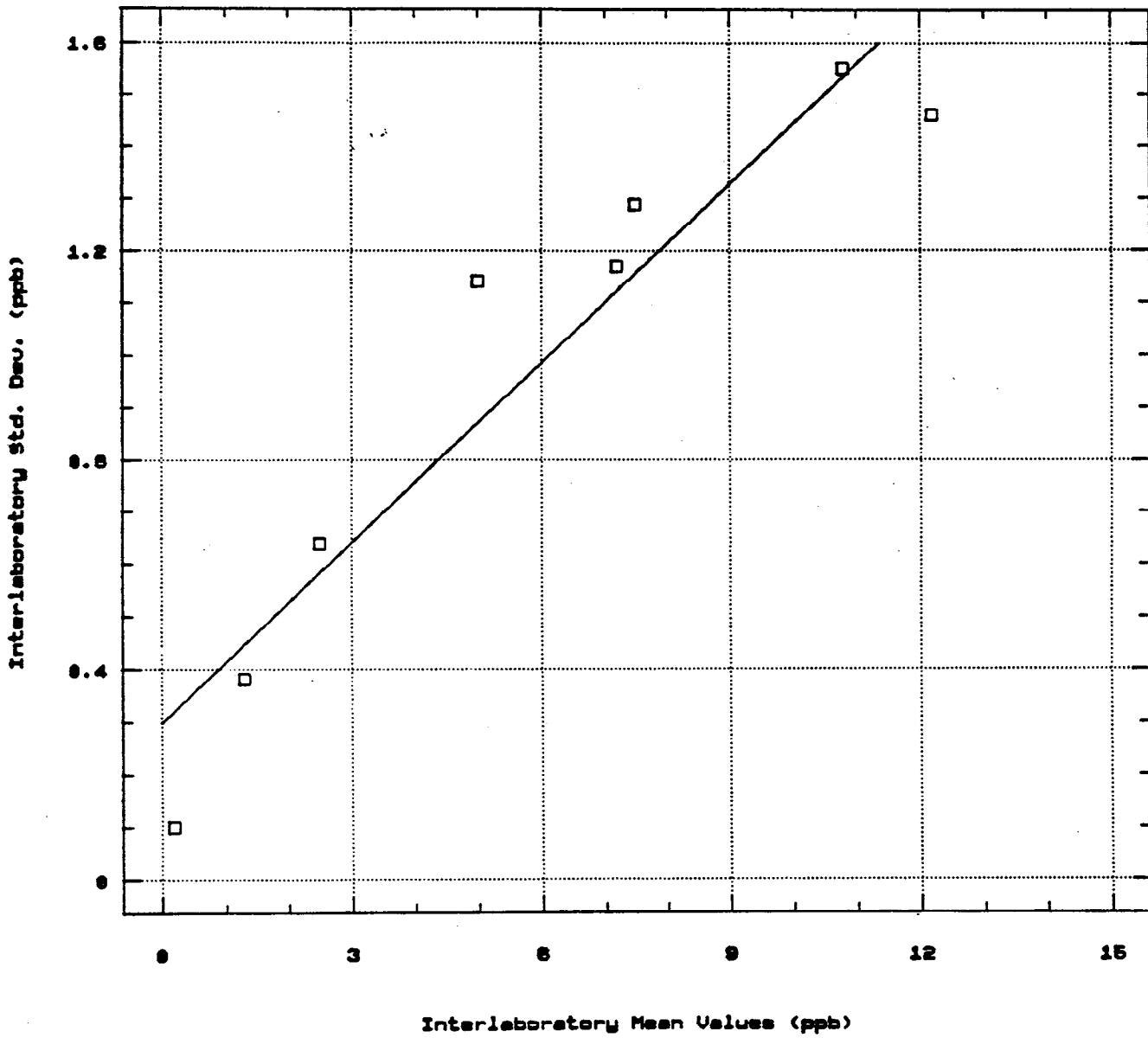
B0: 0.4927 SE: 0.092032 T: 5.3535

B1: 0.004753 SE: 5.7168E-3 T: 14.025

CORR: 0.98013 MSE: 0.027915 DF: 9

POINTS DELETED:

# Cadmium In Water



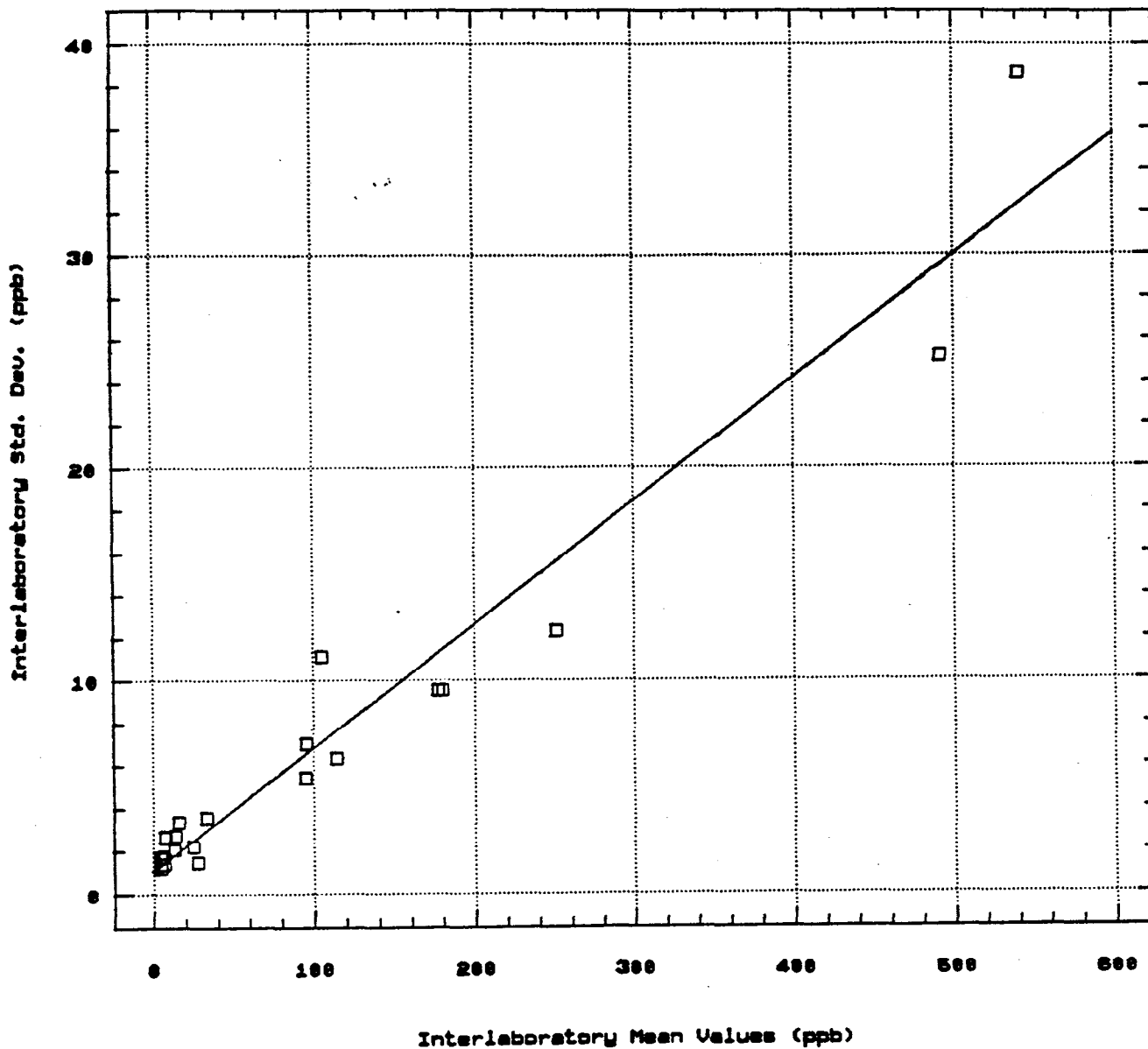
B0: 0.29763 SE: 0.1137 T: 2.6177

B1: 0.11454 SE: 0.01595 T: 7.1612

CORR: 0.94646 MSE: 0.034073 DF: 6

POINTS DELETED:

# Zinc In Water



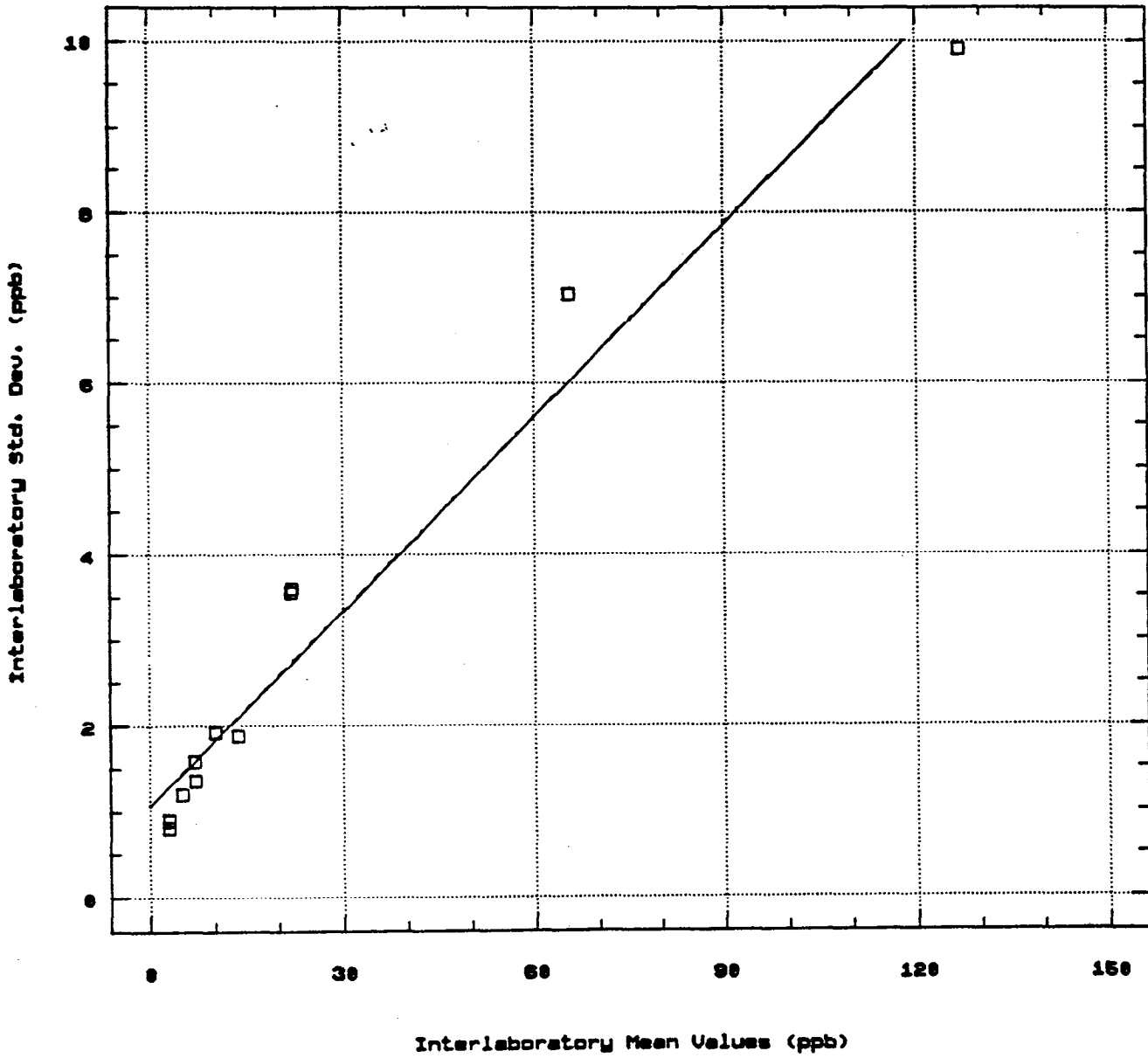
S0: 1.0398 SE: 0.65058 T: 1.5983

S1: 0.057837 SE: 3.4573E-3 T: 16.729

CORR: 0.96931 MSE: 5.5344 DF: 18

POINTS DELETED:

# Lead In Water



S0: 1.0667 SE: 0.21448 T: 4.9733

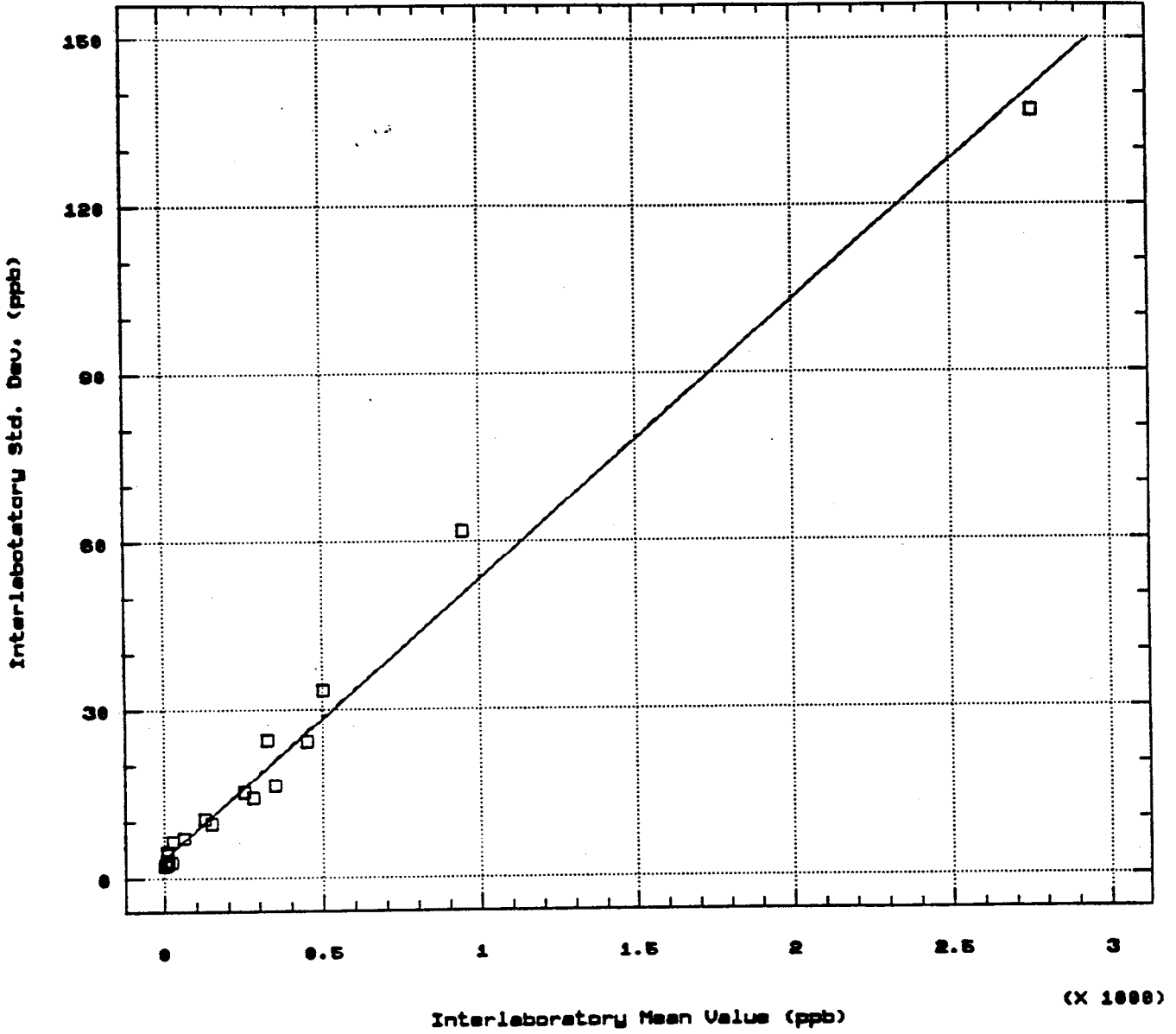
S1: 0.075454 SE: 5.0265E-3 T: 15.011

CORR: 0.97052 MSE: 0.37011 DF: 10

POINTS DELETED:



# Iron In Water



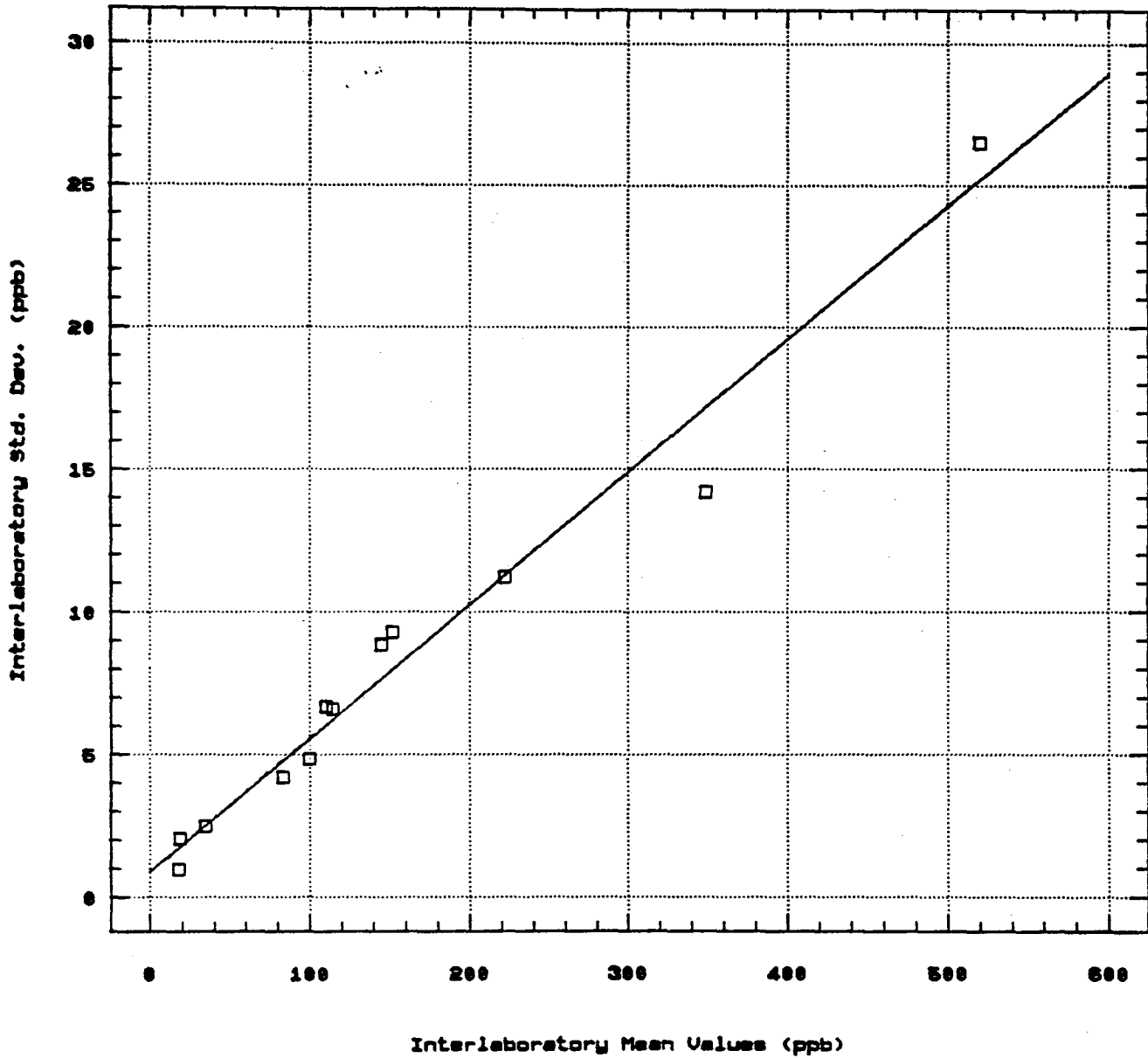
B0: 3.3377 SE: 0.91083 T: 3.6644

B1: 0.049795 SE: 1.329E-3 T: 37.468

CORR: 0.99365 MSE: 13.049 DF: 18

POINTS DELETED:

# Manganese In Water



B0: 0.05705 SE: 0.54030 T: 1.6045

B1: 0.046733 SE: 2.5726E-3 T: 10.166

CORR: 0.99510 MSE: 1.5011 DF: 10

POINTS 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 for then for  $x_2$  (the UBC result).

These  $y_{x_1}$  and the  $y_{x_2}$  values were then inserted into the following formula and the confidence intervals for each metal were estimated.

$$\text{Confidence interval} = 5 \times \sqrt{y_{x_1}^2 + y_{x_2}^2}$$

When the differences between the paired results differed by more than five standard deviations the pairs of data were considered as unacceptable. Such pair weres flagged as not acceptable. 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 3.

Copper - Pore & Peeper Waters

Precision equation:  $y = mx + b$

ID	m	b	ASL Result (x <sub>1</sub> )	UBC Result (x <sub>2</sub> )	ASL Y <sub>1</sub>	UBC Y <sub>2</sub>	5xSTD	(x <sub>1</sub> -x <sub>2</sub> ) / 5xSTD	DECISION
	0.0848	0.493							
M1			1	1.2	0.578	0.595	4.146	0.048	accept
M7			4	1.0	0.832	0.578	5.066	0.592	accept
M9			2	1.1	0.663	0.586	4.424	0.203	accept
M30			24	20.0	2.528	2.189	16.721	0.239	accept
M37			2	1.1	0.663	0.586	4.424	0.203	accept
M54			2	1.1	0.663	0.586	4.424	0.203	accept
M58			3	1.6	0.747	0.629	4.883	0.287	accept
M60			13	8.9	1.595	1.248	10.127	0.405	accept
M69			1	1.1	0.578	0.586	4.116	0.024	accept
M72			1	1.0	0.578	0.578	4.086	0.000	accept
M73			2	1.7	0.663	0.637	4.596	0.065	accept
M88			1	1.7	0.578	0.637	4.301	0.163	accept
M90			1	1.7	0.578	0.637	4.301	0.163	accept
M98			3	2.3	0.747	0.688	5.079	0.138	accept
M99			1	1.1	0.578	0.586	4.116	0.024	accept
M112			3	3.7	0.747	0.807	5.499	0.127	accept
M118			1	1.4	0.578	0.612	4.207	0.095	accept
M146			1	1.5	0.578	0.620	4.238	0.118	accept
M176			3	2.4	0.747	0.697	5.108	0.117	accept
M178			2	1.3	0.663	0.603	4.480	0.156	accept

**Cadmium - Pore & Peeper Waters**

Precision equation:  $y = mx + b$

ID	Precision equation: $y = mx + b$		ASL Y <sub>1</sub>	UBC Y <sub>2</sub>	5xSTD	(x <sub>1</sub> -x <sub>2</sub> )   / 5xSTD	DECISION
	m ASL Result (x <sub>1</sub> )	b UBC Result (x <sub>2</sub> )					
M1	<0.2	0.03	--	--	--	--	N/A
M7	<0.2	0.03	--	--	--	--	N/A
M9	<0.2	0.03	--	--	--	--	N/A
M30	<0.2	<0.024	--	--	--	--	N/A
M37	<0.2	0.03	--	--	--	--	N/A
M54	<0.2	<0.024	--	--	--	--	N/A
M58	<0.2	<0.024	--	--	--	--	N/A
M60	<0.2	0.03	--	--	--	--	N/A
M69	<0.2	<0.024	--	--	--	--	N/A
M72	<0.2	<0.024	--	--	--	--	N/A
M73	<0.2	<0.024	--	--	--	--	N/A
M88	<0.2	0.03	--	--	--	--	N/A
M90	<0.2	<0.024	--	--	--	--	N/A
M98	<0.2	0.2	--	--	--	--	N/A
M99	<0.2	0.04	--	--	--	--	N/A
M112	0.9	1	0.401	0.413	2.877	0.035	accept
M118	<0.2	<0.024	--	--	--	--	N/A
M146	<0.2	0.07	--	--	--	--	N/A
M176	<0.2	0.09	--	--	--	--	N/A
M178	<0.2	0.08	--	--	--	--	N/A

N/A = not applicable

**Zinc - Pore & Peeper Waters**

Precision equation:  $y = mx + b$

ID	Precision equation: $y = mx + b$		ASL Y <sub>1</sub>	UBC Y <sub>2</sub>	5xSTD	(x <sub>1</sub> -x <sub>2</sub> ) / 5xSTD	DECISION
	m 0.0578 ASL Result (x <sub>1</sub> )	b 1.040 UBC Result (x <sub>2</sub> )					
M1	9	10	1.560	1.618	11.238	0.089	accept
M7	7	7.9	1.445	1.497	10.400	0.087	accept
M9	7	7.5	1.445	1.474	10.318	0.048	accept
M30	2	2.7	1.156	1.196	8.316	0.084	accept
M37	7	8.2	1.445	1.514	10.463	0.115	accept
M54	1	1.7	1.098	1.138	7.907	0.089	accept
M58	5	1.5	1.329	1.127	8.712	0.402	accept
M60	2	2.3	1.156	1.173	8.233	0.036	accept
M69	<1	83	- -	- -	- -	- -	N/A
M72	40	57	3.352	4.335	27.397	0.620	accept **
M73	70	82	5.086	5.780	38.494	0.312	accept
M88	100	302	6.820	18.496	98.565	2.049	flagged
M90	100	262	6.820	16.184	87.810	1.845	flagged
M98	100	121	6.820	8.034	52.691	0.399	accept
M99	30	50	2.774	3.930	24.052	0.832	accept **
M112	700	503	41.500	30.113	256.372	0.768	accept **
M118	100	235	6.820	14.623	80.676	1.673	flagged
M146	7	7.7	1.445	1.485	10.359	0.068	accept
M176	9	8.5	1.560	1.531	10.931	0.046	accept
M178	9	9.2	1.560	1.572	11.073	0.018	accept

N/A = not applicable

\*\* refers to data flagged when the difference was more than 3 standard deviations

Lead - Pore & Peeper Waters

Precision equation:  $y = mx + b$

ID	Precision equation: $y = mx + b$		ASL Y <sub>1</sub>	UBC Y <sub>2</sub>	5xSTD	(x <sub>1</sub> -x <sub>2</sub> )   / 5xSTD	DECISION
	m 0.0755 ASL Result (x <sub>1</sub> )	b 1.067 UBC Result (x <sub>2</sub> )					
M1	<0.5	0.1	--	--	--	--	N/A
M7	<0.5	0.1	--	--	--	--	N/A
M9	<0.5	0.1	--	--	--	--	N/A
M30	15	8.2	2.200	1.686	13.857	0.491	accept
M37	2	0.1	1.218	1.075	8.121	0.234	accept
M54	<0.5	0.2	--	--	--	--	N/A
M58	3	0.9	1.294	1.135	8.604	0.244	accept
M60	10	5.0	1.822	1.445	11.626	0.430	accept
M69	2	0.6	1.218	1.112	8.247	0.170	accept
M72	2.0	1.0	1.218	1.143	8.350	0.120	accept
M73	4	2.0	1.369	1.218	9.162	0.218	accept
M88	6	4.3	1.520	1.392	10.304	0.165	accept
M90	5	3.3	1.445	1.316	9.771	0.174	accept
M98	1	0.8	1.143	1.127	8.025	0.025	accept
M99	0.5	0.5	1.105	1.105	7.812	0.000	accept
M112	5	2.9	1.445	1.286	9.670	0.217	accept
M118	5	3.9	1.445	1.361	9.925	0.111	accept
M146	2	1.3	1.218	1.165	8.428	0.083	accept
M176	1	1.1	1.143	1.150	8.105	0.012	accept
M178	4	2.0	1.369	1.218	9.162	0.218	accept

N/A = not applicable



Iron - Pore & Peeper Waters

Precision equation:  $y = mx + b$

ID	Precision equation: $y = mx + b$		ASL Result ( $x_1$ )	UBC Result ( $x_2$ )	ASL $Y_1$	UBC $Y_2$	5xSTD	$  (x_1 - x_2)   /$ 5xSTD	DECISION
	m	b							
	0.0498	3.34							
M1			3	15	3.489	4.087	26.870	0.447	accept
M7			10	5	3.838	3.589	26.273	0.190	accept
M9			20	6	4.336	3.639	28.303	0.495	accept
M30			2000	1720	102.940	88.996	680.385	0.412	accept
M37			46	6	5.631	3.639	33.521	1.193	flagged
M54			8	26	3.738	4.635	29.773	0.605	accept **
M58			180	80	12.304	7.324	71.594	1.397	flagged
M60			1000	915	53.140	48.907	361.101	0.235	accept
M69			10000	540	501.340	30.232	2511	3.767	flagged
M72			47000	9730	2344	487.894	11971	3.113	flagged
M73			60	9990	6.328	500.842	2504	3.965	flagged
M88			10000	43300	501.340	2160	11086	3.004	flagged
M90			32000	43200	1597	2155	13410	0.835	accept **
M98			400	63	23.260	6.477	120.725	2.791	flagged
M99			80	325	7.324	19.525	104.267	2.350	flagged
M112			46000	33000	2294	1647	14120	0.921	accept **
M118			300	45300	18.280	2259	11297	3.983	flagged
M146			45000	111	2244	8.868	11222	4.000	flagged
M176			70	46	6.826	5.631	44.244	0.542	accept
M178			80	55	7.324	6.079	47.591	0.525	accept

N/A = not applicable

\*\* refers to data flagged when the difference was more than 3 standard deviations

**Manganese - Pore & Peeper Waters**

Precision equation:  $y = mx + b$

ID	m		b		ASL	UBC	5xSTD	$ (x_1 - x_2)  / 5xSTD$	DECISION
	ASL Result ( $x_1$ )	UBC Result ( $x_2$ )	ASL $Y_1$	UBC $Y_2$					
	0.0467	0.867							
M1	2	<1.6	0.960	--	--	--	--	N/A	
M7	1	<1.6	0.914	--	--	--	--	N/A	
M9	2	<1.6	0.960	--	--	--	--	N/A	
M30	100	107	5.537	5.864	40.325	0.174		accept	
M37	17	<1.6	1.661	--	--	--	--	N/A	
M54	2	13	0.960	1.474	8.797	1.250		flagged	
M58	60	56	3.669	3.482	25.292	0.158		accept	
M60	100	97	5.537	5.397	38.660	0.078		accept	
M69	10000	7750	467.867	362.792	2960	0.760		accept **	
M72	10000	11850	467.867	554.262	3627	0.510		accept	
M73	11000	13000	514.567	607.967	3982	0.502		accept	
M88	10000	10750	467.867	502.892	3434	0.218		accept	
M90	10000	12200	467.867	570.607	3689	0.596		accept	
M98	4000	1220	187.667	57.841	981.892	2.831		flagged	
M99	1300	4750	61.577	222.692	1155	2.986		flagged	
M112	7000	10700	327.767	500.557	2992	1.237		flagged	
M118	60	11600	3.669	542.587	2713	4.254		flagged	
M146	11000	60	514.567	3.669	2573	4.252		flagged	
M176	45	282	2.969	14.036	71.734	3.304		flagged	
M178	400	37	19.547	2.595	98.592	3.682		flagged	

N/A = not applicable

\*\* refers to data flagged when the difference was more than 3 standard deviations

## Appendix B - Data

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### Buttle Lake Water Column Data - But-4

But-4A Depth (m)	Conduct (µmhos/cm)	Hardness mg/L	pH	Alk mg/L	Cl mg/L	SO <sub>4</sub> mg/L	NH <sub>4</sub> N mg/L	NO <sub>3</sub> N mg/L	Total P mg/L	T-As mg/L	T-Cd mg/L	T-Ca mg/L
0	63	32.8	7.95	22.7	1	7.6	<0.005	0.017	0.003	0.0002	<0.0002	12.1
5	66	32.9	7.31	23.7	1.1	8	<0.005	0.013	0.002	0.0002	<0.0002	11.9
10	67	33.3	7.34	24.4	1.1	8.6	0.006	0.008	0.002	0.0002	<0.0002	12.1
15	47	30.5	7.47	22	0.7	5.8	<0.005	0.026	0.002	0.0002	<0.0002	11.2
20	63	33	7.9	22.8	1.2	7.6	<0.005	0.024	0.001	0.0002	<0.0002	12
25	66	33	7.6	22.3	1	8.6	<0.005	0.043	0.002	0.0001	<0.0002	12.3
25	64	33.2	7.48	25.5	1.2	8.4	<0.005	0.045	0.002	0.0001	<0.0002	12.1
30	67	32.3	7.72	23.8	1.1	9.3	<0.005	0.048	0.002	0.0001	<0.0002	11.7
35	65	34.5	7.51	21.5	0.9	10.9	<0.005	0.053	0.002	0.0001	<0.0002	12.6
<b>But-4B</b>												
<b>Depth (m)</b>												
0	66	32.7	7.35	24.1	1.1	9.5	<0.005	0.019	0.002	0.0001	<0.0002	11.8
5	66	33.7	7.3	23.8	1.1	9.1	<0.005	0.025	0.002	0.0002	<0.0002	12.4
5	-	-	-	-	-	-	-	-	-	-	-	-
10	67	33.7	7.24	23.9	1.2	9.4	<0.005	0.021	0.002	0.0002	<0.0002	12.3
10	66	33.4	7.29	25.3	0.8	10	<0.005	0.024	0.002	0.0002	<0.0002	12.3
15	64	32.1	7.23	23.9	1.1	9.3	<0.005	0.041	0.003	0.0002	<0.0002	11.8
15	-	-	-	-	-	-	-	-	-	-	-	-
20	65	33.1	7.01	24.7	1	9.4	0.005	0.045	0.002	0.0002	<0.0002	12
25	67	33.7	6.99	24.2	0.8	10.4	<0.005	0.053	0.002	0.0001	<0.0002	12.2
30	67	33.1	7.07	23.6	0.9	8	<0.005	0.046	0.002	0.0002	<0.0002	12.1
35	69	35	7.05	24.6	1.1	10	<0.005	0.069	0.002	0.0001	<0.0002	12.9
35	70	34.9	7.13	24.3	1.2	9.7	<0.005	0.064	0.002	0.0001	<0.0002	12.7
35	-	-	-	-	-	-	-	-	-	-	-	-

(continued)

**Buttle Lake Water Column Data - But-4**

<b>But-4A</b> Depth (m)	<b>T-Cu</b> mg/L	<b>T-Fe</b> mg/L	<b>T-Pb</b> mg/L	<b>T-Mg</b> mg/L	<b>T-Mn</b> mg/L	<b>T-Hg</b> mg/L	<b>T-K</b> mg/L	<b>T-Na</b> mg/L	<b>T-Zn</b> mg/L	<b>D-As</b> mg/L	<b>D-Cd</b> mg/L	<b>D-Ca</b> mg/L
0	0.0015	0.044	<0.0005	0.831	0.031	<0.00001	0.102	0.796	0.015	0.0001	<0.0002	11.8
5	0.0015	0.03	<0.0005	0.773	0.01	<0.00001	0.11	0.773	0.022	0.0001	<0.0002	11.9
10	0.002	0.026	<0.0005	0.798	0.008	<0.00001	0.104	0.79	0.019	0.0001	<0.0002	12
15	0.002	0.04	<0.0005	0.707	0.011	<0.00001	0.117	0.751	0.015	0.0001	<0.0002	11
20	0.002	0.024	<0.0005	0.787	0.008	<0.00001	0.113	0.779	0.028	0.0001	<0.0002	11.9
25	0.002	0.016	<0.0005	0.773	0.008	<0.00001	0.12	0.767	0.023	0.0001	<0.0002	12
25	0.0015	0.019	<0.0005	0.781	0.008	<0.00001	0.122	0.769	0.023	0.0001	<0.0002	12
30	0.002	0.022	<0.0005	0.753	0.01	<0.00001	0.124	0.801	0.016	0.0001	<0.0002	11.7
35	0.002	0.022	<0.0005	0.758	0.008	<0.00001	0.123	0.82	0.024	0.0001	<0.0002	12.6
<b>But-4B</b>												
<b>Depth (m)</b>												
0	0.0015	0.02	<0.0005	0.798	0.006	<0.00001	0.15	0.754	0.014	0.0001	<0.0002	11.8
5	0.0025	0.034	<0.0005	0.799	0.01	<0.00001	0.106	0.8	0.03	0.0001	<0.0002	12.2
5	-	-	-	-	-	-	-	-	-	0.0001	<0.0002	12.1
10	0.0015	0.027	<0.0005	0.798	0.008	<0.00001	0.111	0.781	0.014	0.0002	<0.0002	12.2
10	0.0015	0.027	<0.0005	0.797	0.008	<0.00001	0.112	0.79	0.016	0.0002	<0.0002	12.1
15	0.0015	0.035	<0.0005	0.746	0.01	<0.00001	0.11	0.766	0.015	0.0002	<0.0002	11.6
15	-	-	-	-	-	-	-	-	-	0.0002	<0.0002	11.7
20	0.002	0.028	<0.0005	0.764	0.008	<0.00001	0.11	0.824	0.02	0.0002	<0.0002	12
25	0.002	0.016	<0.0005	0.766	0.009	<0.00001	0.12	0.772	0.02	0.0001	<0.0002	12.2
30	0.002	0.026	<0.0005	0.765	0.01	<0.00001	0.12	0.799	0.014	0.0001	<0.0002	12
35	0.002	0.022	<0.0005	0.772	0.012	<0.00001	0.144	0.807	0.027	0.0001	<0.0002	12.8
35	0.0025	0.02	<0.0005	0.752	0.012	<0.00001	0.144	0.824	0.025	0.0001	<0.0002	12.7
35	-	-	-	-	-	-	-	-	-	0.0001	<0.0002	12.6

(continued)

**Buttle Lake Water Column Data - But-4**

<b>But-4A Depth (m)</b>	<b>D-Cu mg/L</b>	<b>D-Fe mg/L</b>	<b>D-Pb mg/L</b>	<b>D-Mg mg/L</b>	<b>D-Mn mg/L</b>	<b>D-Hg mg/L</b>	<b>D-K mg/L</b>	<b>D-Na mg/L</b>	<b>D-Zn mg/L</b>	<b>DOC mg/L</b>	<b>TOC mg/L</b>
0	0.0013	0.01	<0.0005	0.785	0.003	<0.00001	0.101	0.782	0.012	0.83	0.88
5	0.001	0.013	<0.0005	0.772	0.005	<0.00001	0.11	0.77	0.007	0.88	1.22
10	0.001	0.01	<0.0005	0.798	0.003	<0.00001	0.102	0.762	0.009	0.68	0.68
15	0.0012	0.018	<0.0005	0.697	0.007	<0.00001	0.116	0.741	0.009	0.9	0.9
20	0.0013	0.011	<0.0005	0.787	0.003	<0.00001	0.111	0.773	0.01	0.73	0.73
25	0.0012	0.005	<0.0005	0.752	0.004	<0.00001	0.112	0.754	0.02	0.73	0.74
25	0.0013	0.005	<0.0005	0.772	0.004	<0.00001	0.122	0.767	0.018	0.76	0.77
30	0.0017	0.007	<0.0005	0.745	0.005	<0.00001	0.122	0.797	0.016	0.9	0.9
35	0.0016	0.007	<0.0005	0.758	0.008	<0.00001	0.12	0.802	0.024	0.77	0.8
<b>But-4B</b>											
<b>Depth (m)</b>											
0	0.0013	0.007	<0.0005	0.798	0.002	<0.00001	0.112	0.753	0.008	0.7	0.71
5	0.0012	0.013	<0.0005	0.776	0.005	<0.00001	0.102	0.788	0.007	0.9	1.1
5	0.0024	0.013	<0.0005	0.769	0.005	<0.00001	0.1	0.776	0.016	-	-
10	0.001	0.012	<0.0005	0.793	0.004	<0.00001	0.11	0.776	0.009	0.81	0.81
10	0.001	0.012	<0.0005	0.797	0.004	<0.00001	0.107	0.768	0.009	0.86	1
15	0.0015	0.015	<0.0005	0.723	0.006	<0.00001	0.11	0.762	0.012	0.87	0.87
15	0.0014	0.013	<0.0005	0.741	0.006	<0.00001	0.11	0.77	0.008	-	-
20	0.0016	0.012	<0.0005	0.764	0.004	<0.00001	0.11	0.821	0.009	1	1.3
25	0.0017	0.006	<0.0005	0.766	0.004	<0.00001	0.111	0.771	0.02	0.75	0.81
30	0.0014	0.011	<0.0005	0.757	0.005	<0.00001	0.117	0.799	0.011	0.91	0.94
35	0.0015	0.007	<0.0005	0.764	0.005	<0.00001	0.142	0.766	0.025	0.9	1.4
35	0.0017	0.007	<0.0005	0.752	0.005	<0.00001	0.143	0.821	0.024	1.1	1.2
35	0.0019	0.007	<0.0005	0.76	0.006	<0.00001	0.14	0.8	0.024	-	-

**Buttle Lake Water Column Data - But-6**

<b>But-6A</b> Depth (m)	<b>Conduct</b> (µmhos/cm)	<b>Hardness</b> mg/L	<b>pH</b> pH	<b>Alk</b> mg/L	<b>Cl</b> mg/L	<b>SO<sup>4</sup></b> mg/L	<b>NH<sup>4</sup>N</b> mg/L	<b>NO<sup>3</sup>N</b> mg/L	<b>Total P</b> mg/L	<b>T-As</b> mg/L	<b>T-Cd</b> mg/L	<b>T-Ca</b> mg/L
0	67	33.4	7.38	24.8	1	9.3	<0.005	0.018	0.003	0.0001	<0.0002	12.2
5	59	33.5	8.31	23.2	0.8	8.5	<0.005	0.02	0.003	0.0001	<0.0002	12.1
10	66	32.8	8.27	21.3	0.9	10.6	0.006	0.026	0.002	0.0001	<0.0002	12
15	67	33.7	7.73	23.5	1	9.5	<0.005	0.016	0.001	0.0001	<0.0002	12.3
20	60	32.6	7.25	20.2	0.9	9.1	<0.005	0.039	0.002	0.0001	<0.0002	11.9
20	60	32.6	7.21	21.6	1.2	8.6	<0.005	0.042	0.002	0.0001	<0.0002	11.8
25	67	32.8	7.41	22.6	1	9.5	<0.005	0.049	0.002	0.0001	<0.0002	12
30	68	33.7	7.38	24.8	0.9	10.7	<0.005	0.059	0.002	0.0001	<0.0002	12.2
<b>But-6B</b>												
<b>Depth (m)</b>												
0	66	33.1	7.37	24.1	0.9	8.5	<0.005	0.013	0.003	0.0002	<0.0002	11.9
5	67	33.1	7.29	24.5	1	9.6	<0.005	0.016	0.002	0.0002	<0.0002	12.1
10	68	32.3	7.22	21.9	1.1	11.3	<0.005	0.035	0.003	0.0002	<0.0002	11.8
10	-	-	-	-	-	-	-	-	-	-	-	-
15	64	32.3	7.22	21.5	1.2	9.9	<0.005	0.026	0.003	0.0002	<0.0002	11.7
15	63	32.5	7.19	23.6	1	9.8	<0.005	0.024	0.002	0.0002	<0.0002	11.8
20	66	32.5	7.2	22.7	0.9	8.1	0.005	0.038	0.002	0.0002	<0.0002	11.8
20	-	-	-	-	-	-	-	-	-	-	-	-
25	67	32.3	7.14	23.5	1	7.7	0.009	0.022	0.002	0.0002	<0.0002	11.7
30	68	33.9	7.03	24.9	1	8.7	<0.005	0.054	0.002	0.0001	<0.0002	12.3
30	-	-	-	-	-	-	-	-	-	-	-	-

(continued)

### Buttle Lake Water Column Data - But-6

But-6A Depth (m)	T-Cu mg/L	T-Fe mg/L	T-Pb mg/L	T-Mg mg/L	T-Mn mg/L	T-Hg mg/L	T-K mg/L	T-Na mg/L	T-Zn mg/L	D-As mg/L	D-Cd mg/L	D-Ca mg/L
0	0.001	0.02	<0.0005	0.818	0.007	<0.00001	0.106	0.782	0.009	0.0001	<0.0002	12.1
5	0.001	0.023	<0.0005	0.798	0.007	<0.00001	0.107	0.796	0.009	0.0001	<0.0002	12.1
10	0.0015	0.044	<0.0005	0.746	0.011	<0.00001	0.123	0.851	0.02	<0.0001	<0.0002	11.9
15	0.002	0.027	<0.0005	0.819	0.007	<0.00001	0.119	0.866	0.016	<0.0001	<0.0002	12.2
20	0.0015	0.014	<0.0005	0.757	0.005	<0.00001	0.123	0.767	0.02	0.0001	<0.0002	11.8
20	0.0015	0.013	<0.0005	0.759	0.005	<0.00001	0.114	0.767	0.017	0.0001	<0.0002	11.8
25	0.002	0.019	<0.0005	0.759	0.007	<0.00001	0.114	0.809	0.023	0.0001	<0.0002	11.9
30	0.0015	0.015	<0.0005	0.762	0.007	<0.00001	0.135	0.798	0.022	0.0001	<0.0002	12.2
<b>But-6B</b>												
<b>Depth (m)</b>												
0	0.0021	0.022	<0.0005	0.801	0.006	<0.00001	0.107	0.792	0.014	0.0002	<0.0002	11.9
5	0.002	0.024	<0.0005	0.798	0.007	<0.00001	0.109	0.797	0.018	0.0002	<0.0002	12
10	0.0015	0.044	<0.0005	0.72	0.011	<0.00001	0.114	0.852	0.017	0.0002	<0.0002	11.8
10	-	-	-	-	-	-	-	-	-	0.0002	<0.0002	11.9
15	0.0015	0.053	<0.0005	0.754	0.008	<0.00001	0.116	0.799	0.013	0.0002	<0.0002	11.7
15	0.0015	0.053	<0.0005	0.754	0.009	<0.00001	0.116	0.819	0.013	0.0002	<0.0002	11.8
20	0.002	0.025	<0.0005	0.743	0.006	<0.00001	0.118	0.79	0.025	0.0002	<0.0002	11.8
20	-	-	-	-	-	-	-	-	-	0.0002	<0.0002	11.8
25	0.0015	0.029	<0.0005	0.745	0.008	<0.00001	0.122	0.802	0.016	0.0002	<0.0002	11.7
30	0.0015	0.017	<0.0005	0.759	0.007	<0.00001	0.119	0.802	0.022	0.0001	<0.0002	12.3
30	-	-	-	-	-	-	-	-	-	0.0001	<0.0002	12.2

(continued)



### Buttle Lake Water Column Data - But-6

<b>But-6A</b> Depth (m)	<b>D-Cu</b> mg/L	<b>D-Fe</b> mg/L	<b>D-Pb</b> mg/L	<b>D-Mg</b> mg/L	<b>D-Mn</b> mg/L	<b>D-Hg</b> mg/L	<b>D-K</b> mg/L	<b>D-Na</b> mg/L	<b>D-Zn</b> mg/L	<b>DOC</b> mg/L	<b>TOC</b> mg/L
0	0.001	0.01	<0.0005	0.812	0.003	<0.00001	0.102	0.744	0.008	0.9	1.1
5	0.001	0.01	<0.0005	0.798	0.003	<0.00001	0.107	0.79	0.007	0.77	0.81
10	0.0015	0.017	<0.0005	0.731	0.007	<0.00001	0.121	0.831	0.02	0.93	0.98
15	0.0015	0.01	<0.0005	0.81	0.003	<0.00001	0.119	0.822	0.01	0.78	0.97
20	0.0014	0.005	<0.0005	0.749	0.002	<0.00001	0.122	0.767	0.017	0.88	0.89
20	0.0014	0.006	<0.0005	0.759	0.002	<0.00001	0.11	0.762	0.011	0.84	0.97
25	0.0016	0.009	<0.0005	0.759	0.003	<0.00001	0.114	0.8	0.011	0.84	0.84
30	0.0013	0.005	<0.0005	0.762	0.002	<0.00001	0.135	0.788	0.014	0.88	0.92
<b>But-6B</b>											
<b>Depth (m)</b>											
0	0.0021	0.009	<0.0005	0.801	0.002	<0.00001	0.101	0.767	0.01	0.97	1
5	0.0017	0.01	<0.0005	0.777	0.003	<0.00001	0.102	0.783	0.007	0.76	0.76
10	0.0015	0.02	<0.0005	0.711	0.008	<0.00001	0.111	0.844	0.015	1	1.3
10	0.002	0.038	<0.0005	0.718	0.009	<0.00001	0.133	0.85	0.015	-	-
15	0.0014	0.015	<0.0005	0.737	0.004	<0.00001	0.113	0.799	0.012	0.88	0.97
15	0.0014	0.015	<0.0005	0.754	0.004	<0.00001	0.112	0.802	0.012	0.85	0.95
20	0.0016	0.008	<0.0005	0.743	0.003	<0.00001	0.118	0.767	0.011	1.1	1.5
20	0.0015	0.055	<0.0005	0.745	0.005	<0.00001	0.114	0.791	0.014	-	-
25	0.0012	0.011	<0.0005	0.745	0.003	<0.00001	0.121	0.8	0.011	0.93	0.97
30	0.0013	0.005	<0.0005	0.755	0.002	<0.00001	0.117	0.777	0.013	0.88	0.97
30	0.002	0.005	<0.0005	0.744	0.002	<0.00001	0.168	0.811	0.018	-	-

### Buttle Lake Water Column Data - But-7

But-7A Depth (m)	Conduct ( $\mu$ mhos/cm)	Hardness mg/L	pH mg/L	Alk mg/L	Cl mg/L	SO <sup>4</sup> mg/L	NH <sup>4</sup> N mg/L	NO <sup>3</sup> N mg/L	Total P mg/L	T-As mg/L	T-Cd mg/L	T-Ca mg/L
0	60	31.2	7.3	25.8	0.9	6	<0.005	0.012	0.003	0.0002	<0.0002	11.2
0	63	31	7.16	24.8	0.8	6.9	<0.005	0.009	0.002	0.0002	<0.0002	11.1
5	61	30.1	7.3	25.4	0.8	6.6	<0.005	0.013	0.006	0.0002	<0.0002	10.8
10	36	30.8	8.78	25.1	<0.5	5.2	<0.005	0.008	0.002	0.0002	<0.0002	11.2
15	62	23.5	7.29	22.3	0.6	6.9	<0.005	0.031	0.002	0.0002	<0.0002	11.7
20	62	30.3	7.41	23.4	0.6	6.5	<0.005	0.022	0.002	0.0002	<0.0002	11.1
25	65	30.9	7.82	24.7	0.7	6.9	<0.005	0.042	0.002	0.0001	<0.0002	11.2
25	62	31	7.46	22.6	0.9	7.2	<0.005	0.039	0.002	0.0001	<0.0002	11.1
30	69	31.2	7.08	20.5	3.9	6.6	<0.005	0.043	0.002	0.0001	<0.0002	11.3
35	64	30.8	7.13	24.2	0.7	6.5	<0.005	0.054	0.002	0.0001	<0.0002	11.3
<b>But-7B</b>												
<b>Depth (m)</b>												
0	58	28.3	8.62	23.2	0.6	6.1	<0.005	0.011	0.002	0.0002	<0.0002	10.1
5	59	30.3	7.35	22.5	0.6	5.7	<0.005	0.006	0.002	0.0003	<0.0002	11.1
10	61	30.2	7.37	24	0.6	5.8	<0.005	<0.005	0.002	0.0003	<0.0002	11
15	62	31.4	7.36	22.9	<0.5	6.8	<0.005	0.032	0.002	0.0002	<0.0002	11.4
15	61	31.4	7.26	25.3	<0.5	6.5	<0.005	0.042	0.001	0.0002	<0.0002	11.3
20	61	31.2	8.2	24.5	0.5	5.8	<0.005	0.018	0.003	0.0002	<0.0002	11.2
25	65	32	7.23	24.3	0.7	7	<0.005	0.049	0.005	0.0002	<0.0002	11.7
30	64	31.4	7.29	24.3	0.6	6.9	<0.005	0.042	0.002	0.0002	<0.0002	11.7
35	64	31.6	7.3	23.8	0.6	5.6	<0.005	0.049	0.002	0.0001	<0.0002	11.3

(continued)

**Buttle Lake Water Column Data - But-7**

<b>But-7A</b> Depth (m)	<b>T-Cu</b> mg/L	<b>T-Fe</b> mg/L	<b>T-Pb</b> mg/L	<b>T-Mg</b> mg/L	<b>T-Mn</b> mg/L	<b>T-Hg</b> mg/L	<b>T-K</b> mg/L	<b>T-Na</b> mg/L	<b>T-Zn</b> mg/L	<b>D-As</b> mg/L	<b>D-Cd</b> mg/L	<b>D-Ca</b> mg/L
0	0.001	0.016	<0.0005	0.772	0.003	<0.00001	0.099	0.769	0.008	0.0002	<0.0002	11.2
0	0.001	0.016	<0.0005	0.774	0.004	<0.00001	0.099	0.783	0.008	0.0002	<0.0002	11.1
5	0.001	0.021	<0.0005	0.76	0.005	<0.00001	0.098	0.702	0.008	0.0002	<0.0002	10.8
10	0.0015	0.017	<0.0005	0.781	0.004	<0.00001	0.098	0.734	0.011	0.0002	<0.0002	11.1
15	0.0015	0.021	<0.0005	0.828	0.005	<0.00001	0.107	0.73	0.012	0.0002	<0.0002	9.44
20	0.002	0.017	<0.0005	0.8	0.004	<0.00001	0.112	0.79	0.013	0.0002	<0.0002	10.8
25	0.002	0.027	<0.0005	0.809	0.004	<0.00001	0.122	0.744	0.015	0.0001	<0.0002	11.1
25	0.002	0.027	<0.0005	0.789	0.004	<0.00001	0.112	0.76	0.015	0.0001	<0.0002	11.1
30	0.002	0.018	<0.0005	0.855	0.004	<0.00001	0.104	0.993	0.013	0.0001	<0.0002	11.1
35	0.001	0.016	<0.0005	0.83	0.004	<0.00001	0.102	0.72	0.011	0.0001	<0.0002	11
<b>But-7B</b>												
<b>Depth (m)</b>												
0	0.001	0.017	<0.0005	0.738	0.004	<0.00001	0.096	0.707	0.008	0.0002	<0.0002	10.1
5	0.001	0.024	<0.0005	0.797	0.005	<0.00001	0.092	0.704	0.009	0.0003	<0.0002	10.8
10	0.001	0.018	<0.0005	0.793	0.005	<0.00001	0.092	0.719	0.008	0.0002	<0.0002	10.8
15	0.0015	0.019	<0.0005	0.804	0.004	<0.00001	0.101	0.73	0.01	0.0002	<0.0002	11.3
15	0.0015	0.018	<0.0005	0.791	0.004	<0.00001	0.1	0.734	0.01	0.0002	<0.0002	11.3
20	0.001	0.02	<0.0005	0.817	0.004	<0.00001	0.093	0.704	0.009	0.0002	<0.0002	11.2
25	0.001	0.02	<0.0005	0.844	0.005	<0.00001	0.113	0.779	0.01	0.0002	<0.0002	11.4
30	0.0015	0.016	<0.0005	0.838	0.004	<0.00001	0.107	0.734	0.011	0.0001	<0.0002	11.3
35	0.0015	0.015	<0.0005	0.837	0.003	<0.00001	0.106	0.71	0.01	0.0001	<0.0002	11.3

(continued)

### Buttle Lake Water Column Data - But-7

But-7A Depth (m)	D-Cu mg/L	D-Fe mg/L	D-Pb mg/L	D-Mg mg/L	D-Mn mg/L	D-Hg mg/L	D-K mg/L	D-Na mg/L	D-Zn mg/L	DOC mg/L	TOC mg/L
0	0.001	0.007	<0.0005	0.772	0.001	<0.00001	0.099	0.722	0.007	0.72	0.81
0	0.001	0.007	<0.0005	0.774	0.001	<0.00001	0.092	0.72	0.007	0.77	0.89
5	0.0008	0.008	<0.0005	0.76	0.002	<0.00001	0.097	0.682	0.006	0.78	0.81
10	0.001	0.006	<0.0005	0.781	0.001	<0.00001	0.098	0.705	0.006	0.72	0.76
15	0.001	0.007	<0.0005	0.597	0.002	<0.00001	0.101	0.725	0.008	0.76	0.76
20	0.0015	0.005	<0.0005	0.788	0.001	<0.00001	0.107	0.782	0.011	0.74	0.74
25	0.0012	0.004	<0.0005	0.794	0.002	<0.00001	0.103	0.74	0.01	0.75	0.76
25	0.0013	0.004	<0.0005	0.789	0.002	<0.00001	0.104	0.757	0.01	0.75	0.76
30	0.002	0.006	<0.0005	0.855	0.002	<0.00001	0.103	0.889	0.012	0.81	0.81
35	0.0009	0.005	<0.0005	0.818	0.002	<0.00001	0.102	0.711	0.011	0.81	0.84
<b>But-7B</b>											
<b>Depth (m)</b>											
0	0.0009	0.006	<0.0005	0.738	0.001	<0.00001	0.094	0.702	0.007	0.8	0.9
5	0.001	0.011	<0.0005	0.788	0.002	<0.00001	0.091	0.702	0.005	0.88	0.97
10	0.001	0.007	<0.0005	0.782	0.002	<0.00001	0.09	0.717	0.008	0.71	0.71
15	0.0013	0.012	<0.0005	0.801	0.002	<0.00001	0.1	0.73	0.008	0.8	0.81
15	0.0012	0.01	<0.0005	0.791	0.002	<0.00001	0.1	0.732	0.008	0.83	0.92
20	0.001	0.006	<0.0005	0.805	0.001	<0.00001	0.091	0.699	0.007	0.78	0.86
25	0.001	0.009	<0.0005	0.827	0.004	<0.00001	0.112	0.72	0.009	0.71	0.71
30	0.001	0.007	<0.0005	0.81	0.002	<0.00001	0.101	0.732	0.01	0.77	0.81
35	0.0011	0.005	<0.0005	0.832	0.001	<0.00001	0.101	0.701	0.009	0.8	0.81

### Buttle Lake Sediments - Core-4A

Core-4A Depth (cm)	Al (Wt. %)	As (ppm)	Cd (ppm)	Cr (ppm)	Co (ppm)	Cu (ppm)	Fe (Wt. %)	Pb (ppm)	Mg (Wt. %)	Mn (ppm)
0 - 0.5	8.1	36.9	3.7	58	27	340	7.55	73	0.91	6040
0.5 - 1	8.32	30.5	2.8	59	27	340	7.29	100	0.99	3210
1 - 1.5	8.24	28.7	3.5	58	26	346	6.84	91	0.94	2370
1.5 - 2	8.54	39.9	4.3	58	23	439	7.62	111	0.90	1280
2 - 3	9.01	39.2	4.7	57	18	438	7.17	140	0.90	649
3 - 4	12.4	26.8	6.5	74	7	513	4.75	373	0.85	264
4 - 5	12.3	26.8	7.7	81	7	521	4.7	358	0.90	225
4 - 5	11.2	23.9	7.7	73	7	538	4.35	335	0.91	229
5 - 6	12.2	73.7	18.3	76	13	1210	4.93	803	1.70	484
6 - 8	12.3	66.3	16.7	77	14	1320	5.13	801	1.65	484
8 - 10	12	93.1	20.3	71	16	1690	5.28	993	1.64	446
10 - 12	11.9	89.2	20.1	62	13	1500	4.9	828	1.67	438
12 - 14	11.4	93.2	17.3	56	14	1360	5.11	1070	1.44	484
12 - 14		-	17.3	-	13	1300		963		490
14 - 18	11.6	98.9	30.1	50	10	1590	6.85	1090	1.73	532
18 - 22	12.6	108	37.6	42	7	1690	8.73	1360	2.18	1020
18 - 22	12.4	104	40.0	42	9	1750	8.69	1360	2.18	1050
22 - 26	12.3	151	31.4	69	19	2850	6.76	1690	2.17	1050
26 - 30	8.77	37.1	1.7	62	37	191	6.69	58	1.78	1520
30 - 34	8.7	34.4	0.4	63	37	127	6.47	22	1.97	1510
34 - 38	8.66	24.5	0.5	63	35	119	6.24	12	1.97	1490

(continued)

### Buttle Lake Sediments - Core-4A

Core-4A Depth (cm)	Hg (ppm)	Ni (ppm)	K (Wt. %)	Na (Wt. %)	Zn (ppm)	C organic (Wt. %)	Total N (Wt. %)	S (Wt. %)	CaCO <sub>3</sub> (Wt. %)
0 - 0.5	0.074	17	0.807	1.48	1250	6.01	0.35628	0.37353	0.62
0.5 - 1	0.075	17	0.541	1.62	1380	5.59	0.29634	0.27859	0.22
1 - 1.5	0.068	16	0.879	1.56	1090	5.57	0.33632	0.32142	0.24
1.5 - 2	0.072	16	0.566	1.55	1310	5.36	0.32885	0.37123	0.19
2 - 3	0.079	14	1.29	1.51	1720	4.71	0.28582	0.60468	0.29
3 - 4	0.098	18	3.49	0.63	2570	0.90	0.086257	2.66	0.31
4 - 5	0.103	18	3.53	0.56	3020	0.62	0.060107	3.0264	0.30
4 - 5	0.105	19	3.24	0.52	3210				
5 - 6	0.325	37	3.69	0.63	7550	0.80	0.077162	2.9521	0.50
6 - 8	0.246	31	2.24	0.73	6770	1.12	0.080447	2.5818	0.43
8 - 10	0.282	30	2.36	0.54	7400	0.96	0.075939	3.4153	0.49
10 - 12	0.263	30	2.36	0.57	7880	0.74	0.065145	3.4688	0.86
12 - 14	0.296	28	1.93	0.67	7230	1.47	0.084656	3.3278	0.76
12 - 14	-	27			6880				
14 - 18	0.293	28	2.51	0.48	9580	0.42	0.05636	6.3815	1.14
18 - 22	0.495	27	1.07	0.53	10900	0.35	0.037969	8.2347	1.58
18 - 22	0.498	33	2.39	0.52	11300				
22 - 26	0.295	37	2.61	0.85	8420	1.56	0.095645	4.6241	0.79
26 - 30	0.09	34	0.763	1.62	474	6.85	0.32895	0.28629	0.12
30 - 34	0.08	34	0.774	1.72	185	6.07	0.31535	0.11362	0.11
34 - 38	0.075	35	0.776	1.76	170	5.68	0.29175	0.10223	0.26

### Buttle Lake Sediments - Core-4B

Core-4B Depth (cm)	Al (Wt. %)	As (ppm)	Cd (ppm)	Cr (ppm)	Co (ppm)	Cu (ppm)	Fe (Wt. %)	Pb (ppm)	Mg (Wt. %)	Mn (ppm)
0 - 0.5	7.86	69	5.8	59	68	563	7.61	121	1.90	13200
0.5 - 1	8.43	59.5	5.3	60	48	504	7	117	1.90	4930
1 - 1.5	8.58	64.5	7.4	62	51	791	6.93	200	1.79	1630
1 - 1.5	8.72	65	7.8	61	52	805	7.09	200	1.83	1630
1.5 - 2	8.61	94.5	8.6	57	47	925	7.76	222	1.76	1540
2 - 3	11	81	11.7	66	23	985	5.51	640	1.61	714
3 - 4	12.7	52	13.5	65	12	1010	4.67	723	1.54	415
4 - 5	12	72.5	17.8	77	14	1190	4.8	835	1.66	473
5 - 6	12.3	77	16.0	77	15	1280	5.03	835	1.72	530
6 - 8	12.3	74	19.5	74	14	1670	5.23	930	1.69	538
8 - 10	12	93	18.8	59	12	1470	4.92	960	1.53	405
8 - 10	12	107	20.3	60	11	1600	4.93	1070	1.66	432
10 - 12	11.8	110	18.2	59	15	1520	5.28	1170	1.51	544
12 - 14	12.3	132	24.9	57	10	1800	5.4	1220	1.38	393
14 - 18	12.3	109	37.9	28	8	1600	8.4	1310	2.21	771
18 - 22	12.1	112	27.1	64	17	1950	6.92	1370	1.91	915
18 - 22		-	28.7	-	16	2040		1430		951
22 - 26	8.36	36.4	0.9	62	40	156	6.31	27	1.82	1530
26 - 30	8.7	27.6	0.3	63	37	127	6.27	15	1.93	1540
30 - 34	8.69	18.1	0.2	64	35	107	6.09	10	1.78	1330
30 - 34	8.53	18.9	0.2	64	35	106	6	10	1.71	1290

(continued)

### Buttle Lake Sediments - Core-4B

Core-4B Depth (cm)	Hg (ppm)	Ni (ppm)	K (Wt. %)	Na (Wt. %)	Zn (ppm)	C organic (Wt. %)	Total N (Wt. %)	S (Wt. %)	CaCO <sub>3</sub> (Wt. %)
0 - 0.5	0.15	33	0.646	1.48	1700	5.48	0.32892	0.29716	0.68
0.5 - 1	0.12	33	0.883	1.63	1670	5.61	0.30905	0.32502	0.23
1 - 1.5	0.14	27	0.827	1.57	2430	5.87	0.37523	0.31748	0.13
1 - 1.5	0.135	33	0.973	1.62	2560				
1.5 - 2	0.145	32	0.739	1.59	3110	5.09	0.31735	0.37954	0.11
2 - 3	0.17	30	3.14	0.96	4310	2.22	0.14443	1.6777	0.10
3 - 4	0.175	34	3.97	0.58	5140	0.63	0.065774	2.8068	0.28
4 - 5	0.26	32	3.41	0.62	6730	0.79	0.069768	3.0253	0.27
5 - 6	0.195	33	3.16	0.74	6730	1.08	0.089687	2.495	0.41
6 - 8	0.21	34	3.99	0.70	7510	1.23	0.096831	2.7866	0.47
8 - 10	0.205	28	3.86	0.54	6420	0.76	0.089398	3.4398	0.53
8 - 10	0.235	31	3.66	0.55	7020				
10 - 12	0.24	29	2.22	0.72	7520	1.53	0.10675	3.2652	0.66
12 - 14	0.395	25	3.34	0.54	7820	0.60	0.06078	4.1386	0.59
14 - 18	0.45	27	3.08	0.53	10700	0.44	0.050491	7.8942	0.68
18 - 22	0.35	31	2.28	0.93	6720	2.25	0.14733	4.3986	0.69
18 - 22	-	32			7090				
22 - 26	0.136	34	0.864	1.61	341	7.19	0.3363	0.16658	0.26
26 - 30	0.133	35	0.911	1.75	166	5.99	0.31401	0.083393	0.08
30 - 34	0.103	31	0.866	1.82	129	5.44	0.27845	0.089948	0.27
30 - 34	0.099	33	0.859	1.77	125				



### Buttle Lake Sediments - Core-6A

Core-6A Depth (cm)	Al (Wt. %)	As (ppm)	Cd (ppm)	Cr (ppm)	Co (ppm)	Cu (ppm)	Fe (Wt. %)	Pb (ppm)	Mg (Wt. %)	Mn (ppm)
0 - 0.5	8.54	60.3	9.0	63	44	561	6.71	186	1.57	5030
0.5 - 1.0	8.64	61	7.8	65	55	563	6.87	180	1.63	9310
1 - 1.5	8.59	79.4	10.8	66	59	809	7.19	277	1.95	8360
1.5 - 2	8.68	67.8	15.0	63	35	795	6.85	367	1.42	4120
2 - 3	8.46	74.9	18.4	62	28	902	7.03	453	1.29	2410
3 - 4	6.99	83.5	32.1	36	19	842	7.28	695	1.26	881
4 - 5	6.17	64.3	35.0	43	15	732	6.93	738	1.08	654
4 - 5	6.29	69.7	36.6	32	16	742	7.04	764	1.14	699
5 - 6	5.23	78.3	66.0	30	18	1030	10.3	1030	0.90	423
6 - 8	5.73	71.9	66.1	40	12	950	8.69	948	0.90	500
8 - 10	6.13	70.5	55.9	41	12	917	7.37	836	1.02	538
10 - 12	6.51	73.4	36.9	45	12	764	7.88	703	1.12	597
12 - 14	6.15	67.1	46.2	42	12	761	8.87	832	1.01	535
14 - 18	6.25	79.4	58.3	28	12	931	7.62	971	0.95	485
18 - 22	6.44	81	59.3	45	15	909	8.39	1010	1.04	526
18 - 22	6.31	87	56.7	44	16	873	8.24	926	1.06	506
22 - 26	6.23	65.7	82.7	39	16	1070	7.85	1290	1.08	570
26 - 30	6.85	76.5	59.9	49	15	1100	7.89	1140	1.06	553
30 - 34	6.47	73.4	52.2	47	20	894	8.5	1060	0.96	523
34 - 38	5.45	74.1	67.0	37	17	1210	10.9	1310	0.89	453
38 - 42	6.9	59.4	28.8	46	21	759	8.95	879	1.39	694

(continued)

### Buttle Lake Sediments - Core-6A

Core-6A Depth (cm)	Hg (ppm)	Ni (ppm)	K (Wt. %)	Na (Wt. %)	Zn (ppm)	C organic (Wt. %)	Total N (Wt. %)	S (Wt. %)	CaCO <sub>3</sub> (Wt. %)
0 - 0.5	0.177	29	1.08	1.51	2390	4.75	0.29395	0.58391	0.53
0.5 - 1.0	0.171	30	1.05	1.56	2200	4.74	0.30036	0.33509	0.52
1 - 1.5	0.22	37	1.08	1.49	3050	5.18	0.34946	0.52757	0.36
1.5 - 2	0.236	28	1.39	1.28	3950	4.63	0.30281	1.2703	1.17
2 - 3	0.283	29	1.65	1.12	5200	3.65	0.24215	2.2433	2.18
3 - 4	0.502	35	2.1	0.58	8510	1.04	0.070914	5.8891	5.15
4 - 5	0.504	34	2.04	0.43	9110	0.31	0.030812	7.1599	5.73
4 - 5	0.5	39	2.09	0.44	9510				
5 - 6	0.859	44	1.77	0.34	16300	0.06	0.014869	12.208	3.96
6 - 8	0.783	40	1.97	0.33	16800	0.01	0.014143	10.068	5.98
8 - 10	0.697	37	2.12	0.36	14000	0.04	0.01403	8.4574	5.98
10 - 12	0.526	35	2.3	0.37	9770	0.07	0.014167	8.5277	5.93
12 - 14	0.587	38	2.17	0.35	12200	0.03	0.01084	8.9286	5.68
14 - 18	0.709	34	2.17	0.35	15200	0.03	0.01309	8.791	4.77
18 - 22	0.769	43	2.02	0.34	14600	0.02	0.011561	9.2236	5.93
18 - 22	0.715	39	2.2	0.32	14500				
22 - 26	1.18	43	2.04	0.37	23200	0.02	0.009209	8.708	5.87
26 - 30	0.811	40	2.27	0.36	15800	0.03	0.010985	8.1314	5.59
30 - 34	0.793	37	2.3	0.34	13800	0.02	0.012271	8.9591	5.48
34 - 38	0.822	43	1.85	0.32	16400	0.02	0.0080653	12.47	4.67
38 - 42	0.407	46	2.25	0.39	8370	0.02	0.014467	9.7724	5.93

### Buttle Lake Sediments - Core-7A

Core-7A Depth (cm)	Al (Wt. %)	As (ppm)	Cd (ppm)	Cr (ppm)	Co (ppm)	Cu (ppm)	Fe (Wt. %)	Pb (ppm)	Mg (Wt. %)	Mn (ppm)
0 - 0.5	8.11	55.4	0.2	142	53	216	8.47	7	2.27	1120
0.5 - 1	7.93	58.5	0.2	139	52	210	8.2	6	2.21	1040
0.5 - 1	7.93	57.7	0.3	141	53	218	8.38	6	2.25	1060
1 - 1.5	8.06	48.3	0.3	139	52	215	8.38	7	2.31	1060
1.5 - 2	8.06	55.3	0.2	146	47	213	8.47	7	2.01	949
2 - 3	7.86	46.7	0.2	137	50	198	8.24	6	2.18	1040
3 - 4	7.98	49.4	0.2	138	50	211	8.33	5	2.27	1090
4 - 5	7.85	51.6	0.2	135	48	211	8.26	5	2.10	1030
5 - 6	7.87	61.7	0.3	142	57	257	8.27	5	2.47	1230
6 - 8	7.72	51.7	0.1	141	53	215	8.3	3	2.08	1090
6 - 8	7.82	54.4	0.1	143	50	214	8.35	3	2.10	1070
8 - 10	7.76	57	0.3	132	54	238	8.07	4	2.28	1270
10 - 12	7.97	38.3	0.3	133	48	205	7.98	5	2.21	1210
12 - 14	7.9	33.5	0.3	122	53	212	7.82	5	2.34	1270
14 - 18	7.87	30	0.3	123	49	207	7.83	6	2.15	1270
18 - 22	7.7	22.4	0.3	132	46	200	7.95	5	1.97	1200
22 - 26	8	26.8	0.4	131	53	220	8.06	5	2.27	1300
26 - 30	8.06	22.3	0.4	125	46	186	8.04	5	2.01	1130
26 - 30	8.16	24	0.4	127	51	191	8.15	5	2.15	1200

(continued)

### Buttle Lake Sediments - Core-7A

Core-7A Depth (cm)	Hg (ppm)	Ni (ppm)	K (Wt. %)	Na (Wt. %)	Zn (ppm)	C organic (Wt. %)	Total N (Wt. %)	S (Wt. %)	CaCO <sub>3</sub> (Wt. %)
0 - 0.5	0.136	74	0.407	1.31	188	4.39	0.23681	0.048473	0.10
0.5 - 1	0.11	72	0.432	1.28	144	4.42	0.24036	0.044217	0.17
0.5 - 1	0.104	75	0.413	1.29	142				
1 - 1.5	0.24	73	0.412	1.32	141	4.52	0.24723	0.06455	0.08
1.5 - 2	0.109	67	0.382	1.32	134	4.71	0.25069	0.057372	0.08
2 - 3	0.104	68	0.42	1.29	132	4.55	0.24198	0.052497	0.12
3 - 4	0.106	72	0.397	1.31	127	4.68	0.25205	0.043339	0.13
4 - 5	0.112	69	0.4	1.28	121	4.99	0.26057	0.046644	0.14
5 - 6	0.133	83	0.346	1.29	139	5.24	0.25757	0.06618	0.14
6 - 8	0.137	71	0.345	1.26	119	5.06	0.2353	0.048581	0.22
6 - 8	0.126	71	0.337	1.28	118				
8 - 10	0.095	73	0.395	1.25	125	6.13	0.31235	0.057078	0.14
10 - 12	0.121	68	0.476	1.27	129	5.73	0.31301	0.085428	0.13
12 - 14	0.131	68	0.452	1.25	138	5.60	0.32189	0.059028	0.14
14 - 18	0.139	67	0.438	1.23	139	5.93	0.33211	0.069267	0.14
18 - 22	0.118	62	0.363	1.22	113	6.51	0.30377	0.071912	0.13
22 - 26	0.15	70	0.413	1.29	134	5.31	0.27982	0.081529	0.11
26 - 30	0.121	62	0.434	1.32	117	4.09	0.24982	0.064625	0.16
26 - 30	0.139	66	0.433	1.34	127				

### Buttle Lake Porewaters - Core-4A

Bottle #	Depth (cm)	Cd (ppb)	SLRS2		Cu (ppb)	TM21		As (ppb, ASL)	Replicate
			SLRS2	TM21		SLRS2	TM21		
M36	-5	0.068	0.049	4.86	0	3.01	6.63	<0.5	<0.5
M37	0.25	0.035			2.66			1.7	
M38	0.75	0			2.98			1.7	
M39	1.25	0.097			11.1			3.7	
M40	1.75	0			0			4	
M41	2.5	0			1.12			7.7	
M42	3.5	0			1.63			13.2	
M43	4.5	0			1.09			13.9	
M44	5.5	0.012			1.04			15.1	
M45	7	0			1.33			36	
M46	9	0.002			1.45			58.5	52.5
M47	11	0.027			4.85			90	
M48	13	0.029			3.93			74.5	71.5
M49	16	0.105			52			240	
M50	20	0.018			23.9			168	
M51	28	0.012			1.3			74	
M52	32	0.02	0.044	4.67	1.95	2.69	6.31	83	75.5

(continued)

### Buttle Lake Porewaters - Core-4A

Bottle #	Depth (cm)	Pb (ppb)		Zn (ppb)		Hg (ppb)		rep	
		SLRS2	TM21	SLRS2	TM21	SLRS2	TM21		
M36	-5	0.592	4.88	0.173	26.3	3.87	6.87	<0.1	<0.1
M37	0.25	1.36			37.8			0.2	
M38	0.75	1.18			15.7			0.3	
M39	1.25	5.58			49.6			0.4	
M40	1.75	0.097			6.5			0.3	
M41	2.5	0.571			13.2			0.4	
M42	3.5	1.51			25.9			0.1	0.1
M43	4.5	0.695			59.7			0.3	
M44	5.5	0.267			66.4			0.2	
M45	7	0.386			92.7			0.1	
M46	9	0.361			139			0.2	0.2
M47	11	2.16			79.9			0.1	
M48	13	1.38			77.5			0.2	0.2
M49	16	16.7			171			0.1	
M50	20	12.49			124			0.1	
M51	28	0.371			4.41			0.2	
M52	32	0.02	4.45	0.148	6.44	3.31	6.31	0.2	0.2

### Buttle Lake Porewaters - Core-4B

Bottle #	Depth (cm)	Cd (ppb)	SLRS2		Cu (ppb)		As (ppb, ASL)		Replicate
			SLRS2	TM21	SLRS2	TM21	SLRS2	TM21	
M53	-5	0.081	0.04	4.43	1.56	2.75	6.73	30.5	<0.5
M54	0.25	0.062			5.72			1.3	
M55	0.75	0.264			20.8			3	
M56	1.25	0.232			18.6			5.1	
M57	1.75	0.028			4.27			3.8	
M58	2.5	0.021			1.98			9.8	10.1
M59	3.5	0.037			0.84			5.3	
M60	4.5	0.022			1.31			14.8	
M61	5.5	0.022	0.033	4.34	1.46	2.71	7	17.5	
M62	7	0.03			1.52			11.2	11.1
M63	9	0.028			4.16			38.5	39
M64	11	0.019			1.98			33	
M65	13	0.047			2.04			22.5	
M66	16	0.07			4.34			135	
M67	20	0.062			7.34			136	
M68	24	0.042			1.73			59	
M69	28	0.024	0.031	4.56	1.79	2.9	7.25	73.5	

(continued)

### Buttle Lake Porewaters - Core-4B

Bottle #	Depth (cm)	Pb (ppb)	SLRS2	TM21	Zn (ppb)	SLRS2	TM21	Hg (ppb)	rep
M53	-5	0.278	21.1	3.26	21.1	3.26	7.4	<0.1	<0.1
M54	0.25	1.46	0.129	4.57	14.7			<0.1	
M55	0.75	7.24			64.4			--	
M56	1.25	6.48			66			0.2	
M57	1.75	0.857			27.3			0.4	
M58	2.5	0.864			32.2			0.3	0.2
M59	3.5	0.549			68.9			0.2	
M60	4.5	0.919			59.7			0.4	
M61	5.5	0.645	0.127	4.42	35.5	3.19	7.6	0.1	
M62	7	0.059			94.5			0.2	0.1
M63	9	2.02			128			0.1	0.2
M64	11	0.194			12.2			<0.1	
M65	13	0.564			44.5			0.1	
M66	16	1.59			129			0.1	
M67	20	5.36			26.8			0.1	
M68	24	0.401			6.77			0.1	
M69	28	0.246	0.129	4.39	5.11	3.41	8	0.2	



### Buttle Lake Porewaters - Core-6A

Bottle #	Depth (cm)	Cd (ppb)	SLRS2		Cu (ppb)		As (ppb, ASL)		Replicate
			SLRS2	TM21	SLRS2	TM21	SLRS2	TM21	
M19	-5	0.095	0.031	4.56	1.61	2.9	7.25	0.5	0.7
M20	0.25	0.163			9.33			1.6	
M21	0.75	0.266			7.07			1.2	
M22	1.25	0.321			10.9			1.4	
M23	1.75	0.192			3.09			1.4	
M24	2.5	0.083			2.38			2.5	2.4
M25	3.5	0.086			2.65			2.9	
M26	4.5	0.039			5.34			2.9	
M27	5.5	0.342	0.032	4.43	11.3	2.73	6.83	6.3	
M28	7	0.045			0.79			4.5	
M29	9	0.05			0.39			2.2	
M30	11	0.147			0.57			2.3	
M31	13	0.083			0.37			2.2	2.2
M32	16	0.184			0.58			4.1	
M33	20	0.418			3.73			4.5	4.3
M34	24	0.26			1.27			5.7	
M35	28	0.363	0.035	4.46	1.82	2.71	6.87	4.9	

(continued)

### Buttle Lake Porewaters - Core-6A

Bottle #	Depth (cm)	Pb (ppb)	SLRS2		TM21		Zn (ppb)	Hg (ppb)		rep.
			SLRS2	TM21	SLRS2	TM21		SLRS2	TM21	
M19	-5	0.787	0.129	4.39	33	3.41	8	<0.1	<0.1	
M20	0.25	1.96			42.1			0.3		
M21	0.75	1.59			51.9			<0.1		
M22	1.25	4.35			72.9			0.4		
M23	1.75	0.981			66.9			0.4		
M24	2.5	0.68			77.8			0.1	0.1	
M25	3.5	1.57			64.7			0.1		
M26	4.5	0.242			44.9			0.2		
M27	5.5	63.3	0.129	4.55	78.6	3.48	7.55	<0.1		
M28	7	1.74			6.15			--		
M29	9	0.702			2.68			<0.1		
M30	11	9.31			53.9			<0.1		
M31	13	0.965			2.88			<0.1	<0.1	
M32	16	5.05			23.9			<0.1		
M33	20	41.4			46.4			<0.1		
M34	24	18.8			12.9			<0.1		
M35	28	35.7	0.134	4.61	31.8	3.67	7.7	<0.1		

### Buttle Lake Porewaters - Core-7A

Bottle #	Depth (cm)	Cd (ppb)		Cu (ppb)		As (ppb, ASL)		Replicate
		SLRS2	TM21	SLRS2	TM21	SLRS2	TM21	
M1	-5	0.078		1.19		<0.5		
M3	-5	0.047		20.8		8.5		
M2	0.25	0.102		1.21		<0.5		
M4	0.75	0.085		29.8				
M5	1.25	0.054		34.6		15.6		
M6	1.75	0.052		8.97		11.9		
M7	2.5	0.048		18.7		27.9		
M8	3.5	0.05		15.1		42		
M9	4.5	0.038	0.032	14.7	4.56	50	2.77	6.83
M10	5.5	0.042		12.4		52		
M11	7	0.038		8		52.2		49.5
M12	9	0.033		7.1		43.5		
M13	11	0.038		8.9		37.5		
M14	13	0.039		8.5		33.5		
M15	16	0.018		2.18		37.5		
M16	20	0.032		3.84		39		
M17	24	0.018		5.61		35.5		
M18	28	0.038	0.025	5.76	4.24	29.5	2.64	6.65

(continued)

### Buttle Lake Porewaters - Core-7A

Bottle #	Depth (cm)	Pb (ppb)		Zn (ppb)		Hg (ppb)		rep.
		SLRS2	TM21	SLRS2	TM21	SLRS2	TM21	
M1	-5	0.061	4.61	13.6	4.61	<0.1		
M3	-5	0.708		11.5		<0.1		
M2	0.25	0.666		13		<0.1		
M4	0.75	3.29		23.3				
M5	1.25	0.99		3.79				
M6	1.75	0.452		24.2		<0.1		
M7	2.5	0.541		7.72		0.1		
M8	3.5	0.492		2.6		<0.1		
M9	4.5	0.447	4.71	2.49	4.71	0.1		
M10	5.5	0.347		2.24		0.1		0.1
M11	7	0.244		2.07		0.1		<0.1
M12	9	0.238		1.44		0.1		0.1
M13	11	0.296		1.51		0.1		0.1
M14	13	0.313		4.74		0.1		0.1
M15	16	0.107		1.61		0.1		0.1
M16	20	0.145		2.02		0.1		
M17	24	0.182		1.64		0.2		
M18	28	0.167	4.45	1.89	4.45	0.2		0.2

Buttle Lake Survey - But-4 Peeper-14 Left

Sample #	Cell #	Depth (cm)	As (ppb)	Cu (ppb)	rep	SLRS2	TM21	Cd (ppb)	rep	SLRS2	TM21	Hg (ppb)	rep
61	1	-17.04	<0.5	4.2		2.66	6.77	0.22		0.03	4.57	<0.10	
62	5	-12	<0.5	3.1				0.13	0.07			<0.10	
63	10	-5.7	<0.5	2.5	1.5			0.12				<0.10	
66	13	-1.92	<0.5	2.7				0.16				<0.10	
67	14	-0.66	<0.5	1				0.03				<0.10	<0.10
68	15	0.6	1.2	0.5				0.01				<0.10	
69	16	1.9	1.3	1.1		2.79	7.13	0.02		0.027	4.55	0.10	
70	17	3.1	1.5	1				0.01				0.10	
71	18	4.4	5.8	0.7				0				0.10	
72	19	5.6	5.0	1				0				0.20	
73	20	6.9	11.4	1.7				0.01				0.20	
74	21	8.2	14.5	1.7	1.9			0.01	0.01			0.40	
75	22	9.4		2				0.02					
76	23	10.7	19.8	2.3				0.02				0.30	
77	24	11.9	17.4	2.5		2.86	7.22	0.02		0.03	4.31	0.30	
78	26	14.5	29.7	2.5				0.03				0.40	
79	28	17.6	21.6	3.1				0.03				0.40	
80	30	19.5	31.5	3.3				0.04				<0.10	
81	32	22.0	18.6	2.4				0.02				0.30	
82	34	24.5	39.0	2.6				0.02				<0.10	<0.10
84	38	29.6	20.7	1.8				0.02				0.20	
86	42	34.6	26.7	2				0.02				<0.10	
88	46	39.7	28.5	1.7	1.7			0.02	0.03			0.20	
90	50	44.7	33.3	1.7				0				0.10	

(continued)

### Buttle Lake Survey - But-4 Peeper-14 Left

Sample #	Cell #	Depth (cm)	Zn (ppb)	rep	SLRS2	TM21	Pb (ppb)	rep	SLRS2	TM21
61	1	-17.04	117		3.51	7.99	1.57	1.52	0.131	4.4
62	5	-12	67				0.41			
63	10	-5.7	57	34			0.5	0.2		
66	13	-1.92	120				0.63			
67	14	-0.66	50				0.32			
68	15	0.6	138				0.17			
69	16	1.9	83		3.52	8.02	0.6		0.123	4.5
70	17	3.1	43				0.45			
71	18	4.4	34				0.53			
72	19	5.6	57				1			
73	20	6.9	82				2			
74	21	8.2	86	91			2.3			
75	22	9.4	112				2.7	2.2		
76	23	10.7	88				2.4			
77	24	11.9	108		3.54	7.96	3.3		0.122	4.23
78	26	14.5	94				3.4			
79	28	17.6	93				3.2			
80	30	19.5	109				3.7			
81	32	22.0	154				2.7			
82	34	24.5	175				3.7			
84	38	29.6	227				2.7			
86	42	34.6	299				2.4			
88	46	39.7	299	304			4.3	4.2		
90	50	44.7	262				3.3			

(continued)

### Buttle Lake Survey - But-4 Peeper-14 Left

Sample #	Cell #	Depth (cm)	Fe (ppb)	rep	TM11	TM21	Mn (ppb)	rep	TM11	TM21
61	1	-17.04	37.8			6.3	1.8			6.6
62	5	-12	11.6				2.8			
63	10	-5.7	10.8				1.7			
66	13	-1.92	25.2				83.9			
67	14	-0.66	168.4		279.3		1936.0		51.7	
68	15	0.6	474.4				6239.0			
69	16	1.9	543.7				7749.0			
70	17	3.1	1026.0				10815.0			
71	18	4.4	8542.0			6.3	8619.0	7508.0		7.0
72	19	5.6	9733.0				11851.0			
73	20	6.9	9985.0				13001.0			
74	21	8.2	17237.0				10108.0			
75	22	9.4	18861.0				12843.0		50.5	
76	23	10.7	26207.0				8590.0			
77	24	11.9	29670.0				8283.0			
78	26	14.5	32628.0				9316.0			
79	28	17.6	30981.0	28577.0			7884.0			
80	30	19.5	35973.0			6.2	7195.0			7.3
81	32	22.0	26502.0	25509.0			8637.0	8231.0		
82	34	24.5	34991.0				4405.0			
84	38	29.6	28200.0	32051.0			10866.0		53.5	
86	42	34.6	40333.0		269.4		8997.0	7499.0		
88	46	39.7	43315.0				10754.0			
90	50	44.7	43232.0				12200.0			

Buttle Lake Survey - But-4 Peeper-14 Right

Sample #	Cell #	Depth (cm)	As (ppb)	Cu (ppb)	rep	SLRS2	TM21	Cd (ppb)	rep	SLRS2	TM21	Hg (ppb)	rep
91	1	-17.04		10		3	7.72	1		0.034	4.47	<0.10	
92	5	-12	0.5	2.8				0.1				<0.10	
93	10	-5.7	<0.5	3.9	3.9			0.09				<0.10	
96	13	-1.92	<0.5	3.8				0.54				<0.10	
97	14	-0.66	<0.5	3.4				0.39				<0.10	
98	15	0.6	<0.5									<0.10	
99	16	1.9	1.7	1.1				0.04				<0.10	<0.10
100	17	3.1	2.2	0.7		2.89	7.34	0.01		0.032	4.58	0.20	
101	18	4.4	2.8	0.8				0				0.30	
102	19	5.6	6.3	0.9				0.01				0.20	
103	20	6.9	8.1	1.3				0.02				0.30	
104	21	8.2	7.9	1.5	1.5			0.01				0.30	
105	22	9.4	7.7	1.9				0.01				0.30	
106	23	10.7	8.4	1.7				0.01				0.20	
107	24	11.9		4.1				0.03				0.30	
108	26	14.5	13.8	2.5				0.01				0.20	
109	28	17.6	15.0	3.2		3	7.79	0.02		0.039	4.61	0.40	
110	30	19.5	42.6	3.1				0.03				0.40	0.3
111	32	22.0	32.0	2.8				0.03				0.30	
112	34	24.5	27.0	3.7				1				0.20	
114	38	29.6	18.0	1.4				0.02				0.20	
116	42	34.6	23.1	1.5				0.02				0.20	
118	46	39.7	31.2	1.4	1.4			0.01				0.30	
120	50	44.7	37.8	1.1				0.01				0.30	

(continued)



### Buttle Lake Survey - But-4 Peeper-14 Right

Sample #	Cell #	Depth (cm)	Zn (ppb)	rep	SLRS2	TM21	Pb (ppb)	rep	SLRS2	TM21
91	1	-17.04	412		3.71	8.69	6.3		0.116	4.13
92	5	-12	51				0.4			
93	10	-5.7	48	50			0.3			
96	13	-1.92	224				1.3			
97	14	-0.66	160				1.3			
98	15	0.6								
99	16	1.9	50				0.5			
100	17	3.1	30		3.66	8.39	0.4		0.129	4.38
101	18	4.4	28				0.3			
102	19	5.6	44				1			
103	20	6.9	50				1.6			
104	21	8.2	62	60			2			
105	22	9.4	74				2			
106	23	10.7	87				1.5			
107	24	11.9	77				4.7			
108	26	14.5	104				3.2			
109	28	17.6	99		3.86	8.82	3.6		0.121	4.11
110	30	19.5	118				3.5			
111	32	22.0	159				3.7			
112	34	24.5	503				2.9			
114	38	29.6	139				1.1			
116	42	34.6	197				3.5			
118	46	39.7	235	234			3.9			
120	50	44.7	256				4.1			

(continued)

### Buttle Lake Survey - But-4 Peeper-14 Right

Sample #	Cell #	Depth (cm)	Fe (ppb)	rep	TM11	TM21	Mn (ppb)	rep	TM11	TM21
91	1	-17.04	1940.0				14.2			7.4
92	5	-12	11.3	10.5		5.4	3.3			
93	10	-5.7	9.7				2.7			
96	13	-1.92	29.4			5.8	9.3	9.1		
97	14	-0.66	20.9				94.6		53.9	
98	15	0.6								
99	16	1.9	324.7				4749.0			
100	17	3.1	430.3	509.6			7301.0			
101	18	4.4	1567.0				8360.0			5.8
102	19	5.6	1322.0			5.5	10091.0			
103	20	6.9	5156.0				9428.0			
104	21	8.2	7132.0				9316.0			
105	22	9.4	7973.0				10513.0			7.2
106	23	10.7	12424.0			5.4	9109.0			
107	24	11.9	12915.0				7783.0			
108	26	14.5	19691.0				6690.0			
109	28	17.6	26224.0				6879.0		54.1	
110	30	19.5	25081.0		268.8		6346.0			
111	32	22.0	33906.0				9049.0			
112	34	24.5	33032.0				10719.0			
114	38	29.6	29703.0				15515.0			6.3
116	42	34.6	34645.0			5.7	15085.0			
118	46	39.7	45269.0				11555.0			
120	50	44.7	50396.0		267.1		11012.0			

### Buttle Lake Survey - But-6 Peeper-15 Left

Sample #	Cell #	Depth (cm)	As (ppb)	Cu (ppb)	rep	SLRS2	TM21	Cd (ppb)	rep	SLRS2	TM21	Hg (ppb)	rep
121	1	-27.72	<0.5	2.1		3.1	7.81	0.06		0.038	4.6	<0.10	
123	10	-16.38	<0.5	1.8				0.04				<0.10	<0.10
125	20	-3.78	<0.5	2	2			0.07	0.07			0.1	
127	21	-2.52	<0.5	1.9				0.06				0.1	
128	21.5	-1.89	<0.5	2.4				0.09				0.1	
129	22	-1.26	<0.5	2.2				0.09				0.1	
130	22.5	-0.63	<0.5	1.9				0.1				0.1	
131	23	0	<0.5	2		3.1	7.92	0.1		0.036	4.58	<0.10	
132	23.5	0.63	<0.5	2.5				0.14				0.20	
133	24	1.26	0.6	2.6				0.14				0.10	
134	24.5	1.89	0.7	2.6	2.6			0.17	0.19			0.30	
135	25	2.52	<0.5	2.5				0.14				<0.10	
136	25.5	3.15	<0.5	2.6				0.21				<0.10	
137	26	3.78	0.7	2.7				0.14				<0.10	
138	26.5	4.41	0.8	3.2				0.31				<0.10	
139	27	5.04		2.7				0.17				<0.10	
140	27.5	5.67	1.1	2.8		3.06	7.59	0.31		0.042	4.63	<0.10	
141	28	6.3	1.4	1.4				0.05				<0.10	
142	29	7.6	1.8	1.6				0.05				0.20	
143	30	8.8	1.2	1.5				0.05				<0.10	
144	32	11.3	1.3	2				0.07				0.10	
146	38	18.9	1.1	1.5				0.07				<0.10	
148	46	29.0	1.2	1.3	1.3			0.09	0.08			<0.10	
150	54	39.1	1.5	0.9				0.1				<0.10	<0.10

(continued)

Buttle Lake Survey - But-6 Peeper-15 Left

Sample #	Cell #	Depth (cm)	Zn (ppb)	rep	SLRS2	TM21	Pb (ppb)	rep	SLRS2	TM21
121	1	-27.72	22		3.93	8.66	0.7		0.123	4.08
123	10	-16.38	18				0.8			
125	20	-3.78	22	22			17	17		
127	21	-2.52	22				1.1			
128	21.5	-1.89	24				1.8			
129	22	-1.26	24				1.1			
130	22.5	-0.63	27				1.3			
131	23	0	31		3.89	8.81	1.2		0.124	4.16
132	23.5	0.63	40				3.5			
133	24	1.26	42				2.7			
134	24.5	1.89	48	47			3.7	3.9		
135	25	2.52	37				1.9			
136	25.5	3.15	58				2.3			
137	26	3.78	40				2.4			
138	26.5	4.41	60				3.8			
139	27	5.04	46				34			
140	27.5	5.67	75		3.79	8.54	4.7		0.123	4.22
141	28	6.3	17				1.4			
142	29	7.6	10				1.3			
143	30	8.8	7.9				1			
144	32	11.3	11				1.8			
146	38	18.9	7.7				1.3			
148	46	29.0	8.7	8.9			1.7	1.7		
150	54	39.1	8.6				1.5			

(continued)

Buttle Lake Survey - But-6 Peeper-15 Left

Sample #	Cell #	Depth (cm)	Fe (ppb)	rep	TM11	TM21	Mn (ppb)	rep	TM11	TM21
121	1	-27.72	7.1			6.6	1.6			5.8
123	10	-16.38	4.6	4.2			4.0			
125	20	-3.78	13.3	11.1			2.6			
127	21	-2.52	5.8				2.9			
128	21.5	-1.89	10.7		275.7		2.7		47.5	
129	22	-1.26	8.5				3.0			
130	22.5	-0.63	8.4				4.0			
131	23	0	7.3				5.0			
132	23.5	0.63	14.0			6.5	9.7			5.8
133	24	1.26	13.6				8.1			
134	24.5	1.89	8.3	7.3			9.7			
135	25	2.52	10.6				12.0			
136	25.5	3.15	13.8		269.0		12.4		48.2	
137	26	3.78	25.4				57.5			
138	26.5	4.41	25.3				53.6			
139	27	5.04	42.3				216.4			
140	27.5	5.67	30.1			6.6	370.2			6.0
141	28	6.3	76.0				428.5			
142	29	7.6	78.1				298.1	313.1		
143	30	8.8	94.6				230.0			
144	32	11.3	109.0		277.4		182.1		47.3	
146	38	18.9	111.3				56.5	63.8		
148	46	29.0	77.2	70.7			54.2			
150	54	39.1	91.6				32.7			

### Buttle Lake Survey - But-6 Peeper-15 Right

Sample #	Cell #	Depth (cm)	As (ppb)	Cu (ppb)	rep	SLRS2	TM21	Cd (ppb)	rep	SLRS2	TM21	Hg (ppb)	rep
151	1	-28.98	<0.5	2.2		3.15	7.85	0.06		0.036	4.48	<0.10	
153	10	-17.64	<0.5	2.4				0.06				<0.10	<0.10
155	20	-5.04	<0.5	2	2.1			0.06	0.06			<0.10	
157	21	-3.78	<0.5	2				0.06				<0.10	
158	21.5	-3.15	<0.5	1.7				0.06				<0.10	
159	22	-2.52	<0.5	2.1				0.08				<0.10	
160	22.5	-1.89	<0.5	1.8				0.08				<0.10	
161	23	-1.26	<0.5	2.6		3.03	7.61	0.12		0.036	4.62	<0.10	
162	23.5	-0.63	0.8	1.9				0.12				<0.10	
163	24	0	<0.5	2.5				0.12				<0.10	
164	24.5	0.63	<0.5	2.1	2.1			0.12	0.12			0.10	
165	25	1.26		3				0.1				<0.10	
166	25.5	1.89		2.4				0.13				<0.10	
167	26	2.52	0.8	2.9				0.17				<0.10	
168	26.5	3.15	0.5	2.6				0.17				<0.10	
169	27	3.78	1.2	1.4				0.06				<0.10	
170	27.5	4.41	1.1	1.4		3.03	7.63	0.06		0.041	4.6	<0.10	<0.10
171	28	5.04	1.3	7				0.07				<0.10	
172	29	6.3	2.5	1.5				0.08				<0.10	
173	30	7.6		1.4				0.07				<0.10	
174	32	10.1	0.6	1.5				0.07				<0.10	
176	38	17.6	1.0	2.4				0.09				0.10	0.1
178	46	27.7	0.9	1.3	1.3			0.08	0.08			<0.10	
180	54	37.8	1.3	0.9				0.09				<0.10	

(continued)

### Buttle Lake Survey - But-6 Peeper-15 Right

Sample #	Cell #	Depth (cm)	Zn (ppb)	rep	SLRS2	TM21	Pb (ppb)	rep	SLRS2	TM21
151	1	-28.98	23		3.97	8.6	1.2		0.12	3.98
153	10	-17.64	22				117			
155	20	-5.04	22	22			1.1	1		
157	21	-3.78	21				1			
158	21.5	-3.15	21				1			
159	22	-2.52	24				0.9			
160	22.5	-1.89	27				1			
161	23	-1.26	35		3.86	8.44	1.2		0.124	4.22
162	23.5	-0.63	36				1.8			
163	24	0	35				2.1			
164	24.5	0.63	39	40			1.9	1.8		
165	25	1.26	32				2.7			
166	25.5	1.89	34				44			
167	26	2.52	50				4.8			
168	26.5	3.15	42				2.7			
169	27	3.78	14				1.3			
170	27.5	4.41	17		3.86	8.6	1.5		0.126	4.17
171	28	5.04	14				1.5			
172	29	6.3	10				1.8			
173	30	7.6	11				1.9			
174	32	10.1	8.9				1.4			
176	38	17.6	8.5				1.1			
178	46	27.7	9.2	9.1			2	2		
180	54	37.8	5.1				1.2			

(continued)

### Buttle Lake Survey - But-6 Peeper-15 Right

Sample #	Cell #	Depth (cm)	Fe (ppb)	rep	TM11	TM21	Mn (ppb)	rep	TM11	TM21
151	1	-28.98	8.3			6.3	2.2			5.9
153	10	-17.64	5.7				2.1			
155	20	-5.04	8.6				2.7			
157	21	-3.78	5.8				2.3			
158	21.5	-3.15	5.1		273.2		3.4		47.0	
159	22	-2.52	5.2				2.5			
160	22.5	-1.89	6.8				3.6			
161	23	-1.26	6.7				4.9			
162	23.5	-0.63	10.6			6.1	7.4			5.7
163	24	0	10.5				8.1			
164	24.5	0.63	14.6				8.6			
165	25	1.26	19.0				33.8			
166	25.5	1.89	14.5			7.8	27.9			7.3
167	26	2.52	19.6				226.5	199.3		
168	26.5	3.15	20.3				134.4	113.1		
169	27	3.78	99.5				453.4			
170	27.5	4.41	102.2		270.7		497.3		57.1	
171	28	5.04	100.1				403.9			
172	29	6.3	108.3				298.8			
173	30	7.6	81.5				183.3			
174	32	10.1	106.7			6.5	119.7			5.9
176	38	17.6	46.0				287.7	275.1		
178	46	27.7	54.7				37.0			
180	54	37.8	33.4		265.0		9.2	9.3	45.9	



### Buttle Lake Survey - But-7 Peeper-13 Left

Sample #	Cell #	Depth (cm)	As (ppb)	Cu (ppb)	rep	SLRS2	TM21	Cd (ppb)	rep	SLRS2	TM21	Hg (ppb)	rep
1	1	-17.64	<0.5	1.2		2.65	6.68	0.03		0.022	4.24	<0.10	
2	5	-12.6	<0.5	1.2				0.03				<0.10	
3	10	-6.3	<0.5	1.1	1.1			0.03	0.03			<0.10	
5	12	-3.78	<0.5	1				0.03				<0.10	
6	13	-2.52	<0.5	1				0.03				<0.10	
7	14	-1.26	<0.5	1		2.56	6.54	0.03		0.026	4.33	<0.10	
8	15	0	<0.5	1				0.04				<0.10	0.10
9	16	1.26	<0.5	1.1				0.03				0.10	
10	17	2.52	<0.5	1.2				0.03				<0.10	
11	18	3.78	0.7	1.2				0.01				<0.10	
12	19	5.04	0.5	0.9				0.02				<0.10	
13	20	6.3	1	0.9				0.02				<0.10	
14	22	8.82	1.4	0.9	0.9	2.77	7.07	0.01	0.01	0.028	4.43	<0.10	
15	24	11.34	1.5	0.9				0.01				<0.10	
16	26	13.86	1.6	0.8				0.01				<0.10	
17	28	16.38	1.4	0.8				0.01				<0.10	
18	30	18.9	1.1	0.9				0.01				<0.10	
20	34	23.9	1.0	1.2				0.01				0.10	<0.10
22	38	29.0	0.6	1.7				0.03				<0.10	
24	42	34.0	1.1	1.5				0.03				<0.10	
26	46	39.1	1.5	1.3				0.01				<0.10	<0.10
28	54	49.1	2.3	2.2	2.2			0.01	0.02			<0.10	
30	60	56.7	5.4	20				0.02				<0.10	

(continued)

### Buttle Lake Survey - But-7 Peeper-13 Left

Sample #	Cell #	Depth (cm)	Zn (ppb)	rep	SLRS2	TM21	Pb (ppb)	rep	SLRS2	TM21
1	1	-17.64	10		3.47	7.64	0.14		0.124	4.32
2	5	-12.6	10				0.16			
3	10	-6.3	9.2	9.2			0.1	0.11		
5	12	-3.78	8.3				0.1			
6	13	-2.52	8.3				0.11			
7	14	-1.26	7.9		3.34	7.6	0.1		0.126	4.38
8	15	0	7.9				0.12			
9	16	1.26	7.5				0.1			
10	17	2.52	6.5				0.1			
11	18	3.78	1.5				0.08			
12	19	5.04	2.3				0.1			
13	20	6.3	2.4				0.08			
14	22	8.82	1.2	1.2	3.61	8.38	0.22	0.23	0.126	4.32
15	24	11.34	0.8				0.22			
16	26	13.86	0.9				0.12			
17	28	16.38	0.9				0.14			
18	30	18.9	1.1				0.14			
20	34	23.9	1				0.2			
22	38	29.0	5.1				0.18			
24	42	34.0	2.6				0.2			
26	46	39.1	1.8				0.27			
28	54	49.1	1.3	1.3			1.1	1		
30	60	56.7	2.7				8.2			

(continued)

Buttle Lake Survey - But-7 Peeper-13 Left

Sample #	Cell #	Depth (cm)	Fe (ppb)	rep	TM11	TM21	Mn (ppb)	rep	TM11	TM21
1	1	-17.64	14.9			6.7	1.4			6.6
2	5	-12.6	12.6				1.9			
3	10	-6.3	5.9				1.4			
5	12	-3.78	5.8				1.6			
6	13	-2.52	6.1		274.7		1.8		52.4	
7	14	-1.26	5.1	4.6			1.4			
8	15	0	6.9				1.5			
9	16	1.26	6.2				1.3			
10	17	2.52	7.7			6.0	1.9			2.7
11	18	3.78	10.4	10.4			3.8			
12	19	5.04	7.8				25.1	21.9		
13	20	6.3	11.9				18.6			
14	22	8.82	24.2		269.6		31.8		52.3	
15	24	11.34	27.4				36.0			
16	26	13.86	25.2				38.6			
17	28	16.38	14.8	12.6			39.1			
18	30	18.9	19.8			6.6	39.8			7.3
20	34	23.9	23.7				21.6			
22	38	29.0	20.2				11.5	10.2		
24	42	34.0	23.7				13.5			
26	46	39.1	39.1		268.2		29.7			5.7
28	54	49.1	74.4				65.8			
30	60	56.7	1635.0	1800.8			107.1			

### Buttle Lake Survey - But-7 Peeper 13-Right

Sample #	Cell #	Depth (cm)	As (ppb)	Cu (ppb)	rep	SLRS2	TM21	Cd (ppb)	rep	SLRS2	TM21	Hg (ppb)	rep
31	1	-17.64	<0.5	1.5		2.72	6.81	0.03		0.033	4.53	0.10	
32	5	-12.6	<0.5	1.2				0.03				<0.10	
33	10	-6.3	<0.5	1.2	1.1			0.03	0.03			<0.10	
35	12	-6.3	<0.5	1.1				0.03				<0.10	
36	13	-2.52	<0.5	1.2				0.03				<0.10	<0.10
37	14	-1.26	<0.5	1.1				0.03				0.10	
38	15	0	<0.5	1.3				0.03				<0.10	
39	16	1.26		1.2		2.68	6.71	0.02		0.031	4.52	<0.10	
40	17	2.52	1	1.4				0.02				<0.10	
41	18	3.78	1.2	0.9				0.01				<0.10	
42	19	5.04	1.2	0.9				0.02				<0.10	
43	20	6.3	1.1	0.9				0.01				0.10	
44	22	8.82	1.8	0.8	0.8			0.01	0.01			0.10	
45	24	11.34	1.8	1.2				0.01				0.10	
46	26	13.86	1.5	0.7				0				<0.10	
47	28	16.38	2	0.7				0.02				<0.10	
48	30	18.9		0.9		2.69	6.77	0.01		0.03	4.5	<0.10	
50	34	23.9	1.4	1				0.01				<0.10	<0.10
52	38	29.0	0.8	1.2				0.01				<0.10	
54	42	34.0	1.0	1.1				0.01				<0.10	
56	46	39.1	1.4	1.1				0.02				<0.10	<0.10
58	54	49.1	2.1	1.6	1.5			0.01	0.01			<0.10	
60	60	56.7	3.8	8.9				0.03				<0.10	

(continued)

### Buttle Lake Survey - But-7 Peeper 13-Right

Sample #	Cell #	Depth (cm)	Zn (ppb)	rep	SLRS2	TM21	Pb (ppb)	rep	SLRS2	TM21
31	1	-17.64	8		3.56	8.07	31	0.15		0.127
32	5	-12.6	7.7				32	0.12		
33	10	-6.3	8.4	8.2			33	0.11	0.1	
35	12	-6.3	8.9				35	0.12		
36	13	-2.52	8.2				36	0.14		
37	14	-1.26	8.2				37	0.1		
38	15	0	7.8				38	0.11		
39	16	1.26	6.7		3.52	8.03	39	0.1		0.126
40	17	2.52	2.2				40	0.11		
41	18	3.78	1.4				41	0.11		
42	19	5.04	0.7				42	0.11		
43	20	6.3	1				43	0.15		
44	22	8.82	0.7	0.7			44	0.18	0.19	
45	24	11.34	1.1				45	0.67		
46	26	13.86	1.1				46	0.47		
47	28	16.38	1.1				47	0.32		
48	30	18.9	0.9		3.58	8.12	48	0.37		0.129
50	34	23.9	1.2				50	0.24		
52	38	29.0	1.1				52	0.18		
54	42	34.0	1.7				54	0.16		
56	46	39.1	1.6				56	0.16		
58	54	49.1	1.5	1.4			58	0.87	0.87	
60	60	56.7	2.3				60	4.97		

(continued)

### Buttle Lake Survey - But-7 Peeper 13-Right

Sample #	Cell #	Depth (cm)	Fe (ppb)	rep	TM11	TM21	Mn (ppb)	rep	TM11	TM21
31	1	-17.64	4.38	7.7				1.4		
32	5	-12.6		13.4			6.6	1.4	51.1	
33	10	-6.3		5.1				1.5		
35	12	-6.3		5.4				1.4		
36	13	-2.52		6.4				1.4		
37	14	-1.26		5.5		266.5		1.4		6.2
38	15	0		7.3				1.5		
39	16	1.26	4.38	13.0				2.3		
40	17	2.52		8.7	8.5			6.9		
41	18	3.78		13.3			6.1	27.1	51.7	
42	19	5.04		11.2				25.0		
43	20	6.3		17.8				20.9		
44	22	8.82		24.0				22.8		
45	24	11.34		221.2	208.1		6.2	37.8		6.3
46	26	13.86		58.5				43.6		
47	28	16.38		51.5				38.8		
48	30	18.9	4.37	62.2				33.9		
50	34	23.9		24.3		278.9		20.7	50.8	
52	38	29.0		24.1				11.9		
54	42	34.0		26.1				13.1		
56	46	39.1		14.5				21.2		
58	54	49.1		79.6			5.6	56.3		6.2
60	60	56.7		898.6	929.2			96.8	50.4	

### Buttle Lake Survey - But-4 NWRI Peeper-4a

Bottle #	Depth (cm)	Cu (ppb)	Replicate	SLRS2	TM21	Cd (ppb)	Replicate	SLRS2	TM21
1	-32	22.1		2.85	7.49	0.12		0.027	4.47
10	-23	14.8				0.35			
20	-13	4.75				0.033			
25	-8	10.1				0.073			
27	-6	6.5				0.037			
29	-4	15.3	15.2			0.366	0.353		
31	-2	8.46	8.48			0.06	0.058		
32	-1	7.24				0.032			
33	0	22.2	25.5			0.262	checked		
34	1	5.14		2.72	7.23	0.025		0.029	4.51
35	2	6.65				0.056			
36	3	6.09				0.055			
37	4	9.02				0.026			
38	5	6.65				0.047			
40	7	13.2	13.4			0.035			
42	9	9.24				0.051			
44	11	6.97				0.044			
46	13	8.51				0.03			
48	15	13.6	14.4			0.107	0.097		
50	17	6.14		2.8	7.38	0.06		0.044	4.53

(continued)

### Buttle Lake Survey - But-4 NWRI Peeper-4a

Bottle #	Depth (cm)	Pb (ppb)	Replicate	SLRS2	TM21	Zn (ppb)	Replicate	SLRS2	TM21
1	-32	45.4		0.14	4.4	465		3.5	8.14
10	-23	24.6				228			
20	-13	13.7				171			
25	-8	14.2				126			
27	-6	6.88				73.3			
29	-4	15.3	15			149	checked		
31	-2	7.39	7.22			79.8	80.7		
32	-1	5.26				81.9			
33	0	17.2	21.2			169	checked		
34	1	4.02		0.13	4.25	70.3		3.33	8.15
35	2	4.11				78.3			
36	3	4.33				80.2			
37	4	4.4				82.7			
38	5	4.38				80.3			
40	7	11.35	12.7			185	checked		
42	9	4.95				66.2			
44	11	6.54				99.5			
46	13	7.19				115	checked		
48	15	12.6	14.9			213	checked		
50	17	10.1		0.12	4.23	73.3	checked	3.8	7.94

(continued)



### Buttle Lake Survey - But-4 NWRI Peeper-4a

Bottle #	Depth (cm)	Fe (ppb)	TM21	rep (next day)	TM21	SLRS2	rep (next day)	TM21	Mn (ppb)	TM21
1	-32	63878	5.56						8756	6.09
10	-23	54247		54247	6.63	132.5			11090	
20	-13	48615							10909	
25	-8	52715							11124	
27	-6	47953	5.17						11064	6.65
29	-4	49485							1116	
31	-2	51597							11245	
32	-1	51431	5.47						10840	
33	0	53170	6.12						10298	6.34
34	1	50189	6.12						10332	
35	2	48325	5.47	53502	6.63	132.5			10151	
36	3	51100							10780	
37	4	47373	4.9						10401	6.22
38	5	48905							9962	
40	7	52342							10375	
42	9	50893							9807	
44	11	50437	5.27						10160	6.66
46	13	49816							10039	
48	15	52177							10082	
50	17	51141	4.9	54454	6.63	132.5			10108	6.33

(continued)

### Buttle Lake Survey - But-4 NWRI Peeper-4a

Bottle #	Depth (cm)	Fe (ppb) (next day)	TM21	SLRS2	rep	TM21	SLRS2	As (ppb)	Lab Rep	Hg (ppb)
1	-32	64807		153.3				110		0.28
10	-23	57726						43		0.26
20	-13	53377						30		0.23
25	-8	51348						35		0.18
27	-6	52342		148.3				27		0.22
29	-4	56028						29		0.18
31	-2	48947	6.26		48698	5.9		28		0.20
32	-1	55241						31	28	0.24
33	0	55200		141.2				31		0.20
34	1	52425						25		0.4
35	2	51928						23		0.17
36	3	55779						24		2.40
37	4	53129		135.1				27		0.21
38	5	54578						26		0.38
40	7	55282						37	34	0.25
42	9	54496						28		0.26
44	11	55158		139.3				25		0.24
46	13	50396						28		0.21
48	15	51638						29	29	0.19
50	17	50934	7.25							

### Buttle Lake Survey - But-4 NWRI Peeper-4b

Bottle #	Depth (cm)	Cu (ppb)	Replicate	SLRS2	TM21	Cd (ppb)	Replicate	SLRS2	TM21
1	-32	18.3		2.8	7.38	0.265		0.044	4.53
10	-23	19.1				0.145			
20	-13	9.65				0.125			
25	-8	10.9				0.327			
27	-6	9.4				0.125			
29	-4	10.5				0.095			
31	-2	12.6				0.081			
32	-1	15.6				0.204			
33	0	14.3				0.07			
34	1	10.9		2.66	6.96	0.126		0.031	4.39
35	2	7.64	7.07			0.12	0.128		
36	3	10.6		2.79	7.04	0.08		0.021	4.37
37	4	7.87				0.022			
38	5	11.1				0.12			
40	7	6				0.19			
42	9	7.65				0.055			
44	11	9.68				0.082			
46	13	24.6	26.9			0.15			
48	15	9.79				0.028			
50	17	3.7	3.17	2.83	6.98	0.047	0.045	0.035	3.94

(continued)

### Buttle Lake Survey - But-4 NWRI Peeper-4b

Bottle #	Depth (cm)	Pb (ppb)	Replicate	SLRS2	TM21	Zn (ppb)	Replicate	SLRS2	TM21
1	-32	26.3		0.12	4.23	352		3.8	7.94
10	-23	14.3				241			
20	-13	12.2				147			
25	-8	6.83				92.5			
27	-6	7.53				63			
29	-4	7.98				69.4			
31	-2	7.45				57.9			
32	-1	16.4				95.8			
33	0	12.9				92.2			
34	1	10		0.14	4.42	87.7		3.13	7.51
35	2	9.3	9.48			116	checked		
36	3	9.91		0.11	4.39	125	checked	3.19	7.53
37	4	6.74				101			
38	5	11.9				130	checked		
40	7	4.01				264	checked		
42	9	4.1				75.6			
44	11	8.7				95.8			
46	13	18.1	20			135	checked		
48	15	6.28				88.3			
50	17	1.75		0.13	3.86	99.3	104	3.44	7.28

(continued)

### Buttle Lake Survey - But-4 NWRI Peeper-4b

Bottle #	Depth (cm)	Fe (ppb)	TM21	rep (next day)	TM21	SLRS2	rep (next day)	TM21	Mn (ppb)	TM21
1	-32	65718	4.9						7620	6.33
10	-23	50603							9230	
20	-13	51887		54454	7.34	138.2			10616	
25	-8	50520							10298	
27	-6	50313	5.59						10366	6.29
29	-4	52135							10823	
31	-2	52715							10668	
32	-1	49444							10168	
33	0	54330	4.71						10590	6.04
34	1	55075		55655	7.34	138.2			10685	
35	2	51804							10573	
36	3	54827							10582	
37	4	50851	4.97						10177	6.09
38	5	51183							10401	
40	7	49444							10435	
42	9	54454		60873	7.34	138.2	62322	7.28	11141	
44	11	56152	5.84						10849	6.24
46	13	59133							10917	
48	15	56235							10797	
50	17	54910	6.12						11107	6.93

(continued)

### Buttle Lake Survey - But-4 NWRI Peeper-4b

Bottle #	Depth (cm)	Fe (ppb) (next day)	TM21	SLRS2	rep	TM21	SLRS2	As (ppb)	Lab Rep	Hg (ppb)
1	-32	7783	6.93	69403	7.25			159		0.60
10	-23			51390				58		0.32
20	-13			53005				44		0.22
25	-8			52756				38		0.31
27	-6			50562	6.79			33		0.25
29	-4			53709				31		0.21
31	-2			55075				26		0.16
32	-1			52798				25	25	0.12
33	0			53419		139.6		36		0.24
34	1			54289				36		0.22
35	2			52342				37		0.32
36	3			53129				36		0.36
37	4			53295	6.51			36		0.38
38	5			54330				41		0.23
40	7			52549				33	33	0.28
42	9			57436				38		0.23
44	11			52881		128.7		46		0.34
46	13			54827				45		0.25
48	15			52508				44	44	0.34
50	17			50106	6.26			33		0.33

### Buttle Lake Survey - But-6 NWRI Peeper-6a

Bottle #	Depth (cm)	Cu (ppb)	Replicate	SLRS2	TM21	Cd (ppb)	Replicate	SLRS2	TM21
1	-15	12.9		2.83	6.98	1.8		0.035	3.94
10	-6	6.7				1.66			
12	-4	85.1	49.8			5.66	2.81		
13	-3	9.45				1.25			
14	-2	7.65				1.36			
15	-1	8.54				2.13			
16	0	5.64				1.49			
17	1	4.38				0.897			
18	2	3.87				0.317			
20	4	3.69		2.75	6.86	0.07		0.037	4.28
22	6	4.12				0.097			
24	8	5.99				0.613	1.55		
26	10	3.38				0.062			
28	12	4.33				0.113			
30	14	5.98				0.115			
34	18	25.3	32.6			0.65	0.9		
38	22	28.9				0.648			
42	26	24.7				0.449			
46	30	33.9				0.602			
50	34	57.6		2.71	6.53	1.11	1.36	0.027	4.05

(continued)

### Buttle Lake Survey - But-6 NWRI Peeper-6a

Bottle #	Depth (cm)	Pb (ppb)	Replicate	SLRS2	TM21	Zn (ppb)	Replicate	SLRS2	TM21	Hg (ppb)
1	-15	20.3		0.13	3.86	335		3.44	7.28	<0.05
10	-6	12.8				376				<0.05
12	-4	68.9	checked			729	checked			0.10
13	-3	13.8				327				<0.05
14	-2	8.25				292	checked			<0.05
15	-1	8.71				465	checked			<0.05
16	0	11	11.8			349	checked			<0.05
17	1	9.63				183				<0.05
18	2	6.61				57.6				<0.05
20	4	1.51		0.13	4.12	10.3		3.13	7.59	<0.05
22	6	1.68				21.6				<0.05
24	8	32.8	checked			388	checked			0.14
26	10	1.17				11.5				0.12
28	12	2.36				19.8				0.10
30	14	2.33				20.7				0.12
34	18	16.7				205	checked			<0.05
38	22	24.7				214				0.14
42	26	18.4				135				0.12
46	30	31.5				198				<0.05
50	34	67.5	checked	0.11	3.86	474	checked	3.08	6.83	0.26

(continued)



### Buttle Lake Survey - But-6 NWRI Peeper-6a

Bottle #	Depth (cm)	Fe (ppb)	TM21	rep (next day)	TM21	SLRS2	rep (next day)	TM21	Mn (ppb)	TM21	As (ppb)	Lab Rep
1	-15	572.8		6.25			75.19	5.88			13	
10	-6	28.59					199				0.9	
12	-4	8432					240.1				113	
13	-3	110					163				0.5	
14	-2	123.3		7.05			153.3	6.48			0.6	
15	-1	76.01					310.3				0.6	
16	0	61.04					371.4				1	1
17	1	48.18					215.8				0.8	
18	2	21.96		6.46	17.62	5.68	130.8	6.34			1.4	
20	4	41.74					40.48		38.72	6.7	1.4	
22	6	170					39.06				1.3	
24	8	189.2					81.3				<0.5	
26	10	55	53.84	7.38			98.44	6.26			0.7	
28	12	110.6	105.9				129.6				1.1	
30	14	106.4	103.2				127.5				1.4	
34	18	550.2	504.7				49.96				2	
38	22	575.6		5.99			35.2	6.4			4	
42	26	507.2					35.88				4.9	
46	30	569.1					18.96		17.92		5.1	
50	34	1226		5.74			19.28	6.09	19.04	6.33	8.2	

### Buttle Lake Survey - But-6 NWRI Peeper-6b

Bottle #	Depth (cm)	Cu (ppb)	Replicate	SLRS2	TM21	Cd (ppb)	Replicate	SLRS2	TM21
1	-13	23.6		2.71	6.53			0.027	4.05
10	-4	6.44				3.38	1.83		
12	-2	7.05				1.16			
13	-1	6.92				1.37			
14	0	6				0.915			
15	1	4.97		2.89	6.8	0.925			
16	2	5.25				0.173		0.0286	4.41
17	3	7.7				0.163			
18	4	12.3				0.338			
20	6	10.9	13.6	3.1	7.32	0.435			
22	8	17.5				0.55	0.673	0.036	4.46
24	10	12.2				0.514			
26	12	10.6				0.382			
28	14	28.1				0.359			
30	16	55.4				0.838			
34	20	142	checked			1.39	1.38		
38	24	44.3				5.08	2.68		
42	28	33.5				1.08			
46	32	39.9				0.601			
50	36	34		2.71	6.58	0.694			
						0.713		0.024	4.11

(continued)

### Buttle Lake Survey - But-6 NWRI Peeper-6b

Bottle #	Depth (cm)	Pb (ppb)	Replicate	SLRS2	TM21	Zn (ppb)	Replicate	SLRS2	TM21
1	-13	73.5	35.6			304	checked	3.08	6.83
10	-4	12.8				235			
12	-2	20.9				268			
13	-1	18.7				232			
14	0	7.75				184			
15	1	6.01		0.15	4.72	37.8		3.53	7.6
16	2	5.9				32.5			
17	3	9.24				63.2			
18	4	16.4				104			
20	6	16.9	16.7	0.2	4.84	143	checked		
22	8	18.2				155	checked	3.85	8.2
24	10	15.8				92.1			
26	12	14.8				75.3			
28	14	32.9				210			
30	16	56.7	57.4			423	checked		
34	20	173	82.6			756	checked		
38	24	43.9				295			
42	28	23.5				127			
46	32	40.7				186			
50	36	27		0.14	4.51	160		3.37	8.45

(continued)

### Buttle Lake Survey - But-6 NWRI Peeper-6b

Bottle #	Depth (cm)	Fe (ppb)	rep (next day)	rep (next day)	TM21	Mn (ppb)	As (ppb)	Lab Rep	Hg (ppb)
1	-13	608	5.74	68.64	6.09				<0.01
10	-4	53.32		118			2.7		<0.01
12	-2	94.49	5.68	133.3			0.6		<0.01
13	-1	99.22		256.7			0.9		<0.01
14	0	216.8	5.38	201.4	6.71		1.6		<0.01
15	1	83.64		105.2		100.5	2.3		<0.01
16	2	129.3		42.21		43.4	2.6		<0.01
17	3	242.8		31.08		27.68	3.3	3.1	<0.01
18	4	329.5	5.97	24.04	6.4		2.9		<0.01
20	6	287.5		42.64			2.9		<0.01
22	8	622.2		83.88			2.5		<0.01
24	10	270.8		86.57			2.9		<0.01
26	12	285.9	5.35	49.12	6.96		2.3		<0.01
28	14	809.5		31.16			2.8		<0.01
30	16	1461		31.88			3.8		<0.01
34	20	3986		76.1			6.2		<0.01
38	24	748.4	6.17	17.24		15.69	10.1		<0.01
42	28	392.9		15.6			6.8		<0.01
46	32	588.4		19.63			4.6		<0.01
50	36	686.3	5.68	14.59	6.7		5.5		<0.01
							5.6		0.10

### Buttle Lake Survey - But-7 NWRI Peeper-7a

Bottle #	Depth (cm)	Cu (ppb)	SLRS2		TM21		Replicate	SLRS2	TM21
1	-11	3.59	2.71	6.58	0.071		0.024	4.11	
5	-7	3.2			0.063				
10	-2	3.11			3.01	2.31			
11	-1	3.09			0.074				
12	0	4.73			0.052	0.073			
13	1	6.47			0.073				
14	2	3.48			0.059				
15	3	4.8			0.343				
16	4	5.23			0.083				
17	5	6.16	2.59	6.23	0.111		0.04	4.05	
18	6	4.62			0.131				
19	7	7.76			0.211				
20	8	5.45			0.078				
21	9	7.37			0.075				
22	10	5.39			0.163	0.203			
24	12	5.74			0.062				
26	14	5.65			0.108				
30	18	6.04			0.148				
34	22	3.55			0.183				
38	26	4.86			0.099				
42	30	3.92	2.56	6.27	0.053		0.033	4.05	

(continued)

### Buttle Lake Survey - But-7 NWRI Peeper-7a

Bottle #	Depth (cm)	Pb (ppb)	Replicate	SLRS2	TM21	Zn (ppb)	Replicate	SLRS2	TM21	Hg (ppb)
1	-11	0.76		0.14	4.51	15.4		3.37	8.45	<0.05
5	-7	0.27				13.6				<0.05
10	-2	0.3	0.28			13.1	12.2			<0.05
11	-1	0.25				28.1				<0.05
12	0	0.27	0.28			16.8	16.8			<0.05
13	1	0.27				14.2				<0.05
14	2	0.25				15.4				<0.05
15	3	0.24				42.6				<0.05
16	4	0.44				14.9				0.10
17	5	0.52		0.14	4.48	18.3		3	6.6	<0.05
18	6	1.29				16				0.10
19	7	0.59				23				<0.05
20	8	0.26				13.2				<0.05
21	9	0.6				21.4				<0.05
22	10	0.53	0.61			24.8	25.9			<0.05
24	12	0.35				16.2				0.60
26	14	0.48				15.1				<0.05
30	18	1.41				37.2				<0.05
34	22	0.55				21.7				<0.05
38	26	0.95				23.1				<0.05
42	30	0.94		0.14	4.47	16		3.07	6.88	<0.05

(continued)

### Buttle Lake Survey - But-7 NWRI Peeper-7a

Bottle #	Depth (cm)	Fe (ppb)	TM21	rep (next day)	TM21	SLRS2	TM21	Mn (ppb)	As (ppb)	Lab Rep
1	-11			49.64	6.71		2.88	6.68	0.5	
5	-7	36.56	6.27				3.15		<0.5	
10	-2	94.68					3.41		<0.5	
11	-1	18.08		16.53	5.69		2.75		<0.5	
12	0	15	6.65				3.23	6.8	<0.5	
13	1	16.64					3.01		<0.5	
14	2	18.62					2.91		<0.5	
15	3	19.88					3		<0.5	<0.5
16	4	22.68	6.24				3.13	6.85	0.7	
17	5	52.7					3.54		<0.5	
18	6	24.28					3.58		<0.5	
19	7	66.44					4.05		<0.5	
20	8	36.36	6.28				3.92	7.1	<0.5	
21	9	147					4.72		0.6	
22	10	87.56					6.33		0.7	
24	12	60.17		48.6		50.24	6.7		<0.5	
26	14	55.36	6.1				8.08	6.92	<0.5	
30	18	332.4					426		1.7	
34	22	245.3								
38	26	506.1					1635		4.2	
42	30	989.3	6.36				1216	7.61	6.4	

### Buttle Lake Survey - But-7 NWRI Peeper-7b

Bottle #	Depth (cm)	Cu (ppb)	Replicate	SLRS2	TM21	Cd (ppb)	Replicate	SLRS2	TM21	Hg (ppb)
1	-11	3.76	4.48	2.56	6.27	0.123	0.126	0.033	4.05	<0.05
5	-7	2.9				0.06				<0.05
10	-2	2.87				0.049				<0.05
11	-1	3.04				0.072				<0.05
12	0	3.03				0.076				<0.05
13	1	5				0.117				<0.05
14	2	4.02				0.081				<0.05
15	3	4.76				0.085				<0.05
16	4	4.7				0.168				<0.05
17	5	5.18		2.53	6.26	0.272		0.039	4.09	<0.05
18	6	5.17				0.073				<0.05
19	7	8.51				0.14				0.05
20	8	7.31				0.245				<0.05
21	9	14.8	17.8			0.158				<0.05
22	10	7.94				0.152				<0.05
24	12	5.54				0.064				<0.05
26	14	6.74				0.082				<0.05
30	18	9.73	11.4			0.126	0.141			<0.05
34	22	16.4				0.138				0.06
38	24	6.8				0.124				<0.05
42	28	8.52				0.084				<0.05

(continued)



### Buttle Lake Survey - But-7 NWRI Peeper-7b

Bottle #	Depth (cm)	Pb (ppb)	Replicate	SLRS2	TM21	Zn (ppb)	Replicate	SLRS2	TM21
1	-11	1.65	1.55			14.4			
5	-7	0.27				13.1			
10	-2	0.22				13.1			
11	-1	0.24				12.9			
12	0	0.34				19.8			
13	1	0.39				19.1			
14	2	0.29				15.6			
15	3	0.56				16.8			
16	4	0.4				20		3.14	6.63
17	5	0.89		0.14	0.45	14.3			
18	6	0.44				18.2			
19	7	1.07				26			
20	8	0.8				30.9	40		
21	9	2.58	2.74			23.9			
22	10	0.91				14.9			
24	12	0.29				22.5			
26	14	0.64				30.4	30.9		
30	18	1.27	1.25			38.5			
34	22	4.16				8.95			
38	24	1.67				7.55			
42	28	1.05							

(continued)



**Buttle Lake Survey - But-2  
(October 23, 1993)**

Depth m	Temp. °C	Light Transm. %
1	14.236	83.4
2	14.227	79.3
4	14.239	80.9
5	14.225	83.6
6	13.714	83.2
7	13.279	83.0
8	12.978	82.7
9	12.182	80.1
10	11.598	81.4
12	10.243	83.0
13	9.460	84.1
14	8.650	84.6
15	8.191	84.8
16	7.735	84.7
18	7.415	84.7
19	7.304	85.0
20	7.200	85.1
21	7.104	85.3
22	6.967	85.3
23	6.895	85.4
24	6.828	85.4
26	6.738	85.4
27	6.704	85.4
28	6.670	85.4
29	6.597	85.4
31	6.510	85.3
32	6.385	85.2
33	6.315	84.9
34	6.240	84.7
35	6.200	84.6
36	6.145	84.6
37	6.094	84.5
39	6.029	84.4
40	5.966	84.4
41	5.914	84.6
42	5.884	84.6
43	5.840	84.6
45	5.794	84.5
46	5.727	84.5
47	5.672	84.4
48	5.651	84.3
49	5.633	84.3
50	5.622	84.3

(continued)

**Buttle Lake Survey - But-2  
(October 23, 1993)**

<b>Depth m</b>	<b>Temp. °C</b>	<b>Light Transm. %</b>
51	5.602	84.1
52	5.572	84.3
53	5.536	84.5
54	5.497	84.4
56	5.480	84.3
57	5.476	84.3
58	5.461	84.3
59	5.437	84.2
60	5.427	84.1
61	5.426	84.2
62	5.425	84.1
64	5.424	84.1
65	5.422	83.9
66	5.416	83.9
67	5.388	83.6
68	5.375	83.4
69	5.353	83.4
70	5.282	83.5

**Buttle Lake Survey - But-4  
(October 22, 1993)**

<b>Depth m</b>	<b>Temp. °C</b>	<b>Light Transm. %</b>
1	14.325	85.4
2	14.327	85.4
3	14.325	85.4
4	14.320	85.2
5	14.306	85.4
7	13.958	85.4
8	13.177	85.3
9	11.759	85.1
10	10.594	84.8
11	9.732	84.8
12	9.035	85.1
13	8.482	85.2
14	8.109	85.2
15	7.791	85.2
16	7.635	84.9
17	7.414	84.8
18	7.234	85.2
19	7.163	85.4
21	7.046	85.1
22	6.967	85.2
23	6.871	85.1
24	6.803	85.0
25	6.772	84.4
26	6.740	84.1
27	6.702	84.1
28	6.664	84.4
29	6.657	84.3
30	6.619	84.0
31	6.520	83.4
32	6.416	83.3
33	6.353	83.1
34	6.295	83.3
35	6.142	84.1
37	6.001	84.2
38	5.970	84.1
39	5.933	84.0

(continued)

**Buttle Lake Survey - But-4  
(October 27, 1993)**

<b>Depth m</b>	<b>Temp. °C</b>	<b>Light Transm. %</b>
1	12.905	82.8
2	12.896	82.7
4	12.884	82.7
5	12.882	82.7
6	12.769	82.5
7	12.685	82.0
8	12.518	81.9
9	12.319	82.1
10	11.765	81.7
11	11.676	81.3
12	11.244	81.2
13	10.456	79.1
14	8.435	80.8
15	7.831	83.0
17	7.653	83.7
18	7.480	84.0
19	7.335	84.2
20	7.250	84.2
21	7.165	84.1
22	7.017	84.2
23	6.945	83.8
24	6.915	83.9
25	6.877	83.7
27	6.817	83.6
28	6.759	83.4
29	6.683	83.5
30	6.618	83.4
31	6.570	83.2
32	6.506	82.9
33	6.423	82.7
34	6.364	82.6
35	6.287	83.0
36	6.235	83.2

(continued)

**Buttle Lake Survey - But-6**  
**(October 22, 1993)**

<b>Depth m</b>	<b>Temp. °C</b>	<b>Light Transm. %</b>
1	14.344	82.8
2	14.343	83.6
3	14.341	83.8
4	14.341	83.9
5	14.341	84.0
6	13.367	79.5
7	12.800	77.2
8	12.563	82.3
9	12.370	83.8
11	11.572	82.8
12	9.173	79.3
13	9.044	79.6
14	8.710	83.1
15	8.340	84.3
16	7.904	84.8
17	7.644	85.0
18	7.374	85.1
19	7.167	85.4
20	7.079	85.5
22	7.016	85.6
23	6.972	85.6
24	6.933	85.5
25	6.892	85.5
26	6.821	85.6
27	6.787	85.6
28	6.692	85.5

**Buttle Lake Survey - But-6  
(October 27, 1993)**

<b>Depth m</b>	<b>Temp. °C</b>	<b>Light Transm. %</b>
1	12.975	67.8
2	12.971	66.9
3	12.976	66.3
5	12.956	59.5
6	12.800	71.1
7	12.629	81.5
8	12.283	81.2
9	11.615	81.2
10	10.859	79.9
12	10.156	78.4
13	9.332	79.3
14	8.892	80.8
15	8.483	81.0
16	8.052	81.8
17	7.619	83.5
18	7.376	83.9
19	7.194	84.1
20	7.112	84.2
21	7.006	84.2
22	6.947	84.2
24	6.849	84.0
25	6.762	84.1
26	6.708	84.0



**Buttle Lake Survey - But-7  
(October 22, 1993)**

<b>Depth m</b>	<b>Temp. °C</b>	<b>Light Transm. %</b>
1	14.351	79.8
2	14.307	78.9
4	14.257	80.8
5	14.201	81.7
6	13.856	81.7
7	13.646	77.2
8	13.358	72.6
9	12.962	67.8
10	12.083	71.6
12	11.437	76.3
13	10.484	81.7
14	9.318	83.4
15	8.130	84.4
16	7.815	85.3
17	7.474	85.5
18	7.114	85.2
19	6.871	85.7

**Buttle Lake Survey - But-7**  
**(October 26, 1993)**

<b>Depth m</b>	<b>Temp. °C</b>	<b>Light Transm. %</b>
1	13.265	55.5
2	13.264	83.1
3	13.259	83.2
5	13.062	82.8
6	12.955	82.8
7	12.755	82.8
8	12.525	82.7
9	12.044	82.0
11	11.187	81.5
12	10.870	81.5
13	9.277	82.7
14	7.937	83.5
16	7.471	83.9
17	7.362	83.9
18	7.315	84.0
19	7.310	84.0
20	7.289	84.0
21	7.209	84.0
22	7.034	84.0
23	6.867	84.0
24	6.717	84.1
25	6.648	84.1
26	6.535	84.1
28	6.395	84.1
29	6.333	84.0

**Buttle Lake Survey - Station North Deep  
(October 23, 1993)**

Depth m	Temp. °C	Light Transm. %
1	14.175	84.8
2	14.175	84.9
3	14.171	84.9
5	14.170	85.0
6	14.168	85.0
7	14.163	84.9
8	14.099	84.9
9	13.603	84.6
10	12.879	81.2
12	11.907	77.6
13	11.190	81.5
14	9.988	84.4
15	9.017	85.1
17	8.410	85.1
18	7.902	85.2
19	7.415	85.3
20	7.170	85.4
21	7.034	85.5
22	6.860	85.6
23	6.744	85.7
25	6.632	85.8
26	6.490	85.9
27	6.428	85.9
28	6.283	85.8
29	6.196	85.8
30	6.065	85.9
32	5.971	85.8
33	5.824	85.7
34	5.761	85.7
35	5.701	85.6
36	5.646	85.7
37	5.628	85.7
39	5.607	85.6
40	5.574	85.5
41	5.557	85.4
42	5.536	85.5
44	5.521	85.4
45	5.507	85.4
46	5.488	85.4
47	5.473	85.4
48	5.453	85.5

(continued)

**Buttle Lake Survey - Station North Deep  
(October 23, 1993)**

Depth m	Temp. °C	Light Transm. %
50	5.423	85.6
51	5.385	85.7
52	5.345	85.8
53	5.323	85.7
55	5.309	85.8
56	5.289	85.9
57	5.262	85.6
58	5.237	85.5
59	5.223	85.4
61	5.208	85.3
62	5.192	85.3
63	5.159	85.8
64	5.137	85.8
65	5.124	85.7
66	5.107	85.8
68	5.080	85.9
69	5.066	86.0
70	5.048	86.0
71	5.032	86.0
72	5.015	86.1
74	5.001	86.1
75	4.986	86.0
76	4.974	86.0
77	4.960	86.0
78	4.943	86.0
80	4.926	86.1
81	4.910	86.1
82	4.902	86.1
83	4.889	86.1
84	4.878	86.2
86	4.873	86.1
87	4.864	86.2
88	4.857	86.2
89	4.853	86.2
90	4.849	86.0
91	4.839	86.0
93	4.834	86.0
94	4.822	86.0
95	4.816	86.0
96	4.811	86.0
97	4.809	86.0

(continued)

**Buttle Lake Survey - Station North Deep  
(October 23, 1993)**

<b>Depth m</b>	<b>Temp. °C</b>	<b>Light Transm. %</b>
98	4.805	85.9
100	4.798	86.0
101	4.794	85.9
102	4.786	85.9
103	4.778	86.0
105	4.774	86.0
106	4.773	86.0
107	4.771	86.1
108	4.761	86.1
110	4.750	86.1
111	4.745	86.1
112	4.740	86.1
113	4.734	85.9
114	4.731	85.8
116	4.727	85.8
117	4.725	85.8
118	4.721	85.7
119	4.716	85.6
120	4.713	85.4
122	4.712	85.4
123	4.710	84.8
124	4.710	84.4

**Buttle Lake Survey - Station North Deep  
(October 27, 1993)**

<b>Depth m</b>	<b>Temp. °C</b>	<b>Light Transm. %</b>
94	4.818	83.6
95	4.818	83.5
96	4.814	83.4
98	4.809	83.4
99	4.805	83.4
100	4.802	83.5
101	4.801	83.5
102	4.796	83.5
103	4.794	83.5
104	4.791	83.4
105	4.779	83.5
106	4.777	83.5
108	4.775	83.5
109	4.770	83.6
110	4.765	83.6
111	4.760	83.5
112	4.758	83.3
113	4.758	83.1
114	4.757	83.0
115	4.759	82.9
116	4.757	83.0
118	4.754	82.9
119	4.753	82.9
120	4.747	82.9

**Buttle Lake Survey - Station North Deep  
(October 27, 1993)**

<b>Depth m</b>	<b>Temp. °C</b>	<b>Light Transm. %</b>
48	5.311	83.3
50	5.300	83.3
51	5.290	83.3
52	5.279	83.4
53	5.262	83.6
54	5.236	83.7
55	5.200	83.9
56	5.192	83.9
57	5.178	83.9
58	5.161	83.9
60	5.144	84.0
61	5.135	84.0
62	5.114	83.9
63	5.088	83.6
64	5.079	83.6
65	5.070	83.6
66	5.062	83.7
67	5.041	83.7
69	5.027	83.7
70	5.010	83.7
71	4.989	83.7
72	4.967	83.8
73	4.958	83.8
74	4.950	83.7
75	4.943	83.7
76	4.919	83.7
77	4.910	83.8
79	4.894	83.8
80	4.886	83.8
81	4.881	83.8
82	4.873	83.8
83	4.869	83.8
84	4.857	83.9
85	4.852	84.0
86	4.848	83.9
87	4.839	84.0
89	4.834	83.9
90	4.830	83.9
91	4.828	83.7
92	4.825	83.7
93	4.822	83.6

(continued)

**Buttle Lake Survey - Station North Deep  
(October 27, 1993)**

<b>Depth m</b>	<b>Temp. °C</b>	<b>Light Transm. %</b>
1	13.235	82.3
2	13.197	82.1
4	13.191	82.1
5	13.184	82.1
6	13.175	82.1
7	13.169	82.1
8	13.065	82.2
10	12.799	82.0
11	12.657	82.0
12	12.214	82.0
13	11.470	80.9
14	10.552	82.0
16	8.828	82.8
17	8.167	82.9
18	7.701	83.1
19	7.163	83.2
21	6.826	83.5
22	6.772	83.5
23	6.579	83.6
24	6.338	83.7
25	6.201	83.7
26	6.089	83.8
27	5.929	83.9
28	5.833	83.8
30	5.769	83.7
31	5.695	83.7
32	5.644	83.7
33	5.612	83.5
34	5.580	83.3
36	5.554	83.3
37	5.543	83.2
38	5.530	83.2
39	5.518	83.2
40	5.476	83.4
42	5.438	83.4
43	5.412	83.4
44	5.390	83.5
45	5.375	83.6
46	5.355	83.6
47	5.325	83.4

(continued)



MYRA CREEK AT M2

SEAM Site 0124785

PERMIT PE-6858

## MONITORING RESULTS

Legend: - Below Detection Limit

DATE mm/dd/yr	pH	T-Zn mg/l	D-Zn mg/l	T-Cu mg/l	D-Cu mg/l	T-Pb mg/l	D-Pb mg/l	T-Cd mg/l	D-Cd mg/l	T-Fe mg/l	D-Fe mg/l
01/13/93	7.21	0.261	0.219	0.004	0.004	-0.001	-0.001	0.0010	0.0010	-0.030	-0.030
02/25/93	7.34	0.147	0.129	0.011	0.005	0.001	-0.001	0.0003	0.0003	0.076	-0.030
03/15/93	7.06	0.135	0.126	0.008	0.007	-0.001	-0.001	0.0003	0.0003	-0.030	-0.030
04/26/93	7.26	0.129	0.128	0.015	0.013	0.001	-0.001	0.0006	0.0006	0.056	-0.030
05/25/93	7.37	0.041	0.041	0.004	0.004	-0.001	-0.001	-0.0001	-0.0001	0.040	0.032
06/30/93	7.50	0.064	0.061	0.004	0.004	-0.001	-0.001	-0.0001	-0.0001	-0.030	-0.030
07/06/93	7.35	0.064	0.062	0.004	0.003	-0.001	-0.001	-0.0001	-0.0001	-0.030	-0.030
08/25/93	7.05	0.078	0.074	0.005	0.004	-0.001	-0.001	-0.0001	-0.0001	-0.030	-0.030
09/27/93	7.17	0.217	0.216	0.007	0.005	-0.001	-0.001	0.0005	0.0005	-0.030	-0.030
10/14/93	7.30	0.264	0.254	0.008	0.006	-0.001	-0.001	0.0005	0.0005	-0.030	-0.030
11/23/93	7.17	0.090	0.086	0.006	0.006	-0.001	-0.001	-0.0001	-0.0001	-0.030	-0.030
12/21/93	7.65	0.169	0.152	0.013	0.010	-0.001	-0.001	0.0006	0.0006	-0.030	-0.030

DATE mm/dd/yr	T-Al mg/l	D-Al mg/l	T-As mg/l	D-As mg/l	T-P mg/l	D-P mg/l	N(NH3) mg/l	NO3NO2 mg/l	Temp C	SO4 mg/l
01/13/93	0.076	0.063	-	-	0.036	0.033	0.069	0.252	1.0	117.0
02/25/93	0.370	0.058	0.0002	0.0001	0.056	0.052	0.100	0.269	4.0	96.5
03/15/93	0.159	0.102	0.0001	0.0001	0.037	0.036	0.051	0.060	3.8	82.6
04/26/93	0.159	0.095	-	-	0.015	0.013	0.017	0.047	4.2	33.5
05/25/93	0.079	0.012	-	-	0.005	0.003	-0.005	0.024	5.8	12.7
06/30/93	0.030	0.026	-	-	0.002	0.002	0.009	0.035	9.5	27.7
07/06/93	0.033	0.027	-	-	0.005	0.004	0.011	0.041	10.2	31.4
08/25/93	0.031	0.022	0.0001	0.0001	0.004	0.004	0.005	0.051	11.0	31.5
09/27/93	0.020	0.018	0.0002	0.0002	0.005	0.002	0.005	0.201	9.2	144.0
10/14/93	0.022	0.020	-	-	0.003	0.003	-0.005	0.239	9.5	156.0
11/23/93	0.043	0.037	0.0002	0.0001	0.002	0.002	0.007	0.050	1.3	35.3
12/21/93	0.081	0.053	-	-	0.002	0.002	0.010	0.086	3.6	86.6

BUTTLE LAKE AT HENSHAW CREEK  
 WATER CHEMISTRY  
 PERMIT PE-6858

SITE #0130082

DEPTH: 0 M

1994

DATE mm/dd/yr	pH	Susp.Sol. mg/l	Turb. NTU	SO4 mg/l	SiO2 mg/l	N(NH3) mg/l	NO3/NO2 mg/l
03 / 28	7.70	-1.0	0.37	9.0	2.8	-0.005	0.047
04 / 25	7.27	-1.0	0.32		2.8	-0.005	0.035
05 / 30	7.60	-1.0	0.16	6.4	2.6	-0.005	0.026
07 / 26	7.63	-1.0	0.14	5.9	2.7	-0.005	0.013
09 / 28	7.66	1.0	0.14	5.0	2.8	-0.005	-0.005

DATE mm/dd/yr	Tot. P mg/l	Diss. P mg/l	Tot. Al mg/l	Diss. Al mg/l	Tot. As mg/l	Diss. As mg/l	Tot. Ca mg/l
03 / 28	0.002	0.002	0.028	0.023	0.0002	0.0002	9.91
04 / 25	0.002	0.002	0.027	0.022	0.0002	0.0002	9.63
05 / 30	0.005	0.005	0.020	0.020	-0.0001	-0.0001	9.86
07 / 26	0.002	0.001	0.014	0.014			10.50
09 / 28	0.004	0.004	0.015	0.015	0.0002	0.0002	10.00

DATE mm/dd/yr	Diss. Ca mg/l	Tot. Cd mg/l	Diss. Cd mg/l	Tot. Cu mg/l	Diss. Cu mg/l	Tot. Fe mg/l	Diss. Fe mg/l
03 / 28	9.82	0.0001	0.0001	0.004	0.003	-0.030	-0.030
04 / 25	9.50	-0.0001	-0.0001	0.003	0.003	-0.030	-0.030
05 / 30	9.70	-0.0001	-0.0001	0.003	0.003	-0.030	-0.030
07 / 26	10.10	-0.0001	-0.0001	0.006	0.002	-0.030	-0.030
09 / 28	9.76	-0.0002	-0.0002	0.002	-0.001	-0.030	-0.030

DATE mm/dd/yr	Tot. Mn mg/l	Diss. Mn mg/l	Tot. Pb mg/l	Diss. Pb mg/l	Tot. Zn mg/l	Diss. Zn mg/l	Chlphyll 'a' ugm/l	Secchi Disk m
03 / 28	0.005	-0.005	-0.001	-0.001	0.025	0.024	0.25	8.0
04 / 25	-0.005	-0.005	-0.001	-0.001	0.020	0.020	0.09	9.5
05 / 30	-0.005	-0.005	-0.001	-0.001	0.020	0.020	0.26	10.5
07 / 26	-0.005	-0.005	-0.001	-0.001	0.010	0.010	0.00	15.5
09 / 28	-0.005	-0.005	-0.001	-0.001	-0.005	-0.005	0.26	12.5

BUTTLE LAKE AT HENSHAW CREEK  
 WATER CHEMISTRY  
 PERMIT PE-6858

SITE #0130082

1994

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DEPTH: 60 M

DATE mm/dd	pH	SUSP. SOL mg/l	TURB NTU	SO4 mg/l	SiO2 mg/l	N(NH3) mg/l	NO3/NO2 mg/l
03 / 28	7.70	-1.0	0.53	13.8	2.7	-0.005	0.048
04 / 25	6.96	-1.0	0.44		2.8	-0.005	0.047
05 / 30	7.16	-1.0	0.19	11.3	3.0	-0.005	0.048
07 / 26	7.11	-1.0	0.18	11.5	2.9	-0.005	0.054
09 / 28	6.97	-1.0	0.17	10.3	3.2	0.005	0.051

DATE mm/dd	Tot. P mg/l	Diss. P mg/l	Tot. Al mg/l	Diss. Al mg/l	Tot. As mg/l	Diss. As mg/l	Tot. Ca mg/l
03 / 28	0.001	0.001	0.037	0.025	0.0002	0.0002	11.80
04 / 25	0.002	0.002	0.033	0.026	0.0002	0.0002	11.10
05 / 30	0.008	0.004	0.027	0.027	-0.0001	-0.0001	11.70
07 / 26	0.003	-0.001	0.023	0.023			12.90
09 / 28	0.004	0.004	0.021	0.017	0.0002	0.0002	11.40

DATE mm/dd	Diss. Ca mg/l	tot. Cd mg/l	Diss. Cd mg/l	Tot. Cu mg/l	Diss. Cu mg/l	Tot. Fe mg/l	Diss. Fe mg/l
03 / 28	11.50	0.0001	0.0001	0.005	0.004	-0.030	-0.030
04 / 25	10.80	-0.0001	-0.0001	0.004	0.003	-0.030	-0.030
05 / 30	11.60	-0.0001	-0.0001	0.004	0.004	-0.030	-0.030
07 / 26	12.40	-0.0001	-0.0001	-0.001	-0.001	-0.030	-0.030
09 / 28	11.10	-0.0002	-0.0002	0.003	0.002	-0.030	-0.030

DATE mm/dd	Tot. Mn mg/l	Diss. Mn mg/l	Tot. Pb mg/l	Diss. Pb mg/l	Tot. Zn mg/l	Diss. Zn mg/l
03 / 28	0.009	0.005	-0.001	-0.001	0.042	0.039
04 / 25	0.007	-0.005	-0.001	-0.001	0.036	0.036
05 / 30	-0.005	-0.005	-0.001	-0.001	0.033	0.032
07 / 26	-0.005	-0.005	-0.001	-0.001	0.035	0.035
09 / 28	-0.005	-0.005	-0.001	-0.001	0.030	0.029

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BUTTLE LAKE AT HENSHAW CREEK  
 DEPTH PROFILE  
 PERMIT PE-6858

SEAM Site 0130082

Date: Apr. 19/93					Date: Jul. 09/93				
DEPTH	TEMP	D-O2	pH	SPCOND	DEPTH	TEMP	D-O2	pH	SPCOND
m	C	mg/l		mmhos/ cm	m	C	mg/l		mmhos/ cm
00	7.77	11.94	6.89	0.072	00	17.35	10.21	6.70	0.096
05	6.73	11.87	6.95	0.076	05	16.84	10.15	6.50	0.118
10	6.22	11.65	6.91	0.077	10	16.62	10.09	6.52	0.083
15	5.92	11.58	6.89	0.080	15	15.54	10.21	6.67	0.088
20	5.65	11.53	6.90	0.082	20	10.50	10.86	6.78	0.093
25	4.86	11.34	6.88	0.086	25	7.19	11.09	6.81	0.160
30	4.81	11.33	6.88	0.089	30	6.57	11.10	6.82	0.097
35	4.79	11.31	6.88	0.088	35	6.31	11.04	6.83	0.100
40	4.72	11.29	6.89	0.089	40	6.06	10.95	6.85	0.142
45	4.66	11.27	6.89	0.089	45	5.76	10.86	6.86	0.105
50	4.68	11.25	6.90	0.088	50	5.62	10.79	6.91	0.126

Date: Oct.5/93					Date: Dec.30/93				
DEPTH	TEMP	D-O2	pH	SPCOND	DEPTH	TEMP	D-O2	pH	SPCOND
m	C	mg/l		mmhos/ cm	m	C	mg/l		mmhos/ cm
00	15.94	9.65	7.25	0.130	00	5.65	11.26	8.20	0.125
05	15.86	9.62	6.11	0.112	05	5.42	11.30	7.63	0.125
10	14.61	9.65	6.14	0.125	10	5.39	11.25	7.31	0.119
15	8.83	10.77	6.30	0.114	15	5.37	11.23	7.12	0.120
20	7.44	10.75	6.29	0.108	20	5.34	11.25	6.93	0.118
25	7.06	10.74	6.33	0.108	25	5.33	11.25	6.80	0.116
30	6.68	10.40	6.35	0.163	30	5.37	11.16	6.69	0.123
35	6.29	10.29	6.35	0.119	35	5.37	11.04	6.60	0.124
40	6.04	10.27	6.37	0.123	40	5.36	10.98	6.53	0.126
45	5.92	10.14	6.39	0.241	45	5.33	10.99	6.48	0.125
50	6.03	10.06	6.40	0.150	50	5.30	10.95	6.44	0.126

BUTTLE LAKE AT HENSHAW CREEK  
 WATER CHEMISTRY  
 PERMIT PE-6858

SITE #0130082

DEPTH: 0 M

1993

DATE mm/dd	pH	SUSP.SOL mg/l	TURB NTU	SO4 mg/l	SiO2 mg/l	N(NH3) mg/l	NO3/NO2 mg/l
01/	no sample, no access due to winter conditions						
04/19	7.07	<1	0.40	8.9	2.7	<0.005	0.049
07/09	7.55	<1	0.69	5.5	2.9	<0.005	<0.005
10/05	7.34	1	0.20	6.6	2.5	<0.005	0.015
12/30	7.22	<1	0.65	8.9	2.7	<0.005	0.048

DATE mm/dd	Tot. P mg/l	Diss. P mg/l	Tot. Al mg/l	Diss. Al mg/l	Tot. As mg/l	Diss. As mg/l	Tot. Ca mg/l
04/19	0.003	0.003	0.058	0.041	-	-	11.4
07/09	0.002	0.002	0.015	0.014	0.0002	0.0002	9.00
10/05	<0.001	<0.001	0.006	0.006	-	-	11.0
12/30	0.003	0.003	0.030	0.019	-	-	10.5

DATE mm/dd	Diss. Ca mg/l	Tot. Cd mg/l	Diss. Cd mg/l	Tot. Cu mg/l	Diss. Cu mg/l	Tot. Fe mg/l	Diss. Fe mg/l
04/19	11.1	<0.0001	<0.0001	0.003	0.003	<0.030	<0.030
07/09	8.69	<0.0001	<0.0001	0.002	0.002	<0.030	<0.030
10/05	10.1	<0.0001	<0.0001	0.001	<0.001	<0.030	<0.030
12/30	10.4	0.0001	0.0001	0.004	0.004	0.045	<0.030

DATE mm/dd	Tot. Mn mg/l	Diss. Mn mg/l	Tot. Pb mg/l	Diss. Pb mg/l	Tot. Zn mg/l	Diss. Zn mg/l	Chlphyll 'a' ug/l
04/19	0.007	<0.005	<0.001	<0.001	0.019	0.019	0.34
07/09	<0.005	<0.005	<0.001	<0.001	0.009	0.009	0.15
10/05	<0.005	<0.005	<0.001	<0.001	0.007	0.007	0.48
12/30	0.008	<0.005	0.001	<0.001	0.015	0.015	0.11

BUTTLE LAKE AT HENSHAW CREEK  
 WATER CHEMISTRY  
 PERMIT PE-6858

SITE #0130082

1993

DEPTH: 60 M

DATE mm/dd	pH	SUSP.SOL mg/l	TURB NTU	SO4 mg/l	SiO2 mg/l	N(NH3) mg/l	NO3/NO2 mg/l
01/	-						
04/19	9.6	1	1.30	15.6	2.6	<0.005	0.065
07/09	7.07	<1	0.36	14.1	3.2	<0.005	0.056
10/05	7.30	<1	0.22	12.3	2.8	<0.005	0.080
12/30	7.06	<1	0.44	11.7	2.7	<0.005	0.052

DEPTH: 60 M

DATE mm/dd	Tot. P mg/l	Diss. P mg/l	Tot. Al mg/l	Diss. Al mg/l	Tot. As mg/l	Diss. As mg/l	Tot. Ca mg/l
04/19	0.005	0.004	0.081	0.054	-	-	13.7
07/09	0.003	0.003	0.023	0.021	0.00023	0.0002	11.4
10/05	0.002	0.001	0.011	0.011	-	-	12.9
12/30	0.004	0.002	0.035	0.019	-	-	11.6

DEPTH: 60 M

DATE mm/dd	Diss. Ca mg/l	Tot. Cd mg/l	Diss. Cd mg/l	Tot. Cu mg/l	Diss. Cu mg/l	Tot. Fe mg/l	Diss. Fe mg/l
04/19	13.5	<0.0001	<0.0001	0.007	0.005	0.032	<0.030
07/09	11.1	<0.0001	<0.0001	0.003	0.003	<0.030	<0.030
10/05	11.9	0.0001	0.0001	0.003	0.003	<0.030	<0.030
12/30	11.6	0.0001	0.0001	0.004	0.004	0.038	<0.030

DEPTH: 60 M

DATE mm/dd	Tot. Mn mg/l	Diss. Mn mg/l	Tot. Pb mg/l	Diss. Pb mg/l	Tot. Zn mg/l	Diss. Zn mg/l
04/19	0.014	0.008	<0.001	<0.001	0.037	0.037
07/09	0.006	<0.005	<0.001	<0.001	0.027	0.024
10/05	<0.005	<0.005	<0.001	<0.001	0.033	0.033
12/30	0.010	<0.005	<0.001	<0.001	0.032	0.025

WESTMIN RESOURCES LIMITED  
MYRA FALLS OPERATIONS

MYRA CREEK AT M1

SEAM Site 0124784

PERMIT PE-6838

MONITORING RESULTS

Legend: - Below Detection Limit

DATE mm/dd/yyr	pH	T-Zn mg/l	D-Zn mg/l	T-Cu mg/l	D-Cu mg/l	T-Pb mg/l	D-Pb mg/l	T-Cd mg/l	D-Cd mg/l	T-Fe mg/l	D-Fe mg/l	T-Al mg/l	D-Al mg/l	T-As mg/l	D-As mg/l	Temp C
01/26/94	7.15	-0.005	-0.005	0.008	0.003	-0.001	-0.001	-0.0001	-0.0001	-0.030	-0.030	0.045	0.045	0.0001	0.0001	3.0
02/21/94	7.08	-0.005	-0.005	0.003	0.003	-0.001	-0.001	-0.0001	-0.0001	-0.030	-0.030	0.021	0.020	-0.0001	-0.0001	2.0
03/23/94	6.72	-0.005	-0.005	0.013	0.003	-0.001	-0.001			-0.030	-0.030	0.021	0.018	-0.0001	-0.0001	2.1
04/26/94	6.63	-0.005	-0.005	0.003	0.002	-0.001	-0.001			-0.030	-0.030	0.046	0.044	-0.0001	-0.0001	5.5
05/17/94	7.36	-0.005	-0.005	0.001	0.001	-0.001	-0.001			-0.030	-0.030	0.033	0.032	-0.0001	-0.0001	5.8
06/01/94	8.20	-0.005	-0.005	0.003	0.002	-0.001	-0.001			-0.030	-0.030	0.036	0.036	-0.0001	-0.0001	5.2
07/20/94	7.24	-0.005	-0.005	0.001	-0.001	-0.001	-0.001			-0.030	-0.030	0.015	0.010			11.6
08/29/94	7.03	-0.005	-0.005	0.001	0.001	-0.001	-0.001			-0.030	-0.030	0.016	0.016			11.6
09/19/94	7.47	-0.005	-0.005	0.004	0.004	-0.001	-0.001	-0.0001	-0.0001	-0.030	-0.030	0.021	0.021	-0.0001	-0.0001	11.2
10/17/94	7.62	-0.005	-0.005	0.001	-0.001	-0.001	-0.001	-0.0001	-0.0001	-0.030	-0.030	0.057	0.016			7.4
11/14/94	7.27	-0.005	-0.005	0.004	0.004	-0.001	-0.001			-0.030	-0.030	0.064	0.064			4.3
12/05/94	7.30	-0.005	-0.005	0.001	-0.001	-0.001	-0.001	-0.0001	-0.0001	-0.030	-0.030	0.021	0.021			

MYRA CREEK AT M1

SEAM Site 0124784

PERMIT PE-6858

MONITORING RESULTS

Legend: - Below Detection Limit

DATE mm/dd/yr	pH	T-Zn mg/l	D-Zn mg/l	T-Cu mg/l	D-Cu mg/l	T-Pb mg/l	D-Pb mg/l	T-Cd mg/l	D-Cd mg/l	T-Fe mg/l	D-Fe mg/l	T-Al mg/l	D-Al mg/l	T-As mg/l	D-As mg/l	Temp C
01/13/93	7.60	-0.005	-0.005	0.001	0.001	-0.001	-0.001			-0.030	-0.030	0.031	0.029			10
02/25/93	7.48	-0.005	-0.005	0.001	0.001	-0.001	-0.001			-0.030	-0.030	0.026	0.021			15
03/15/93	7.05	-0.005	-0.005	0.002	0.002	-0.001	-0.001			-0.030	-0.030	0.027	0.027			2.1
04/26/93	7.32	-0.005	-0.005	0.002	0.002	-0.001	-0.001			-0.030	-0.030	0.085	0.084			35
05/25/93	7.60	-0.005	-0.005	0.004	0.003	-0.001	-0.001			0.032	-0.030	0.082	0.073			50
06/30/93	7.33	-0.005	-0.005	0.003	0.003	-0.001	-0.001	-0.0001	-0.0001	-0.030	-0.030	0.022	0.019			90
07/06/93	7.55	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.0001	-0.0001	-0.030	-0.030	0.024	0.017			102
08/24/93	7.22	-0.005	-0.005	0.002	0.002	-0.001	-0.001			-0.030	-0.030	0.030	0.030	-0.0001	-0.0001	10.7
09/27/93	7.22	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.0001	-0.0001	-0.030	-0.030	0.015	0.014	0.0001	-0.0001	8.8
10/14/93	7.80	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001			-0.030	-0.030	0.088	0.007			90
11/23/93	7.04	-0.005	-0.005	0.001	-0.001	-0.001	-0.001			-0.030	-0.030	0.032	0.027	0.0001	0.0001	10
12/22/93	8.20	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001			-0.030	-0.030	0.017	0.017			2.9



WESTMIN RESOURCES LIMITED  
MYRA FALLS OPERATIONS

MYRA CREEK AT M2

SEAM Site 0124785

PERMIT PE-6858

MONITORING RESULTS

Legend: --- Below Detection Limit

DATE mm/dd/yr	pH	T-Zn mg/l	D-Zn mg/l	T-Cu mg/l	D-Cu mg/l	T-Pb mg/l	D-Pb mg/l	T-Cd mg/l	D-Cd mg/l	T-Fe mg/l	D-Fe mg/l
01/26/94	7.50	0.115	0.107	0.014	0.014	--0.001	--0.001	0.0004	0.0004	--0.030	--0.030
02/23/94	7.30	0.199	0.182	0.013	0.011	--0.001	--0.001	0.0007	0.0007	0.030	--0.030
03/23/94	7.50	0.193	0.182	0.014	0.011	--0.001	--0.001	0.0007	0.0007	--0.030	--0.030
04/26/94	7.31	0.068	0.066	0.006	0.006	--0.001	--0.001	0.0003	0.0003	0.030	--0.030
05/17/94	7.48	0.055	0.054	0.005	0.005	--0.001	--0.001	0.0004	0.0004	--0.030	--0.030
06/01/94	7.50	0.039	0.039	0.005	0.005	--0.001	--0.001	--0.0001	--0.0001	--0.030	--0.030
07/20/94	7.32	0.072	0.070	0.005	0.004	--0.001	--0.001	--0.0001	--0.0001	--0.030	--0.030
08/29/94	7.18	0.158	0.151	0.009	0.007	--0.001	--0.001	0.0007	0.0007	--0.030	--0.030
09/19/94	7.21	0.122	0.120	0.008	0.008	--0.001	--0.001	0.0004	0.0004	0.030	--0.030
10/17/94	7.08	0.108	0.100	0.005	0.005	--0.001	--0.001	0.0005	0.0005	--0.030	0.030
11/14/94	7.36	0.134	0.111	0.001	--0.001	--0.001	--0.001	--0.0001	--0.0001	0.076	0.065
12/05/94	7.13	0.198	0.171	0.014	0.010	--0.001	--0.001	0.0005	0.0004	0.043	--0.030

DATE mm/dd/yr	T-Al mg/l	D-Al mg/l	T-As mg/l	D-As mg/l	T-P mg/l	D-P mg/l	N(NH3) mg/l	NO3NO2 mg/l	Temp C	SO4 mg/l
01/26/94	0.122	0.077	0.0001	0.0001	0.028	0.018	--0.005	0.035	4.0	40.4
02/21/94	0.076	0.046	0.0003	0.0001	0.002	0.002	0.012	0.079	2.7	68.4
03/23/94	0.090	0.047	0.0001	0.0001	0.004	0.004	0.010	0.059	4.3	71.0
04/26/94	0.045	0.049	0.0001	0.0001	--0.001	--0.001	--0.005	0.132	7.0	23.7
05/17/94	0.033	0.033	0.0001	--0.0001	0.001	0.001	--0.005	0.025	5.8	18.7
06/01/94	0.037	0.036	--0.0001	--0.0001	0.008	0.007	--0.005	0.020	7.0	13.5
07/20/94	0.010	0.010			0.004	0.004	--0.005	0.036		313.0
08/29/94	0.020	0.020			0.002	0.002	0.014	0.108	11.3	73.6
09/19/94	0.036	0.023	0.0002	0.0002	0.001	0.001	0.043	0.089	11.8	65.9
10/17/94	0.029	0.025			0.005	0.004	0.050	0.095	7.0	60.8
11/14/94	0.142	0.098			0.014	0.013	0.026	0.099	4.6	42.1
12/05/94	0.169	0.103			0.019	0.018	0.079	0.181		77.9

# Appendix C - Core Logs

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## APPENDIX C - CORE LOGS

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### **But-7, Core 7a - October 21, 1993**

Natural sediments, water depth 31 m; sunny, no wind. Core virtually undisturbed, surface slightly sloped. Several crawling worms (?) and swimming “spiders”. Core about 45 cm long.

- 0 - 2 cm: light orangy brown gelatinous ooze filled with small twigs (terrestrial) - heavily bioturbated.
- 2 - 14 cm: slightly less brown (more grey, olive-brown).
- 14 - 30 cm: more compacted (homogenous) olive-grey-brown (occasional blotch of darker brown).
- 30 cm - end: undifferentiated lighter, olive-grey-brown.

### **But-6, Core 6a - October 22, 1993**

Core collected at about 11:00 a.m. Overcast with occasional shower. Core has had some channelling up sides.

- 0 - 4 cm: natural sediments, orangy-brown layer admixed with tails (some infauna); strong demarcation (discontinuity) at 4 cm where tails start.
- 4 cm - end: undifferentiated tails to end of core - some methane degassing; lots of sparkly pyrite (?) visible throughout core.

### **But-4, Core 4a - October 23, 1993**

Core collected at about 12:30 p.m. Raining very hard. Water depth 38 m. Core about 54 cm long. Slightly turbid supernatant on retrieval but interface looks good.

- 0 - 2.5 cm: brown to rusty brown “natural” deposit.
- 25 - ~30 cm: tailings.
- 30 cm - end: natural sediments.

- upper 20 cm very well laminated, laminae showing distinct tilting (10-20°), unclear whether due to angled coring or real “slope feature”. Surface wood debris, twig fragments and fecal casts (?).
- several mm to 1 cm of medium brown gelatinous organics (?). Silty material overlying distinct chocolate brown lamina (2 mm thick) in turn overlying distinct rusty-orange lamina (~1.5 mm thick) then 2 - 2.5 cm of same material as surface layer (weakly laminated).
- upper 20 cm of tails are finely laminated (1 - 4 mm thick). Uneven contact with natural sediments at ~28 cm; bottom 8 - 10 cm weakly laminated.
- rest of core is olive-green, methane-bearing natural sediments.

### **But-4, Core 4b - October 24, 1993**

Replicate core collected ~9:30 a.m. Sunny, clear, calm. Water depth about 37 m. Core about 60 cm in length, very similar to Core 4a.

- 3.5 mm of medium-brown silt overlying same 2-layer chocolate brown (2 mm) orange, rusty-brown (1 mm) layer. Underlain by ~16 - 20 mm of medium chocolate brown, weakly laminated natural sediments.
- 2.5 - 17.5 cm: tailings laminated (as in 4a).
- 17.5 - ~32 cm: bulk tailings (some CH<sub>4</sub> bubbles evident at 25 to 30 cm).
- 32 cm to end: natural sediments. CH<sub>4</sub> present.
- lamination in tailings is very similar to Core 4a.
- thin lamination of natural sediments as in Core 4a at 12 cm.

## **Appendix D - Response to Peer Review**

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## APPENDIX D - RESPONSE TO PEER REVIEW

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The peer review of the Buttle Lake Final Report resulted in three comments that warranted further discussion. The first involved a justification for the method of preservation for dissolved Hg in peeper samples and core porewaters. Second, Westmin's Myra Creek data set was to be interpreted more fully. And third, the inter-lab disparity for dissolved Fe warranted additional blind comparisons on a select suite of porewaters. Following are the specific responses to these issues.

### 1. Mercury Preservation

Loss of total mercury from aqueous environmental samples soon after collection or during subsequent storage can be caused by adsorption on container walls and/or reduction of Hg species to the atomic state and consequent volatilization. To combat such losses, strong acids and oxidants are usually added to the solutions immediately after sample collection (Lansens *et al.* 1990). These have two roles: prevention of adsorption to plastic surfaces, and inhibition of reduction to the volatile species Hg(0). Both HCl and HNO<sub>3</sub> have been investigated for their suitability as preservatives for total mercury in aqueous solutions. In general, nitric acid is not considered to be acceptable for storage of mercury-bearing solutions. However, this limitation appears to be more important for standards made by spiking distilled water with mercury, rather than for natural waters. For example, Stoeppler and Mathes (1978) found that the total mercury content ( $\sim 1 \mu\text{g L}^{-1}$ ) remained constant for at least 2.5 months in seawater samples acidified to pH 2.5 with HNO<sub>3</sub>, although methylmercury chloride degraded quite quickly to Hg<sup>2+</sup> under these storage conditions. CH<sub>3</sub>HgCl did not degrade as quickly when HCl was used. Ambe and Suwabe (1977) noted that mercury in standard solutions (minimum  $1 \mu\text{g L}^{-1}$ ) prepared with distilled water was stabilized upon addition of sodium chloride, suggesting that complex or ion pair formation helps to prevent Hg loss. Carron and Agemian (1977) found that distilled water acidified with HNO<sub>3</sub> and spiked with mercury to a level of  $0.25 \mu\text{g L}^{-1}$  lost 80% of the metal in 8 days through the walls of high density linear polyethylene containers. In marked contrast, ground water at a level of  $0.10 \mu\text{g L}^{-1}$  under the same conditions did not show appreciable loss of mercury after more than 1.5 months (Carron and Agemian 1977), presumably as a result of complexation by naturally-present ligands. Loucharn *et al.* (1992) recently

used both HNO<sub>3</sub> and HCl as preservatives for natural water samples collected in northern Quebec, and found that they worked equally well for the analysis of total Hg several weeks after collection. Thus, it can be concluded that mercury in solutions with different matrices is stable to differing degrees. As noted by Carron and Agemian (1977), HNO<sub>3</sub> is not suitable as a preservative for all types of samples, but it does appear to reduce, if not entirely eliminate, loss of mercury from many natural water samples.

The very small volumes of pore waters collected in the Buttle Lake survey precluded extraction of separate aliquots and their preservation for total mercury analysis by adding H<sub>2</sub>SO<sub>4</sub> and K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub>, as recommended by Carron and Agemian (1977). All samples collected and analyzed in this survey were preserved solely with HNO<sub>3</sub>. Thus, although this technique has yielded accurate total mercury assays in some previous studies of natural waters, the Hg concentrations discussed in this report may represent underestimates.

### **2. Comments on the Myra Creek Source of Metals**

The flow into the south basin from Myra Creek remains a source of dissolved metals, as can be seen from the monthly time series data for Zn and Cu collected downstream of the mine site (Station M2) during 1993 and 1994 (Figure D-1). The metal concentrations are much reduced from the mg L<sup>-1</sup> levels observed in the early 1980s but are still much higher than would be expected in runoff from a pristine watershed. The zinc and copper enrichments apparently derive from acid rock drainage; evidence for this is provided by the strong seasonal correlation of the metal concentrations and dissolved sulphate (Figure D-1). Highest concentrations occur during the winter months when much of the precipitation in the watershed collects as snow. The lowest values are coincident with the freshet in May-June of both years (Figure D-1). There is a slight negative correlation between pH and the metals concentrations; during the freshet in both years, the pH is relatively high (~7.5), implying dilution of the ARD, while during the dry late summer and early fall months, a higher relative input of ARD can account for both the slightly lower pH (~7.1) and the higher metals contents.

The metal-laden plume from Myra Creek presumably sinks in the south basin to a neutral buoyancy depth that will vary seasonally, generally adding dissolved metals to sub- or lower-thermocline waters. Since the creek is largely fed by cold

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snow and ice melt in summer, the density of the creek water should prohibit contribution of the flow to the surface waters in the lake during that season. In the cold winter months, the creek water is cooler than the temperature of maximum density (Appendix B), so it is unlikely that the creek water reaches the bottom in the south basin during that period of the year.

### 3. Comments on the Iron Analytical Problem

To investigate the source of the poor comparability between some of the dissolved iron measurements made by UBC and ASL during the intercalibration exercise (see Appendix A), a set of six pore water samples was selected from those collected in the Anderson Lake summer survey, and iron was remeasured by both labs using the following procedure. The samples were analyzed at ASL by flame AAS on neat solution, and by graphite-furnace AAS on pore waters serially diluted with 2% HNO<sub>3</sub>. A split of the final diluted sample was sent to UBC and analyzed blindly using GFAAS only. The intention of this experiment was to evaluate comparability for Fe in the absence of dilution differences between the two labs. The results are given in Table D-1.

**Table D-1  
Results of Inter-Lab comparison of dissolved Fe analyses**

Sample ID	ASL Dilution Factor for GFAAS	ASL Analysis of Diluent by GFAAS $\mu\text{g L}^{-1}$	UBC Additional Dilution Factor	UBC Analysis of Diluent by GFAAS $\mu\text{g L}^{-1}$	UBC Final Concentration (Calculated) $\text{mg L}^{-1}$	ASL Flame AAS, Final Concentration $\text{mg L}^{-1}$	ASL GFAAS, Final Concentration (Calculated) $\text{mg L}^{-1}$
A	4000	26.5	-	41.4	166	120	106
B	4000	30	-	27.8	112	107	120
C	4000	25	-	32.1	128	106	100
D	2000	32	2	29.94	119	65	64
E	1000	34	-	41.3	41	34	34
F	1000	19	-	24.0	24	19	19
TM-02			2	25.43	50.9 $\mu\text{g L}^{-1}$		
TM-02			2	25.48	50.9 $\mu\text{g L}^{-1}$		

Comparison of the results indicates that differences in concentration of up to nearly twofold exist in iron measurements between the two labs when the analyses are

carried out on exactly the same diluted pore solution. The contrasts appear to be systematic, with UBC results being higher in five of the six cases. In the Anderson Lake and Buttle Lake surveys a slightly different approach was employed in that pore water samples were independently diluted in each laboratory. High serial dilution factors were used (similar to those above) and these would have contributed to the poor comparability of the Fe results. However, the data above suggest that dilution artifacts cannot be the sole explanation for the different results for iron produced by the two laboratories. In addition, the contrasts cannot be due to poor inter-sample analytical precision at UBC since the pore water profiles for dissolved iron in both the Buttle and Anderson Lake surveys are quite smooth, indicating acceptable internal consistency. Accuracy in both laboratories is regularly and frequently assessed by running certified reference materials, and in both cases the results are consistently of high quality.

In order to determine with more rigour why comparability for iron (and to some extent, Mn) is relatively poor, while that for Cd, Cu, Pb and Zn is reasonable to very good, further work would be required. To put this requirement in perspective, it is important to realize that it is the comparability between the two labs that is at issue, not the internal consistency of the iron or manganese data used to produce the pore water profiles. Thus, it is suggested that directing further effort toward understanding the comparability problem will not result in improvement of the existing interpretation of diagenetic behaviour of the tailings deposits in either Anderson or Buttle Lake.