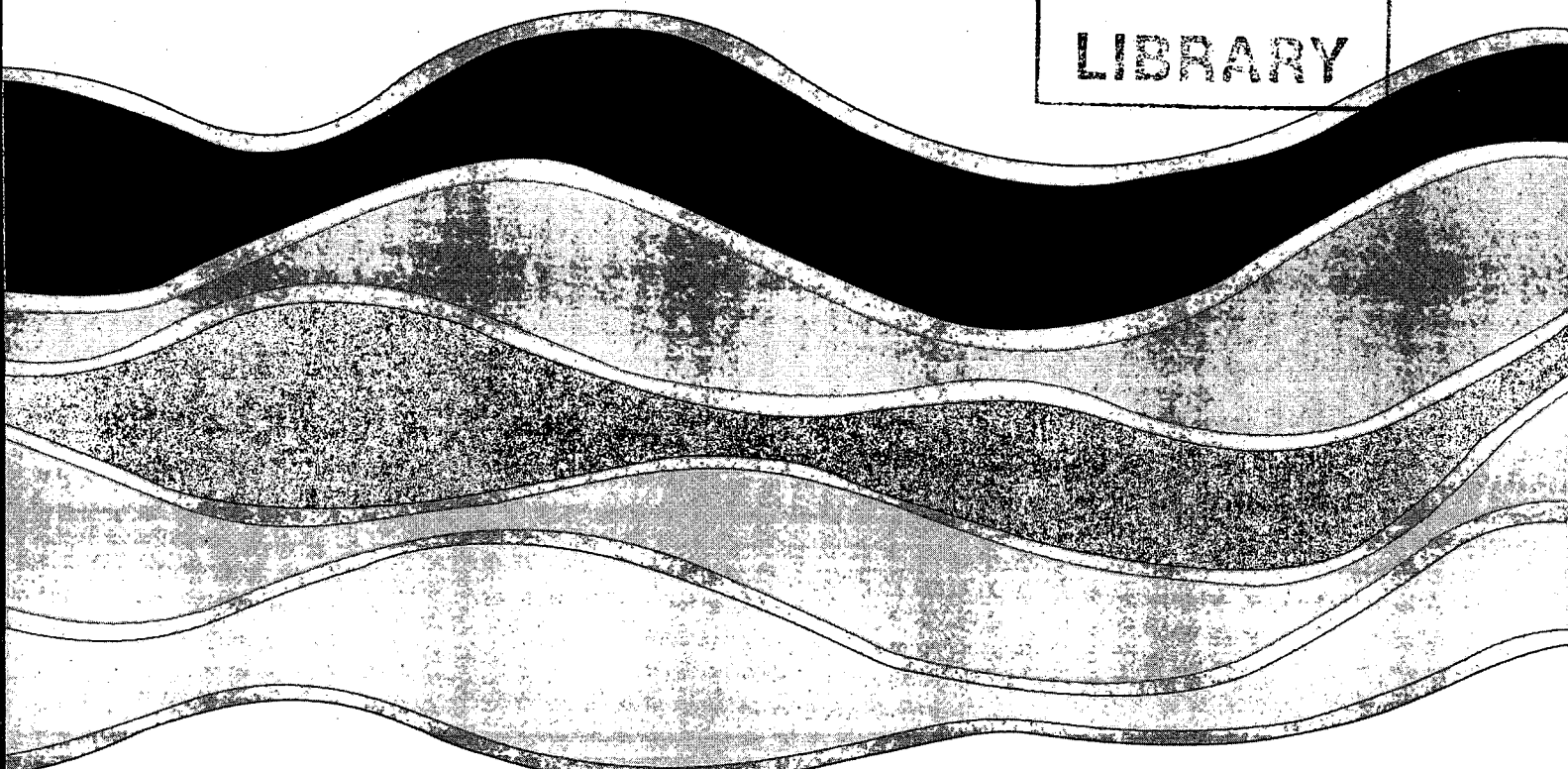
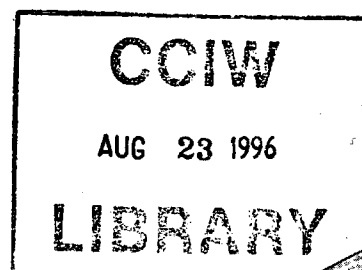
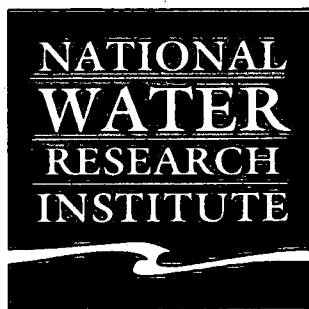


93-23 c1



**PRELIMINARY REPORT ON THE EFFECTS OF
ABANDONED MINE TAILINGS AT WELLS, B.C.,
ON THE AQUATIC ECOSYSTEM OF
JACK OF CLUBS LAKE**

**A. Mudroch, G.E.M. Hall, J. Azcue, T.A. Jackson,
T.B. Reynoldson and F. Rosa**

NWRI Contribution No. 93-23

TD
226
N87
No. 93-
23
c.1

PRELIMINARY REPORT
ON THE EFFECTS OF ABANDONED MINE TAILINGS AT WELLS, B.C.,
ON THE AQUATIC ECOSYSTEM OF JACK OF CLUBS LAKE

Part I: Reconnaissance Study

A.Mudroch, G.E.M.Hall¹, J.Azcue, T.A.Jackson, T.Reynoldson and
F.Rosa

Lakes Research Branch
National Water Research Institute
P.O.Box 5050
Burlington, Ontario L7R 4A6

¹ Geological Survey Canada
601 Booth Street
Ottawa, Ontario

FOREWORD

This report contains unpublished original data from a study which is still in progress. None of the information contained herein is to be cited or quoted or used in any way without the written permission of the authors.

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

The study is a part of the project on assessment of effects of mining activities on aquatic ecosystems in Canada under the leadership of A. Mudroch, Lakes Research Branch, National Water Research Institute, Burlington, Ontario. The field work was carried out by the authors with the help of Mr. M. Mawhinney, and Mr. R. Coker. Ms. K. Andrews, and Mr. D. Sutherland, B.C. Ministry of the Environment, Williams Lake and Prince George, respectively, provided valuable support to the field work. The study was funded by Conservation and Protection, Department of the Environment, Canada, Vancouver, B.C., through the Fraser River Action Plan.

TABLE OF CONTENTS

TABLE OF CONTENTS	3
LIST OF TABLES	5
LIST OF FIGURES	7
TABLE OF NOTATIONS	9
SUMMARY AND CONCLUSIONS	10
SUGGESTIONS FOR FUTURE ENVIRONMENTAL INVESTIGATIONS	17
 1. INTRODUCTION	 19
 2. MATERIAL AND METHODS	 22
2.1. Study Area	22
2.2. Sampling and Analytical Methods	25
2.2.1. Water	25
2.2.1.1. Surface Water	25
2.2.1.2. Pore Water and Groundwater	32
2.2.2. Sediments	33
2.2.2.1. Suspended Sediments	33
2.2.2.2. Bottom Sediments and Tailings	34
2.2.2.3. Sequential leaching of sediments	35
2.2.4. Biota	43
2.2.4.1. Microbial Population	43
2.2.4.2. Benthic Organisms	46
2.2.4.3. Vegetation	50

	4
3. RESULTS AND DISCUSSION	53
3.1. Water Quality	53
3.1.1. Physico-chemical Parameters	53
3.1.2. Major and Trace Elements	70
3.1.3. Pore Water and Groundwater	79
3.2. Sediment Quality	85
3.2.1. Suspended Sediments	85
3.2.2. Bottom Sediments and Tailings	90
3.2.3. Sequential Extraction	95
3.3. Biota	116
3.3.1. Microbial Populations	116
3.3.2. Benthic Organisms and Toxicity Bioassays	124
3.3.3. Lower Vegetation	137
3.3.4. Higher Vegetation	139
4. REFERENCES	150
5. APPENDICES	154

LIST OF TABLES

Table 2.1. Sequential extraction scheme of the sediments . .	36
Table 2.2. Results for the blank analysis and detection limits for quantitative determination of major and trace elements in sediment samples	38
Table 2.3. Operation procedures for toxicity bioassays . . .	49
Table 3.1. Concentrations of particulate and soluble nutrients	54
Table 3.2. Results for elements of interest in water source of Jack of Clubs Lake	75
Table 3.3. Chemistry of Willow River and its feeders from Jack of Clubs Lake to the confluence with Willow Creek .	78
Table 3.4. Chemistry of sediment interstitial water in Jack of Clubs and Bowron Lakes	80
Table 3.5. Major and trace element concentrations (mg/L) in the groundwater of the tailings	84
Table 3.6. Total and organic carbon (%) in suspended and bottom sediments	86
Table 3.7. Major and trace element concentrations ($\mu\text{g/g}$) in suspended sediments	87
Table 3.8. Percent of gravel, sand, silt and clay in bottom sediment samples	88
Table 3.9. Major and trace element concentrations in bottom sediments and tailings	89
Table 3.10. Concentration of PAHs in bottom sediments of Jack of Clubs and Bowron Lakes	92

Table 3.11. Results for stream sediments collected under the National Geochemical Reconnaissance Program	97
Table 3.12. Order of elemental concentration by phase in cores 3 and 10 of Jack of Clubs Lake	117
Table 3.13. Measurements of microbial activities in sediment samples from Jack of Club and Bowron Lakes arranged in the expected order of decreasing severity of pollution	118
Table 3.14. CaCl ₂ -extractable Cu, DTPA-extractable Pb and total Cu, Pb and As concentrations in sediment samples from Jack of Club and Bowron Lakes arranged in the expected order of decreasing severity of pollution	119
Table 3.15. Selected characteristics of sediments in Jack of Club and Bowron Lakes arranged in the expected order of decreasing severity of pollution	120
Table 3.16. Metal concentrations in invertebrate samples from the tailings of Wells B.C. ($\mu\text{g/g}$ dry weight)	126
Table 3.17. Major and trace element concentrations ($\mu\text{g/g}$ wet weight) in lower vegetation from the abandoned mine tailings and surroundings	138
Table 3.18. Precision in the INA analysis of higher vegetation	141

LIST OF FIGURES

Figure 1.1 General map of the study area	21
Figure 2.1. Study area and sampling stations	24
Figure 2.2. Site locations for stream samples	27
Figure 2.3. Site locations for sampling of higher vegetation	52
Figure 3.1 to 3.12 Profiles of temperature, pH, conductivity and oxygen from Jack of Clubs and Bowron Lakes	58
Figure 3.13. Arsenic concentrations in waters	71
Figure 3.14. Iron concentrations in waters	72
Figure 3.15. Sulphate concentrations in waters	73
Figure 3.16. Comparison of arsenic concentrations in Jack of Clubs and Bowron Lakes	81
Figure 3.17. Comparison of arsenic concentrations in Jack of Clubs Lake, Larder Lake and control areas	82
Figure 3.18. Concentrations of As and Pb in six particle size fractions of the tailings	94
Figure 3.19 to 3.26. Results of sequential extractions in sediments from Jack of Clubs Lake	99
Figure 3.27 and 3.28. Percentage of the different fractions in the sequential extraction procedures	113
Figure 3.29. Components of benthic fauna of Jack of Clubs Lake	128
Figure 3.30. Total density of benthic fauna of Jack of Clubs Lake	130

Figure 3.31. Overall abundance of the four most abundant taxa	131
Figure 3.32. Cluster analysis of the different sampling stations of Jack of Clubs Lake	132
Figure 3.33. Bioassay test response in four invertebrate species	135
Figure 3.34. Gold in spruce twigs	147
Figure 3.35. Arsenic in spruce twigs	148
Figure 3.36. Arsenic in willow twigs	149

TABLE OF NOTATIONS

AAS	atomic absorption spectrophotometry
BL	Bowron Lake
CHLA.C	chlorophyll (corrected)
CHLA.U	chlorophyll (uncorrected)
COND	specific conductance
DDI	distilled deionized water
DO	dissolved oxygen
ICP	inductive coupled plasma
INAA	instrumental neutron activation analysis
ISM	inorganic suspended matter
JCL	Jack of Clubs Lake
LOI	loss on ignition
NH ₃	ammonia
OSM	organic suspended matter
POC	particulate organic carbon
REE	rare earth elements
SiO ₂	silica
SO ₄	sulphate
SOP	soluble organic phosphorous
SRP	soluble reactive phosphorous
TFP	total filtered phosphorous
TP	total phosphorous
TPP	total particulate phosphorous
TSM	total suspended matter
PPB	μg/L in dissolved phase and μg/kg in solid phase
PPM	μg/L in dissolved phase and μg/g in solid phase

SUMMARY AND CONCLUSIONS

1. Metal mining has been an important industry in the Fraser basin since the 19th century. Like every industry, mining has generated waste products, such as tailings and waste rock, which contain some naturally occurring and potentially toxic elements found in the metal ore, and toxic elements and compounds introduced during the various stages during the extraction of the metals from the ore.

2. In August 1992, a reconnaissance study was carried out in Jack of Clubs Lake (JCL) at Wells, B.C., and adjacent aquatic and terrestrial environments. The objective of the study was to obtain preliminary information for evaluation of biogeochemical effects of wastes from the past gold mining activity on the aquatic ecosystem of JCL in the Fraser River drainage basin.

3. Bottom sediments and surface and bottom water samples were collected at ten sampling stations in JCL. Concentration profiles of nutrients, chlorophyll, temperature, conductivity, and pH were obtained in the water column at each sampling station. Suspended sediments were collected in the centre of JCL (3 m water depth) and at two stations in the Willow River at Wells. Surficial sediments were collected at several sites in the Willow River and adjacent streams. Sediment samples were collected from the tailings deposited along the northeastern shore of JCL. Samples of low (11 species) and high vegetation (4 species) growing on the surface of the mine tailings and at sites adjacent to Willow River and JCL

were collected. Samples of invertebrates were collected from the water flowing through the tailings. Pore water from the bottom sediments was collected in JCL, and groundwater in the tailings was sampled at selected sites. Bowron Lake (BL) in the Bowron Lake Provincial Park, located about 30 km east of Wells, was selected as a control or reference site for the study.

4. The concentrations of 43 elements (major and trace elements) were determined in collected sediments, sediment pore water and groundwater samples. The association of major and trace elements with different size tailing particles was determined. The water samples were analyzed for 10 nutrients (soluble and particulate) and 33 trace elements. Trace elements (12) were determined in collected vegetation and invertebrate samples from the water flowing through the tailings. Chemical forms of major and trace elements were determined in selected sediment cores from JCL. Benthic community structure was evaluated at ten sampling stations in JCL and laboratory bioassays of sediment toxicity were carried out using different benthic species and sediments from the ten stations in JCL. Microbial activity was determined in sediments from three sites in JCL.

5. The loading of As and Pb from the tailings to the lake is evidenced by a concentration gradient of these elements from the end of the lake where the tailings were deposited (with concentrations of As and Pb in the sediments - 1,104 and 281 $\mu\text{g/g}$,

respectively), to the opposite end (with 98 and 88 $\mu\text{g/g}$ of As and Pb, respectively). Elevated concentrations of Pb in chemically labile forms in JCL sediments suggest that Pb associated with fine particles in the tailings (up to 3,470 $\mu\text{g/g}$) may become transported into the lake.

6. A peak in the concentrations of several trace elements (particularly Fe, As, Ni, Zn and Cu) at the 4 to 6 cm depth in the sediment collected at station 10 in JCL, most likely reflects the inputs of these elements from past gold mining activities at the Cariboo Gold mine around 1940. This assumes the annual sedimentation rate of 1 to 2 mm in the lake. The greatest proportion of As in the sediment cores is associated with iron oxides and sulphides, implying mechanical dispersion from the tailings. Arsenic in true solution appears to be readily scavenged by amorphous iron hydroxides in the lake sediment or by coprecipitation with iron hydroxide on surface media (rocks, tailings themselves) which is prevalent in the area surrounding JCL. Both water and vegetation data suggest that rapid fixation of dissolved As occurs, thus drastically limiting its dispersion in JCL or downstream in Willow River. Therefore, the high concentration of Fe in the tailings originating from pyrite (associated with Au) is actually beneficial and very effective at limiting the migration of undesirable elements.

7. The concentration profiles of As in the sediments at stations 10

and 3 in JCL suggest mechanical and hydromorphic dispersion of As from its source, such as arsenopyrite, in the tailings. The concentrations of As in several water samples indicate the present mobilization of As at low pH, for example, 556 $\mu\text{g/L}$ of As at pH 2.7 in the seep near the old mine. Elevated concentrations of Ni, Co, Cu and Zn in the samples from this and some other seeps support the indication that these elements have been continuously mobilized from the tailings and transported into JCL in dissolved form, as well as particulates from erosion of the tailings. The elevated concentrations of Pb (up to 281 $\mu\text{g/g}$) in JCL sediments appear to be the result of mobilization of Pb from the tailings, such as dissolution and adsorption on sediment particles or physical dispersion of eroded tailing particles into the lake. The greatest concentrations of Pb in finer particles in the tailings support this observation. The increased concentrations of Pb in the sediments (i.e., 12 to 18 cm sediment depth) at station 10 in JCL which accumulated approximately 80 years ago on the lake bottom, are absent from the same sediment depth collected at station 3, which is on the opposite side of the lake from the disposed tailings. This indicates that the northeast part of JCL has been impacted by the tailings deposited on the shore to much greater extent than the southwestern part of the lake.

8. The concentrations of Hg in JCL (up to 0.107 $\mu\text{g/g}$ in bottom sediments, 0.205 $\mu\text{g/g}$ in the suspended sediments, and 0.07 $\mu\text{g/g}$ in the vegetation) are compatible with the concentrations of Hg in

this area. However, elevated concentrations of Hg ($0.400 \mu\text{g/g}$) were found in the suspended matter collected from Willow River, indicating an input of Hg into the system below the outlet of JCL into Willow River.

9. The concentrations of polynuclear aromatic hydrocarbons (PAH) in JCL sediments were comparable to those found in relatively unpolluted sediments. The concentrations of total polychlorinated biphenyls (PCB) in JCL sediments were at or below the detection limit ($0.01 \text{ ng/g dry weight}$) of the analytical method used.

10. The pH in the bottom waters of JCL was lowest near the tailing deposits and increased with the distance from the tailings. However, all pH's were above 7.7 and the difference across the lake was small (about 0.4 to 0.5 pH units) and may reflect either the release of H^+ ions after the oxidation of sulphides in the tailings or an inhibition of microbial activity by contaminants in the tailing particles deposited on the bottom of the lake. The concentrations of sulphate differ significantly between the surface and bottom waters of the lake with the concentrations in the bottom waters about two times greater than those in the surface waters. This indicates a release of the sulphates from the bottom sediments. A low primary production in the lake water was attributed either to N-limitation or to elevated concentrations of bioavailable metals in the lake bottom sediments.

11. The concentrations of As in sediment pore water in JCL was about two orders of magnitude greater than that in the lake water. However, there is no migration of As from the sediments into the overlying water, as evidenced by the concentrations of As in the surface and bottom water in the lake. This indicates that the bottom sediments act as a sink rather than a source of As. On the other hand, relatively great concentrations of As in the pore water may affect the health of the sediment biota. With the exception of As, Ni and Cu, the differences in the concentrations of trace elements in sediment pore water in JCL and Bowron Lake are not statistically different. The average concentrations of As, Ni, Mn and Zn in the groundwater collected from the tailings are similar to those found in the sediment pore water in JCL. However, the average concentrations of Pb, Cd, Fe and Cr in the tailings groundwater are significantly greater than those in the lake sediment pore water. The elevated concentrations of As, Pb, Cd and Cr observed in the vegetation and invertebrates collected from the tailings confirm high mobility of these elements in the tailings.

12. The bioavailability of certain trace elements in sediments increases towards the tailings. There is evidence that the tailings inhibit a variety of microbial activities including enzyme functions, CO₂ production, humification of organic matter, and denitrification. The cause(s) are not yet known, but the degree of inhibition increases with the abundance of bioavailable Cu and Pb

(but not the total concentrations) in the sediments.

13. On preliminary examination, the benthic community data do not demonstrate any major effect of the mine tailings on JCL benthic organisms. There is some indication of reduced overall numbers at station 5, and the bivalves may be particularly sensitive, as implied by their reduced numbers at stations 4 and 5. The sporadic distribution and low numbers of oligochaetes is perhaps indicative of a lake-wide impact, but the high numbers of total organisms at station 6 suggest that effects on the resident community are very local, occurring at stations 4 and 5 only. However, without reference data from other lakes of similar type it is difficult to determine what type of community could be expected. There is certainly a functioning benthic community in the lake. With the exception of the results from the *Hyalella* bioassay, these data give no indication of sediment-associated toxicity. Examination of the test results from the *Hyalella* bioassay with the sediment characterization may provide an explanation for the high variable response of the amphipod.

14. Elevated concentrations of As, Cd and Cu (721, 25 and 301 $\mu\text{g/g}$, respectively) in the invertebrates collected from the streams flowing through the tailings and uptake of As, Cd, Cr and Pb by certain species of the vegetation growing on the tailings suggested the transport of these elements from the tailings into the terrestrial and aquatic environment at the study area.

SUGGESTIONS FOR FUTURE ENVIRONMENTAL INVESTIGATIONS

- a) Investigate the possible source of Hg entering Willow River between the outlet of JCL and downstream of Wells (confluence of Willow River and Williams Creek), and the chemical forms/bioavailability of the Hg in the suspended and bottom sediments in the Willow River downstream of JCL;
- b) evaluate the quality of water, and the processes in sediment and suspended matter in Willow River within a 10-km distance downstream of JCL;
- c) survey the benthic community structure and water chemistry in noncontaminated lakes (3 to 5) near the study area. Selected lakes should have geological setting, water depth and morphometry similar to those of JCL;
- d) estimate sedimentation rates in JCL and areas with permanent sediment accumulation in Willow River. Determine background concentrations of elements of concern in bottom sediments of JCL, Willow River and adjacent streams;
- e) investigate the deformities and changes in chironomidae species to determine the effect of contaminants in the sediments on the

health of the dominant benthic invertebrate species in JCL;

f) determine the uptake of trace elements, particularly As, by different invertebrates living on the tailings, Jack of Club Lake and Willow River, to assess the potential mobilization and bioaccumulation of these elements in the biota;

g) based on the preliminary reconnaissance survey collect additional data on microbial activities in JCL sediments, physico-chemical characteristics of sediments and water, including a study of metal speciation in relation to toxicity and bioavailability, such as, effects of labile Cu on primary production and bioaccumulation of elements in JCL, to prepare a final report on the health of the aquatic environment of JCL and Willow River at Wells, B.C.

1. INTRODUCTION

Gold mining has been a major mining activity in Canada for over a century. The Cariboo region in British Columbia has been an important mining area since the 1800's. By 1960 most of the creeks in the Cariboo region had been prospected. The complex geochemistry of gold ore was a challenge for its extraction. Consequently, the miners practised different extraction techniques, including amalgamation with mercury and cyanidation.

During the 1800's the Cariboo Gold Rush lured thousands of men to this region in the interior of British Columbia, and early in 1861 dozens of gold-bearing creeks were discovered. Lowhee Creek near Barkerville, B.C. became the nucleus of the gold rush. In the boom days of 1863 the population of Barkerville was 15,000, in contrast to the present population of <100. After the first year the entire length of the creek was staked, from the site of the present town of Wells for a distance of two and a half miles through the mountains to its source. In the course of time, gold came to be mined underground, and drift mining was required. In the 1890's the Cariboo Consolidated Mining Company began hydraulic mining, which continued until 1964.

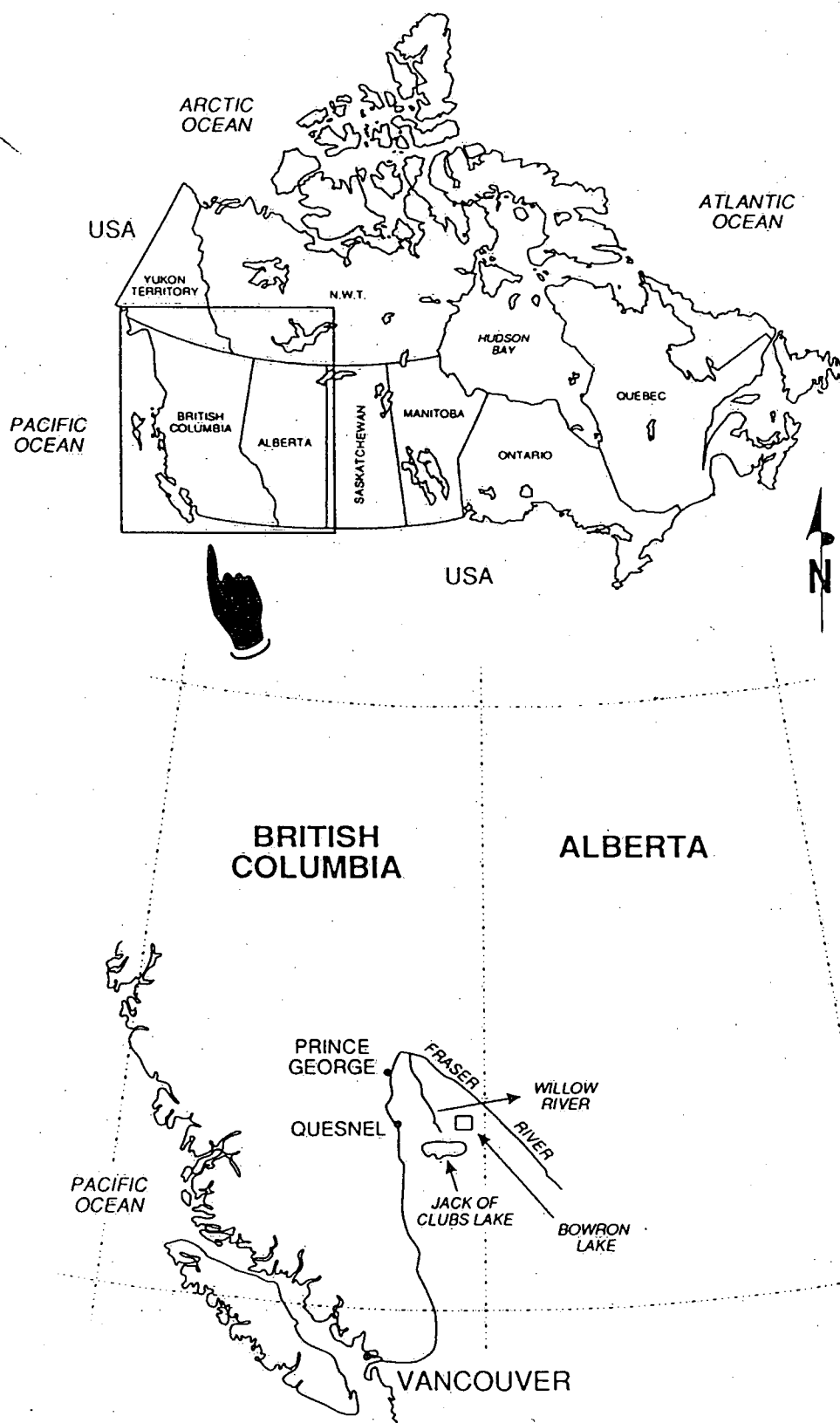
The town of Wells (Figure 1.1), at the northeast shore of Jack of Clubs Lake (JCL), was founded in 1932 by Fred Wells and built on the tailings from the old Lowhee Mine. Starting in 1933, the Gold Quartz Mining Company decided to tunnel the mountain to extract

gold by underground mining rather than panning, dredging, and sluicing. During its 33 years of operation at Wells, the Cariboo Gold Quartz Mining company produced in excess of five million dollars' worth of gold. Further historical information is available in Ludditt (1980), Harris (1984), and Taylor (1978).

Recently, environmental effects of past gold mining activities have received considerable attention. Potential health risks associated with the development of a community recreation site on the abandoned tailing deposits at Wells, B.C., contamination of groundwater, and transport of contaminants in tailing particles by wind have been recently studied (Andrews, 1989; Galbraith, 1991; Rescan, 1990). Mercury concentrations in lake trout (over 45 cm length) from JCL have been shown to exceed the 0.5 mg/Kg Hg guideline for human consumption (Andrews, 1989). However, limited information is available on the effects of the abandoned gold mine tailings on the aquatic ecosystems and the potential for methylation of Hg in JCL and the Willow River. Such information is essential to the identification of pollution sources and assessment of their effects on the Fraser River Basin ecosystem.

A multidisciplinary study was initiated to determine biogeochemical effects of gold-mine tailings deposited in JCL and on adjacent land. Bowron Lake (BL), which is located nearby and is considered essentially pristine, was used for purposes of comparison.

Figure 1.1 General map of the study area



The objectives of this study were as follows:

- a) to conduct a reconnaissance study to determine the distribution of major and trace elements in the different environmental compartments (water, suspended and bottom sediments, interstitial water of sediments and biota) of Jack of Clubs Lake;
- b) to determine the effects of the abandoned tailings on the biota in the lake and on adjacent land; and
- c) to examine the transport of major and trace elements from abandoned tailings into the Fraser River system.

2. MATERIALS AND METHODS

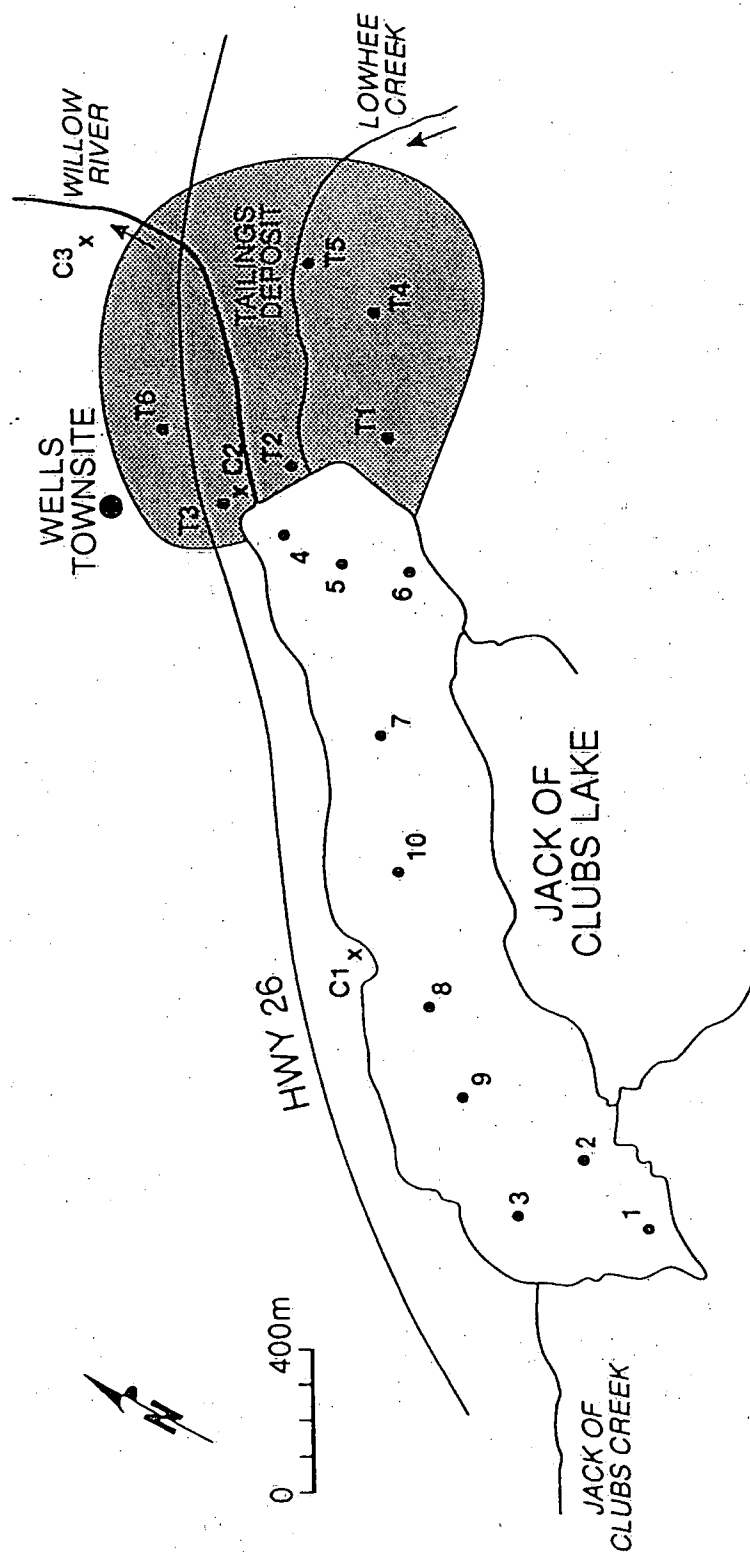
2.1. Study Area

Jack of Clubs Lake (JCL) is located in the Barkerville Terrane, which is mostly underlain by clastic sedimentary rocks, principally Precambrian and Palaeozoic sandstone, greywacke and black and green pelite, with minor proportions of limestone and mafic volcanic rocks (Struik, 1988). The strike of the rock units is parallel to the regional NW-SE structural trend, and the sediments have been metamorphosed to greenschist facies (Robert and Taylor, 1989).

The tailings from the milling and gold extraction by Cariboo Gold Quartz Mine were discharged into the northeast end of JCL, changing the original morphometry of the lake. At present, tailings deposit about 4.5 m thick covers approximately 25 hectares of land adjacent to the lake. The tailings are dissected by Highway 26, Lowhee Creek and Willow River (Figure 2.1).

Lowhee Creek flows through the tailings of the Cariboo Gold Quartz Mine before it empties into the northeast end of Jack of Clubs Lake. During spring runoff the waters of the creek flood an extensive area of the tailings. Most of the sediments that have accumulated near the mouth of the creek are remnants of extensive hydraulic mining activities that occurred during the gold rush (Andrews, 1989). Jack of Clubs Lake is 2.4 km long and 0.5 km wide, with a mean depth of 19 m and a maximum depth of 63 m. Its flushing rate is extremely rapid, averaging 0.8 years (K.I. Andrews, personal communication). A man-made channel dug through the tailings at the northeast end of the lake drains into the Willow River, the only outlet of the lake, which flows for 130 km before discharging into the Fraser River. Part of the water flowing through this channel originates as groundwater seepage from the tailings and does not reach the lake. The field work was carried out during the first week of August, 1992. Samples of sediment and water were collected from Jack of Clubs Lake, Lowhee Creek, Willow River, and Bowron Lake (Figure 2.1). Bowron Lake, located about 30 km east of Wells, was selected as a control or reference lake for the study. The

Figure 2.1. Study area and sampling stations (1 to 10 sampling sites in the lake; T1 to T6 sampling sites in the tailings; C1 to C3 centrifuge locations for suspended sediment sampling)



surface area of the lake is over 121,600 hectares. The bedrock in the watershed of Bowron Lake consists mainly of quartzite, limestone, shale, phyllite, dolomite, and conglomerates. The lake is inside the Bowron Lake Provincial Park, and there are no reports of mining activities, past or present, along the lake. The Bowron River drains the north side of the lake and enters the Fraser River near Prince George. The Cariboo River drains the east and south sides of the lake and flows south to join the Quesnel River, one of the tributaries of the Fraser River. Bowron Lake was not surveyed for benthos because of the different size, morphometry and water depth.

2.2. Sampling and Analytical Methods

2.2.1. Water

2.2.1.1. Surface Water

Water samples for determination of nutrient concentrations were collected 1 m below the surface and 1 m above the lake bottom, at each of the 10 stations in the lake (Figure 2.1) using a van Dorn bottle (Rosa et al., 1991).

The samples were filtered through pre-ignited (500°C) and pre-weighed Whatman GF/C glass fibre filters (pore size 1-2 μm) for determination of total suspended matter (TSM). Water samples collected for analysis were divided into different subsamples which were stabilized with various preservatives (for example, HNO_3 for subsamples to be analyzed for metals). Total suspended matter was

measured gravimetrically after drying the samples at 100°C for 2.5 hours. The inorganic suspended matter (ISM) was determined after igniting the samples at 500°C for 2 hours. The organic suspended matter (OSM) was calculated as the difference between TSM and ISM. Particulate organic carbon (POC), particulate nitrogen (PN), chlorophyll-a corrected and uncorrected for phaeophytin (CHLA-C, CHLA-U), filtered (Whatman GF/C pore size range 1-2µm) and unfiltered total phosphorus (TFP and TP, respectively), and total organic carbon (C-ORG) were determined by the methods of Philbert and Traversy (1974). Particulate phosphorus TPP was calculated as the difference between TP and TFP. The water samples were analyzed for various metals (Pb, Hg, Cu, Cd, Zn, Cr, Ni, Co, V, Ca, and Mg) and for As, by atomic absorption spectrophotometry (AAS); the concentrations of P, N, SO_4^{2-} , and Cl^- were also determined. At all sites continuous surface-to-bottom depth profiles of pH, specific conductance (COND), dissolved oxygen (DO), and temperature were recorded by a HYDROLAB Profiling System, Model DataSonde_R 3.

The lake and stream waters were analyzed for 47 parameters at the Geological Survey of Canada (Finch et al., 1992). Three water samples were collected at each site (Figure 2.2): one unacidified and filtered for anions; one filtered and acidified with Ultrex H_2SO_4 for Hg; and one filtered and acidified with Ultrex HNO_3 at the rate of 0.4% for most trace elements. Membrane filters with 0.45µm pores were used for all filtrations. The methods used are described below.

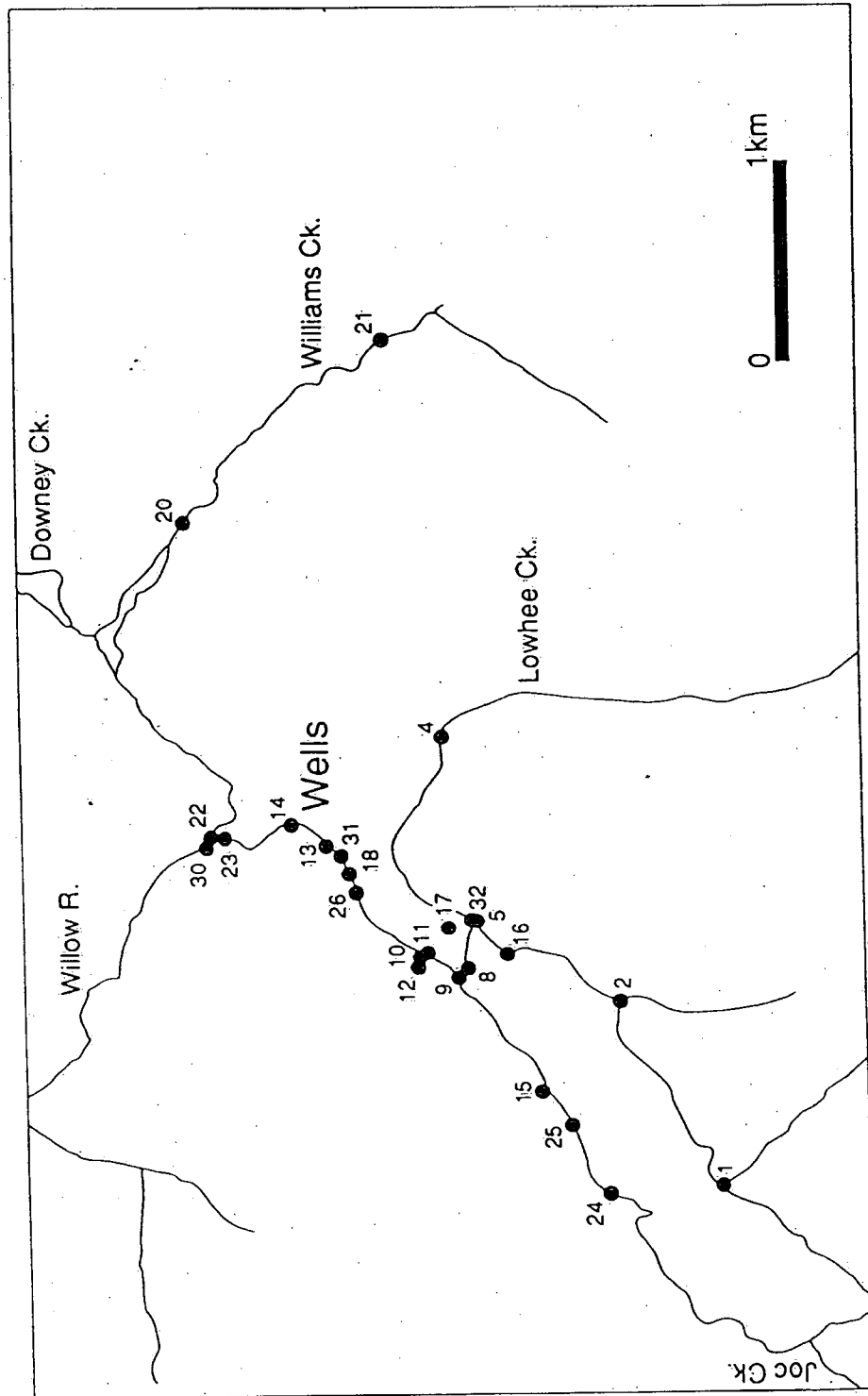


Figure 2.2. Site locations for stream and seepage samples

Major cations (Na^+ , K^+ , Ca^{2+} , Mg^{2+}) were determined by air-acetylene AAS. Cesium at 0.1% was used as an ionisation buffer and La at 0.5% as a releasing agent. Anions (NO_2^- , NO_3^- , F^- , PO_4^{3-} , Br^- , SO_4^{2-} and Cl^-) were determined by ion chromatography with detection by conductivity using a Dionex Ion Chromatography according to the method described by Smee *et al.* 1978.

Hydride-forming elements (As, Sb, Se, Te and Bi) were all determined by formation of their hydrides using NaBH_4 as a reductant followed by analysis employing quartz tube AAS for As inductive coupled plasma mass spectrophotometry (ICP-MS) for Sb, Se, Te, and Bi. Arsenic was reduced with KI and ascorbic acid prior to analysis so that the concentrations reported represent As(III) and As(V). The Sb, Te and Bi were reduced in HCl so that the results for these elements indicate total inorganic concentrations. Values given for Se, however, represent total Se (organic and inorganic), as the subsamples taken for Se determination were digested with $\text{K}_2\text{S}_2\text{O}_8$ (a strong oxidising agent) prior to reduction in 6M HCl and analysis.

Mercury was determined by ICP-MS with introduction as its vapour following reduction with NaBH_4 . Al, Ti, V, Co, Ni, Cu, Zn, Y, Cd, In, La, Ce, Pr, Nd, Sm, Eu, Tb, Gd, Dy, Ho, Er, Tm, Yb, Lu, Pb, U, Mn and Fe were all determined together by ICP-MS following a 10-fold preconcentration using an automated procedure whereby the free ion is chelated on a resin prepared by Dionex, marketed under the name Metpac CC-1, whose properties are very similar to Chelex-

100 but without its undesirable shrinking and swelling characteristics.

The determination of rare-earth elements (REEs) and transition metals in natural waters directly by ICP-MS can be difficult owing to their low concentrations and interferences caused by the presence of alkali and alkaline-earth metals and various anions such as chloride. Recent work by the Analytical Method Development laboratory has resulted in the production of a fully automated system to overcome these difficulties.

The system consists of a Dionex chelation concentration module, a Gilson autosampler and a Foxy fraction collector. The chelation column is the "MetPac CC-1" from Dionex Corporation. The REEs, Cu, Pb, Ni, Co, Zn, Mn, Al, Fe, Y, Ti, Cd, In, and U are retained and preconcentrated on the column, whereas interfering components such as anions, Na, K, Ca, and Mg are not. The sample is recovered in 5% HNO₃ for analysis by ICP-MS.

The water samples were filtered in the field within a few hours of collection using a Millipore glass filter apparatus with 0.45 μ m cellulose acetate filters. They were then acidified with "Ultrex" grade HNO₃ to a final concentration of 0.4% AND sent to the laboratory as quickly as possible and stored at 4°C until analyzed. The water samples were preconcentrated and separated from interferences using the automated system (described in detail

below). A known volume of sample was buffered on-line and passed through the chelation column. The alkali earth metals and anions passed through the column which was then rinsed to remove weakly bound alkaline earth metals. The concentrated REEs and transition metals were eluted with 5 mL of 5% HNO_3 .

The Dionex CCM consists of two units, the sample concentration module (SCM) and the gradient pump module (GPM). The SCM consists of two single piston pumps (one pump is used to transfer the sample from the autosampler to the SCM and the other is used to buffer the sample to pH 5.4 before it is passed through the concentrator column), four 2000 psi, inert double stack four way pneumatically controlled slider valves (only two are used in this application) and the MetPac CC-1 columns used for reagent cleanup and sample preconcentration. The GPM is a microprocessor controlled, high performance quaternary gradient IC pump. This module has twenty programmable steps that allow the time dependant selection and flow rates of up to 4 different eluants and control of the two pneumatic valves in the SCM (valve 5 and valve 6). The GPM can store up to 10 programs and is interfaced to and controlled by the autosampler.

The Foxy fraction collector is fully programmable and has a solenoid valve that can be activated to allow for the collection of each sample in separate test tubes allowing the rest of the eluent to be diverted to waste. It is interfaced to and controlled by the autosampler. Forty samples can be processed in a day.

The autosampler is interfaced with the GPM, the two pumps in the SCM, and the Foxy fraction collector. The current setup we are using in the CCM allows us to use Baker "Intra-Analyzed" grade reagents for the preparation of the ammonium acetate eluent. Both the 2M and the 0.5M ammonium acetate are cleaned on-line by passing each through separate MetPac CC-1 columns. The columns are cleaned by passing 5% HNO₃ through the columns to waste before eluting the sample off the main concentrator column. This has eliminated the need for costly high purity reagents. The samples were analyzed on a Perkin Elmer/Sciex Elan 250 upgraded to a 500. Corrections were made for the spectral interferences of the oxides of the light REEs in the determination of the isotopes of the heavy REEs and for the oxides of Mo and Ti in the determination of the transition metals.

For any series of samples that are being preconcentrated it is necessary to prepare blank reagents which must also be preconcentrated and are used to rinse the autosampler lines. Standards solutions containing the elements being preconcentrated are prepared in the same matrix as the samples and the blank solution. This standard was processed along with the samples to allow for corrections for recovery. There are two controls that are currently in use when preconcentrating water samples: NBS 1643c and an in-house reference standard "tap". Normally one of each of these standards will be included in each batch of samples processed.

2.2.1.2. Pore Water and Groundwater

Interstitial water in sediments was collected at selected sampling stations in Jack of Clubs Lake (Figure 2.1), and bottom sediments were sampled using a modified Kajak-Brinkhurst corer. Sediment core sections 0 to 5, and 5 to 10 cm were extruded from the core liner under an atmosphere of nitrogen and squeezed separately to press out the interstitial water. The time between sample collection and termination of squeezing was less than 5 hours. A squeezer assembly designated by Kalil and Goldhaber (1973) was used for sediment squeezing. During the squeezing process the interstitial water was separated from the sediments by a 0.45 μm Millipore filter. Interstitial water samples from individual sediment sections were collected in vials pre-acidified with two drops of ultra pure conc. HNO_3 in each, and stored at 4°C for laboratory analysis. Trace elements and major ions in all samples were determined by ICP.

Groundwater was sampled by means of piezometers previously inserted into the tailings (T1 to T6 in Figure 2.1). First, the water level in each piezometer well was measured and the standing water was pumped out. The piezometers were allowed to recover overnight, and the next day any water which had accumulated in the piezometers during the night was pumped out at a low flow rate, using prewashed polypropylene tubing. Once the water started to flow, the tubing was attached to an on-line 0.45 μm filter and several mL of water were passed through the filter. Two types of groundwater sample were collected: one was collected in a Nalgene

bottle containing few drops of conc. HCl for determination of cations, and the other was collected in a prewashed bottle with no preservative added for determination of anions. A flow-through cell was attached for determination of pH. The pH was measured by a glass combination electrode (previously calibrated with pH 7.0, 4.0 and 1.68 buffers). If water remained in the piezometer after collection of the samples, the on-line filter was detached, and unfiltered samples (acidified and nonacidified) were collected for determination of cations and anions.

2.2.2. Sediments

2.2.2.1. Suspended Sediments

Suspended sediments were recovered from three locations in the study area (C1, C2 and C3 in Figure 2.1): (1) at the centre of JCL, three meters below the water surface; (2) from the outflow of the lake (the Willow River); and (3) from the Willow River at the end of its passage through the town of Wells (Figure 2.1). About 2,000 litres of water were pumped into a Westfalia separator at a flow rate of 4 L/min to remove the suspended sediments, which were then freeze-dried, weighed, homogenized by grinding, and analyzed for major and trace elements (following the techniques of Mudroch and Duncan, 1986).

2.2.2.2. Bottom Sediments and Tailings

Sediment samples were taken at 10 stations using a miniponar grab sampler. This sampler encompasses an area of 234 cm² and penetrates to an average depth of 5 cm. The sediment was placed in a glass tray, homogenized with a plastic spoon and transferred to plastic vials and prewashed glass vials. Samples in plastic vials were stored at 4°C in the field and freeze-dried when taken back to the laboratory. The concentrations of major and trace elements in freeze-dried samples of whole bulk sediments were determined by ICP using lithium borate fusion followed by aqua regia digestion (Bondar-Clegg, 1992). The samples in glass containers were frozen and used for determination of PAHs by GC/MS, using the method described by Nagy *et al.* (1986).

Particle size frequencies in lake sediments were estimated for wet samples using the sedigraph method (Duncan and LaHaie 1979). Carbon analyses were performed on freeze-dried samples using a LECO-12 Carbon Analyzer, and loss on ignition (LOI) was determined by ashing dry sediment at 450°C to constant weight (approx. 3h). Surface samples of tailings were collected at six different locations (T1-T6 in Fig. 2.1). Tailings samples were separated into six different particle size fractions: 54-140 µm, 40-54 µm, 27-40 µm, 19-27 µm, 13-19 µm, and <13 µm, the method was described earlier by Mudroch and Duncan (1986). Particle size analyses were carried out by the "Sieve and Sedigraph Method", using a Warman Cyclosizer (WR-200) and sieves (LC-10B) (Duncan and LaHaie, 1979).

A modified Kajak-Brinkhurst corer was used to collect sediment

cores to examine vertical profiles of major and trace element concentrations in the sediment. For this purpose, sediment cores were subdivided into 1-cm sections and analyzed by AAS following application of the sequential leach scheme outlined in Table 2.1.

2.2.2.3. Sequential Leaching of the Sediment Cores

Sequential solvent extractions were performed and the extracts analyzed for metals to determine various operationally defined classes of metal species. Although the accuracy of such analyses may not be equivalent to that of total metal determinations, the precision has been found to be excellent in all the R&D carried out previously at the Geological Survey of Canada. The order in which the extractants are used is critical, each being more severe in action or of a different nature (reducing vs. oxidising) than the previous one.

Samples were kept moist and refrigerated at 4°C until analysis was begun. Each interval or segment of core was centrifuged at 2800 rpm for 20 min. to remove the bulk of the water, and 1 g taken for the sequential leach procedure. Another sub-sample of the centrifuged material was oven-dried, the loss in weight ('LOD' in results) recorded, and the sample then analyzed by AAS for 'total' metals following an HF-HClO₄-HCl-HNO₃ extraction. It should be borne in mind that some refractory minerals such as spinels, tourmaline, zircon, etc. are not dissolved effectively by this acid digestion,

Table 2.1. SEQUENTIAL EXTRACTION SCHEME

Extractant	Phase dissolved
1M NaOAc. HOAc pH5 [1g/20 ml; 2 x 6 h constant shaking] (two 6h extractions; app. 2d)	Carbonates, adsorbed metals, exchangeable metals
0.25 M $\text{NH}_2\text{OH}\cdot\text{HCl}$ in 0.25M HCl [At 60°C; first leach for 2 h, second leach for 0.5 h] (2 and 0.5 hour extractions; approx. half a day)	Amorphous oxyhydrates of Fe and Mn. Hydroxylamine hydrochloride is preferred to oxalate reagent as its attack on organic matter is minimal.
1 M $\text{NH}_2\text{OH}\cdot\text{HCl}$ in 25% HOAc [At 90°C; first leach for 3 h, second leach for 1 1/2 h] (3 and 1.5 hours extractions; approx. one day)	Crystalline Fe oxides (e.g. hematite, goethite, magnetite, maghemite, lepidocrocite)
KClO_3/HCl for 0.5 h followed by 4 M HNO_3 at 90°C (30 and 20 min; approx. half a day)	Sulphides, organic matter
HF/ HClO_4 / HNO_3 /HCl evaporation (approx. 1 day)	Silicates, residual crystalline fraction

but the sulphides and oxides of interest in this study are. Arsenic was determined by hydride generation quartz tube AAS, using NaBH_4 as the reductant (detection limits in Table 2.2). Arsenic was first separated from potential interferents such as Cu and Ni by coprecipitation with $\text{La}(\text{OH})_3$, which was formed by adding $\text{La}(\text{NO}_3)_3$ and NH_4OH to the extract. The hydroxide precipitate was filtered off and dissolved in 4 M HCl for subsequent hydride production. All calibration solutions for measurement by AAS were made up in the same matrix as the analytes in each of the five leaches.

Procedures for the sequential leaching of soils for the extraction of elements bound in different (mineral) phases:

1) Adsorbed and exchanged carbonates (phase one)

1. Weigh out 1.0 g of sample into a 50 mL centrifuge tube fitted with a screw cap. Add 20 mL of the 1M sodium acetate solution to each sample and cap the tubes tightly.
2. Suspend the sediment by shaking the samples for 5 seconds using a Vortex mixer. Place the samples horizontally on a motion shaker set at 160 shakes per minute, for a total time of 6 hours.
3. Centrifuge the samples for 10 minutes at 2800 rpm. Decant the liquid into clean and labelled containers.
4. Rinse with 5 mL of DDI water, suspending the sediment using a Vortex mixer and then centrifuging again as in step #3. Add the rinsing to the appropriate containers used in step #3. Repeat with another 5 mL of DDI water. After completion of this step, the

Table 2.2. Results for the blank analysis and detection limits for quantitative determination of major and trace elements in sediment samples.

	Al	As	Ag	Ba	Bi	Ca	Cd	Co	Cr	Cu	Fe	Hg
	%	ug/g	ug/g	ug/g	ug/g	%	ug/g	ug/g	ug/g	ug/g	%	ng/g
Sediments:												
Analytical blank	<0.01	<5	<0.2	<1	<5	<0.01	<0.2	<1	<1	<1	<0.01	<5
Mean value	0.005	2.5	0.1	0.5	2.5	0.005	0.1	0.5	0.5	0.5	0.005	2.5
Accepted value	<0.01	5	0.2	<1	2	<0.01	1	1	1	1	<0.05	5
Detection limit	0.01	5	0.2	1	5	0.01	0.2	1	1	1	0.01	5
Water:												
Detection limit	10						0.01	0.005		0.1	10	
sediments												
	K	Mg	Mn	Mo	Na	Ni	Pb	La	Sb	Sr	V	Zn
	%	%	ug/g	ug/g	%	ug/g	ug/g	ug/g	ug/g	ug/g	ug/g	ug/g
Sediments:												
Analytical blank	<0.01	<0.01	<1	<1	<0.01	<1	<2	<1	<5	<1	<1	<1
Mean value	0.005	0.005	0.5	0.5	0.005	0.5	1	0.5	2.5	0.5	0.5	0.5
Accepted value	<0.01	<0.01	1	1	<0.01	1	2	<1	5	<1	1	1
Detection limit	0.01	0.01	1	1	0.01	1	2	1	5	1	1	1
Water(*):												
Detection limit			1			0.1	0.02	0.01			0.01	0.1

(*) Detection limits for water expressed in ng/g

extraction may be halted and the sediments refrigerated.

5. Repeat steps #1 to #4 exactly as written (with the same sediment sample) and store the tightly capped residual sediments in the refrigerator unless proceeding immediately to the leaching of the hydrous iron and manganese oxides phase.

2) Hydrous iron and manganese oxides (phase two)

1. Add 20 mL of the 0.25M hydroxylamine hydrochloride in 0.25M HCl to the residues from the adsorbed and exchanged carbonates phase. Cap tightly and shake the samples using a Vortex mixer for 5 seconds to suspend the sediment completely.

2. Heat the samples in a water bath set at 60°C, for 2 hours with the caps loosened. Every 20 minutes, re-tighten the caps and shake the samples for 10 seconds each, using a Vortex mixer. Re-loosen the caps and return the samples to the water bath.

3. Centrifuge the samples for 10 minutes at 2800 rpm. Decant the liquid into clean and labelled containers.

4. Rinse the sediment with 5 mL DDI water, suspending the sediment using a Vortex mixer and centrifuging as in step #3. Add the rinsing to the solution from step #3. Repeat with another 5 mL of DDI water. After completion of this step, the extraction may be halted and the sediments refrigerated before continuing.

5. Repeat steps #1 to #4; however, at step #2, heat the mixtures for 30 minutes in the water bath instead of 2 hours. Store the tightly capped residual sediment in the refrigerator unless proceeding immediately to the leaching of the crystalline iron oxides phase.

3) Crystalline iron oxides (phase three)

1. Add 30 mL of the 1M hydroxylamine hydrochloride in 25% acetic acid to residues of the hydrous Fe and Mn oxides phase. Cap the tubes tightly and suspend the sediment, using a Vortex mixer.
2. With the caps tightly screwed on, heat the samples for 3 hours in a water bath at 90°C. Every 20 minutes shake the samples for 10 seconds each using a Vortex mixer.
3. After 3 hours, centrifuge the samples for 10 minutes at 2800 rpm. Decant the liquid into clean and labelled containers.
4. Add 10 mL of the 25% acetic acid to the sediment, and suspend the sediment using a Vortex mixer. Centrifuge the mixtures as in step #3. Add the supernates to the appropriate labelled container used in step #4. Repeat once more, adding the supernates to the same containers. After this step is completed, the extraction may be halted and the sediments refrigerated before continuing.
5. Repeat steps #1 to #4; however, at step #2, heat the sample mixtures for 1.5 hours each instead of 3 hours. Store the tightly capped residual sediments in the refrigerator unless proceeding immediately to the leaching of the sulphides phase.

4) Sulphides/organic (phase four)

1. In a fumehood, add 750 mg potassium chlorate to residues of the crystalline iron oxides phase. Quickly add 5 mL of concentrated HCl to the sediments, cap tightly and shake for 5 second using a Vortex mixer. This should be done for one sample at a time, the sample mixture will froth violently, so the tubes should be capped

immediately to avoid loss of sample or reagent.

2. When the reaction subsides (in approximately 5 to 10 minutes), quickly add a further 10 mL of concentrated HCl to each tube and cap tightly. Once again, this should be done for one sample at a time to minimize losses through frothing. Keeping the samples tightly capped, each mixture is shaken using the Vortex mixer every 10 minutes, for 10 seconds each time, for a total time of 30 minutes. At the end of the 30 minutes, add 15 mL of DDI water to each sample, cap tightly and shake for 5 second using the Vortex mixer.

3. Centrifuge the samples for 10 minutes at 2800 rpm. Decant the liquid into clean, labelled containers. After completion of this step, the extraction may be halted and the sediments refrigerated before continuing.

4. Add 10 mL of 4M HNO₃ to the sediments, cap tightly and suspend the sediment by shaking for 5 seconds using the Vortex mixer. Heat the samples with the caps closed tightly for 20 minutes in a water bath set at 90°C. During this time, each sample mixture is shaken every 5 minutes for 5 seconds duration, using a Vortex mixer.

5. At the end of the 20 minutes digestion time, suspend the sediment thoroughly and transfer the mixture into clean, labelled Teflon pressure tubes ("Oak Ridge" tubes, with rounded bottom, straight sides, and a screw-cap were used).

6. Centrifuge the samples in the pressure tubes for 10 minutes at 2800 rpm. Decant the liquid into the same containers holding the KClO₃/HCl solution from step #3.

7. Rinse the centrifuge tubes with 5 mL of DDI water, suspending any remaining sediment by shaking with a Vortex mixer. Pour this mixture into the appropriate pressure tubes, centrifuge and decant into the same containers from step #3. Repeat with another 5 mL of DDI water. Store the tightly capped residual sediments in the refrigerator unless proceeding immediately to the leaching of the silicates and residual oxides phase.

5) Silicates and residual oxides (phase five)

1. Add 2 mL of concentrated HNO_3 to residues of the sulphides phase. If the sediment has been leached for elements bound in the Organic phase, or if the organic content of the sediment is high, additional nitric acid may be required to decompose the sediment adequately (e.g. 5 to 10 mL of HNO_3 , instead of 2 mL).

2. Place the Teflon pressure tubes in a dry heating block on a hot plate (200°C). Heat uncapped, until less than 0.5 mL of liquid remains in the tube. Remove each sample from the heating block at they evaporate to the appropriate volume. Cool the mixtures for approximately 5 minutes and add 2 mL of concentrated HCl to each sample. Heat the samples uncapped for 20 minutes in a water bath at 90°C . Remove the samples from the bath and allow them to cool.

3. Add 10 mL of the decomposition mixture to each sample and cap the tubes tightly. Heat the mixtures for 1 hour in a water bath (90°C). Transfer the contents of the tubes into 50 mL Teflon beakers, using DDI water to rinse the sediment from the pressure tubes.

4. Place the beakers on a hot plate (70°C) and let them heat overnight. In the morning, raise the heat to approximately 125°C, and evaporate the mixture to incipient dryness. (This step can take a total time of 20 to 24 hours). If a reddish-brown colour remains, i.e. -- evidence of organic compounds, add 5 mL of a 5:2 = $\text{HClO}_4:\text{HNO}_3$ mixture to the sediment, and heat till evaporated to incipient dryness.

5. To each mixture, add 1 mL of HCl to dissolve some of the sediment. Then add 3 mL HNO_3 and swirl to dissolve as much material as possible. (Note that some of the material may remain undissolved.) Add 3 mL DDI water and warm the mixture gently on a hot plate for approximately 5 minutes.

6. Transfer the mixture into a calibrated tube, using DDI water to rinse the beakers. Make the volume up to 20 mL for each mixture with DDI water. Stopper the tubes and mix thoroughly. Leave the mixtures to sit overnight, to allow the solid material to dissolve more completely into the acid solution. Any insoluble material will have settled to the bottom of the tubes at this time.

2.2.4. Biota

2.2.4.1. Microbial Population

Sediment samples for the study of the microbial communities were collected from three sites in Jack of Clubs Lake: one close to the northeast end, where the tailings were deposited (station-4, Figure 2.1); a second one at the centre of the lake (station-9,

Figure 2.1); and a third one near the southwest end, which is farthest from the tailing deposits (station-1, Figure 2.1). Samples were also taken from two sites in Bowron Lake; and, as the data from these two sites were lumped together and averaged, the combined site was simply designated as BL.

Sediment samples collected for determination of pH, Eh, solvent-extractable metal species, and activities of microbes and enzymes were stored in plastic bags at 4°C with exclusion of air to keep them in their native state. Samples collected for other kinds of analyses were frozen. This report deals exclusively with data obtained from fresh sediment samples in their native state; the frozen ones have not yet been analyzed. As the tailings were introduced into the northeast end of the lake, the expected order of decreasing environmental and biological effects of the pollution at the sampling sites was: JCL-4 > JCL-9 > JCL-1 > BL.

Soon after collection of the samples, the sediment pH and Eh were measured. The sediments were then analyzed for microbial dehydrogenase and alkaline phosphatase activity (under an atmosphere of air) and for microbial CO₂ production and denitrification (represented by production of N₂O in the presence of acetylene, which blocks conversion of N₂O to N₂) under both aerobic and anaerobic conditions (under atmospheres of air and He, respectively); the analyses were performed after incubation of sediment samples in stoppered flasks under defined conditions for

different lengths of time. Pore water in sediments was collected by high-speed centrifugation followed by rinsing with water under N_2 and was acidified and then analyzed for metals and As. After removal of the pore water, operationally defined "bio-available" metal species in the solid phase were determined by dividing the material into two sets of subsamples and then extracting one set with 0.5 M $CaCl_2$ (which solubilises weakly adsorbed or exchangeable metals) and the other one with a solution of DTPA (a chelating agent commonly employed in the estimation of the availability of certain soil-bound metals to plants); the extractions were performed under an atmosphere of N_2 using N_2 -purged solvents, and the extracts were analyzed for metals and As. In addition, sedimentary humic matter was extracted with 0.1 M NaOH under N_2 , and the UV-visible absorption spectra and Fe and organic C content of the extracts were recorded; humic content was estimated by measuring the absorbance of the extract at 465 nm (A_{465nm} per unit weight of dry sediment), and the degree of "humic" as distinct from "fulvic" character of the humic matter (in other words, its degree of "maturity" or "humification") was estimated by means of the absorbance ratio A_{465nm}/A_{665nm} (otherwise known as the " E_4/E_6 " ratio).

Fe and Mn oxyhydroxides ($FeOOH$ and $MnOOH$) in sediments were determined by sequential extraction with N_2 -purged solutions of $NH_2OH \cdot HCl$ and citrate-dithionite, in that order, followed by analysis of the extracts for Fe and Mn. The total metal and As concentrations in the sediments were estimated by wet-ashing and

analyzed by AAS. The moisture content of the sediment was measured, and the data were calculated on the basis of dry weight. In addition, the sediments will be analyzed for N, P, and organic C. In the near future frozen sediment samples are to be analyzed for sulphide and for various biochemical substances such as fatty acids and lipid phosphate, which are expected to yield more information on the nature and activities of the microbial populations.

2.2.4.2. Benthic Organisms

Sediment samples for determination of benthic invertebrate community structure were collected by a modified Kajak-Brinkhurst corer using a plexiglas core liner with an inside diameter of 6.6 cm. Only top 10 cm of each core was examined. Thus, the surface area of the sample was 34.2 cm², and the volume was 342 cm³. Benthic community structure was examined at all 10 sampling stations (Figure 2.1) in JCL. At each station five replicates were collected. Each replicate was extruded into a plastic whirl-pak bag. Sieving of the sample was conducted in the field using a 250 μ mesh sieve. Sieved samples were preserved in 4% formalin for sorting and identification in the laboratory.

Following the same methodology, invertebrate organisms were also collected at station T2 in the tailings for metal analysis. The individuals (*chironomid*, *oligochaete* and other *dipterous*) were subdivided haphazardly into two groups to obtain sufficient numbers for metal analysis, and a large sample of *Hirudinoidea* was analyzed

separately. The composite samples were dry at 60°C to constant weight and then digested under pressure as described in section 2.2.4.3. Gut contents of the invertebrates were not purged because the objective of this test was to determine the concentrations of contaminants available to the food chain at the area.

Sediment toxicity to benthic organisms was measured using sediments from the 10 stations in Jack of Clubs Lake. Sediment samples for toxicity testing were collected by a miniponar grab sampler (five grabs per station). The samples were transferred to 4L plastic containers, each of which was filled with a plastic liner, whereupon they were preserved on ice in the field and stored at 4°C in the laboratory before testing. The storage period before testing ranged from 100-180 days. Earlier experiments (Reynoldson et al 1991) have shown that storage up to 168 days does not effect the test results. Toxicity was estimated by means of the *T. tubifex* reproductive bioassay, and growth and survival in *C. riparius*, *H. azteca* and *H. limbata* (Day and Reynoldson, 1991). For each station five field replicates were used separately. The tests were conducted at 22.5°C ($\pm 1^\circ\text{C}$) and the sediment was pre-treated by sieving through a 250 μm net to remove indigenous organisms.

The standard operation procedure (universal), for the bioassay tests can be summarized as follows:

- culture water: charcoal-filtered, dechlorinated City of Burlington (Lake Ontario) tap water.

-Temperature: $23.0 \pm 1.0^{\circ}\text{C}$

-Sediment handling: sediment for bioassays was sieved through a $250\ \mu\text{m}$ sieve by placing enough water for each bioassay in a bucket and enough sediment in the sieve and gently "swirling" the sieve in the water until the sediment had been sieved. The residue on the sieve was discarded. The water with its sieved sediment and suspended sediment load was allowed to stand overnight. The overlying water was then gently decanted into a separate container. The sediment was added to the bioassay beakers and the decanted water was reintroduced to the beakers as overlying water. Thus, the suspended sediment was not lost.

This technique is necessary in order to remove indigenous organisms (i.e., endemic turbificid worms, other chironomid larvae, etc.) which have been shown to interfere with the bioassay results. In some situations, the sieved sediment was frozen for 24h and thawed in order to kill all residual eggs of tubificids. The parameters measured were pH, DO, conductivity, and temperature. All the determinations were done on the five replicate field samples.

Sediment used for bioassays was allowed to settle for 24h before introduction on animals. Water loss through evaporation replaced *ad hoc*. Specific operation procedures (*Chironomus riparius*, *Hexagenia* spp., *Hyalella azteca*, and *Tubifex tubifex*) are summarized in Table 2.3.

Table 2.3. Operation procedures for toxicity bioassays

	Chironomus riparius	Hexagenia spp.	Hyalella azteca	Tubifex tubifex
Culture:	20L aquaria silica sand substrate 3 eggs ropes/chamber 30% repl. if fungus	eggs stored at 4C initiation 23C refer. sediment 300 animals/aquar.	10L aquaria 500um Nitex 50uE/m2/s light Nutrafin flakes	10L aquaria darkened reference sediment init. 200 cocoons
Bioassay:				
Age/size	72h from egg mass deposition	5-10mg wet weight or 6-8 weeks old	1-10 d. juveniles	8 weeks old worms gonadas visible
Chamber	250 mL	1L glass jar	250 mL	250 mL
sediment:water	1:4	1:5	1:4	1:1
Aeration	yes	yes	no	no
Density/beaker	15 1st instar larvae	10 nymphs/rep.	15 animals/rep.	4 mat. worms/rep.
Feeding	Nutrafin 2x weekly 8mg/beaker	500uL weekly	2x weekly	80mg TetraMin added to sediment
Duration	10d	21d	28d	28d
Endpoints	survival (%) dry weight/mean indiv.	survival (%) growth: dry + wet	survival (%) growth dry weight	survival (%) reproduction

2.2.4.3. Vegetation

Lower vegetation. Eleven species of plants were collected from the mine tailings in Wells and from creeks and lakes distant from the tailings. The plants were washed with lake water and placed in plastic bags. Plant identification and nomenclature followed Mackinnon et al. (1992). Once in the laboratory, each sample was washed thoroughly with deionized water to remove inorganic dust particles. Plants were oven-dried at 70°C to constant weight and ground in a Wiley mill. Dry plant material (0.5 g) was weighed into Teflon microwave oven digestion vessel beakers and digested under pressure with 10 ml of aqua regia (HCl:HNO₃, 3:1). Prior to the digestion, the mixture was allowed to stand overnight to prevent a vigorous reaction during heating in the microwave oven. The samples were treated by the following microwave oven program: a) 3 minutes at 30 psi, b) 5 minutes at 50 psi, c) 5 minutes at 100 psi, and d) 5 minutes at 130 psi. Determination of 12 trace elements (As, Au, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Ti, Zn, and Zr) was carried out by ICP-AES, Jobin Yvon Model 74. The results of the blank analyses and the detection limits are presented in Table 2.2.

Aliquots of the final rinse water used during the washing of each plant were kept for analysis. Titanium and Zr, although present in the soils, are known not to be significantly assimilated by plants (Thompson and Walsh, 1988). Consequently, they were determined to test the efficacy of the cleaning procedure. Blanks from all the different reagents employed were analyzed along with

the samples. Quality control analysis was performed by analyzing two certified samples of the National Institute of Standards and Technology (NIST): orchard leaves (NIST 1571) and citrus leaves (NIST 1572). Agreement between the known concentrations of these metals in the reference material and the results of analysis by the ICP method was above 90%.

Higher vegetation. The main species collected comprised: Engelmann spruce (*Picea engelmannii* designated ES.TW and ES.BK, twigs and bark), willow (WI.TW, twigs), Lodgepole pine (*Pinus contorta* LP.TW, twigs), and Subalpine fir (*Abies lasiocarpa* SF.TW, twigs). Care was taken to sample the same number of years of growth for each species to maintain consistency in the data. The spruce is the most prolific conifer in the immediate vicinity of JCL, with various forms of willow (leaves variegated or straight, blue-green or yellow-green) thriving along the banks of the river named after it. The sites at which vegetation was sampled are shown in Figure 2.3; most of the site numbers correspond with those for waters shown in Figure 2.2. Only willow grows on the tailings themselves; the site dictated the variety of species collected. Samples weighing about 200 g were partially dried in their paper bags before return to Ottawa whereupon drying was complete in the open air. Needles or leaves (willow) were then separated by hand (with plastic gloves) from twigs and all organs macerated in a Wiley mill. Samples were then sent to activation laboratories for instrumental neutron activation analysis (INAA) after pressing into 15 g pellets.

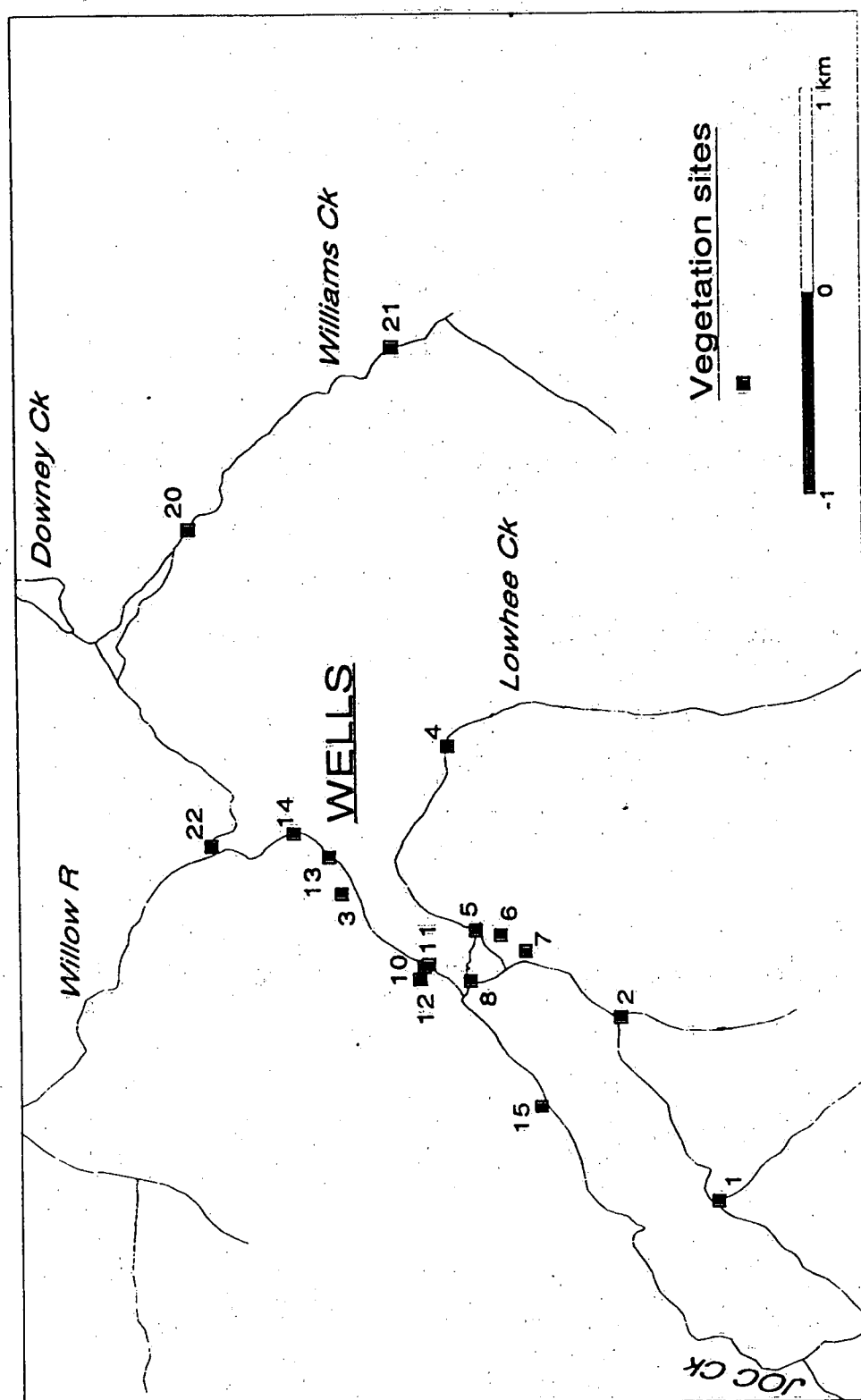


Figure 2.3. Site locations for sampling of higher vegetation

3. RESULTS AND DISCUSSION

3.1. Water Quality

3.1.1. Physico-chemical Parameters

Excessive algal production may arise in any body of water if the nutrient concentrations exceed certain levels. Usually increased levels of phosphorus, nitrogen, and carbon in particular have been related to increased primary production. Although many elements and compounds are required for biosynthesis, nitrogen and phosphorus have long been considered to be the principal limiting nutrients for primary production; evidence also suggests that carbon may also limit production in some situations. Results of nutrient analysis are reported in Table 3.1 (a,b).

Concentrations of particulate nutrients are generally very low, with the exception of suspended matter at some of the bottom samples. This increase is not due to primary production, but to sediment resuspension, caused by sampling too close to the lake bottom. This is confirmed by the low or comparable concentrations of soluble nutrients. Viable chlorophyll as measured by CHLA.C was extremely low or undetected (ND). This implies that primary production, at least during our sampling period, was extremely low. This low production cannot be attributed to low or limiting nutrients, with the possible exception of soluble nitrogen ($\text{NH}_4\text{-N}$, & $\text{NO}_3\text{+NO}_2\text{-N}$). According to Molot and Dillon (1991), the

Table 3.1a

JACK OF CLUBS AND BOWRON LAKE 1992 SOLUBLE NUTRIENTS AND MAJOR IONS

STN/DEPTH # / m	TFP mg/L	SRP mg/L	SOP mg/L	NH3 mg/L	NO3+NO2 mg/L	DIC mg/L	DOC mg/L	CL mg/L	SO4 mg/L	SiO2 mg/L
detection limit >	.0002	.0002	.0001	.005	.010	.1	.1	.05	.02	.02
JCL1-1	0.0034	0.0017	0.0017	ND	ND	7.8	1.6	0.12	9.20	3.10
JCL2-1	0.0038	0.0011	0.0027	ND	ND	7.8	1.6	0.10	9.90	3.17
JCL3-1	0.0017	0.0010	0.0007	ND	ND	7.7	1.6	0.17	10.00	3.11
JCL4-1	0.0050	0.0012	0.0038	ND	ND	8.7	2.0	0.20	10.50	3.09
JCL5-1	0.0033	0.0011	0.0022	ND	ND	7.7	1.6	0.20	10.30	3.10
JCL6-1	0.0039	0.0008	0.0031	ND	ND	7.8	1.6	0.19	9.80	3.11
JCL7-1	0.0021	0.0007	0.0014	ND	ND	7.7	1.5	0.19	10.90	3.12
JCL8-1	0.0025	0.0006	0.0019	ND	ND	7.7	1.6	0.17	10.10	3.08
JCL9-1	0.0027	0.0030	0.0000	0.024	ND	8.4	2.0	0.22	10.90	3.14
JCL10-1	0.0026	0.0006	0.0020	ND	0.011	7.8	1.5	0.15	10.30	3.12
BL1-1	0.0009	0.0008	0.0001	ND	ND	7.6	2.7	0.12	3.40	2.18
BL2-1	0.0054	0.0008	0.0046	ND	ND	7.6	2.4	0.13	3.30	2.14
JCL1-9	0.0042	0.0015	0.0027	ND	ND	8.3	1.9	0.42	12.00	3.15
JCL2-23	0.0023	0.0011	0.0012	ND	ND	9.2	1.6	0.26	18.40	3.56
JCL3-27	0.0020	0.0010	0.0010	ND	ND	9.3	1.6	0.22	18.90	3.56
JCL4-7	0.0036	0.0012	0.0024	ND	ND	9.1	1.9	0.36	21.10	3.26
JCL5-13	0.0034	0.0009	0.0025	ND	ND	9.3	1.8	0.25	18.80	3.44
JCL6-11	0.0027	0.0008	0.0019	ND	ND	8.6	1.5	0.27	17.10	3.23
JCL7-23	0.0022	0.0008	0.0014	ND	ND	9.4	1.6	0.34	19.60	3.49
JCL8-38	0.0027	0.0007	0.0020	ND	ND	9.3	1.6	0.36	18.50	3.46
JCL9-52	0.0018	0.0009	0.0009	ND	ND	9.3	1.9	0.32	18.80	3.62
JCL10-29	0.0028	0.0008	0.0020	0.006	ND	9.5	1.6	0.31	21.90	3.55
BL1-52	0.0002	0.0009	ND	ND	0.120	8.6	2.7	0.14	2.30	3.95
BL2-21	0.0048	0.0010	0.0038	ND	0.110	8.8	2.7	0.14	1.90	3.63

BL = Bowron Lake

JCL = Jack of Clubs Lake

* bottom depths are 1m above sediments

ND = Not detected

Table 3.1b

JACK OF CLUBS AND BOWRON LAKE 1992

PARTICULATE NUTRIENTS

STN/DEPTH # / m	TSM mg/L	ISM mg/L	OSM mg/L	LOI %	CHLA.U ug/L	CHLA.C ug/L	POC mg/L	PN mg/L	TP mg/L	TPP mg/L
detection limit >	.01	.01	.01	.1	.1	.1	.01	.002	.0002	.0001
JCL1-1	1.07	0.53	0.53	50.0	0.3	ND	0.18	0.03	0.0051	0.0017
JCL2-1	0.57	0.06	0.51	90.0	0.6	0.3	0.13	0.02	0.0057	0.0019
JCL3-1	0.76	0.29	0.47	61.5	0.3	ND	0.15	0.03	0.0059	0.0042
JCL4-1	0.60	ND	0.60	100.0	0.1	ND	0.15	0.02	0.0058	0.0008
JCL5-1	0.40	ND	0.40	100.0	0.3	ND	0.11	0.02	0.0056	0.0023
JCL6-1	0.40	ND	0.40	100.0	0.3	ND	0.12	0.02	0.0050	0.0011
JCL7-1	1.13	0.67	0.47	41.2	0.6	0.4	0.12	0.02	0.0035	0.0014
JCL8-1	1.33	0.73	0.60	45.0	0.3	ND	0.21	0.03	0.0061	0.0036
JCL9-1	0.65	0.25	0.40	61.5	0.3	ND	0.21	0.06	0.0044	0.0017
JCL10-1	0.97	0.23	0.74	76.5	0.3	ND	0.16	0.03	0.0062	0.0036
BL1-1	2.00	1.26	0.74	37.1	1.1	ND	0.30	0.05	0.0125	0.0116
BL2-1	1.25	0.40	0.85	68.0	1.3	1.1	0.25	0.04	0.0076	0.0022
JCL1-9	8.53	7.07	1.47	17.2	1.4	0.8	0.54	0.09	0.0113	0.0071
JCL2-23	1.24	0.53	0.71	57.1	0.6	0.4	0.11	0.02	0.0055	0.0032
JCL3-27	1.87	0.80	1.07	57.1	0.8	0.8	0.19	0.03	0.0052	0.0032
JCL4-7	1.07	0.53	0.53	50.0	0.4	0.4	0.21	0.03	0.0060	0.0024
JCL5-13	0.93	0.40	0.53	57.1	0.5	ND	0.17	0.03	0.0070	0.0036
JCL6-11	0.60	0.13	0.47	77.8	0.4	ND	0.13	0.02	0.0045	0.0018
JCL7-23	15.20	13.76	1.44	9.5	0.8	0.5	0.40	0.08	0.0149	0.0127
JCL8-38	14.80	12.93	1.87	12.6	1.1	1	0.45	0.10	0.0242	0.0215
JCL9-52	1.10	0.50	0.60	54.5	0.7	0.3	0.12	0.02	0.0052	0.0034
JCL10-29	27.00	24.30	2.70	10.0	0.7	0.3	0.61	0.10	0.0266	0.0238
BL1-52	1.09	0.51	0.57	52.6	0.3	ND	0.12	0.02	0.0087	0.0085
BL2-21	1.24	0.65	0.59	47.6	0.9	0.3	0.17	0.03	0.0085	0.0037

chlorophyll/phosphorus relationship for 15, nutrient limited, central Ontario lakes can be expressed as:

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

The relationship was established by linear regression using data collected over a 12 year period. Based on this relationship the total chlorophyll concentration of JCL should be in the range of 1.8 to 3.0 $\mu\text{g/L}$. Similarly, based on the above relationship, Bowron Lake, used as a control Lake in this study, has higher chlorophyll concentrations typical of oligotrophic lakes. Based on lake classification models, and concentrations of carbon and phosphorus, the chlorophyll concentrations of Jack of Clubs Lake should range between 2 and 3 $\mu\text{g/L}$; instead the mean surface chlorophyll is only 0.3 $\mu\text{g/L}$, a factor of 10 lower than expected.

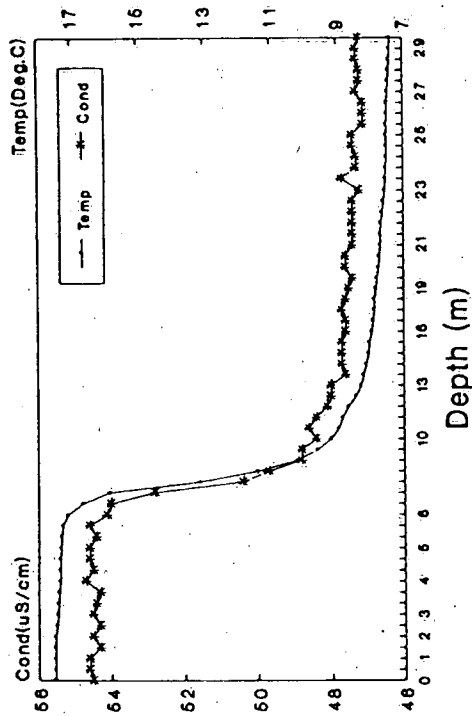
According to other research results presented in section 3.3.1, sediment microbial activities were found to be suppressed by tailings deposited in the lake. It is speculated that the low primary production, based on the chlorophyll levels in the lake, is also affected by the tailings in the lake. Although the concentration of Cu, which is one of the most toxic elements to phytoplankton, in the lake water exceeded the guidelines for the protection of freshwater aquatic life (i.e. 5 $\mu\text{g Cu/L}$, McNeely et al., 1979) only at two sampling stations (Appendix B).

Continuous depth profiles for temperature, conductance, pH, and dissolved oxygen are shown on Figures 3.1 to 3.12. Both JCL and

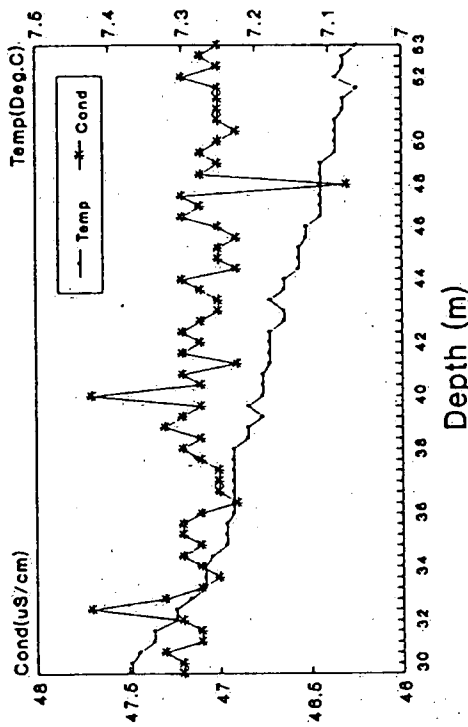
BL are thermally stratified. The thermal layers are typical of a well stratified northern lake, with epilimnion and thermocline thickness between 5 to 7 m, and 2 to 4 m respectively and the remainder of the water column consisting of a cold (7-9°C) hypolimnion. The epilimnion of BL is 1-2 m deeper than JCL, owing to greater exposure to prevailing winds.

Conductivity and pH in BL decrease with depth, and follows the same pattern as temperature (Figures 3.1 and 3.2). In JCL, conductivity values fall to a minimum in the thermocline and increase in the hypolimnion (Figures 3.3 to 3.12). This increase is probably due to regeneration of metal ions from the contaminated bottom sediments. The greatest difference from surface to bottom was recorded at stations 6, 5, and 4; (Figures 3.6 to 3.8), closest to the tailings. Surface water pH decreases from approximately 8.25, to 7.87 from stn #1 (westend) to stn #4 (eastend). The oxygen concentration is greater than 7.5 mg/L at all sampling stations, with a consistent concentration minimum in the thermocline. This minimum is typical in stratified systems, but much more pronounced in other lakes, such as the Great Lakes, and is attributed to decaying organic matter trapped in the thermocline. Neither the lake exhibits an oxygen depletion problem in the hypolimnion, probably owing to the low biological production and correspondingly low organic matter content (see Table 3.1). Moreover, inhibition of microbial activity (see section 3.3.1) undoubtedly reduces oxygen consumption.

BOWRON LAKE
(Stn #1/53m)

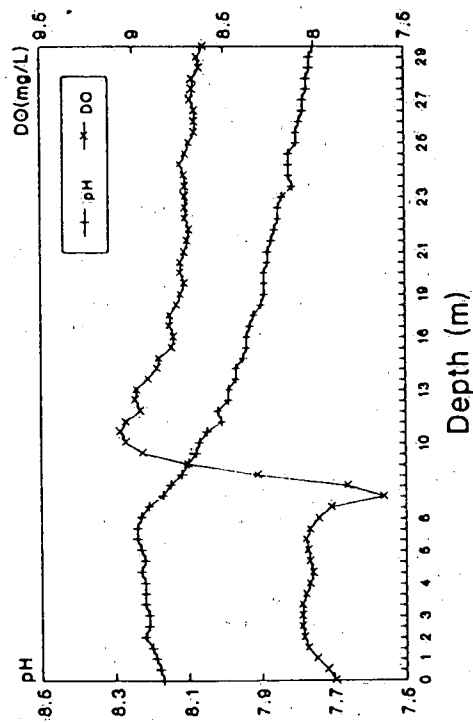


BOWRON LAKE
(Stn #1/53m)

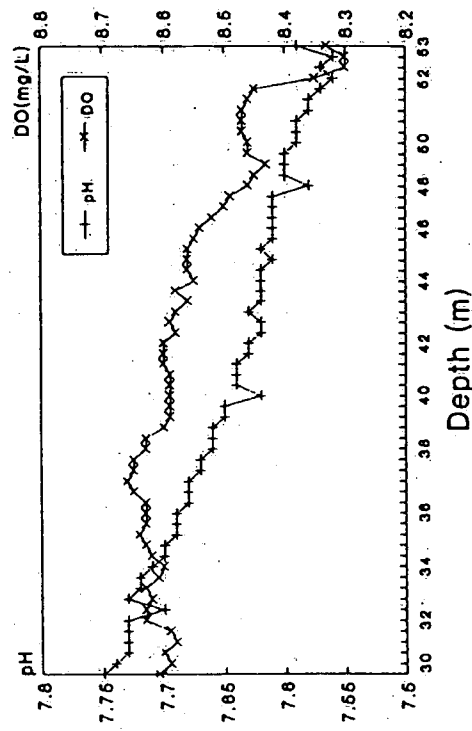


Some depth/data deleted for HQ plot.

BOWRON LAKE
(Stn #1/53m)



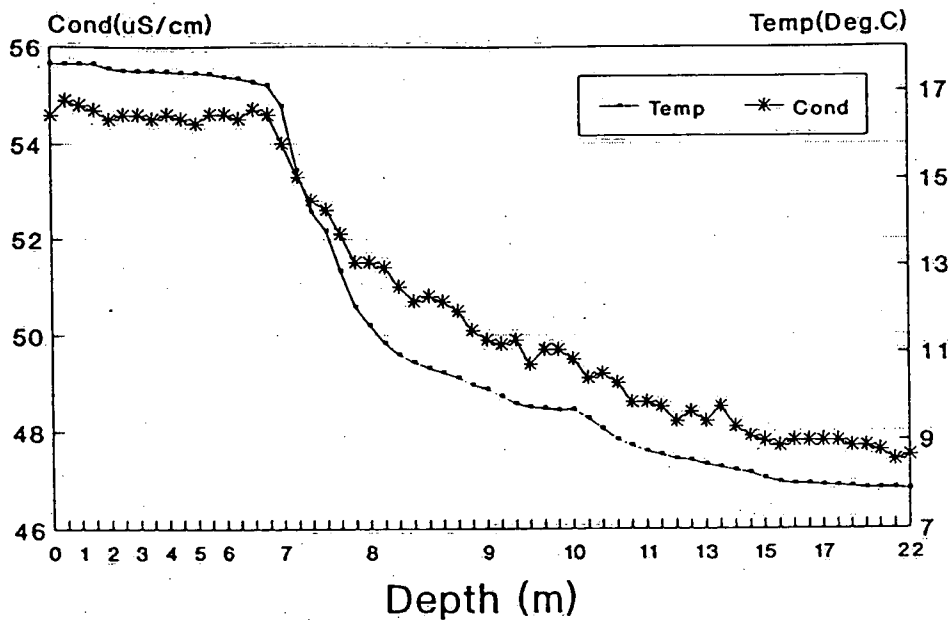
BOWRON LAKE
(Stn #1/53m)



Some depth/data deleted for HQ plot.

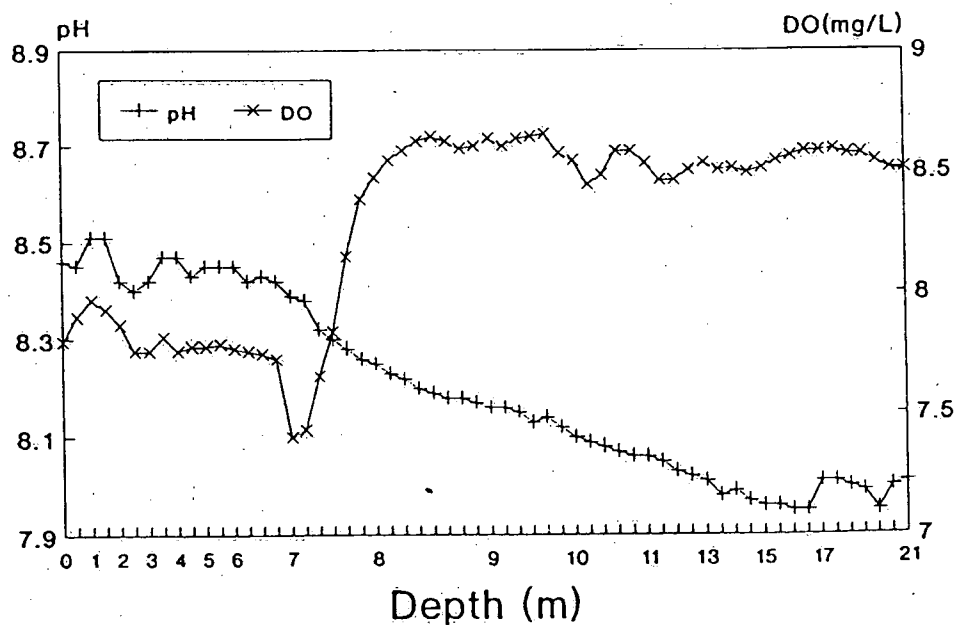
Figure 3.1. Profiles of temperature, pH, conductivity and oxygen from Bowron Lake (Station #1)

BOWRON LAKE (Stn #2/22m)



Some depth/data deleted for HG plot.

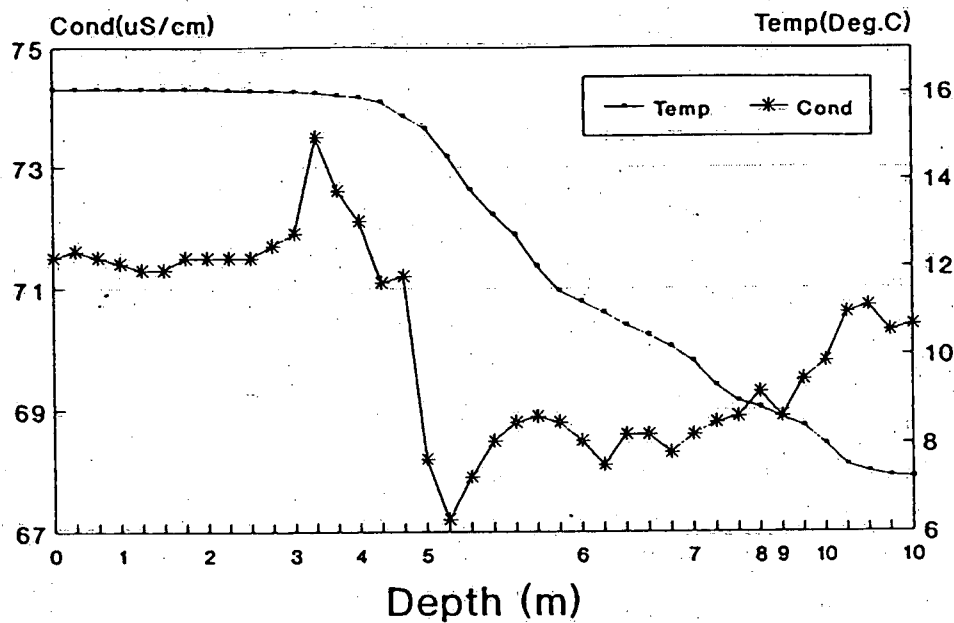
BOWRON LAKE (Stn #2/22m)



Some depth/data deleted for HG plot.

Figure 3.2. Profiles of temperature, pH, conductivity and oxygen from Bowron Lake (Station #2)

JACK OF CLUBS LAKE (Stn #1/10m)



JACK OF CLUBS LAKE (Stn #1/10m)

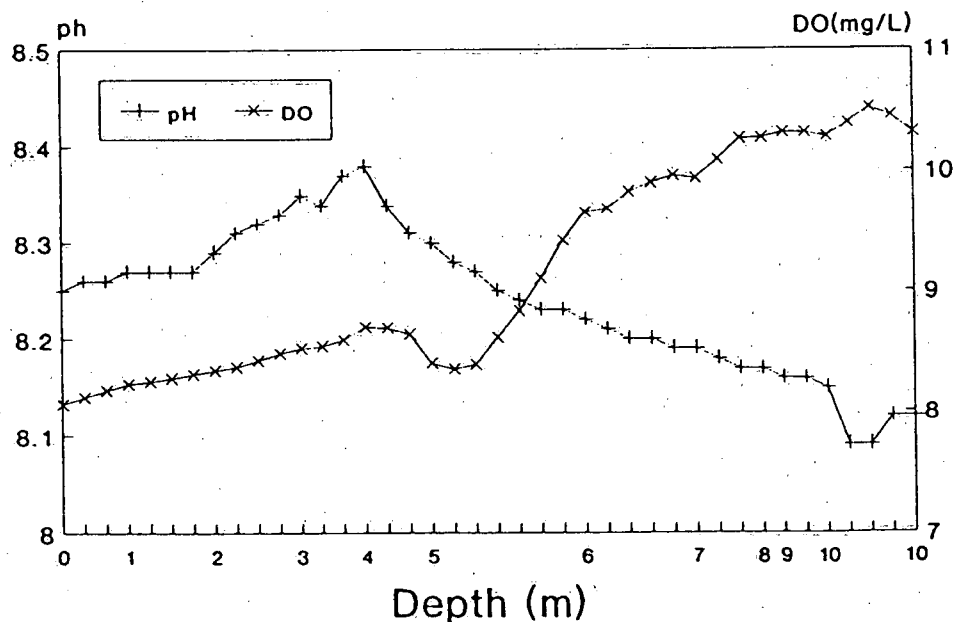
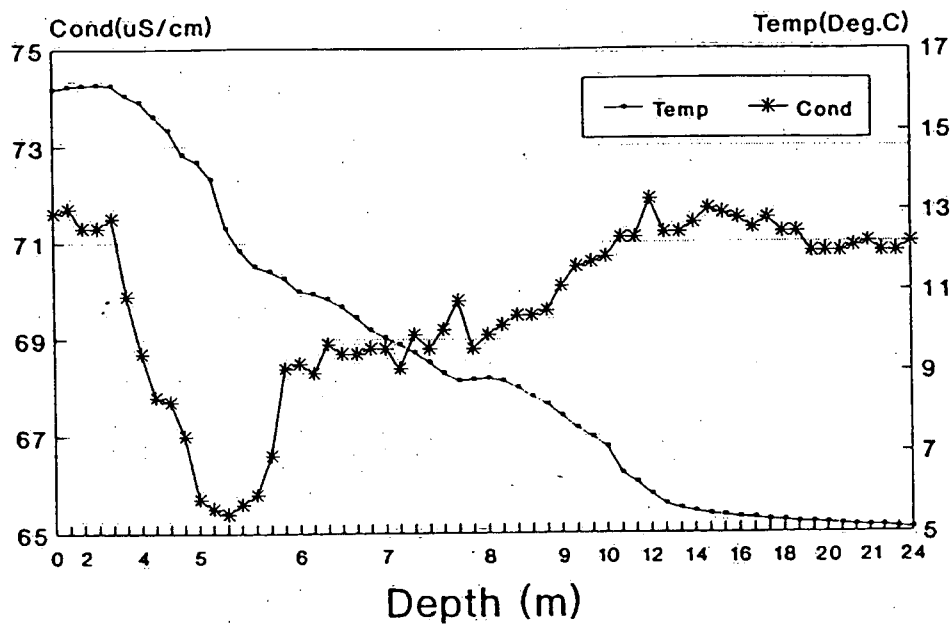


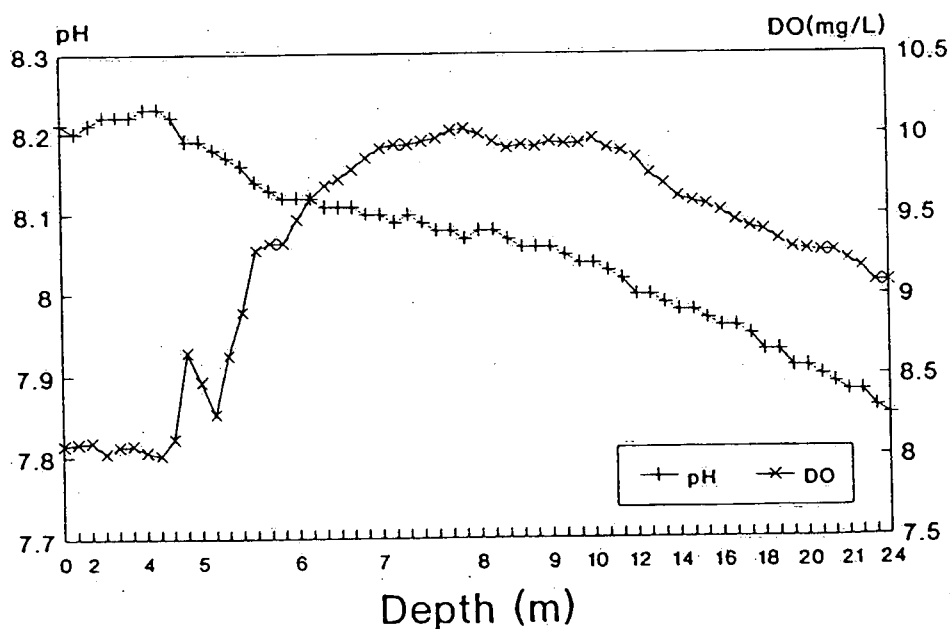
Figure 3.3. Profiles of temperature, pH, conductivity and oxygen from Jack of Clubs Lake (Station #1)

JACK OF CLUBS LAKE (Stn #2/24m)



Some depth/data deleted for HG plot.

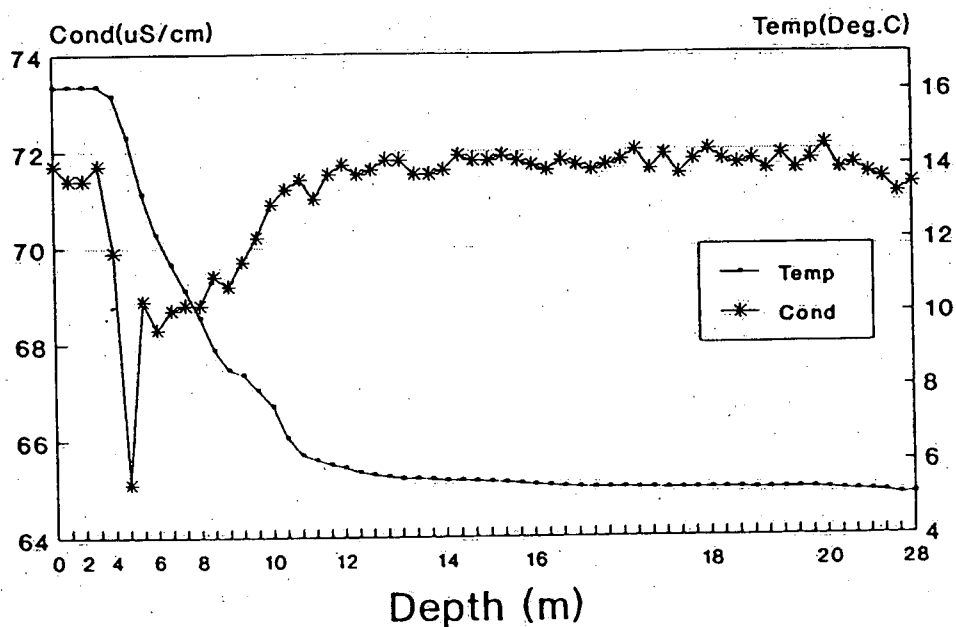
JACK OF CLUBS LAKE (Stn #2/24m)



Some depth/data deleted for HG plot.

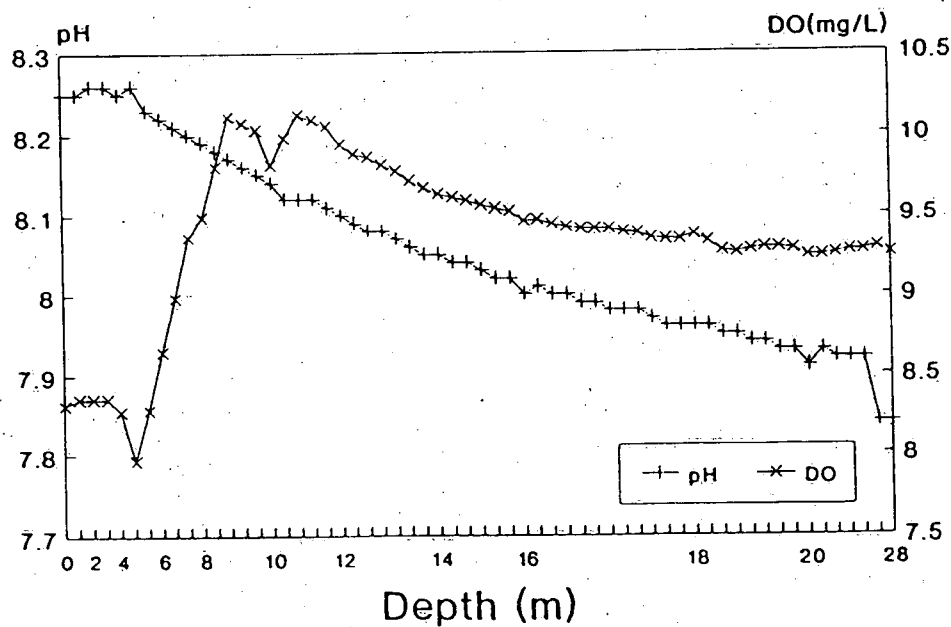
Figure 3.4. Profiles of temperature, pH, conductivity and oxygen from Jack of Clubs Lake (Station #2)

JACK OF CLUBS LAKE (Stn #3/28m)



Some depth/data deleted for HG plot.

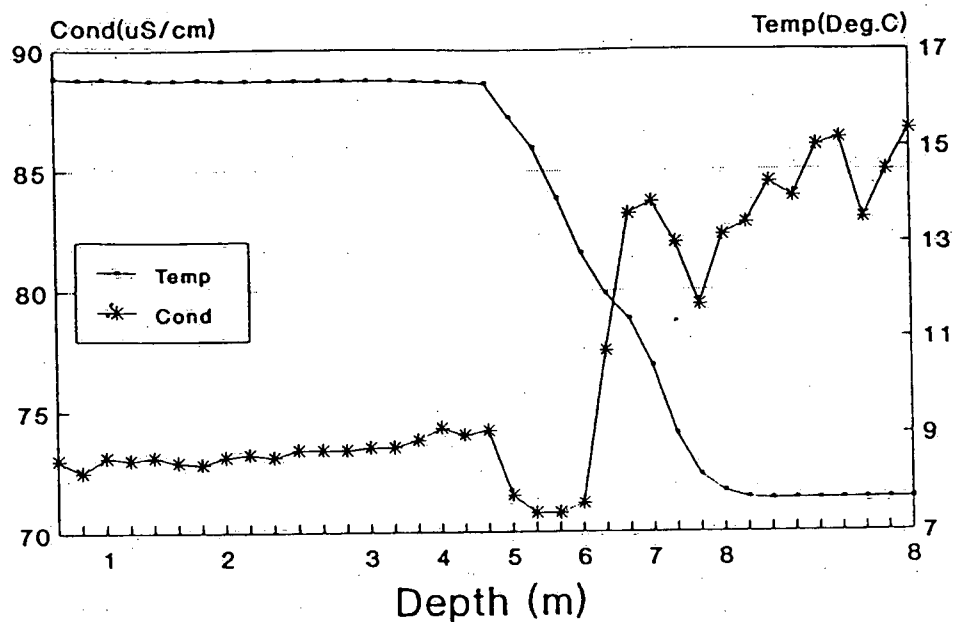
JACK OF CLUBS LAKE (Stn #3/28m)



Some depth/data deleted for HG plot.

Figure 3.5. Profiles of temperature, pH, conductivity and oxygen from Jack of Clubs Lake (Station #3)

JACK OF CLUBS LAKE (Stn #4/8m)



JACK OF CLUBS LAKE (Stn #4/8m)

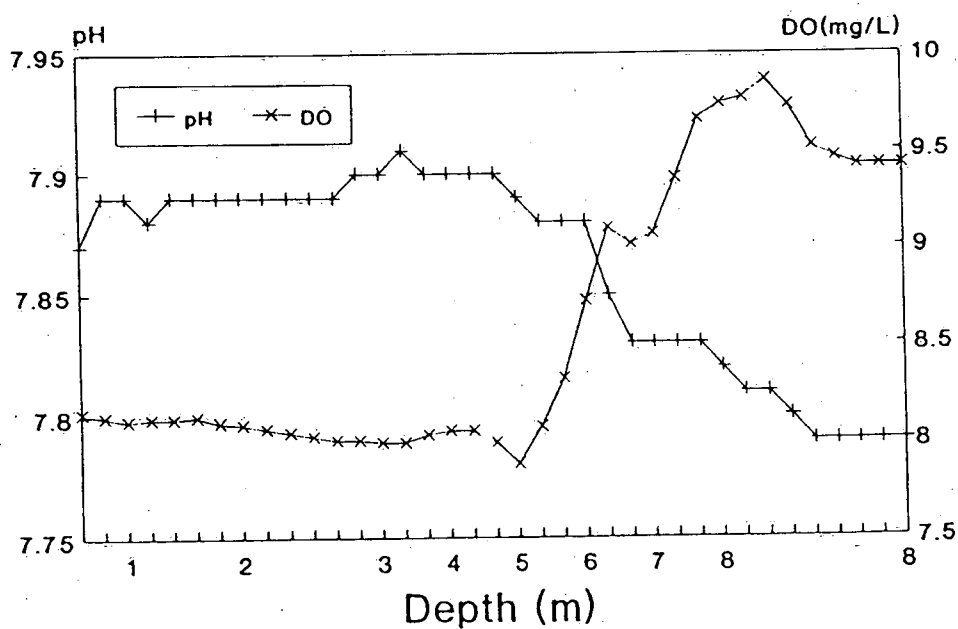
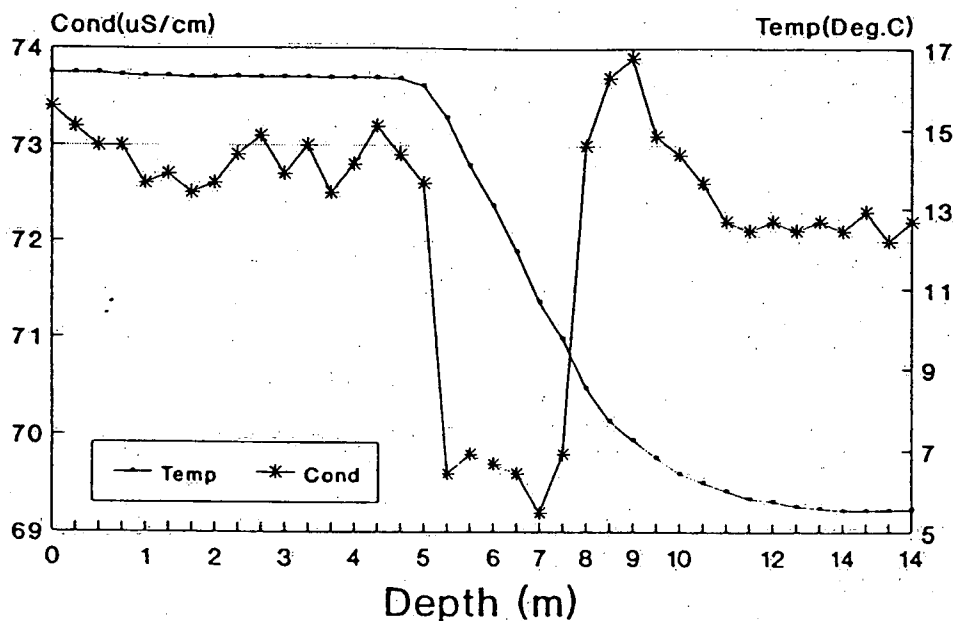


Figure 3.6. Profiles of temperature, pH, conductivity and oxygen from Jack of Clubs Lake (Station #4)

JACK OF CLUBS LAKE (Stn #5/14m)



JACK OF CLUBS LAKE (Stn #5/14m)

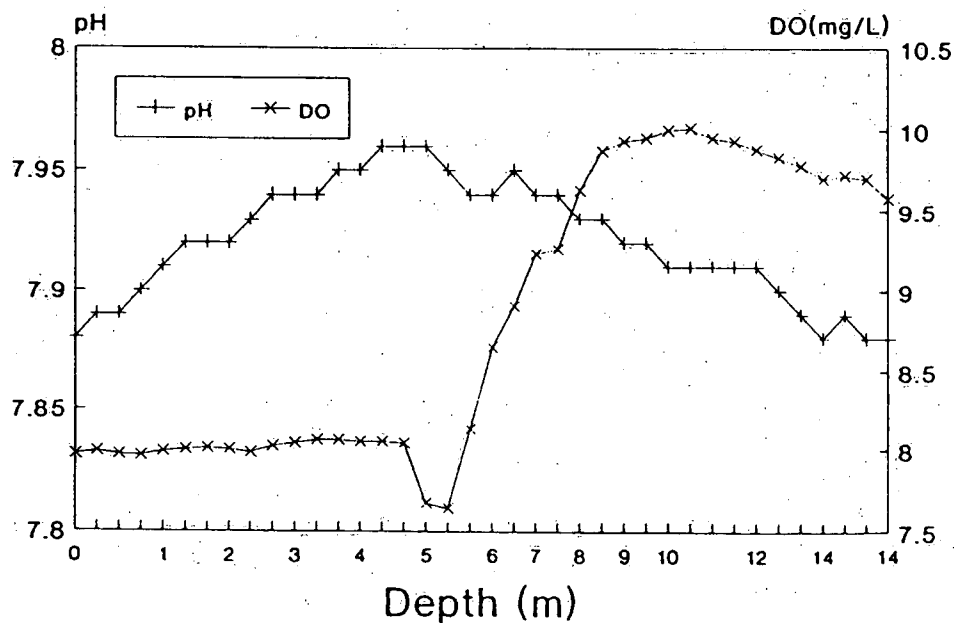
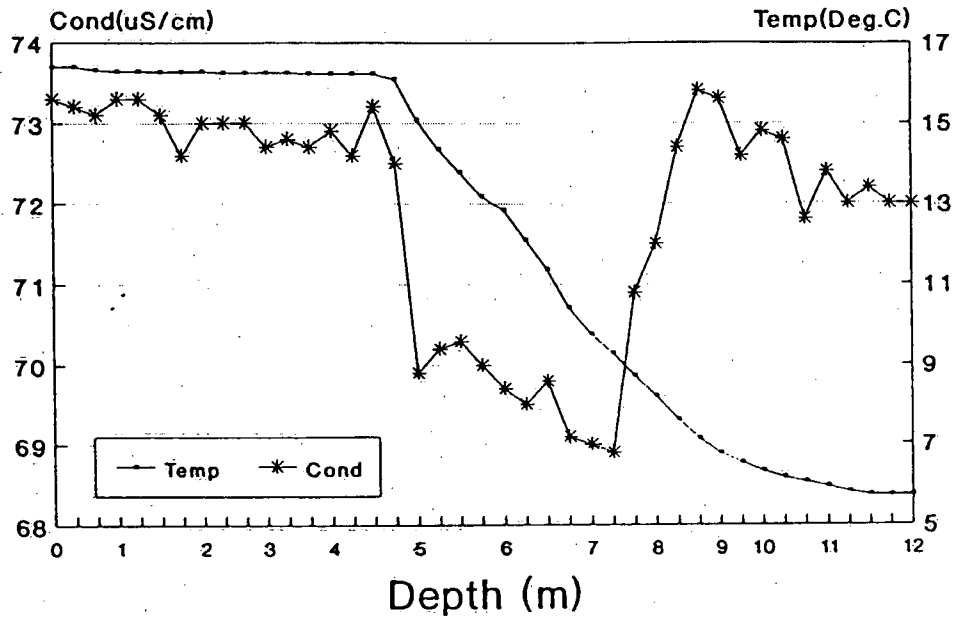


Figure 3.7. Profiles of temperature, pH, conductivity and oxygen from Jack of Clubs Lake (Station #5)

JACK OF CLUBS LAKE (Stn #6/12m)



JACK OF CLUBS LAKE (Stn #6/12m)

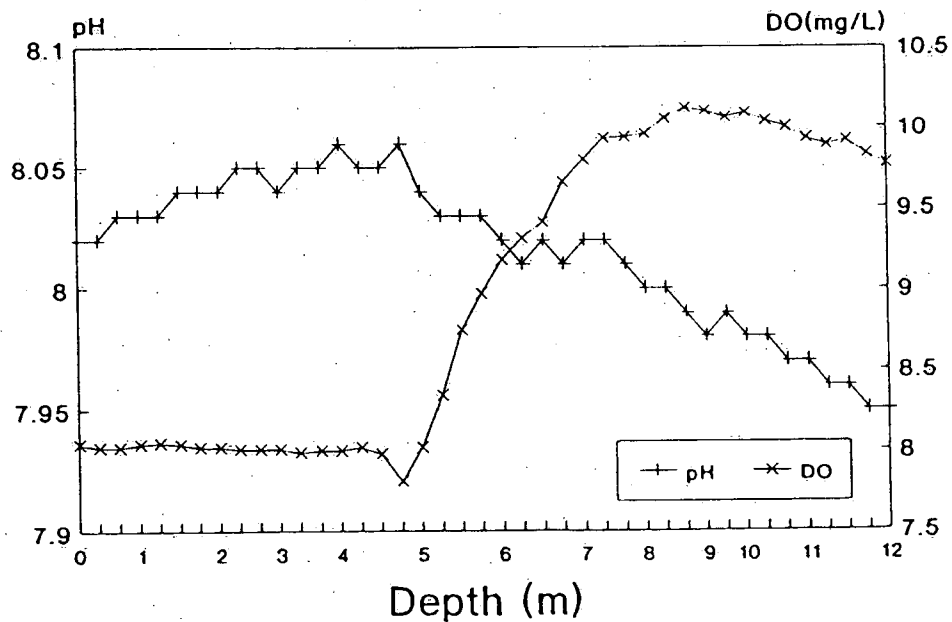
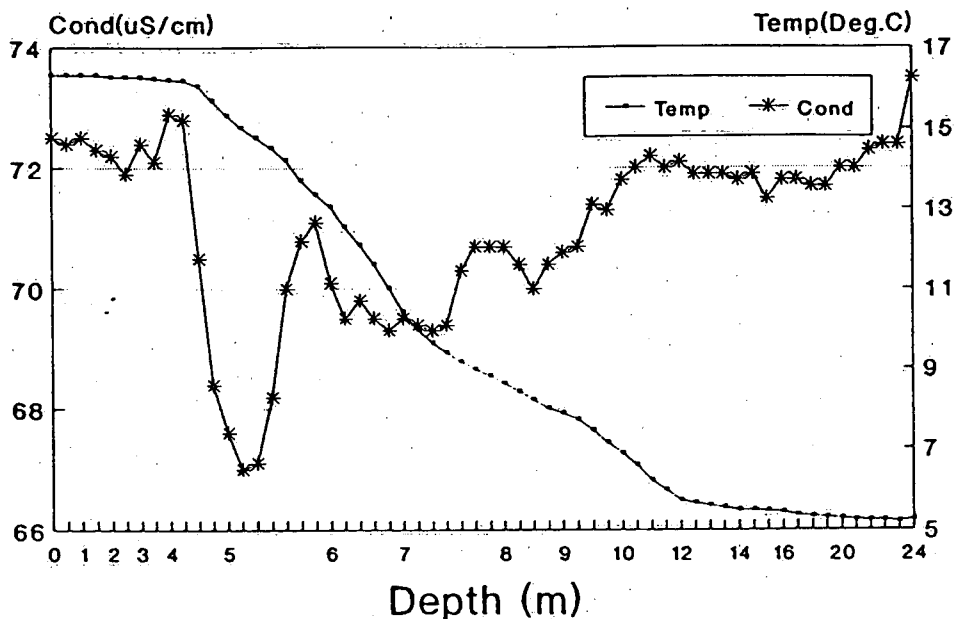


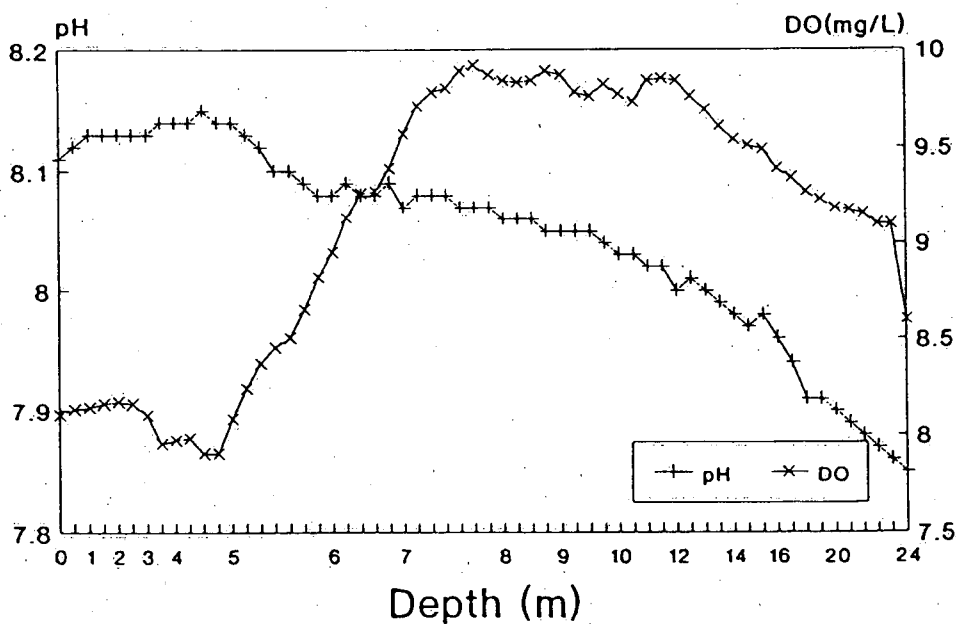
Figure 3.8. Profiles of temperature, pH, conductivity and oxygen from Jack of Clubs Lake (Station #6)

JACK OF CLUBS LAKE (Stn #7/24m)



Some depth/data deleted for HG plot.

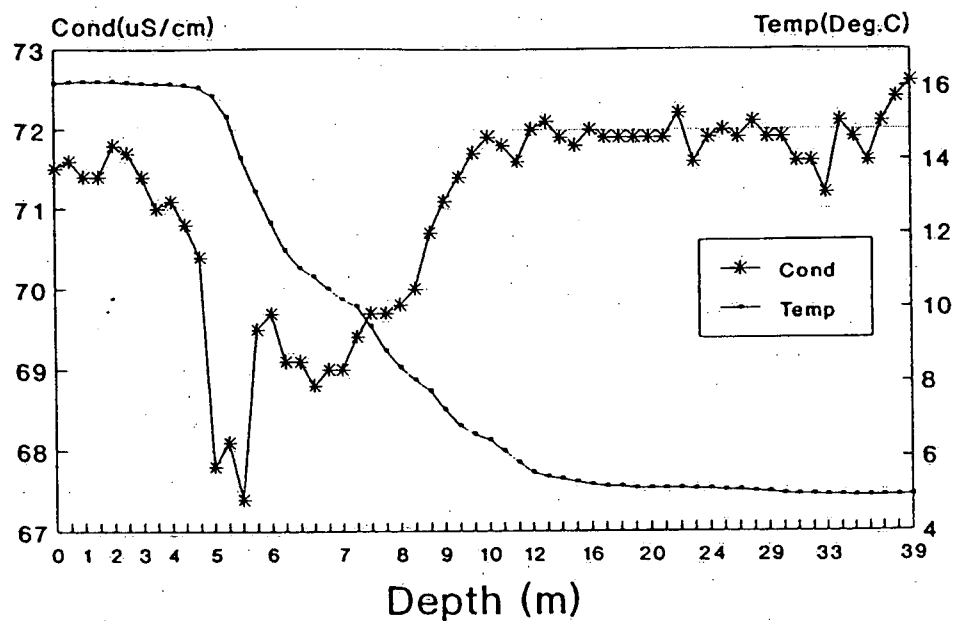
JACK OF CLUBS LAKE (Stn #7/24m)



Some depth/data deleted for HG plot.

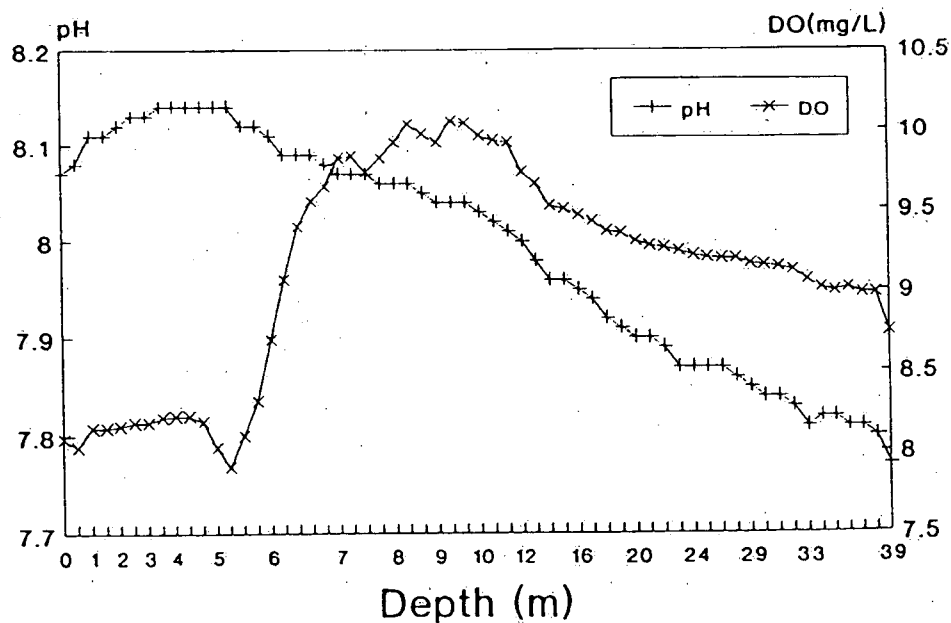
Figure 3.9. Profiles of temperature, pH, conductivity and oxygen from Jack of Clubs Lake (Station #7)

JACK OF CLUBS LAKE (Stn #8/39m)



Some depth/data deleted for HG plot.

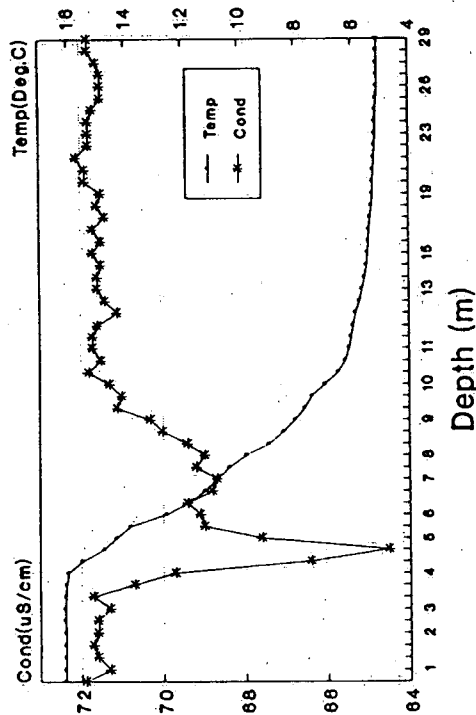
JACK OF CLUBS LAKE (Stn #8/39m)



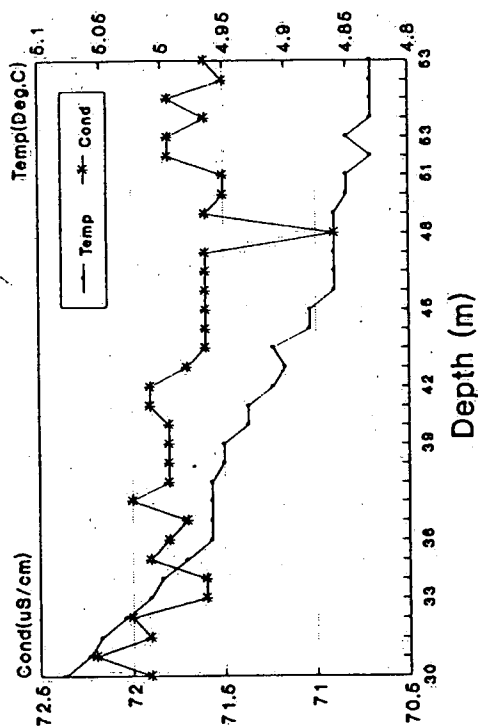
Some depth/data deleted for HG plot.

Figure 3.10. Profiles of temperature, pH, conductivity and oxygen from Jack of Clubs Lake (Station #8)

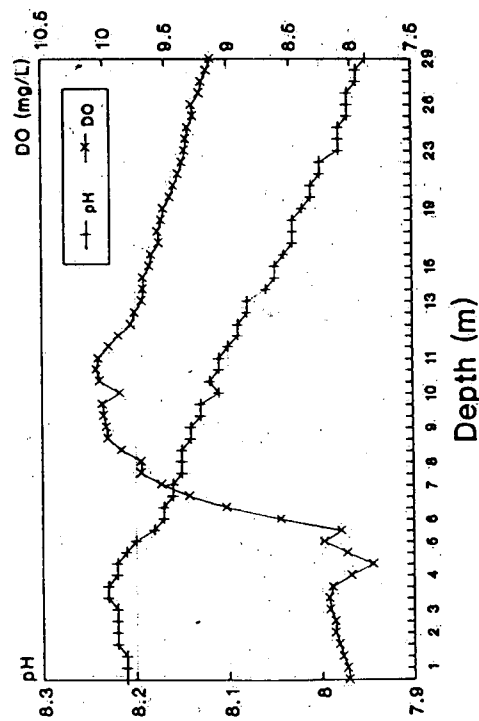
JACK OF CLUBS LAKE
(Stn #9/53m)



JACK OF CLUBS LAKE
(Stn #9/53m)



JACK OF CLUBS LAKE
(Stn #9/53m)



JACK OF CLUBS LAKE
(Stn #9/53m)

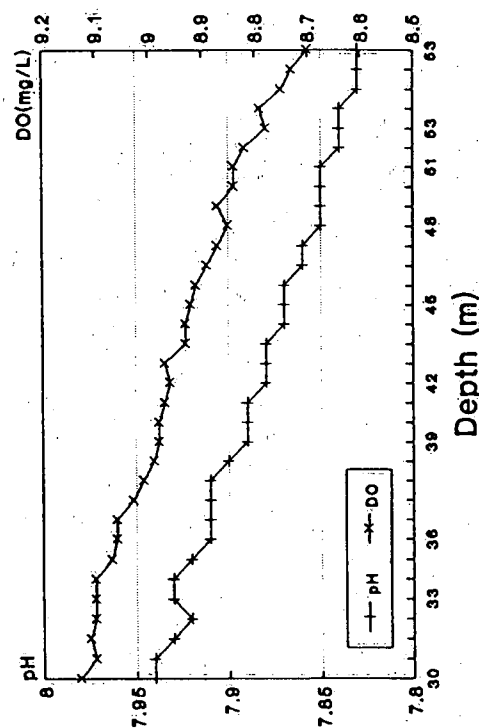
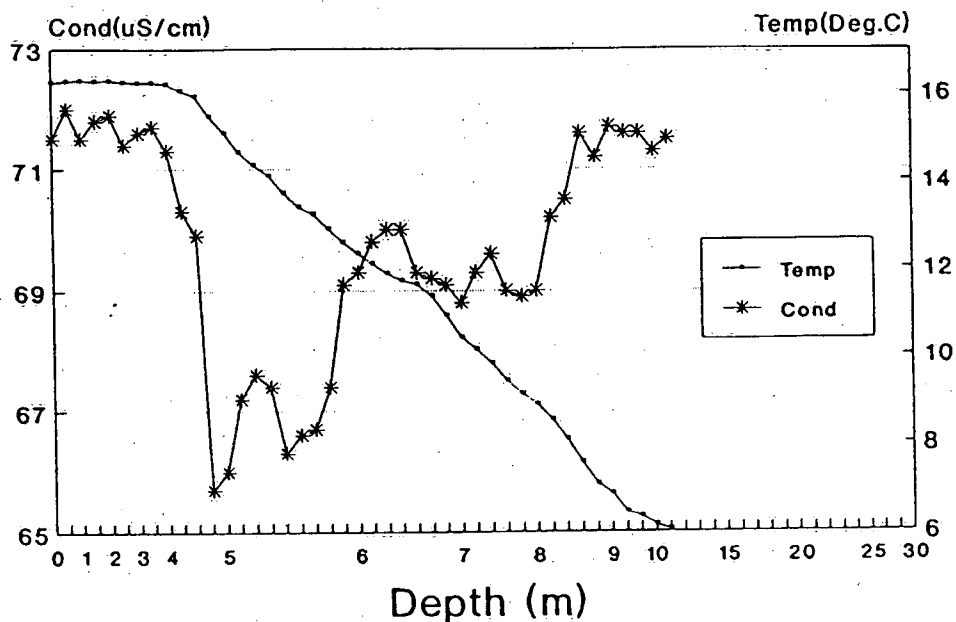


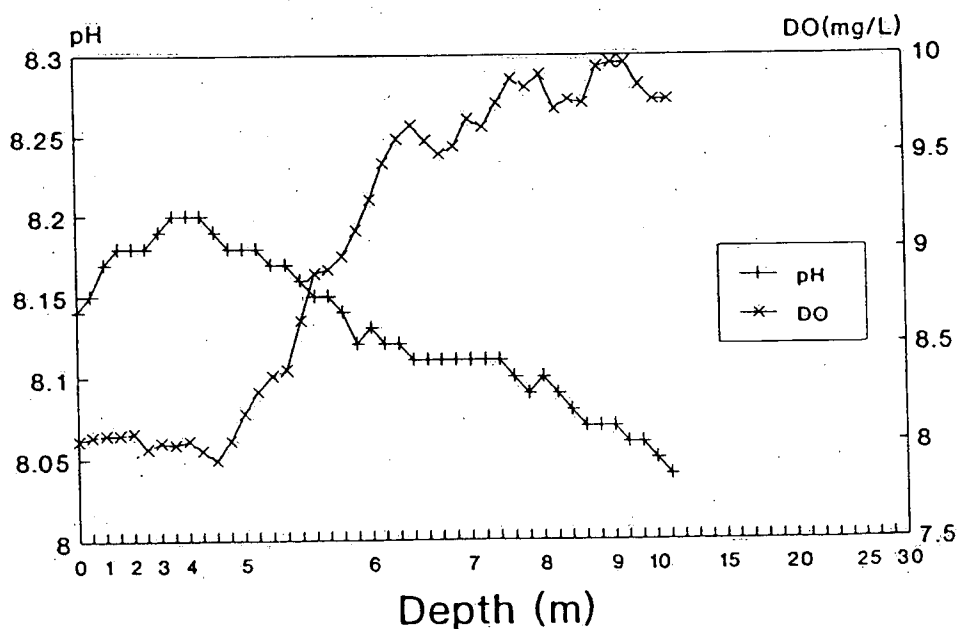
Figure 3.11. Profiles of temperature, pH, conductivity and oxygen from Jack of Clubs Lake (Station #9)

JACK OF CLUBS LAKE (Stn #10/30m)



Power loss at 10m.

JACK OF CLUBS LAKE (Stn #10/30m)



Power loss at 10m.

Figure 3.12. Profiles of temperature, pH, conductivity and oxygen from Jack of Clubs Lake (Station #10)

3.1.2. Major and Trace Elements

The concentrations of major and trace elements in water are given in Appendix B; the detection limits and units being listed at the top of each column. The designation 'D' for some waters denotes a subsample from a later day. The series 01-32 refers to streams (Fig. 2.2) while JCL samples are labelled 1 to 10 (Fig. 2.1) followed by an indication of the sample depth. In Appendix B, BL 01 is Bowron River collected near the lake; the other BL designations refer to Bowron Lake itself, at different water depths. The stream water sample location map is shown in Fig. 2.2, the lake stations are shown in Fig. 2.1. Sites not shown on the JCL location map are: 19 (north-east of Wells on Downey Creek); 27 and 28 (lake site of old mining operation ca. 6 km west of JCL on Hwy. 26); and 29 (Willow River near Prince George). Results for some important parameters (As, Fe and SO₄) are illustrated in Figures 3.13 to 15.

Jack of Clubs Lake (JCL)

The seep at site 05, situated on the tailings just downslope from the abandoned Cariboo Gold Quartz mine operation, was sampled after a rainy night. It contained the greatest concentrations of all trace elements, as might be suspected from its pH of 2.7 (Table 3.2).

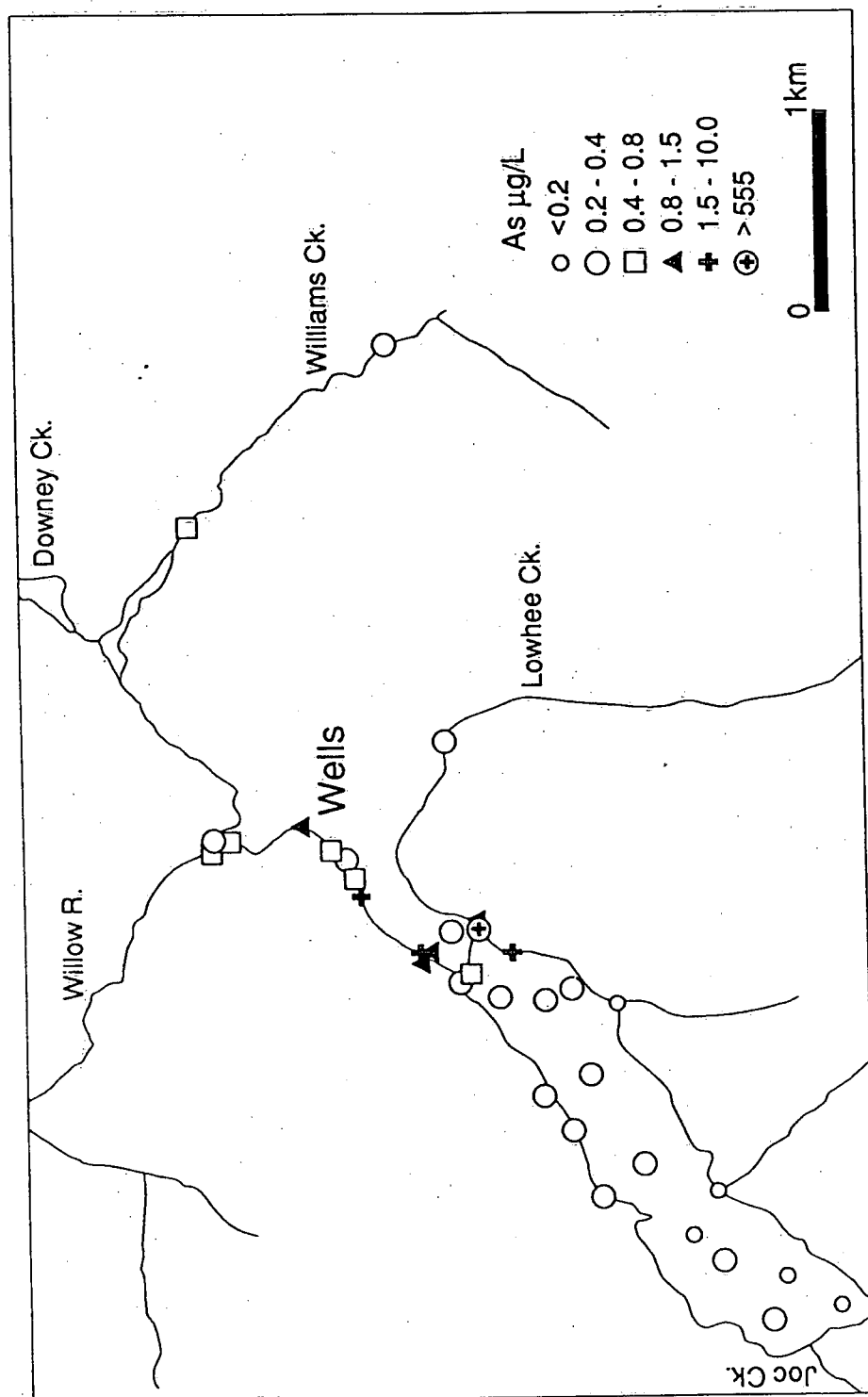


Figure 3.13. Arsenic concentrations in waters (µg/L)

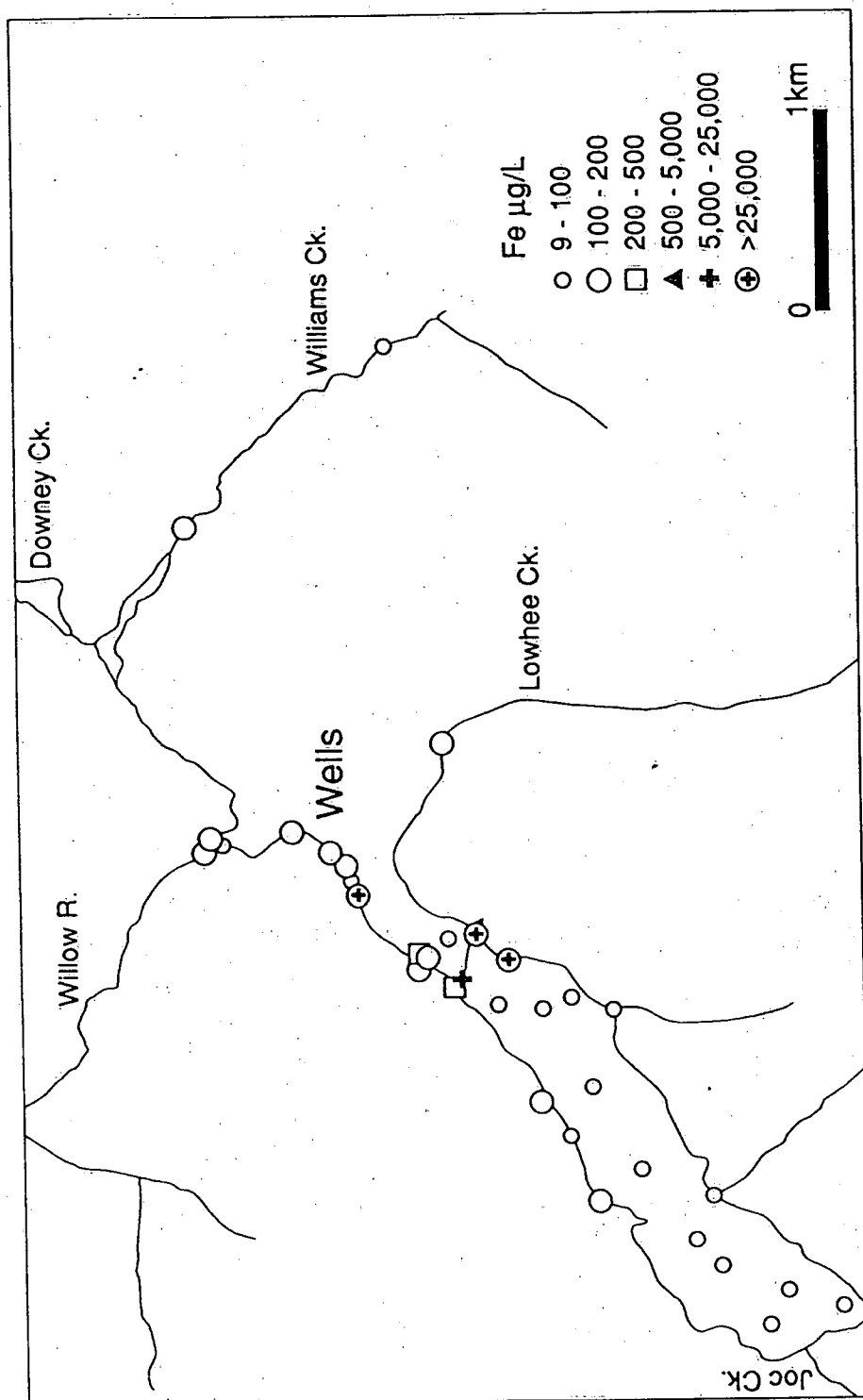


Figure 3.14. Iron concentrations in waters ($\mu\text{g/L}$)

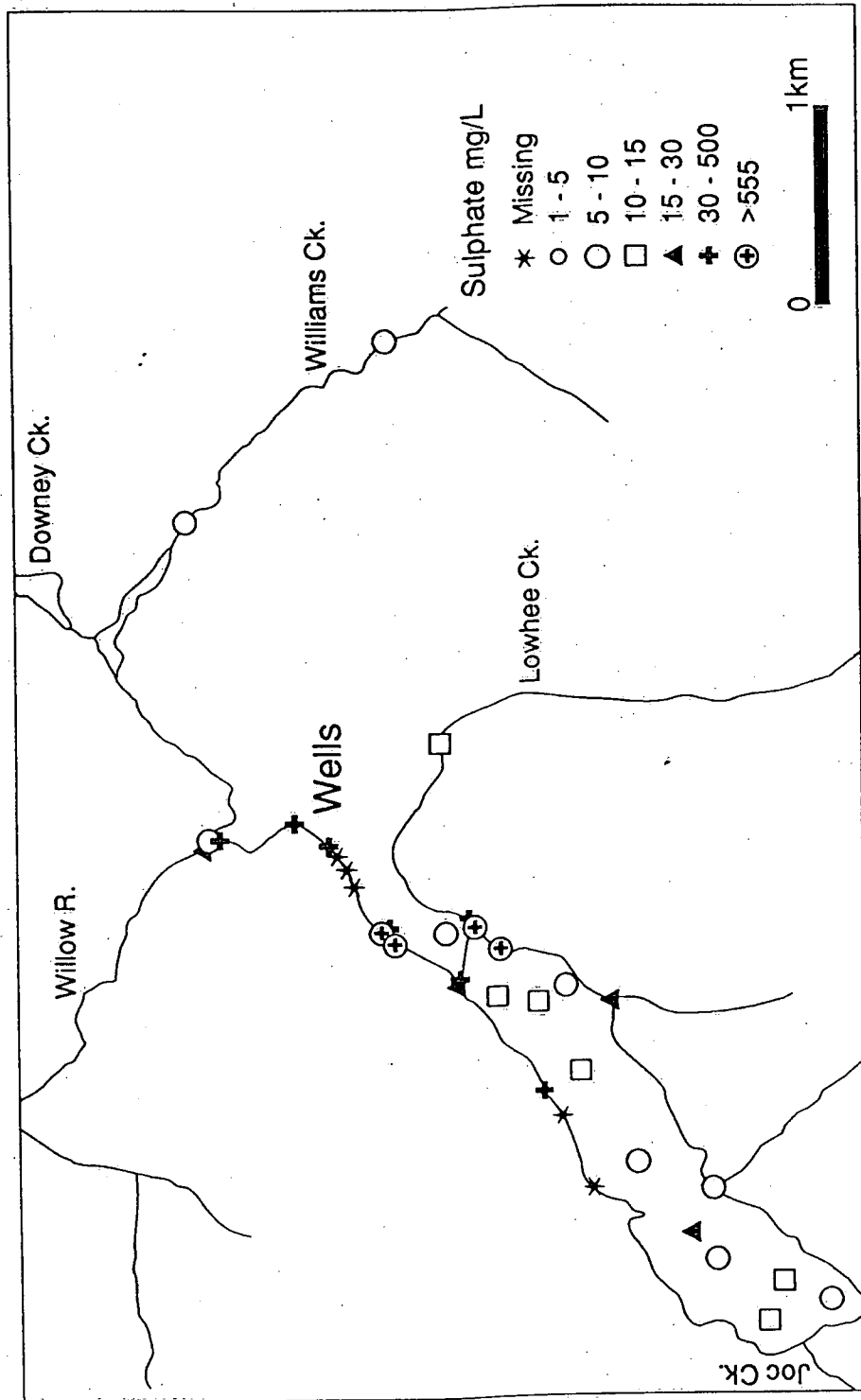


Figure 3.15. Sulphate concentrations in waters

The sample taken concurrently beside it, 32, is a surface runoff rather than a seep and this is reflected in its chemistry. Sample 05 is highly anomalous in the following elements: As at 556 $\mu\text{g/L}$; S as SO_4 at 640 mg/L ; Fe at 163 mg/L ; Pb at 144 $\mu\text{g/L}$; Zn at 116 $\mu\text{g/L}$; Ni at 62 $\mu\text{g/L}$; Cu at 21 $\mu\text{g/L}$; Co at 57 $\mu\text{g/L}$; Al at 357 $\mu\text{g/L}$; Te at 39 ng/L ; and Bi at 109 ng/L . In the rainy season, seepage from this site would reach JCL via the wide gulley running down the south-east side of the tailings. During this collection period, sample 16 represents drainage across the tailings into JCL from the general location of 05. This sample is similarly high in the elements listed above. The major sources of water (and hence possible contaminants) for JCL which were sampled in this project comprise: 16 (from across tailings); 08 (Lowhee Ck having traversed tailings); 15 (drainage through culvert of steep slopes north of Hwy 26); 25 (drainage through culvert from steep slopes on north side of Hwy 26); 01 (stream about 1 m wide at JCL with a rapid flow); and 02 (stream about 0.3 m wide at JCL with a good flow). Data for these samples are compared in Table 3.2 with two surface lake samples, site 4 closest to the tailings and site 3 furthest away at the input of JCL Creek. Clearly, in terms of absolute concentration, samples 16 and 08 are the most significant, though the high values of Se in stream 02 (1810 ng/L) and in drainage samples 15 (783 ng/L) and 25 (461 ng/L) are very interesting. Regardless of these anomalous levels of heavy metals in the surface runoff to JCL, concentrations in the lake itself are low and pH is neutral. Site 4, nearest the tailings, is higher than the other

Table 3.2. Results for elements of interest in water sources for JCL

Sample	pH	cond. µS	SO ₄ mg/L	As µg/L	Se ng/L	Al µg/L	Co µg/L	Ni µg/L	Cu µg/L	Zn µg/L	Cd µg/L	Pb µg/L	U µg/L	Mn µg/L	Fe mg/L
16	2.7	1757	810	7.52	469	468	21	22	6.3	100	1.4	55	1.3	7937	126
08	6.9	663	308	0.51	23	<10	5.2	6.3	3.9	7.3	0.27	0.03	0.17	2874	22.8
15	7.3	225	52	0.33	783	52	0.4	4.9	1.2	2.9	0.02	0.08	0.15	13	0.18
25				0.20	461	37	0.2	1.1	1.7	1.7	0.02	0.16	0.17	7	0.09
01	7.3	151	5.6	<0.20	63	25	0.1	0.6	0.8	0.3	<0.01	0.04	0.23	2	0.06
02	7.5	206	15.3	<0.20	1810	31	0.2	0.6	0.8	0.8	<0.01	0.10	0.44	3	0.07
JCL-4B	7.0	95	10.4	0.30	109	<10	<0.1	0.6	1.3	1.6	0.05	0.11	0.07	2	0.02
JCL-3S	7.0	86	10.2	0.26	109	<10	<0.1	0.6	0.4	0.8	<0.01	<0.02	0.07	<2	0.02
Guid.	6.5	--	--	--	--	100	--	25	5	30	3	30	--	--	0.300

Canadian Guidelines for the protection of freshwater aquatic life

lake samples in only Cl and Pb. The significantly higher concentrations of SO_4 in the bottom lake samples reflects dissolution from the sediment interface. While the major element chemistry of JCL is quite different from that of Bowron, trace element chemistry is fairly similar with the exception of SO_4 (ca. 10-20 mg/L in JCL vs. 2 mg/L in BL) and Se (ca. 100 ng/L vs. 30 ng/L). Unexpected contamination from the sampling or analytical procedure appears to be responsible for high values of Cu, Ni, Co, V, Ti, Al, Bi, Zn, Pb and Fe in several of the BL samples and in JCL 9-12. The lack of any signature in rare-earth elements in JCL is unusual and is probably caused by their efficient removal via coprecipitation with FeOOH , which is abundant in the area. Similarly, As is effectively removed from solution as the pH increases and Fe and Mn oxyhydroxides are precipitated.

Sampling on different days at sites 04 and 08 provides a measure of short term variability of the runoff chemistry; as expected, there is more of a shift in the data for 'Lowhee' (08) after it traverses the tailings because of the leaching. It is interesting to note the disappearance of Lowhee Creek's signature in Se and the rare earth elements after crossing the tailings.

Willow River

Heavy iron oxide staining is visible all along Willow River from JCL to its confluence with Williams Creek (at 30); tailings banks are also present in this area of north Wells. Figures 3.13-15 demonstrate the dispersion of As, Fe and SO₄ from the beginning of Willow (09) to the confluence. The chemistry of sample 10 flowing through a culvert into Willow R. reflects both drainage from the other side of the road and from the tailings closest to the road, while that of sample 11 represents the effluent from the tailings area on the east side and overflow from Lowhee Ck. Sample 12 is a mixture of seepage and drainage from the mineralised slopes on the far side of the road and its chemistry should be similar to that of sample 10. Sample 26 is taken from water flowing rapidly through a disintegrating culvert from the Pooley St W. area, and is drainage from the general site of the Island Mountain Mine. Samples 18, 31, 13, 14, 23 and 30 were all taken in Willow R. itself, as close to the central flow as possible. Data of parameters of interest for these samples has been ordered from the beginning of Willow R. to its confluence with Williams Cr. in Table 3.3. It is clear that the influence of leaching from the main tailings bed (represented by 11) and from the general area of the Island Mountain Mine on the other side of the road (26 and 10) is quickly dissipated so that just before Williams Cr., Fe, SO₄ and As values have fallen to about 100 µg/L, 35-40 mg/L and 0.5 µg/L, respectively. Mixing with Williams dilutes SO₄ concentration to ca. 17 mg/L; it would be of interest to monitor this parameter further downstream. Levels of U

Table 3.3. Chemistry of Willow River and its feeders from JCL to the confluence with Williams Creek

Sample	pH	cond. µS	SO ₄ mg/L	As µg/L	Se ng/L	Co µg/L	Zn µg/L	Pb µg/L	Fe µg/L
09	7.1	108	16.0	0.29	96	0.35	1.4	0.10	331
10*	8.1	1630	1000	2.08	7	0.58	3.4	0.03	127
11	7.8	415	93	0.89	14	0.96	0.9	0.07	213
26*				7.18	101	4.6	13.1	0.04	81042
18				0.57	110	0.40	0.7	0.04	99
31				0.39	105	0.34	0.6	0.06	134
13	7.2	211	54	0.54	81	0.78	1.2	0.11	155
14	7.2	228	58	0.85	83	1.57	4.8	0.14	199
23	7.1	165	37	0.57	99	1.22	13.7	0.08	96
22*	7.5	221	7.3	0.39	192	0.12	0.2	<0.02	121
30	7.4	176	16.8	0.58	127	0.27	16.3	0.10	104

Guidel [#] .	6.5	--	--	--	--	--	30	30	300
-----------------------	-----	----	----	----	----	----	----	----	-----

Canadian Guidelines for the protection of freshwater aquatic life

* feeders, not Willow itself

are high ($>5 \mu\text{g/L}$) in samples 10 and 12 on the north-west side of the road; again, these are rapidly lowered by dilution. Sampling of sites on different days (e.g., at 09, 10 and 13) affords an appreciation of short term temporal variability which appears particularly high in Ni and Zn.

3.1.3 Pore water and Groundwater

Results of pore water analyses are presented on Table 3.4. Concentrations of As in the pore water are approx. 100 times greater than in lake water (Figure 3.16). These concentration differences are not uncommon, even in uncontaminated lakes, and are observed often for many nutrients and trace metals. Differences in the concentrations of trace elements in the pore water in Jack of Clubs and Bowron lakes appear to be different for many trace elements, with the exception of As, Ni and Cu. The greatest concentrations of As, Ni, and Cu were found in the pore water collected from the tailings (Table 3.4). The pore water concentrations of all trace elements are a factor of 10 lower in JCL, compared to other lakes such as Larder Lake, Ontario which has been contaminated by wastes from gold mining activities. Concentration differences for arsenic among JCL, Larder Lake, and Bowron Lake, and are shown in Figure 3.17. The concentrations of trace element species are not different between the surface and bottom waters (Appendix B), thus it follows that the trace elements

Table 3.4.

PORE WATER CHEMISTRY: JACK OF CLUBS AND BOWRON LAKE

Trace & Major Elements (mg/L)

Elements	Be	Cd	Pb	Cr	V	Co	Cu	Li	Mo	Ni
detect. limit>	0.0002	0.001	0.005	0.001	0.001	0.001	0.001	0.001	0.00	0.00
Lake/Station/Layer										
BL1/1	0.0002	0.008	0.010	0.008	0.005	0.013	0.002	0.002	ND	0.014
BL1/2	ND	0.002	0.006	0.005	ND	0.006	0.002	0.002	0.00	0.005
JoCT/1	0.0002	0.002	0.036	0.005	ND	0.013	0.081	0.009	ND	0.065
JoCT/2	ND	0.002	ND	0.001	ND	0.003	ND	0.041	0.02	0.023
JoC3/1	ND	0.002	0.038	0.006	ND	0.01	0.048	0.003	0.00	0.019
JoC3/2	ND	0.001	0.016	0.003	0.002	0.002	0.033	0.002	0.00	0.010
JoC8/1	ND	ND	ND	0.001	0.001	ND	0.008	0.001	ND	0.002
JoC8/2	0.0002	0.008	0.021	0.007	0.004	0.018	0.056	0.001	ND	0.033
JoC9/1	ND	0.003	0.016	0.006	0.003	0.006	0.07	0.002	0.00	0.013
JoC9/2	ND	0.001	0.006	0.003	ND	0.002	0.016	0.002	0.00	0.002
JoC10/1	0.0003	0.054	0.016	0.004	0.01	0.003	0.035	0.002	0.00	0.031
JoC10/2	ND	0.002	0.006	0.003	ND	0.004	0.006	0.001	0.00	0.006

Trace & Major Elements (mg/L)

Elements	Al	Ba	Fe	Mn	Zn	Sr	Ca	Mg	Na	K	As
detect. limit>	0.01	0.001	0.001	0.001	0.001	0.001	0.1	0.1	0.2	0.2	0.0002
Lake/Station/Layer											
BL1/1	0.813	0.653	62.20	6.400	0.126	0.083	22.9	4.6	1.5	0.7	0.023
BL1/2	0.114	0.395	15.05	12.550	0.080	0.077	21.3	4.7	2.3	1.0	0.021
JoCT/1	0.179	0.114	8.30	12.400	0.206	3.170	559.0	153.0	2.1	1.8	NS
JoCT/2	0.058	0.080	10.90	5.580	0.033	3.120	375.0	967.0	3.1	5.9	0.361
JoC3/1	2.086	0.195	10.59	8.775	0.072	0.183	26.2	9.4	1.3	0.7	0.091
JoC3/2	0.656	0.106	4.18	3.755	0.025	0.193	27.5	7.2	2.0	1.1	0.105
JoC8/1	0.196	0.029	0.70	0.379	0.008	0.114	18.7	5.2	1.1	0.3	0.056
JoC8/2	1.530	0.776	67.40	10.600	0.064	0.191	29.2	6.3	1.5	0.4	0.108
JoC9/1	0.909	0.555	30.70	11.200	0.056	0.273	42.1	9.2	1.2	0.7	0.081
JoC9/2	0.333	0.195	9.12	8.920	0.017	0.240	38.2	9.2	1.3	0.6	0.051
JoC10/1	0.351	0.148	4.96	6.310	0.798	0.371	63.2	15.7	2.7	1.4	0.078
JoC10/2	0.148	0.209	4.27	7.530	0.030	0.294	40.9	10.1	2.0	0.7	0.164

1 = 0 - 5 cm layer

JoC = Jack of Clubs Lake

2 = 5 - 10 cm layer

JoCT = Tailings at the north shore of Jack of Clubs Lake

BL = Bowron Lake

ND = Not detected

NS = No Sample

JACK OF CLUBS AND BOWRON LAKE

Arsenic in Pore-Water & Lake Water (ug/l)

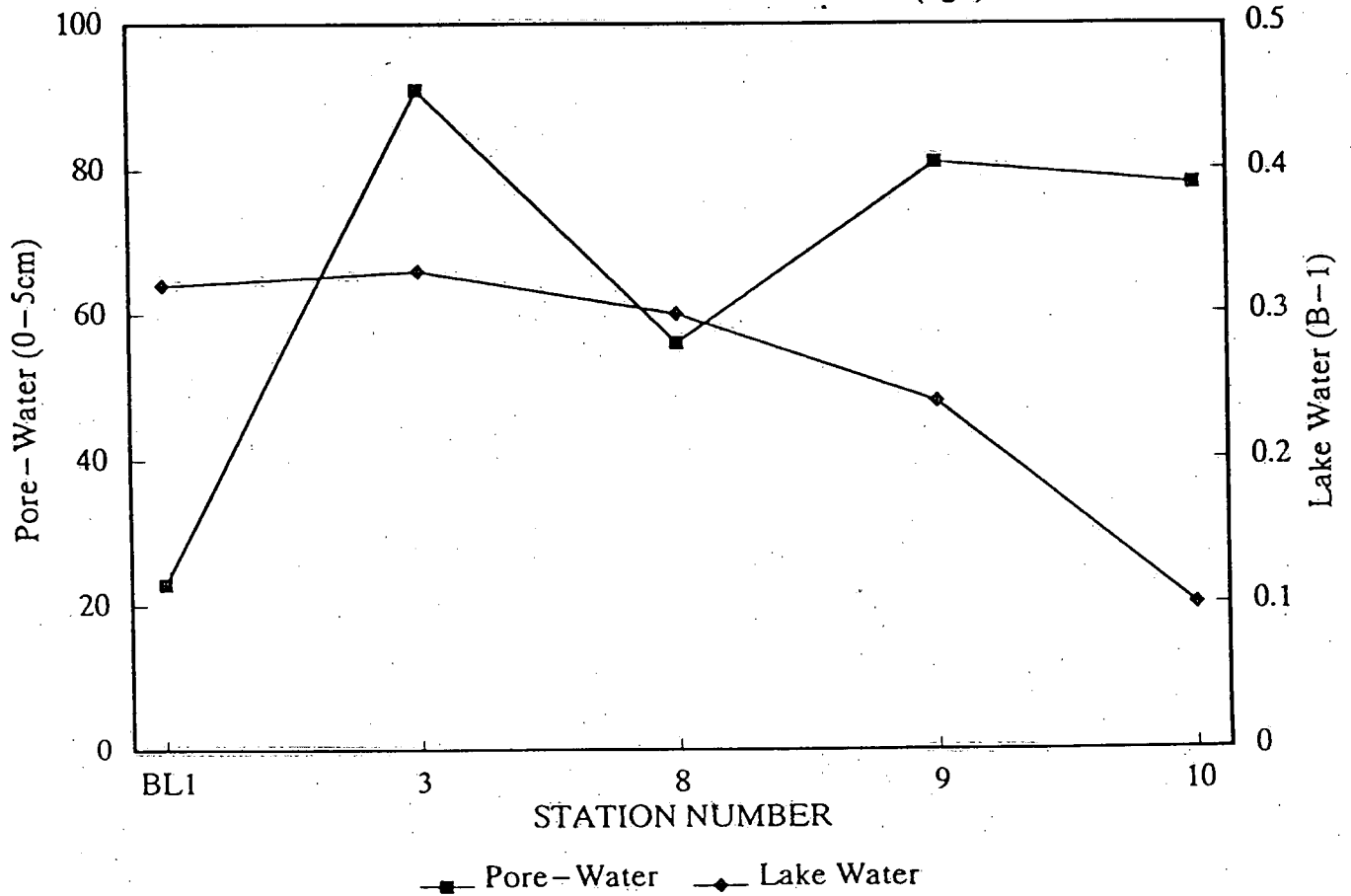
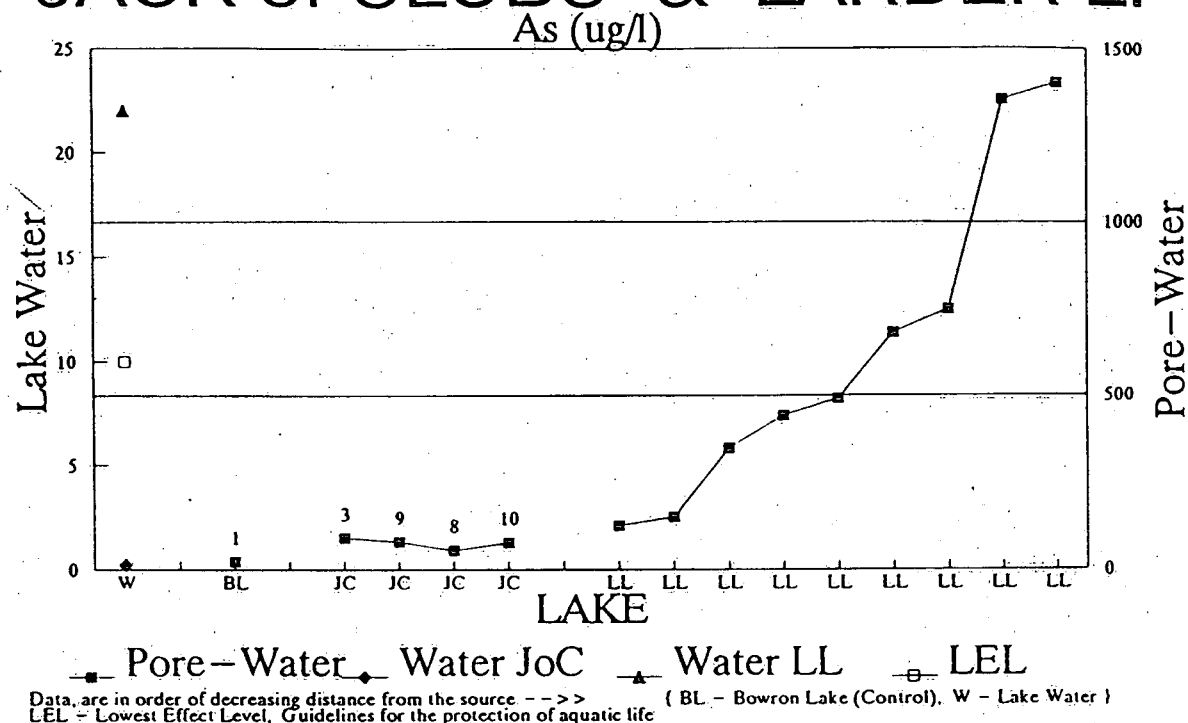


Figure 3.16. Comparison of arsenic concentrations in Jack of Clubs and Bowron Lakes

JACK of CLUBS & LARDER L.



JACK of CLUBS & BOWRON L

Arsenic in Lake Water, at 1m & B-1m

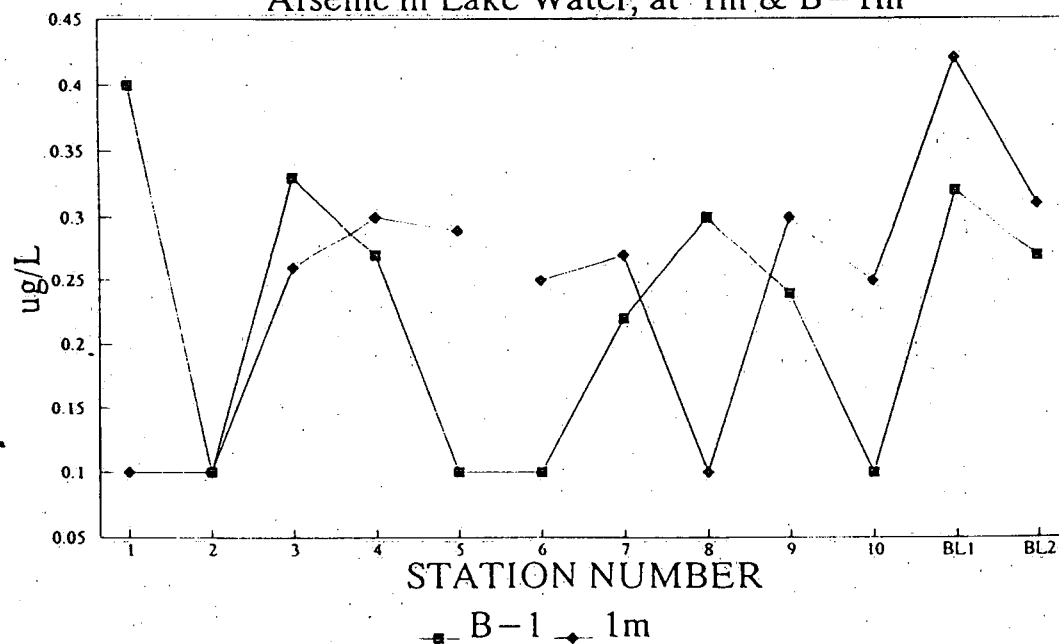


Figure 3.17. Comparison of arsenic concentrations

are not being regenerated from the sediments. At some sampling stations the concentration in the bottom water are lower, as shown for arsenic (Figure 3.17), which implies that the sediments are acting as a 'sink' rather than a 'source'. According to these preliminary results, JCL seems to have been only partially impacted by contaminants towards the north end of the lake. Based on the pore water concentration differences between 0-5, and 6-10 cm sediment depth, there seems to be an improvement in the surface sediment quality, since some surface concentrations are lower than the 6-10 cm layer.

The concentrations of major and trace elements in the groundwater from the tailings are shown in Table 3.5. The average As, Ni, Mn and Zn concentrations are similar to the levels reported for the pore water in the lake (Table 3.4). However, the average concentrations of Pb, Cd, Fe and Cr in the groundwater are much greater than in pore water. The elevated concentrations of As, Pb, Cd and Cr observed in the invertebrates (section 3.3.2.) and vegetation (section 3.3.3.) collected from the tailings confirmed the high mobility of these elements in the tailings.

Table 3.5. Major and trace element concentrations (mg/L) in groundwaters from the tailings (average of duplicates in five stations)

	As	Zn	Pb	Cd	Co	Ni	Mn	Fe	Cr	Cu
Average	0.163	0.201	0.240	0.079	0.042	0.067	7.125	148.20	0.022	0.014
sd	0.057	0.097	0.082	0.038	0.028	0.046	3.973	73.97	0.023	0.019
max.	0.281	0.296	0.322	0.131	0.082	0.132	11.200	249.00	0.052	0.055
min.	0.102	0.053	0.129	0.035	0.014	0.021	0.322	38.200	<0.001	<0.001

3.2. Sediment Quality

3.2.1. Suspended Sediments

The concentrations of total, inorganic and organic carbon in suspended sediments collected at three stations in the study area are shown in Table 3.6. The greatest concentration of organic carbon was found in suspended sediments collected at the centre of JCL. The concentration was up to three times greater in the suspended sediments at this station than in those collected from two stations in the Willow River, suggesting a larger biomass in the lake water than in the Willow River. The greatest concentrations of As, Pb, Zn, Cd and Cr were found in the suspended sediments collected from the Willow River at the outflow from JCL. The concentrations of As, Co and Hg in the suspended sediments in the middle of the lake (Table 3.7) were similar to those in the bottom sediments from the same area (station 8) in the lake (Table 3.9). However, the concentrations of Zn, Pb, Ni and Cu were greater in the bottom sediments at this station, suggesting limited transport of these elements into lake water. The concentrations of As, Cd, Cu, Co and Hg were similar in suspended sediments from the Willow River at the outlet from the lake and bottom sediments at the most severely contaminated site (station 5) in the lake.

With the exception of Cu and Hg, the concentrations of major and trace elements in suspended sediments in the Willow River

Table 3.6. Total and organic carbon (%) in bottom and suspended sediments

Location	Organic	Inorganic	Total
Bottom sediments:			
JOC-1	4.00	0.25	4.26
JOC-2	1.90	0.26	2.15
JOC-3	1.69	0.27	1.96
JOC-4	1.24	0.20	1.44
JOC-5	0.85	0.89	1.75
JOC-6	1.63	0.26	1.89
JOC-7	1.62	0.23	1.85
JOC-8	1.29	0.24	1.53
JOC-9	2.06	0.30	2.46
JOC-10	1.34	0.28	1.63
Bowron L.	3.63	0.17	3.79
WR-L	0.34	0.48	0.82
WR-U	0.89	0.49	1.38
LC-L	1.45	0.14	1.59
LC-U	0.58	0.16	0.74
Tailings	0.62	0.10	0.72
Suspended sediments:			
JOC-8	12.35	0.38	12.73
WR-L	3.52	0.43	3.95
WR-U	4.81	0.16	4.97

WR-L=Willor River at the lake outflow

WR-U=Willor River downstream the town of Wells

LC-L= Lowhee Creek at the lake

LC-U= Lowhee Creek approx. 500m upstream of the tailings

Tailings = near the lake shore

Table 3.7. Major and trace element concentrations (mg/kg) in suspended matter

	As	Zn	Pb	Cd	Co	Ni	Mn	Fe	Cr	Cu	Hg
JOC-8	244	157	103	2.9	33	59	6558	54679	104	42	0.205
WR-L	1215	225	535	6.2	25	81	967	83798	187	49	0.045
WR-U	343	172	149	4.4	17	78	565	52047	73	82	0.425

JOC-8 = sampled at 2m depth

WR-L = Willow River at the outflow from Jack of Clubs Lake

WR-U = Willow River downstream of the town of Wells

Table 3.8. Percent of gravel, sand, silt and clay in bottom sediment samples

Location	Gravel	Sand	Silt	Clay
JCL-1	0	0.26	55.79	43.95
JCL-2	0	0.13	31.14	68.73
JCL-3	0	0.04	31.73	68.16
JCL-4	0	2.95	61.07	35.98
JCL-5	0	0.27	60.91	38.81
JCL-6	0	0.11	43.69	56.2
JCL-7	0	0.32	48.92	50.76
JCL-8	0	0.57	35.28	64.15
JCL-9	0	0.58	40.76	58.66
JCL-10	0	0.33	34.62	65.06
Bowron L.	0	0.11	47.54	52.35
Willow R. (*)	0	46.09	29.92	23.99
Lowhee C. (*)	0	14.75	25.78	59.47
Tailings	0	42.45	33.22	24.33

(*) close to JCL

Table 3.9. Major and trace element concentrations in the bottom sediments (average of triplicate samples)

	Al	As	Ag	Ba	Bi	Ca	Cd	Co	Cr	Cu	Fe	Hg
	%	ug/g	ug/g	ug/g	ug/g	%	ug/g	ug/g	ug/g	ug/g	%	ng/g
JOC-1	1.48	98	1.0	207	6	0.36	1.5	28	34	57	6.49	137
JOC-2	2.16	153	1.2	364	8	0.32	2.4	40	51	76	7.64	127
JOC-3	1.99	168	0.9	337	7	0.32	1.8	39	47	71	7.57	131
JOC-4	1.08	596	1.3	167	8	0.94	2.2	28	28	40	8.15	52
JOC-5	0.98	1104	1.4	140	16	2.74	5.25	28	33	48	0	48
JOC-6	1.53	455	1.4	242	15	0.35	0.8	33	40	63	8.36	166
JOC-7	1.79	268	1.1	248	8	0.48	2	35	45	70	7.19	83
JOC-8	1.81	277	1.3	271	14	0.36	1.7	39	46	75	8	167
JOC-9	2.03	80	0.6	300	<5	0.31	<0.2	35	48	63	6.37	79
JOC-10	1.96	216	1.0	286	8	0.42	0.9	21	48	75	7.35	85
Willow River	0.59	1184	1.6	94	9	0.73	4.5	24	16	15	>10	27
Lowhee Cree	0.25	>2000	7.7	46	48	0.23	12	20	11	26	>10	69
Tailings	0.58	903	2.8	236	15	0.96	3.9	36	27	29	>10	152
Bowron Lake	2.23	21	0.3	409	<5	0.38	1.4	34	54	47	8.92	119

K	Mg	Mn	Mo	Na	Ni	Pb	La	Sb	Sr	V	Zn	
%	%	ug/g	ug/g	%	ug/g	ug/g	ug/g	ug/g	ug/g	ug/g	ug/g	
JOC-1	0.18	0.52	1345	4	0.06	87	88	17	6	29	24	389
JOC-2	0.31	0.71	4346	5	0.07	109	132	20	8	33	36	423
JOC-3	0.3	0.64	5486	7	0.07	102	127	20	8	35	33	383
JOC-4	0.2	0.53	2280	5	0.06	57	132	12	5	33	22	174
JOC-5	0.20	0.85	2911	6	0.07	56	281	12	7	65	17	324
JOC-6	0.22	0.51	2912	4	0.06	78	231	16	7	29	26	450
JOC-7	0.22	0.68	3114	5	0.07	95	129	15	7	33	34	326
JOC-8	0.23	0.59	4745	3	0.07	101	209	16	8	32	30	516
JOC-9	0.22	0.78	2198	4	0.06	90	68	20	7	28	33	229
JOC-10	0.28	0.68	4309	1	0.06	101	121	19	7	36	36	326
Willow River	0.25	0.22	406	2	0.07	32	144	13	<5	31	8	138
Lowhee Cree	0.12	0.09	778	2	0.06	29	965	18	<5	16	2	165
Tailings	0.15	0.15	11670	8	0.06	43	467	20	<5	57	6	303
Bowron Lake	0.25	0.99	6367	1	0.07	66	37	27	8	22	36	137

decreased with increasing distance from the lake. However, suspended sediments in the Willow River below the second bridge (on Hardscrabble Rd) in Wells had greater concentration of Hg than any of the other suspended sediments and bottom sediments collected in the lake and the river, indicating introduction of Hg into the river somewhere between the outflow of the lake and this bridge.

3.2.2. Bottom Sediments and Tailings

Concentrations of total, inorganic, and organic carbon in bottom sediments from JCL, BL, and tailings are summarized in Table 3.6. The greatest concentrations of organic carbon were found in the sediments at station 1 (Figure 2.1) at the southwest end of the lake. Adjacent marshes on the shore most likely contributed organic matter to the bottom sediments in this part of the lake. The lowest concentrations of organic carbon were found in the sediments at station 5, which appeared to be in the area most strongly affected by the tailings on the northeast shore of the lake. The concentrations of inorganic carbon, which probably represents calcite in the sediments, were relatively uniform at all sampling stations with the exception of station 5. The inorganic carbon content was about three times greater in the sediments at this station than in the sediments elsewhere in the lake and in Willow River and Lowhee Creek. The particle size distribution in all the collected sediment samples are shown in Table 3.8.

The greatest concentrations of As, Cd, Pb, Ca and Fe were found in the sediments at station 5 (Table 3.9). However, the concentration of Zn were greatest at stations 2, 6 and 8 (Figure 2.1), suggests a different source of Zn than the tailings on the northeast shore of the lake. The concentrations of Hg were relatively uniform (from 27 to 167 ng/g, Table 3.9) in the sediments in JCL, Willow River, Lowhee Creek and tailings, and were similar to the concentrations found in the sediments in Bowron Lake. The results showed that the northeast end of the lake was the most severely contaminated area and that this area extends about 500 m towards the centre of the lake.

Data presented in Table 3.10 show low PAH concentrations, comparable to those seen in relatively unpolluted sediments. The presence of perylene as the predominant M252 isomer is another characteristic of unpolluted sediments, as perylene can be a natural product. The high levels of phenanthrene may indicate that the PAHs originated from petroleum sources instead of being formed by combustion. The concentrations of total polychlorinated biphenyls (PCB) in the sediments of JCL were at or below detection limit (0.01 ng/g dry weight) of the analytical method used.

The average concentrations of major and trace elements in the tailings are presented in Table 3.9. Generally, the concentrations of As, Fe, Mn and Pb in the tailings are considerably greater than in JCL sediments. However, they are comparable with tailings at

Table 3.10. Concentration (ug/g) of PAHs in bottom sediments of Jack of Clubs Lake

Compound	JOC1	JOC4	JOC9	Lowhee C.	Bowron L.
Naphthalene	0.067	0.024	0.002	0.161	0.035
Acenaphthylene	n.d.	n.d.	n.d.	n.d.	n.d.
Acenaphthene	n.d.	0.005	n.d.	0.005	n.d.
Fluorene	0.022	0.007	0.005	0.014	0.011
Phenanthrene	0.06	0.021	0.019	0.028	0.03
Anthracene	n.d.	n.d.	n.d.	n.d.	n.d.
Fluoranthene	0.011	0.004	0.004	0.009	0.005
Pyrene	0.022	0.008	0.01	0.014	0.009
Benzoanthracene	0.001	0.001	n.d.	0.002	n.d.
Chrysene	0.004	0.002	0.002	0.005	0.002
Bbfluoranthene	n.d.	n.d.	n.d.	0.002	n.d.
Bkfluoranthene	n.d.	n.d.	n.d.	0.002	n.d.
Bapyrene	n.d.	n.d.	n.d.	0.001	n.d.
Indenopyrene	n.d.	n.d.	n.d.	n.d.	n.d.
Dibenzoanthracene	n.d.	n.d.	n.d.	n.d.	n.d.
Benzoperylene	n.d.	n.d.	n.d.	n.d.	n.d.
Total	0.187	0.071	0.043	0.092	0.242
Bepyrene	n.d.	n.d.	n.d.	0.001	n.d.
Perylene	0.188	0.013	0.022	0.0004	0.228

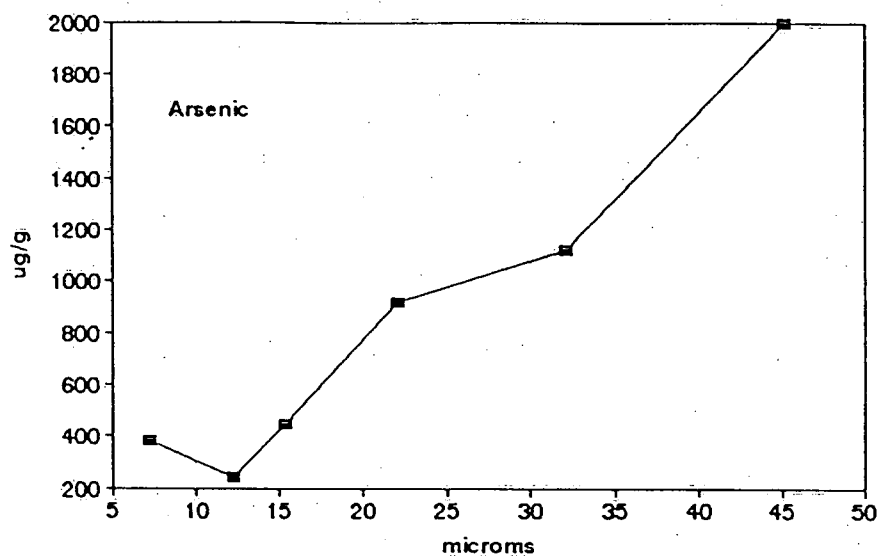
D.L. = 250 pg/g

n.d. = below detection limit

other mining areas (Azcue and Nriagu 1993; Adriano, 1986). Previous studies at the Wells area suggested a very low solubility of As and Pb in the tailings, owing to adsorption onto and/or co-precipitation with ferric oxyhydroxides (Rescan, 1990).

It is well known that the metal concentrations in the different particle size fractions of the sediments are very important in the evaluation of the transport of metals (Forstner, 1982; Mudroch and Duncan, 1986). Figure 3.18 shows the concentrations of As and Pb in six particle size fractions (see section 2.2.2.1) of sediments collected in the tailings. The concentrations of the major elements reflected the mineralogy of each size fraction. The greatest concentration of Pb (3,470 $\mu\text{g/g}$) was found in the $<13 \mu\text{m}$ size fraction, with decreasing concentrations with increasing size fractions. Consequently, large quantities of Pb bound to the fine silt and clay fractions ($<63 \mu\text{m}$ particle size) may be mobilized by erosion of the fine particles and physico-chemical changes of environmental conditions at the site where the fine-grained particles settle. On the other hand, As concentration was greatest ($>2,000 \mu\text{g/g}$) in the $45-53 \mu\text{m}$ size fraction, with decreasing concentrations in the smaller particle size fractions. Thus, As preferentially bound to coarser sediment fractions (i.e. silt) tends to be less mobile by erosional processes.

Arsenic concentration in sediments mine tailings (Wells, BC)



Lead concentration in sediments mine tailings (Wells, BC)

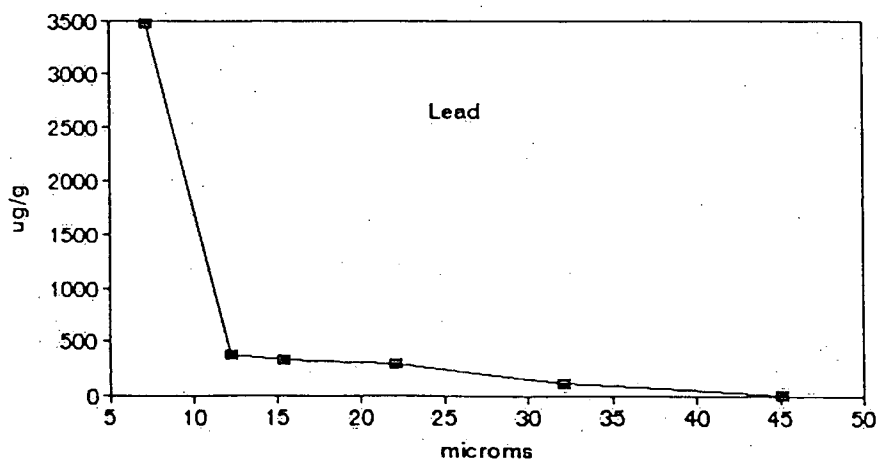


Figure 3.18. Concentrations of As and Pb in six particle size fractions of the tailings separated by a cyclosizer

3.2.3. Sequential Extraction

All results for the five phases extracted, as well as the summation of these concentrations ("phase 6"), are listed in Appendix A. The control data testify to the high precision attained in the analyses: TILL-2 and LKSD-4 (lake sediment) are international standard reference samples produced by the GSC (Lynch, 1990). The variation in elemental concentration with depth in the five phases extracted from each core is shown in Figures 3.19 to 26. The point plotted at 0 cm represents that concentration for the 0-2 cm segment of core, that at 2 cm represents that value for the 2-4 cm interval, and so on. Note the logarithmic scale used in the figures. The distribution of Mn, Fe, Zn, As and Pb amongst the five phases, as a percentage of the total elemental content, is illustrated in Figures 3.27 and 28, respectively, for four selected depths (0-2, 2-4, 4-6 and 16-18 cm) in cores 3 and 10. The results for each element are discussed below. Core 10 was collected at a water depth of ca. 40 m about 1100 m from the tailings, and presumably during spring run-off and times of flooding would receive both material flushed mechanically from the tailings and water carrying high contents of dissolved salts. Core 3 was collected at a water depth of ca. 25 m about 250 m from the mouth of JCL Creek, at the opposite end of the lake (southwest) from the tailings (Fig. 2.1). Thus, while the presence of mine tailings and associated activities would affect the geochemistry of core 10 more than core 3, the latter would be receiving sediment brought into the lake via JCL Creek (Table 3.11).

Iron (Figure 3.19)

The profiles for total Fe (phase 6) in cores 3 and 10 differ markedly. The range is similar - from 6.4 to 9.2% in core 3 and from 5.8 to 9.3% in core 10. The large increase to 9.3% at segment 4-6 cm in core 10 was confirmed by separate analysis of a subsample after an HF-HClO₄-HCl-HNO₃ acid attack. Below 6 cm, the total Fe profile is quite constant. In core 3, there is a noticeable depletion of Fe at 6-8 cm, again confirmed by separate 'total' analysis. Contribution to the total Fe content is derived mainly from phases 2 (amorphous Fe oxyhydroxide), 3 (crystalline Fe oxide) and, to a lesser degree, 4 (sulphides and less soluble organics). Total Fe is more consistent in Bowron cores 1 and 2, ranging from 6.4 to 7.4%, and from 7.6 to 8.6%, respectively.

Both JCL cores are depleted in exchangeable Fe (phase 1) in the top 2 cm, shown clearly in Figures 3.19, 3.27 and 3.28. This Fe varies from 2.7% of total Fe in the 0-2 cm segment of core 3 to 5.8% of total in the 14-16 cm segment; corresponding values in core 10 are 2.7% and 10.5% of the total Fe. Not surprisingly, Fe is enriched in all cores in the amorphous oxyhydroxide component of the surface sediment. It reaches 2.6% (absolute) in the top of core 3 (cf. 3.0% in core 10), and then varies from 1.8 to 2.2% in the remainder (cf. 1.5 to 1.9% in core 10). Iron in this phase

Table 3.11. Results for stream sediments collected under the National Geochemical Reconnaissance Program
(GSC Open File 1107, 1984)

Element	JCL		Bowron Lake		Mean for Map Sheet	
	Site 01	Site 02	Streams to West			
Cu	20	51	14	33	41	22
Pb	10	19	15	12	34	3
Hg	18	46	17	23	26	36
Co	14	8	14	12	6	11
Zn	110	86	78	71	48	62
Ag	.2	.1	.1	.1	.1	.1
Ni	40	20	41	34	16	29
Mn	550	850	720	510	240	670
Fe	3.7	2.4	3.4	2.9	1.5	2.6
As	15.0	5.0	13.0	12.0	1.0	3
pH	8.0	7.8	7.3	7.7	7.0	

(*) Concentrations in $\mu\text{g/g}$ (except Hg in ng/g, and Fe in %)

makes up a notably higher proportion of the total in the BL sediment cores.

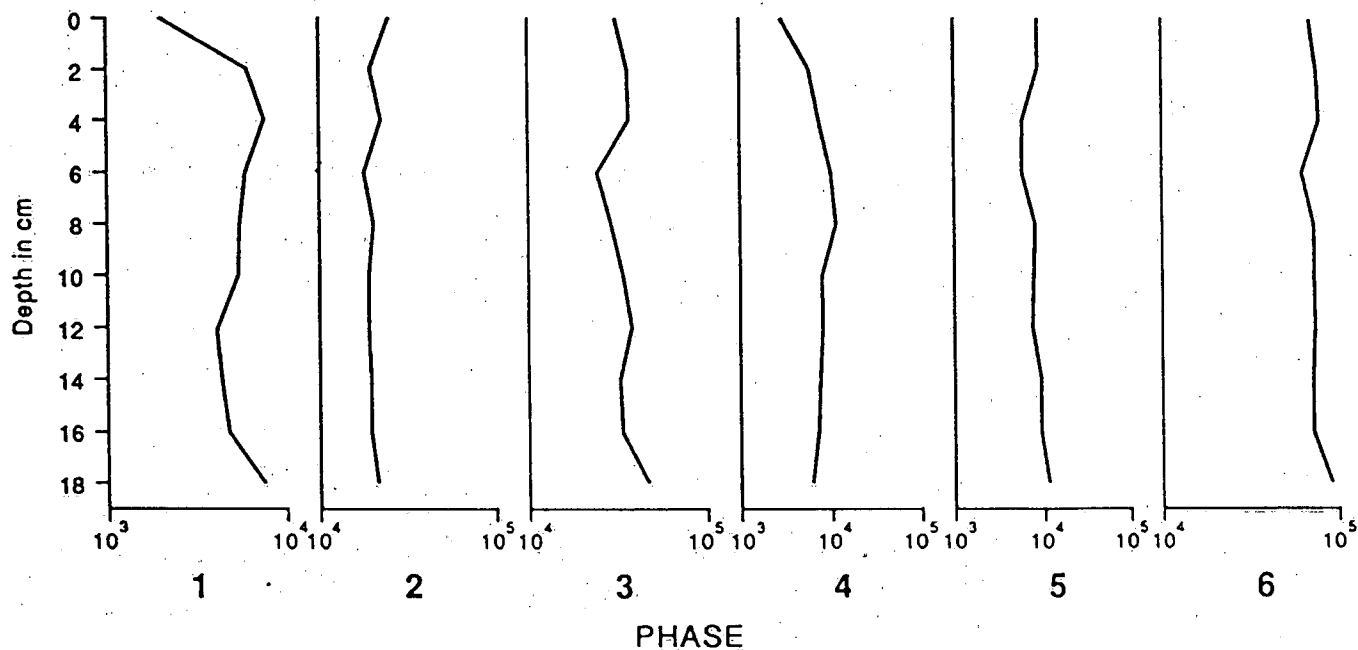
There is a significant difference in profiles of crystalline Fe (phase 3) in cores 3 and 10 which is reflected in the total Fe signatures. The enhancement at 4-6 cm in core 10 is striking, to a value of 3.7%, from a background of 1.7 to 2.6% in the underlying sediment. Generally, phase 3 Fe in core 3 is higher than that in core 10, at 2.4-4.6% compared to 1.7-3.7%. This Fe in the Bowron cores is more consistent and lower in magnitude, at 1.4 to 1.9%, and the spike shown in core 10 is absent from these.

Sulphide/organic bound Fe (phase 4) is relatively constant with depth in core 3, with a depletion to 0.29% at surface. This profile is more erratic for core 10, and the increase shown at 4-6 cm for phase 3 Fe is evident here also, though the concentration is much lower (1.6%). The proportion of Fe in this phase appears higher in core 10 than in core 3. Note, that phase 4 Fe, like crystalline Fe, is considerably lower in both BL sediment cores, though total Fe values are quite similar.

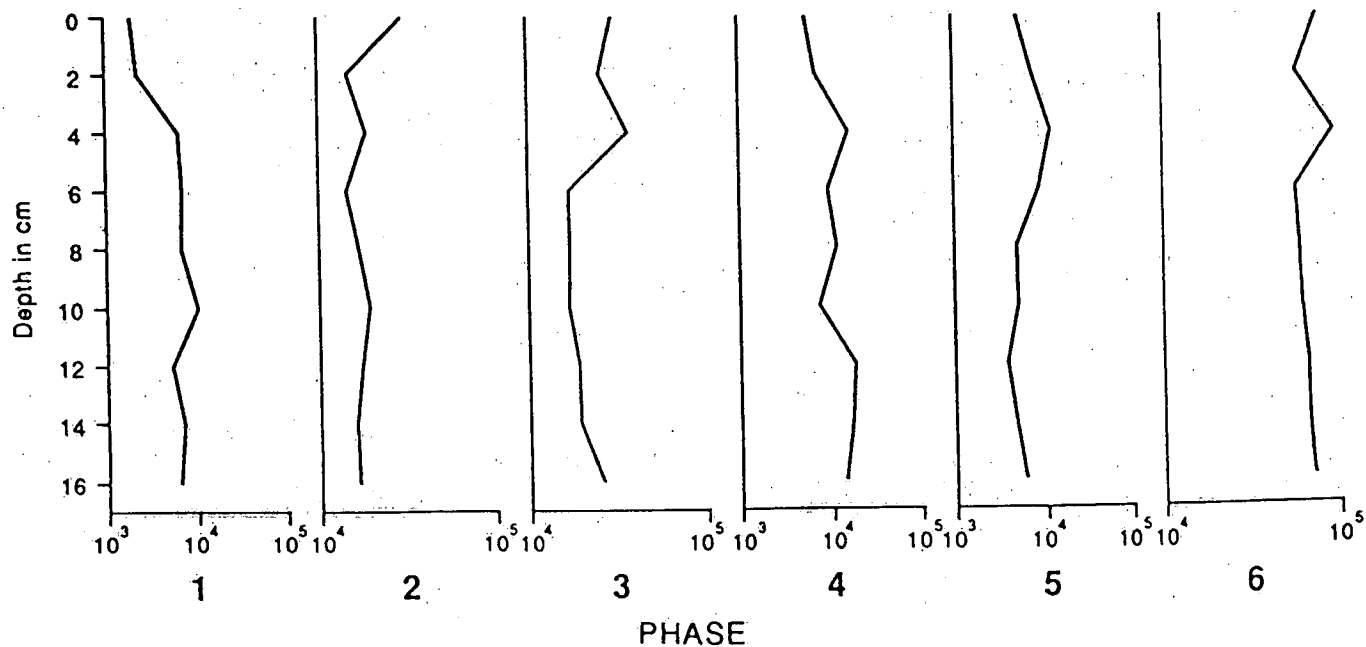
The spike (1.4% Fe) at the 4-6 cm depth in core 10 is evident again in phase 5 Fe, that attributed to silicate and more refractory oxide binding or encapsulation. Such an increase is not apparent in core 3, and in fact there tends to be a decrease in phase 5 Fe from about 4 to 8 cm, as reflected in total Fe.

Figure 3.19. Distribution of Fe in sediments from JCL (concentrations expressed in $\mu\text{g/g}$). [1= adsorbed and exchanged carbonates; 2= hydrous Fe and Mn oxides; 3= crystalline Fe oxides; 4= sulphides/organic; 5= silicates and residual; 6= total]

CORE 3 IRON



CORE 10 IRON



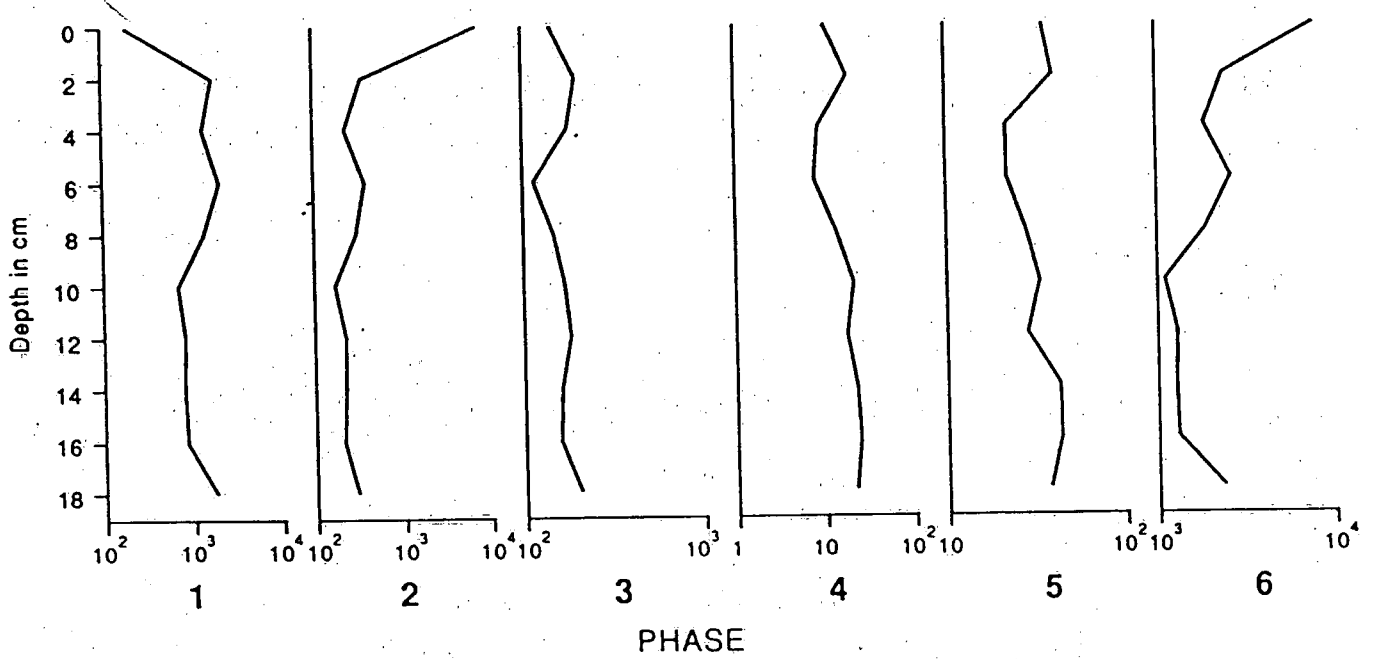
Manganese (Figure 3.20)

There is a large increase in total Mn in all cores at the surface of the sediments most of it in the oxide (phase 2) under the typical oxidising conditions at the interface. Total Mn ranges from 1084 to 8014 $\mu\text{g/g}$ in core 3 and from 1145 to 4861 $\mu\text{g/g}$ in core 10, these concentrations being somewhat lower than those in Bowron cores. The drastic change with depth in the Mn content of the first two phases is best seen by comparing the diagrams in Figures 3.28 and 29. "Exchangeable" Mn is vastly depleted at the surface while oxide Mn is very high. Below 4 cm, phase 1 and 2 Mn profiles are similar, though phase 1 Mn dominates in absolute concentration. This is most likely due to the oxidation of Mn migrating through the sediment pore water to the sediment surface.

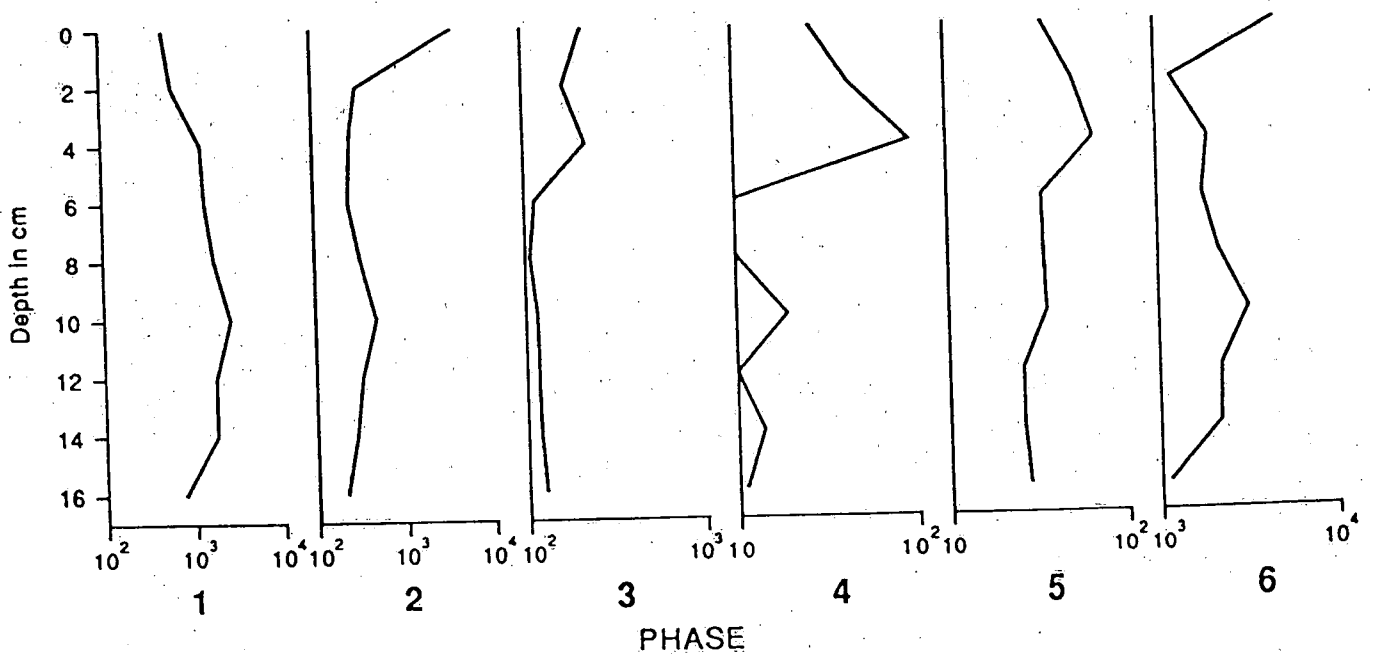
The spike shown at 4-6 cm by phase 3 Fe, in core 10, is evident for Mn in this phase. Similarly, a depletion in Mn is evident in core 3 at 6-8 cm, as is the case for phase 3 Fe. The concentrations of Mn in phases 4 and 5 are, for the most part, well under 100 $\mu\text{g/g}$ and are insignificant with respect to phases 1 and 2. Nevertheless, an enhancement is again seen at 4-6 cm in core 10 for phases 4 and 5 Mn, following the pattern of Fe. Slight depletions are seen in phases 4 and 5 Mn for core 3 at a depth of 4-8 cm.

Figure 3.20. Distribution of Mn in sediments from JCL (legends as in Figure 3.19)

CORE 3 MANGANESE



CORE 10 MANGANESE



Arsenic (Figure 3.21)

There is a large difference in the magnitude of As concentrations between JCL and BL. In sediment cores 1 and 2 from BL, As is in the range 8-25 and 12-23 $\mu\text{g/g}$, respectively. However, in JCL cores 3 and 10, As values lie in the ranges of 78-229 and 93-574 $\mu\text{g/g}$, respectively. By far the dominant phases of As in BL sediment cores are phases 2 and 3 where amorphous Fe and Mn (oxides and oxyhydroxides) and crystalline Fe are preferentially extracted. However, As in JCL is held mainly in phases 3 and 4 (largely sulphides), with 2 being the next most significant. Arsenic values in phase 1 are greater in core 10 (1-15 $\mu\text{g/g}$) than in 3 (0.9-11 $\mu\text{g/g}$). These profiles follow closely those for Fe, with marked depletion at the sediment-water interface.

A large spike (342 $\mu\text{g/g}$ compared to <30 $\mu\text{g/g}$) is present for phase 2 As at 4-6 cm in core 10 and has been confirmed by separate 'total' analysis. A much more subdued high at this depth is shown for core 3. Arsenic tends to be greater in phase 3 in the upper 6 cm of both JCL cores, ranging from 63 to 115 $\mu\text{g/g}$ in core 3 and from 62 to 110 $\mu\text{g/g}$ in core 10.

Profiles in cores 3 and 10 of phase 4 As are distinctly different. Only 3 $\mu\text{g/g}$ was found in this phase at the surface of core 3; this increases with depth to a maximum of 71 $\mu\text{g/g}$ at 8-10 cm and then decreases to 18 $\mu\text{g/g}$ at 18-20 cm. However, in core 10

there are two maxima: at 4-6 cm (116 $\mu\text{g/g}$) and at 12-14 cm (159 $\mu\text{g/g}$). The mean value for phase 4 As below 4 cm is 41 ± 19 $\mu\text{g/g}$ for core 3 and 105 ± 38 $\mu\text{g/g}$ for core 10.

Arsenic in the residual portion extracted with $\text{HF-HClO}_4\text{-HNO}_3$, phase 5, is low at 1 to 4 $\mu\text{g/g}$ in both cores 3 and 10, though the enhancement typical of core 10 at 4-6 cm is visible. There is a similarity between As and Fe in cores 3 and 10, most notably in the latter core for phases 3, 4 and 5. Profiles for core 3 tend to be gradual while those for core 10 are more irregular with significant increase at 4-6 cm.

Cobalt (Figure 3.22)

Total Co concentrations for all cores are low, at about 20-40 $\mu\text{g/g}$, with the greatest single contribution in all cases coming from phase 2, the fraction associated with Fe/Mn oxyhydroxides. Cobalt in phases 4 and 5 in particular is close to the detection limit of 1 $\mu\text{g/g}$. However, one feature distinguishes JCL core 10 from the others. The profiles for this core again show the positive anomaly at 4-6 cm; this was confirmed by independent 'total' analysis separate from application of the sequential scheme (46 vs. 42 $\mu\text{g/g}$). Unlike the other phases in core 10, phase 2 indicates an enrichment in the top 6 cm.

Figure 3.21. Distribution of As in sediments from JCL (legends as in Figure 3.19)

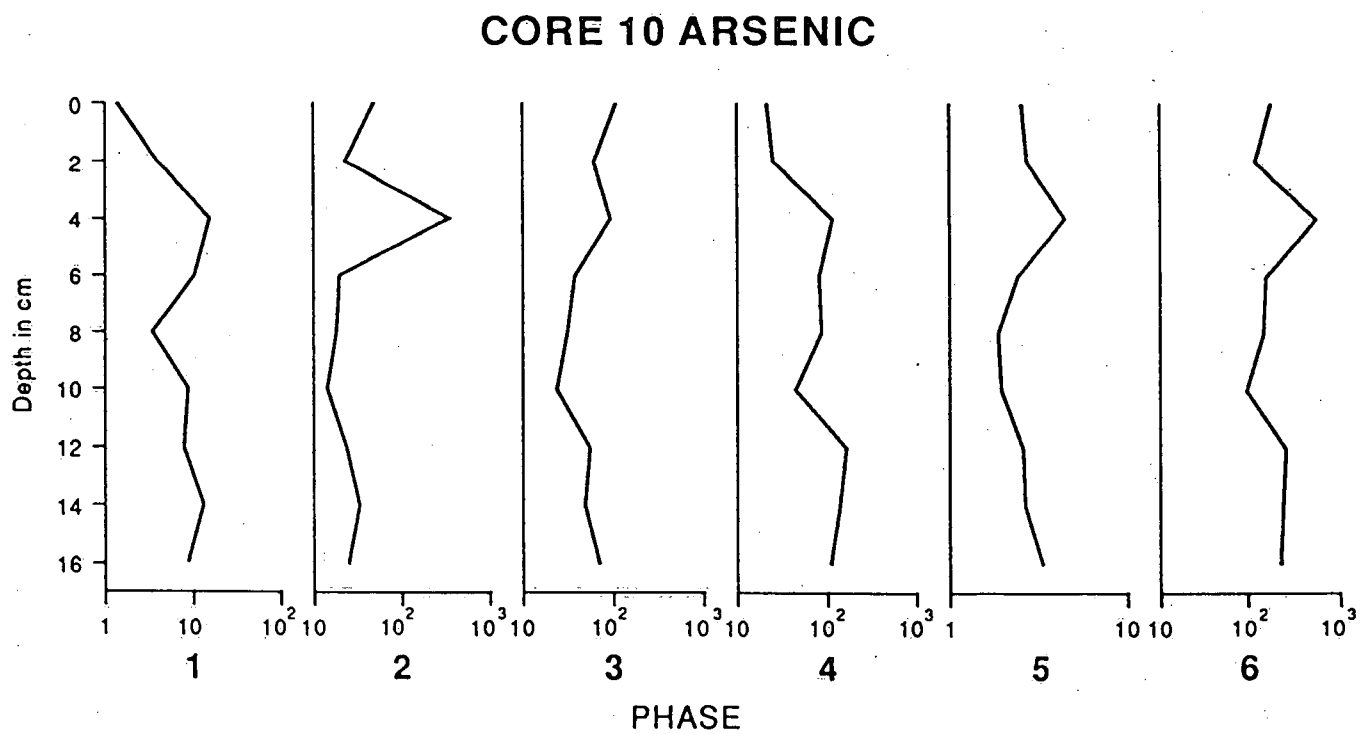
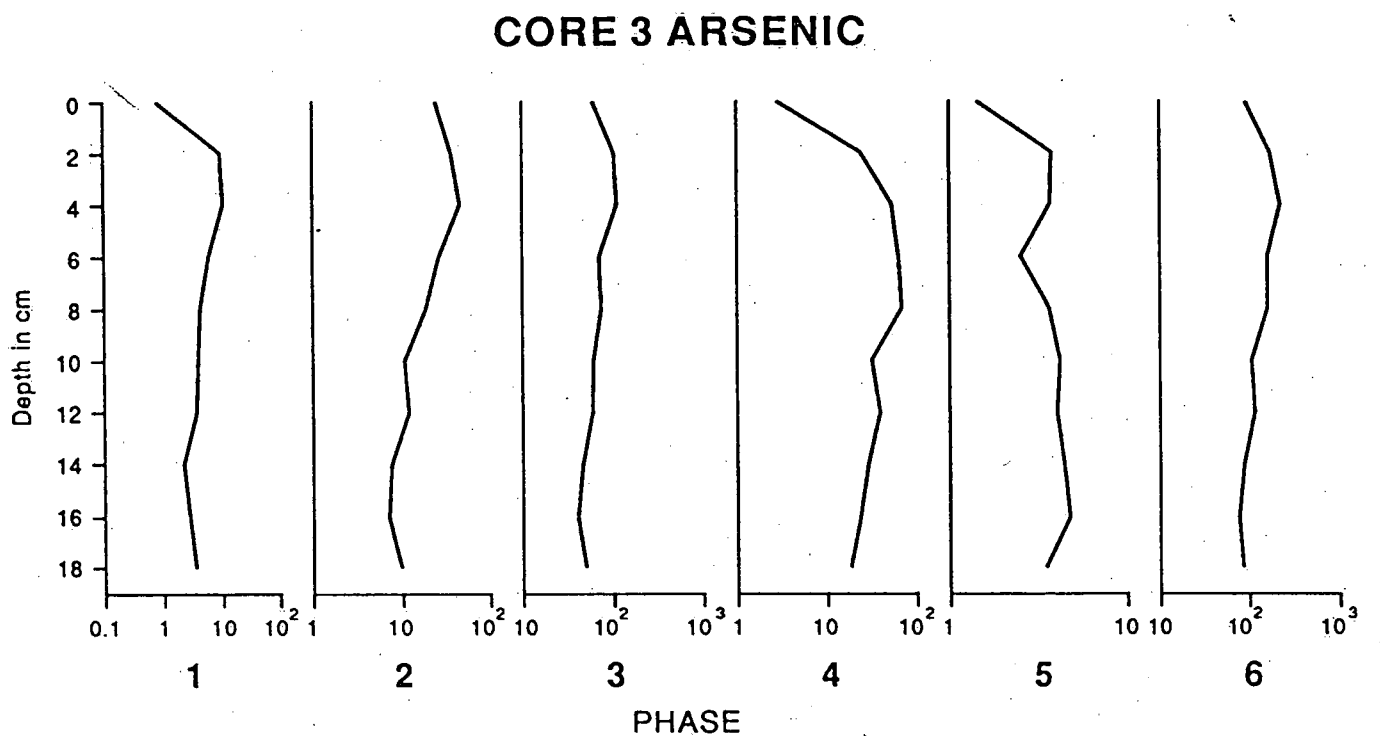
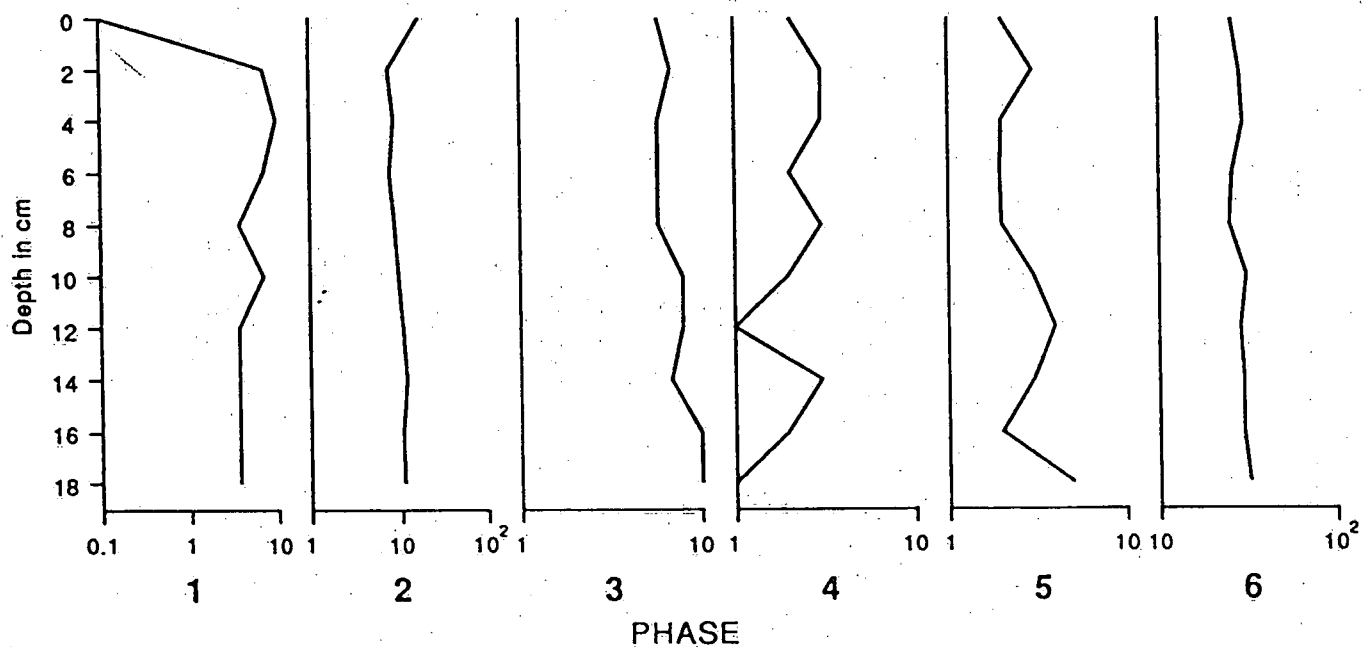
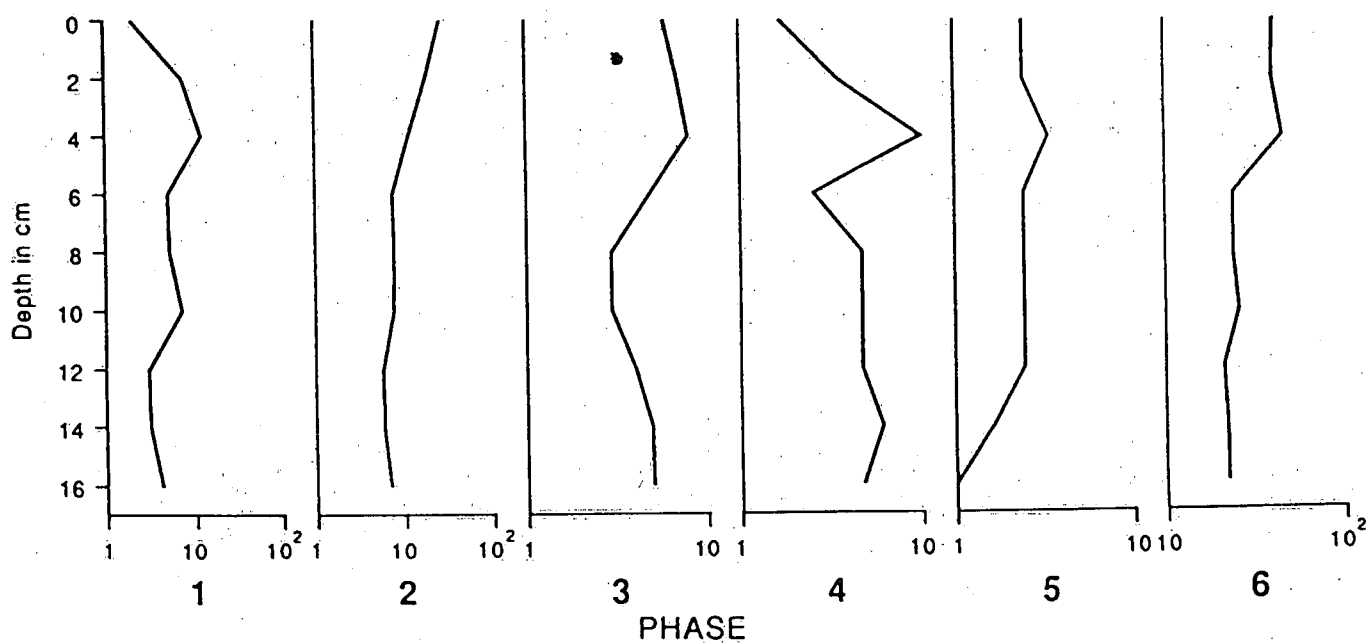


Figure 3.22. Distribution of Co in sediments from JCL (legends as in Figure 3.19)

CORE 3 COBALT



CORE 10 COBALT



Nickel (Figure 3.23)

Nickel is enriched in both JCL cores, particularly in core 10, compared to BL where it ranges from 60 to 80 $\mu\text{g/g}$. Total Ni concentrations are consistent in core 3, fluctuating from 89 to 123 $\mu\text{g/g}$ with no visible trends. However, total Ni is as high as 426 $\mu\text{g/g}$ at 4-6 cm in core 10, falling to a rather inconspicuous minimum of 76 $\mu\text{g/g}$ at 12-14 cm. Nickel is relatively evenly distributed in the BL cores amongst the five phases, with phase 4 (sulphides) containing the least. However, it is the phase 4 Ni in core 10 samples which cause that core to be anomalous. Nickel concentrations here are 66, 131 and 305 $\mu\text{g/g}$, respectively, in the first three segments from the sediment-water interface. More subtle anomalies persist for Ni at 4-6 cm in phases 3 and 5. A second anomaly at 10-12 cm in core 10 is evident for Ni in phases 1, 4 and 5 as is the case for Mn. Profiles in both JCL cores are similar for Ni and Co.

Copper (Figure 3.24)

Total Cu is only slightly higher in JCL cores than in BL cores. Copper fluctuates from 28 to 47 $\mu\text{g/g}$ in core 1 of BL, and from 54 to 63 $\mu\text{g/g}$ in core 2. Total Cu is in the range 88-108 $\mu\text{g/g}$ in core 3 of JCL and 67-79 $\mu\text{g/g}$ in core 10. Phases 2 and 3 Cu are the major components in the all cores but labile Cu in phase 1 becomes significant in JCL core 3 (unlike Bowron). A positive anomaly is seen at 4-6 cm in core 10 for Cu in all phases, and is particularly striking in phase 4 (sulphides/organics). Once again,

Figure 3.23. Distribution of Ni in sediments from JCL (legends as in Figure 3.19).

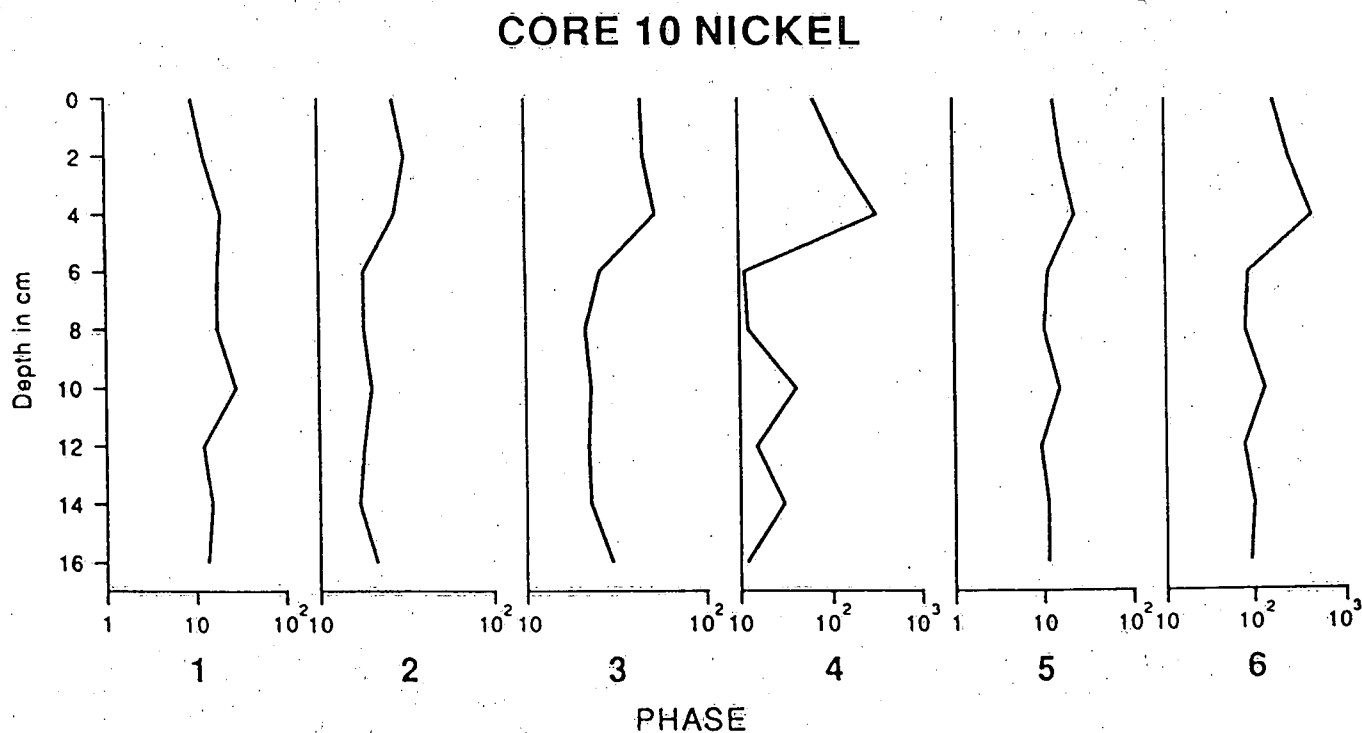
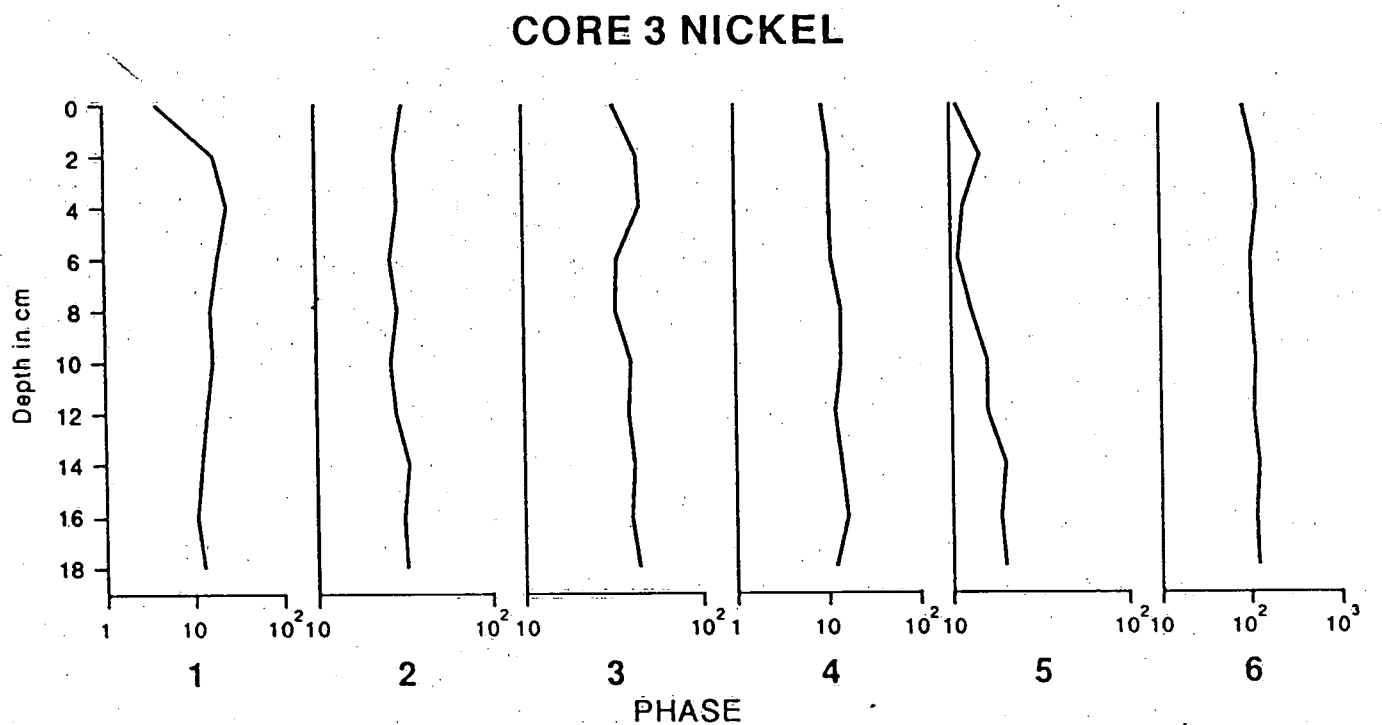
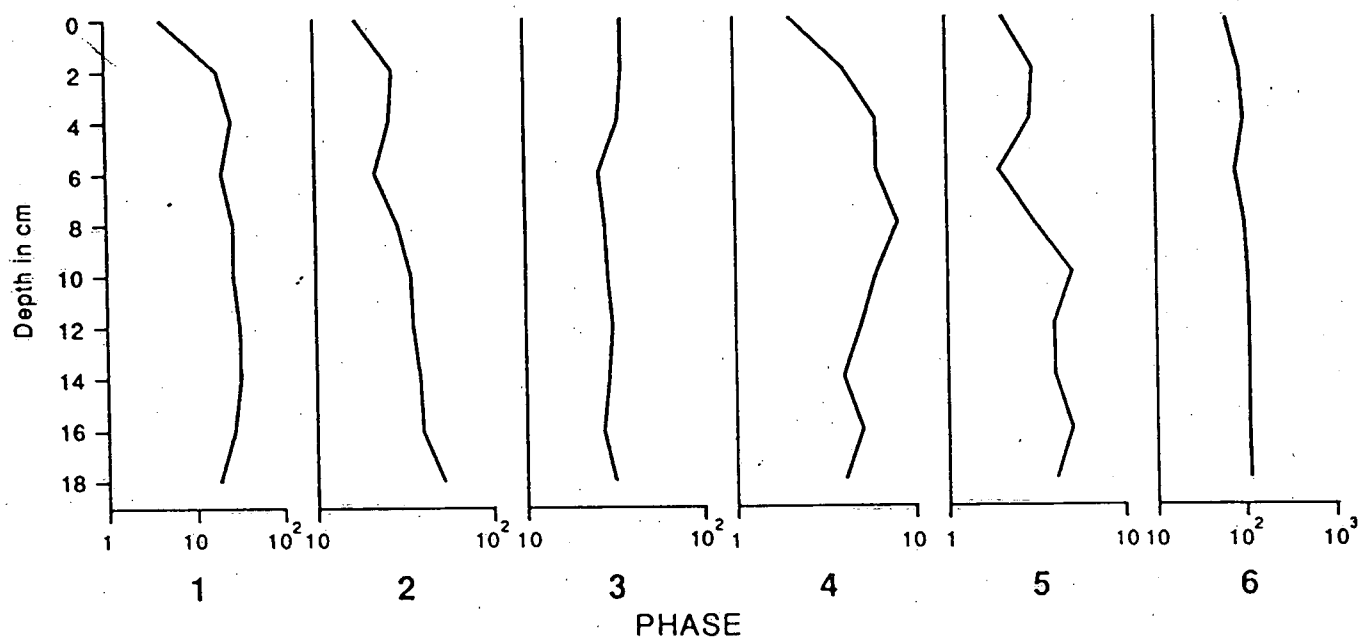
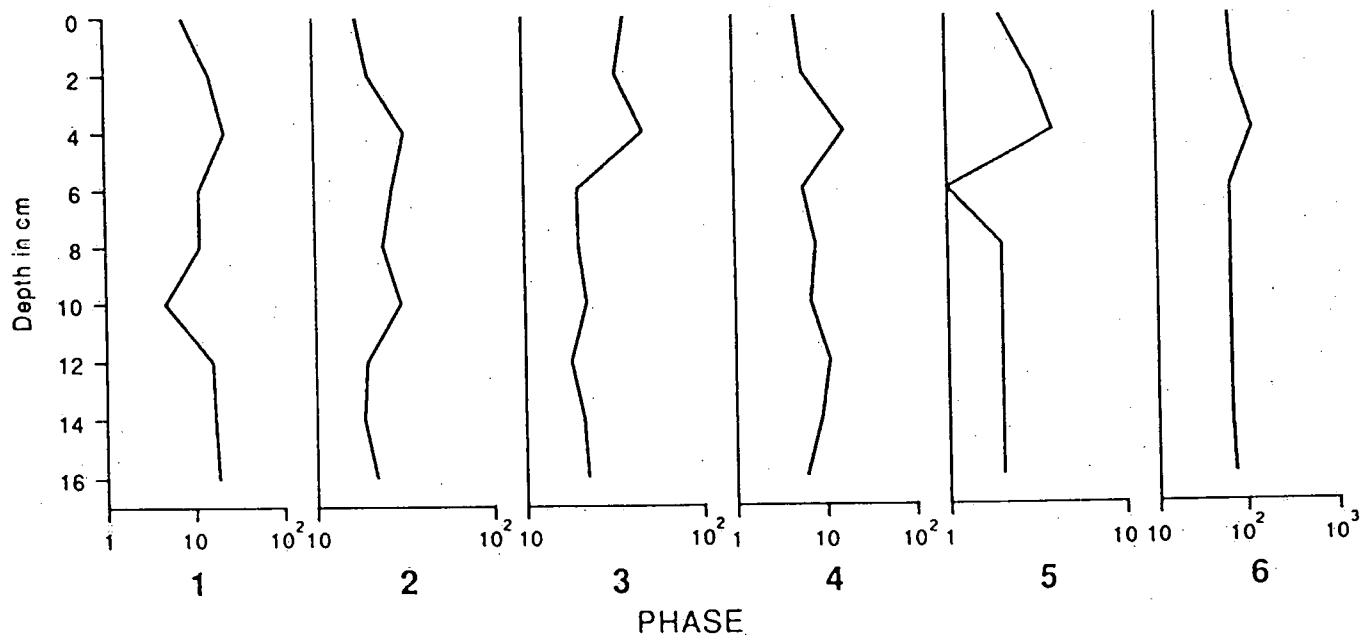


Figure 3.24. Distribution of Cu in sediments from JCL (legends as in Figure 3.19)

CORE 3 COPPER



CORE 10 COPPER

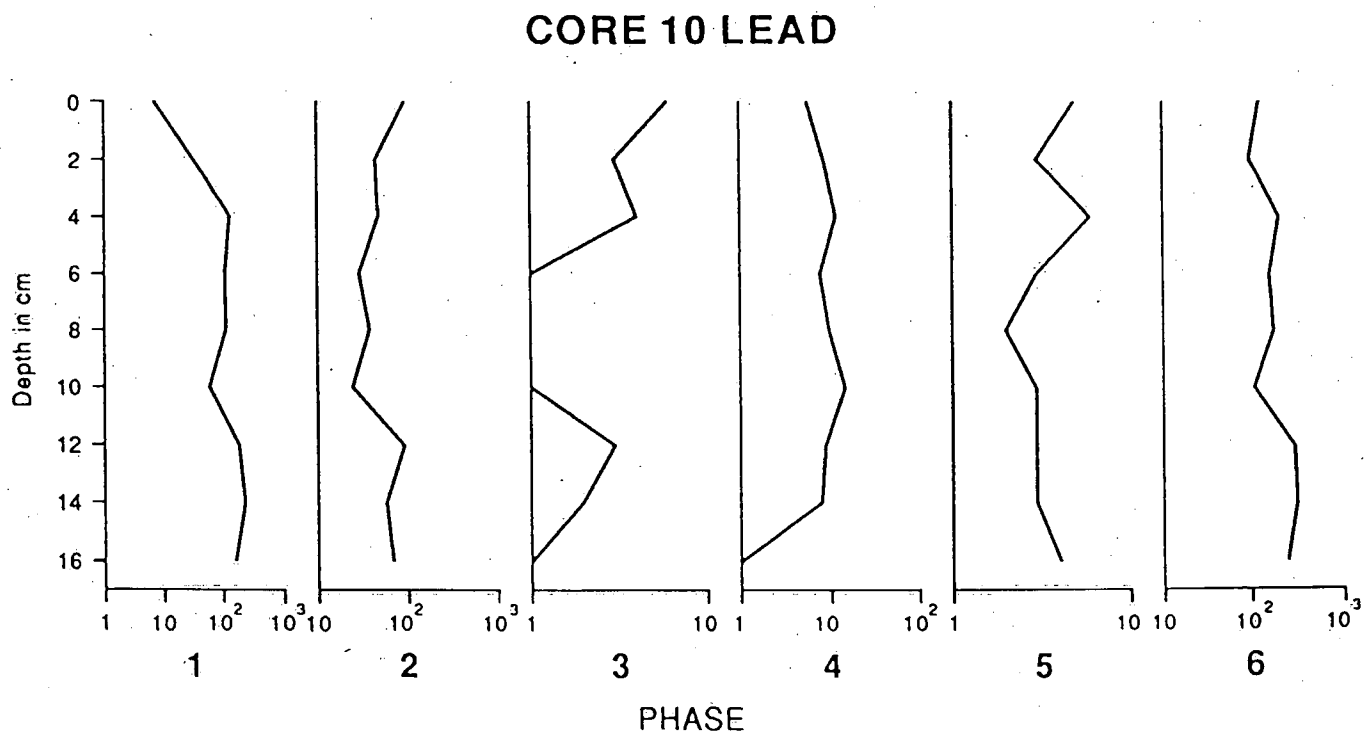
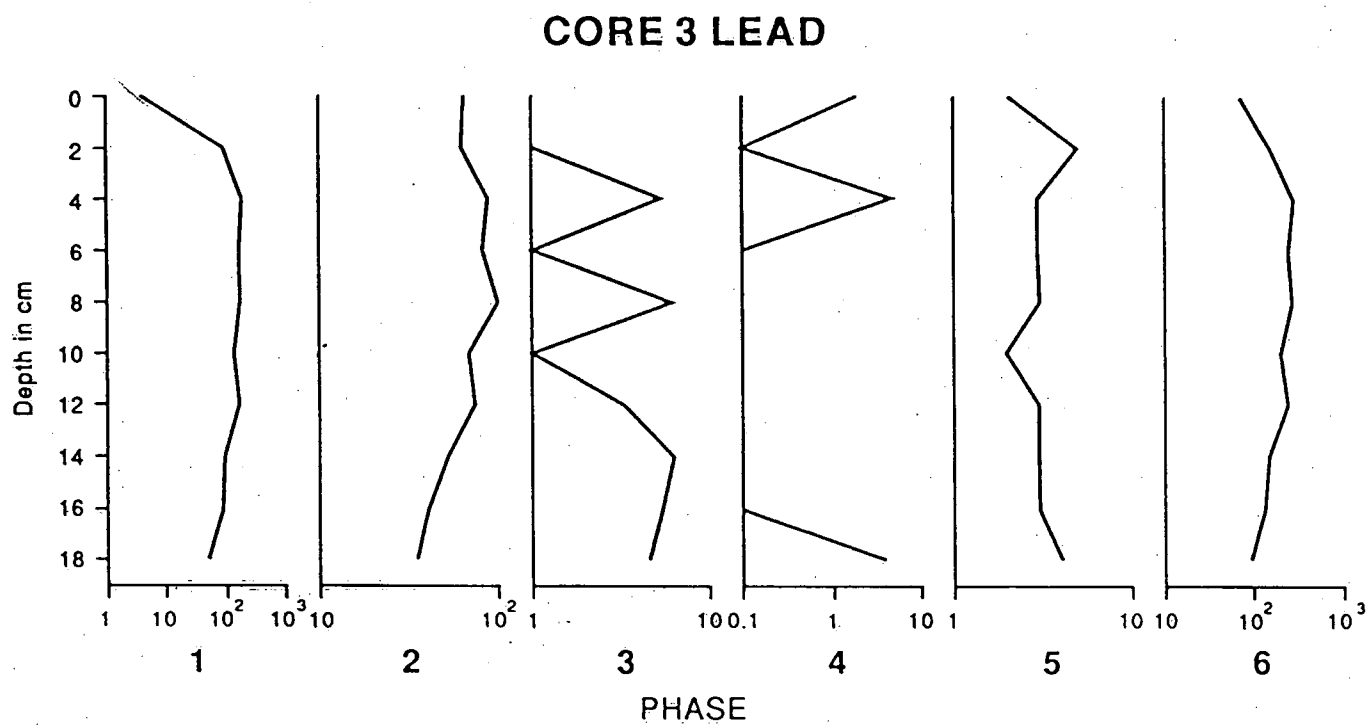


this increase was independently verified by the direct HF based analysis (125 vs 99 $\mu\text{g/g}$). A depletion in Cu in core 3 at 6-8 cm is seen for most phases, similar to Fe, Co and phase 5 for As.

Lead (Figure 3.25)

Lead contents of both Bowron cores are relatively low, at 9-20 $\mu\text{g/g}$ in core 1 and 19-30 $\mu\text{g/g}$ in core 2. Total Pb is much higher in the JCL cores, in the range 71-281 $\mu\text{g/g}$ in core 3 and 95-296 $\mu\text{g/g}$ in core 10. By far the most dominant phases containing Pb in these cores are 1 and 2, suggesting labile forms of the element. With a few exceptions in core 10, Pb levels in phases 3, 4 and 5 are below 5 $\mu\text{g/g}$. The uncharacteristic 'noise' shown in phases 3, 4 and 5 in core 3 is due to data too close to the detection limit (1 $\mu\text{g/g}$). Strong depletion of Pb in phase 1 in the surface sediment is evident for both cores. Phase 1 Pb tends to be higher in the upper portion of core 3 than it is in core 10 but the reverse then occurs below about 12 cm. This pattern reversal between cores also occurs for phase 2 Pb. This behaviour is reflected then in total Pb where Pb levels are greater in the upper 12-14 cm of core 3 than core 10 and lower below this depth.

Figure 3.25. Distribution of Pb in sediments from JCL (legends as in Figure 3.19)



Zinc (Figure 3.26)

Zinc levels in JCL are significantly greater than in BL. Total Zn lies in the range 71-118 $\mu\text{g/g}$ in core 1 and 108-156 $\mu\text{g/g}$ in core 2, mostly contributed from phases 2, 3 and 5. However, Zn concentrations in JCL range from 199 to 544 $\mu\text{g/g}$ in core 3 and from 228 to 397 $\mu\text{g/g}$ in core 10. The increase in levels is due predominantly to Zn held in labile phases 1 and 2, rather than in sulphides or silicates in phases 4 and 5. Both cores show dramatic depletion of Zn in phase 1 at the surface. Profiles for Zn in core 3 are relatively smooth, with the exception of the positive anomaly present at 4-6 cm in phases 1 and 2. This gives rise to a high total Zn of 544 $\mu\text{g/g}$ at this depth, a value verified by direct analysis of a sub-sample following the HF attack (549 $\mu\text{g/g}$ Zn). Interestingly, the high at 4-6 cm in core 10 is due to increases in the non-labile forms of Zn in phases 3, 4 and 5. This results in a high total Zn at 4-6 cm of 388 $\mu\text{g/g}$ (cf. 402 $\mu\text{g/g}$ by the HF attack on a sub-sample). The upper 12 cm of core 3 tend to be more concentrated in Zn than that part of core 10, similar to the pattern for Pb.

Our interpretation of these data must, of course, be regarded as tentative owing to the absence of information on subjects such as sediment stratigraphy, the hydrological history of JCL, dates of core horizons, and pore water data. The salient features of the observations mentioned above are as follows:

Figure 3.26. Distribution of Zn in sediments from JCL (legends as in Figure 3.19)

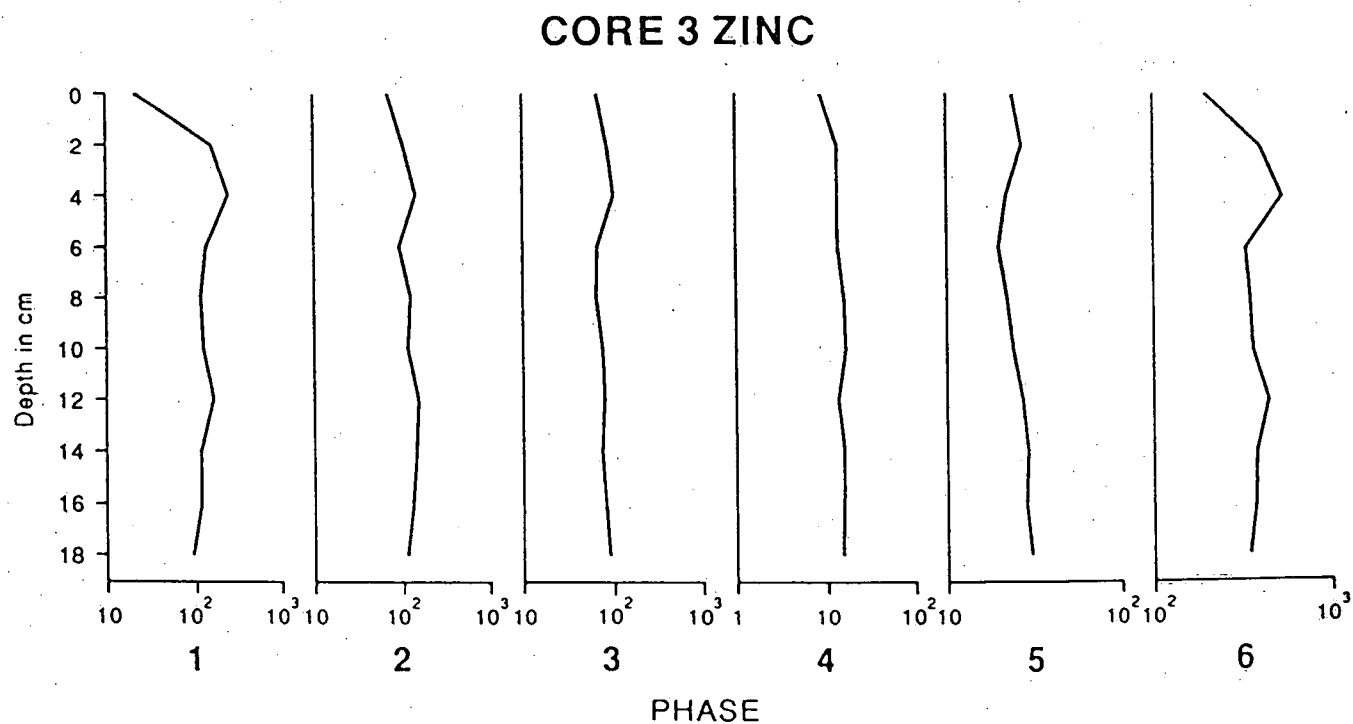
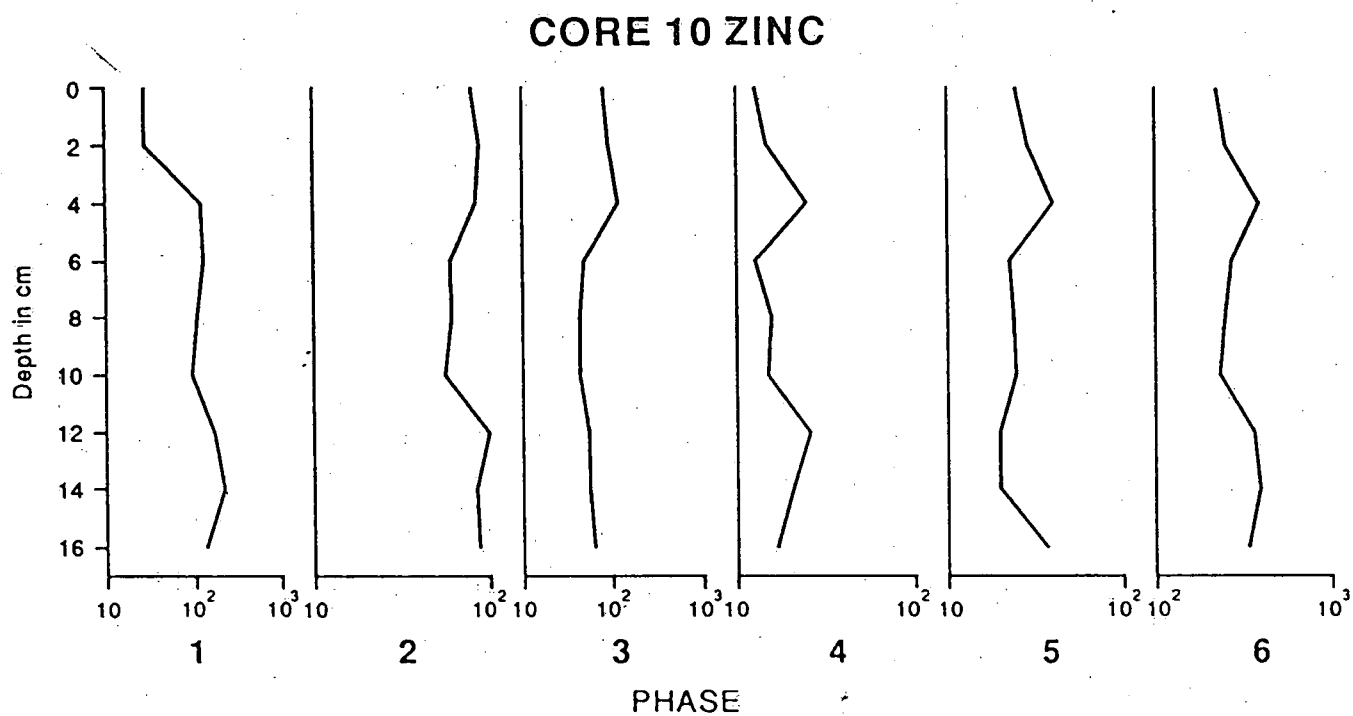


Figure 3.27. Phase distribution of elements with depth in core 3 (legends as in Figure 3.19)

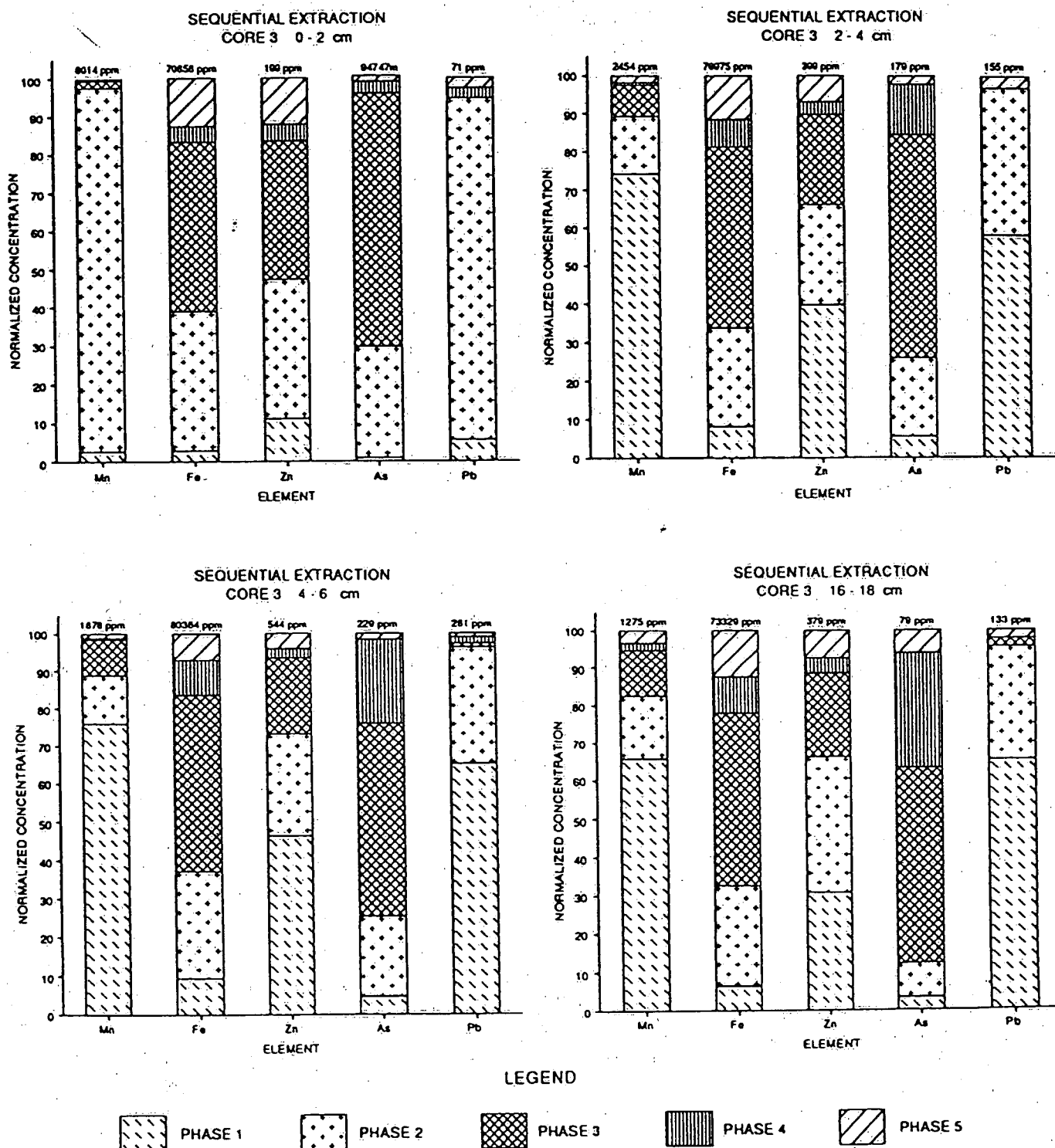
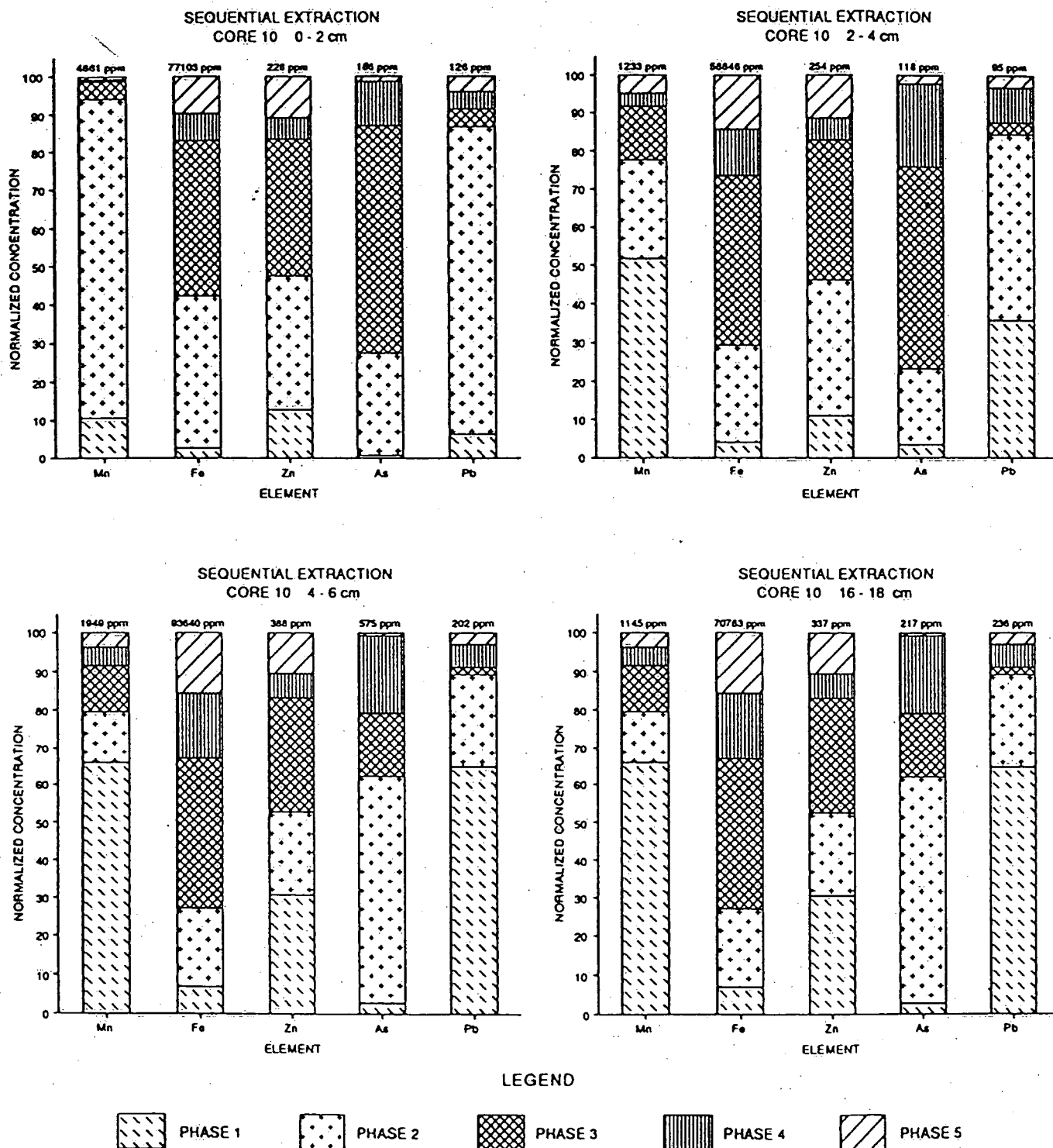


Figure 3.28. Phase distribution of elements with depth in core 10
(legends as in Figure 3.19)



In Core 3:

- Most profiles are smooth and consistent with depth except where elemental concentrations are very close to detection limits;
- Profiles for Fe, As, Cu, Ni and Co are broadly similar;
- Total Zn and As show maxima (544 and 229 $\mu\text{g/g}$) at 4-6 cm due mainly to enhancement in the labile forms for Zn, and to all forms of As but particularly to phase 3 (crystalline Fe oxides);
- An enhancement in Pb exists from 4 to 14 cm (predominantly phase 1)

In Core 10:

- a distinct maximum in total Fe, As, Ni, Zn and Cu at 4-6 cm;
- For Fe, this is due in decreasing order to phases 3, 4 and 5 (i.e. non-labile);
- For As, this is due in decreasing order to phases 2<3<4<1 and 5;
- For Ni, this is due to phase 4 and, to a much lesser extent, 3;
- For Zn, this is due in decreasing order to phases 3, 4 and 5 (i.e. non-labile);
- For Cu, this is due in decreasing order to phases 3, 4 and 1;
- Profiles are broadly similar for Fe, As, Cu, Ni and Co;
- Below 12 cm depth, there are elevated levels of phase 1 and 2 Zn, phase 1 and 2 Pb, and phases 4 and 3 As;

With reference to both JCL cores

- All elements show a depletion at surface in the adsorbed-exchangeable-carbonate phase;
- Mn is extremely elevated in the oxic surface layer in phase 2 (precipitated Mn oxides) of all four cores;

-Both cores are enriched in As and Pb compared to Bowron sediments by an order of magnitude;

-JCL cores with respect to BL cores are generally about 2-3 fold higher in total Zn, slightly elevated in Cu and Ni, and equivalent in Co, Mn and Fe (though phase distribution is much different).

The distribution of metals in cores 10 and 3 are ranked from high to low concentration in Table 3.12.

3.3. Biota

3.3.1. Microbial Populations

The results (Tables 3.13 to 15) showed clear evidence of environmental and biological effects of the tailings deposited at the northeast end of JCL. All microbial activities tended to become increasingly intense with distance away from the northeast end of the lake and were most significant at the southwest end (furthest from the tailings) or in BL (Table 3.13), whereas the concentrations of CaCl_2 -extractable Cu and DTPA-extractable Pb (but not total Cu and total Pb) decreased with distance from the tailings and were lowest at the southwest end of JCL and in BL (Table 3.14). Similarly, the least polluted sediments had the highest concentrations of organic matter, the highest pH values, the highest moisture content and relatively high organic matter content (expressed in Table 3.15 as loss on ignition), the highest humic content ($A_{465\text{nm}}/\text{g}$), and the highest concentrations of $\text{NH}_2\text{OH}\cdot\text{HCl}$ -extractable Fe (poorly crystallised Fe oxyhydroxide) and

Table 3.12. Order of elemental concentration (high to low) by phase in cores 3 and 10 of JCL

Element	Concentration in Core 3				
	(high)----->(low)				
Fe	3	2	5	4	1
Mn	1	2	3	5	4
As	3	4	2	5	1
Cu	3	2	1	4	5
Ni	3	2	5	1	4
Co	2	3	1	5	4
Pb	1	2	5	3	4
Zn	1	2	3	5	4

Element	Concentration in Core 10				
	(high)----->(low)				
Fe	3	2	4	5	1
Mn	1	2	3	5	4
As	4	3	2	1	5
Cu	3	2	1	4	5
Ni	3	2	4	5	1
Co	2	4	3	1	5
Pb	1	2	4	5	3
Zn	1	2	3	5	4

Table 3.13. Measurements of microbial activities in sediment samples from Jack of Clubs Lake (JCL) and Bowron Lake (BL) arranged in the expected order of decreasing severity of pollution. The data are means and ranges for 2-6 replicate values.

Sampling site	Alkaline phosphatase activity (units/g/h)	Total dehydrogenase activity ($\mu\text{mol/g/h}$)	CO ₂ produced by day 10 ($\mu\text{mol/g}$) under He	N ₂ O produced by day 10 ($\mu\text{mol/g}$) under He + acetylene
JCL-4	0.16 (0.14-0.18)	52.5 (51.16-53.25)	4.78 (4.76-4.81)	4.03 (3.79-4.26)
JCL-9	0.28 (0.24-0.32)	125.3 (115.0-135.7)	4.74 (4.51-4.96)	6.66 (6.57-6.75)
JCL-1	0.61 (0.43-0.77)	182.5 (181.2-183.8)	9.67 (9.98-9.35)	35.48 (33.82-37.13)
BL	1.24 (1.00-1.46)	205.9 (205.7-206.1)	10.38 (8.627-12.13)	25.64 (25.04-26.24)

Table 3.14. CaCl_2 -extractable Cu, DTPA-extractable Pb, and total Cu and Pb concentrations in sediment samples from Jack of Clubs Lake (JCL) and Bowron Lake (BL) arranged in the expected order of decreasing severity of pollution. The data are the means of 2-4 replicate values.

Sampling site	CaCl_2 -extractable Cu ($\mu\text{g/g}$)	DTPA-extractable Pb ($\mu\text{g/g}$)	Total Cu ($\mu\text{g/g}$)	Total Pb ($\mu\text{g/g}$)
JCL-4	0.174	1.58	57.2	141
JCL-9	0.086	1.63	100.9	144
JCL-1	0.0785	0.4895	83.3	171
BL	0.0585	0.680	81.9	83.5

Table 3.15. Various data characterising the sediment samples from Jack of Clubs Lake (JCL) and Bowron Lake (BL) arranged in the expected order of decreasing severity of pollution. Except for the pH data for JCL, which are single readings, all values are means of 2-4 replicate values.

Sampling site	Loss on ignition (%)	pH	$A_{465\text{nm}}/\text{g}$	$A_{465\text{nm}}/A_{665\text{nm}}$	$\text{NH}_4\text{OH}\cdot\text{HCl}$ -extractable Fe (mg/g)	NaOH-extractable Fe (mg/g)
JCL-4	4.05	6.55	0.0375	8.27	0.714	0.047
JCL-9	5.7	6.6	0.101	7.22	1.795	0.125
JCL-1	10.35	6.7	0.272	6.97	4.44	1.60
BL	15.6	6.8	0.319	6.32	6.51	1.21

NaOH-extractable ("humic") Fe (Table 3.15). (Note that the total Pb content of the sediments in JCL, in contrast to the DTPA-extractable Pb fraction, increased with distance from the tailings.) Moreover, the humic matter at the least contaminated sites had the lowest values for the $A_{465\text{nm}}/A_{665\text{nm}}$ ratio (Table 3.15), indicating a relatively high proportion of humic to fulvic acids - in other words, a high degree of maturity, which implies relatively intense microbially mediated humification of decomposing organic matter. It is worth emphasising that the biochemical activities of microbes correlated inversely with the concentrations of "bio-available" Cu and Pb species in the sediment but were independent of the total Cu and Pb concentrations.

The data thus far obtained clearly demonstrate that a wide range of microbial activities, including heterotrophic CO_2 production, denitrification, biochemical reactions catalysed by alkaline phosphatase and dehydrogenase, and the process of humification, tend to be suppressed as a result of environmental degradation caused by the tailings deposited in JCL. The cause-and-effect relations are as yet uncertain, but further research, now in progress, may help to clarify the underlying mechanisms. Meanwhile, the available information suggests at least four by no means mutually exclusive working hypotheses which, singly or in combination, could account for the observed relationships:

(1) Weakly bound, and therefore biochemically reactive, Cu and Pb species inhibit enzyme-catalysed biochemical reactions of microbes. Possibly the tailings influenced the availability of the heavy metals by altering the composition, the physicochemical environment, and the biota of the sediments. The fact that the decrease in the abundance of bio-available metal species with distance from the source of pollution is accompanied by an increase in the abundance of Fe oxyhydroxide and humic matter is consistent with the possibility that the binding of Cu and Pb by oxyhydroxides and humic matter renders these metals less available, and therefore less toxic, to microbes. Also note that phosphatase and dehydrogenase showed much stronger inverse correlations with CaCl_2 -extractable Cu than with DTPA-extractable Pb, whereas the reverse was true in the case of denitrification and CO_2 production (Tables 3.14 and 15); this suggests that different bio-available metal fractions have specific or preferential effects on particular biochemical pathways of microbes in sediments.

(2) Mineral detritus from the tailings diminishes microbial activity by diluting the concentrations of organic nutrient substrates in the sediments and by hindering the exchange of nutrients and metabolic wastes between the sediment surface and the water. This explanation invoking purely physical effects is consistent with the fact that the sediments laid down closest to the accumulation of tailings had the lowest organic content (as indicated by their low moisture content and low $A_{465\text{nm}}$ values per

unit weight). On the other hand, the low organic content could reflect inhibition of biological activity by toxic effects of metals, as postulated in section (1), above.

(3) Inhibition of microbes by tailings is due to H^+ ions generated during oxidation of sulfides in the tailings under aerobic conditions. Lowering of the ambient pH could render metals such as Cu and Pb more soluble and consequently more toxic, thus contributing to the process outlined in paragraph (1), above, and other indirect effects are conceivable. However, a significant toxic effect of pH lowering is unlikely, because all pH values were close to neutrality (between 6.5 and 6.8) and varied by only a few tenths of a pH unit throughout the field area. Besides, the observed pH variance could well be an effect, not a cause, of the inhibition of microbes by the tailings. According to this alternate hypothesis, microbial activity was most vigorous in environments unaffected or only slightly affected by tailings, and this activity, in turn, caused the sediment pH to rise to a small but measurable extent with decreasing severity of pollution.

(4) The inhibition of plankton and other higher orders of aquatic life by the tailings depressed microbial activity by depriving heterotrophic microbes of organic nutrient substrates.

In conclusion, there is strong evidence that the contamination of JCL by mine tailings has inhibited a wide spectrum of microbial activities in the bottom sediments of the lake. The most probable mechanisms of inhibition are the poisoning of enzymes by certain bio-available species of Cu and Pb (possibly aggravated slightly by a small reduction in the sediment pH), the dilution of organic nutrient substrates and smothering of microbes by mineral detritus from the tailings, and partial suppression of the production of organic nutrient substrates owing to inhibition of plankton and other aquatic organisms. The cause of the observed inhibition of sedimentary microbes has not been determined with certainty, but it could any one of these phenomena or a combination of them.

3.3.2. Benthic Organisms and Toxicity Bioassays

Metal concentrations in invertebrates from the abandoned tailings

The concentrations of metals in invertebrates collected in the tailings are presented in Table 3.16. In general, the metal levels are comparable to reported values from macroinvertebrates from heavily contaminated environments (Besser and Rabeni, 1987; Burrows and Whitton, 1983; Dixit and Witcomb, 1983; Riedel et al., 1989; Wentzel et al., 1977). However, the As, Cd and Cu levels (721, 25 and 301 $\mu\text{g/g}$, respectively) are significantly higher than those commonly reported in the literature. The metal bioaccumulation (metal in the organism/metal in sediments) by the invertebrates

varies from 0.13 for Mn to 10.4 for Cu. The highest bioaccumulation factors were for Cd, Cu, Cr and Zn.

It is well known that invertebrate organisms can dramatically increase the flux of toxic substances (Aller and Yingst, 1985; Besser and Rabeni, 1987; Frithsen, 1984; Langston, 1980; Riedel et al., 1989). Usually by two main routes, one is by enhancing the release of the substance, and second is direct incorporation and subsequent food chain transfer. The high metal concentrations observed in the invertebrates suggested that they may play an important role in the mobilization of the metals in the tailings. The differences in the bioaccumulation factors may reflect variations in the physico-chemical behaviour of these metals that affect their availability to invertebrates. However, further research is needed in order to determine the role of the different species (size and mode of activity) of benthic invertebrates in the accumulation and transport of metals released from the tailings.

Initial Observations - Benthic Invertebrate Community Structure

This initial examination of the attached data is largely based on qualitative observations and should be treated as such. Note that two sampling devices were used because of difficulties with equipment. However, at two stations both devices were used and in addition a corer was used, for purposes of comparison.

Table 3.16. Metal concentration in Invertebrate samples from the tailings of Wells B.C. (mg/kg dry weight)

	As	Zn	Pb	Cd	Co	Ni	Mn	Fe	Cr	Cu
Invert.-a(*)	288	456	764	36.1	23.0	62.4	1088	29060	23.0	10.7
Invert.-b(*)	961	1514	404	18.7	24.3	79.7	2553	114159	75.7	583.9
Hirudinoidea	915	521	137	20.1	33.8	54.2	1040	71769	116.5	309.6
Average	721	830	435	25.0	27.0	65.4	1553	71663	71.7	301.4
s.d.	307	484	257	7.9	4.8	10.6	707	34742	38.3	234.1
Sediment	903	303	467	3.9	36	43	11670	150000	27	29
bioaccumulation	0.80	2.74	0.93	6.40	0.75	1.52	0.13	0.48	2.66	10.39

(*) Combined samples = major components are Chironomidae, Oligochaeta, and few Diptera

Community Composition

A total of fifteen taxa were found. However the copepods, cladocerans and ostracodes have not been considered as the sampling methods were not appropriate for these groups. Twelve taxa were considered potential indicators of adverse effects of mine tailings.

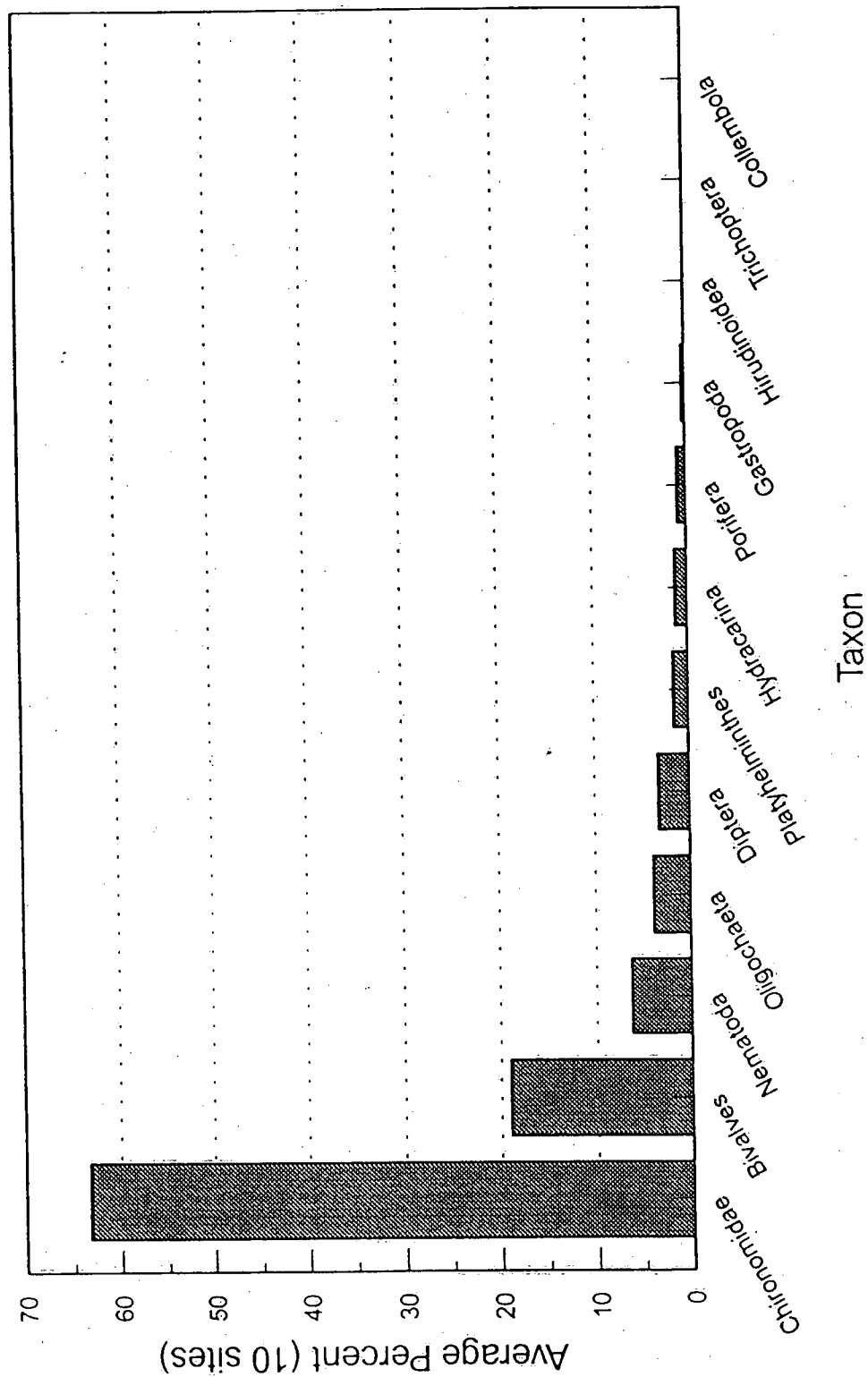
The community is dominated by the Chironomidae (midges) which comprise over 63% of the total organisms found (Figure 3.29). The next most abundant group were the bivalves, largely sphaeriidae, which made up almost 20% of the organisms; other groups were relatively rare overall. The Oligochaeta (segmented worms), which usually are an important component of the benthic community, although fourth in overall abundance, were surprisingly sparse.

Total Abundance

Station 1 is not considered truly representative, as it was the shallowest station (8 m) and was the only station where the Diptera (other than the Chironomidae) were represented. The sediment was richly organic and contained a considerable amount of plant debris. The sample taken with the Ekman had much larger numbers than the samples collected by ponar and corer (Figure 3.30); but as the Ekman sample was taken on a return visit, it is probably not from the same location as the ponar sample and core.

Figure 3.29. Components of Benthic Fauna

Jack of Clubs L. B.C.



excluded ostracods, copepods, cladocera

This may explain the difference in numbers, as the samples from station 2, where other devices were used, show much better agreement between results obtained with different samplers. The greatest density of organisms was found at station 4, the other shallow station (9.2 m); however, the relatively great total number was largely due to the fact that this station had the highest number of nematodes (37.4%). The lowest total abundance occurred at stations 2, 5, 8 and 10. Lower numbers were expected at stations 2, 8 and 10, which were the three deepest stations (33-45 m); however, station 5 was one of the shallower stations (14.5 m) and would be expected to have greater numbers of organisms (Figure 3.30).

Percent Composition at Stations

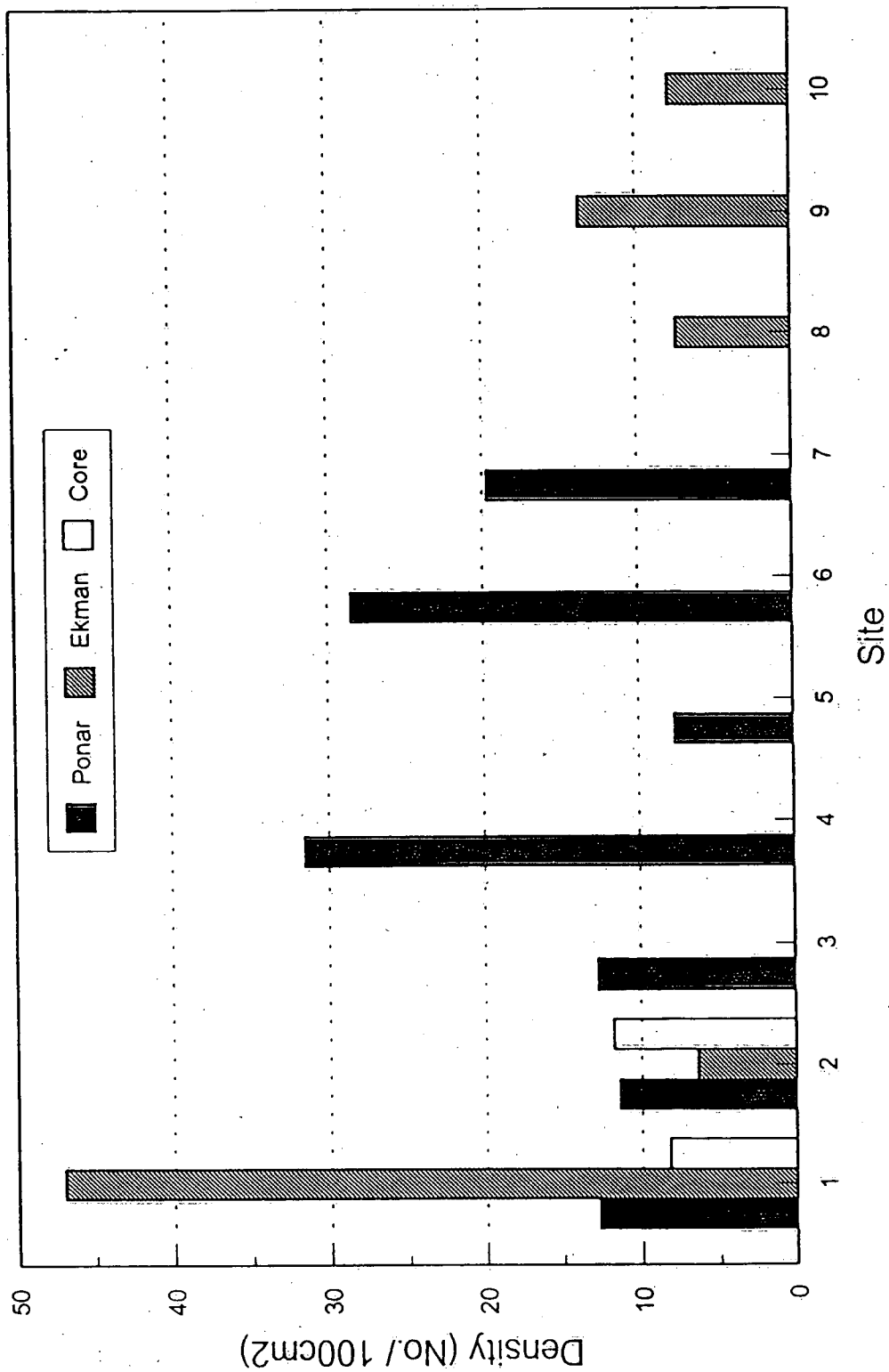
The contribution of the four most abundant taxa (Chironomidae, bivalves, Oligochaeta and Diptera) have been examined at all the stations with regard to their overall abundance (Figure 3.31). Preliminary examination of the stations using cluster analysis shows no real evidence for stations 4 and 5 being distinct (Figure 3.32).

Chironomidae

Numerically the midges are the most important group, making up from 40 (station 6) to 80% (station 2 - ponar) of the community. They show no clear trend, although their numbers are relatively low at station 5.

Figure 3.30. Total Density of Benthic Fauna

Jack of Clubs L.



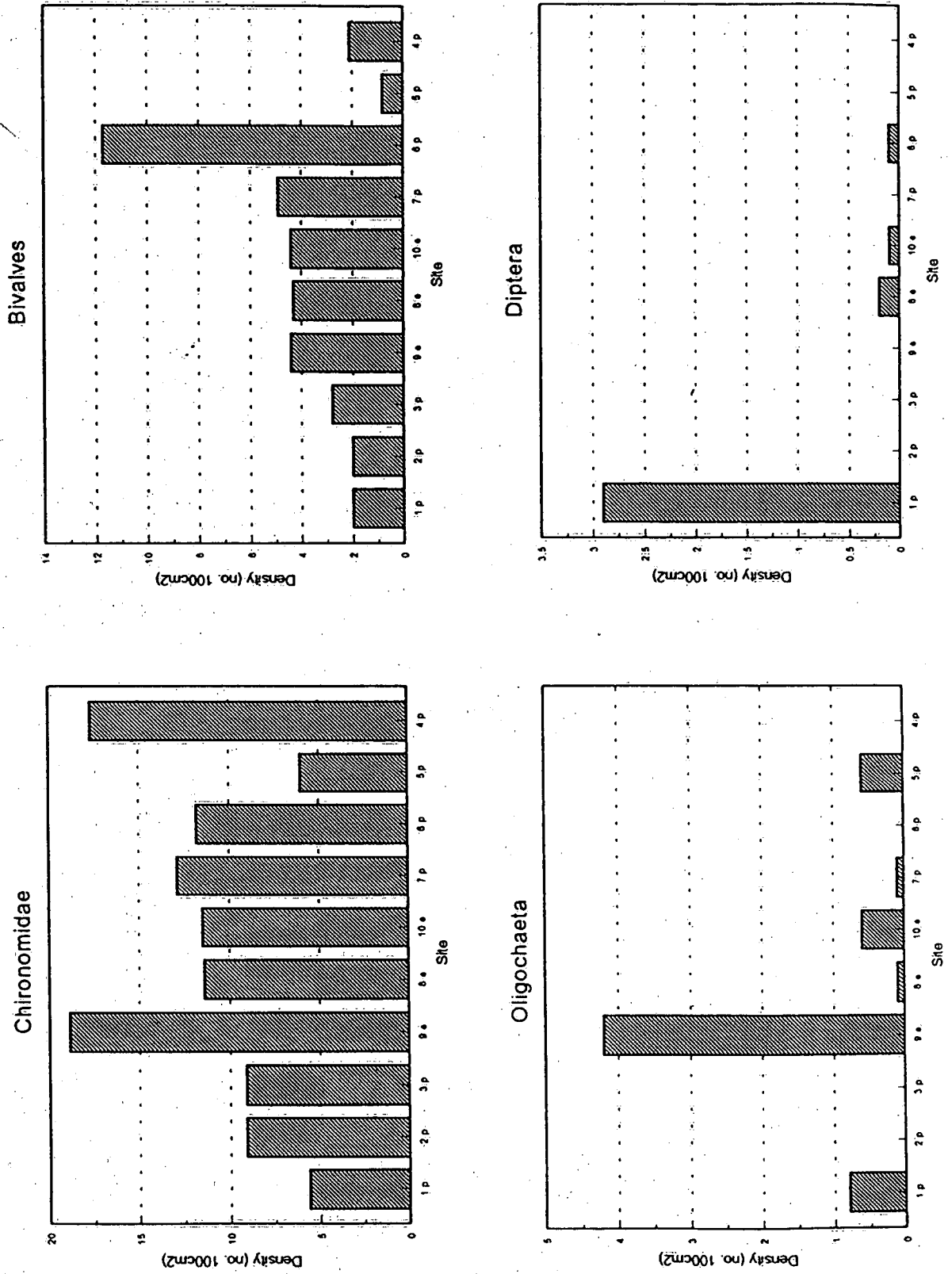
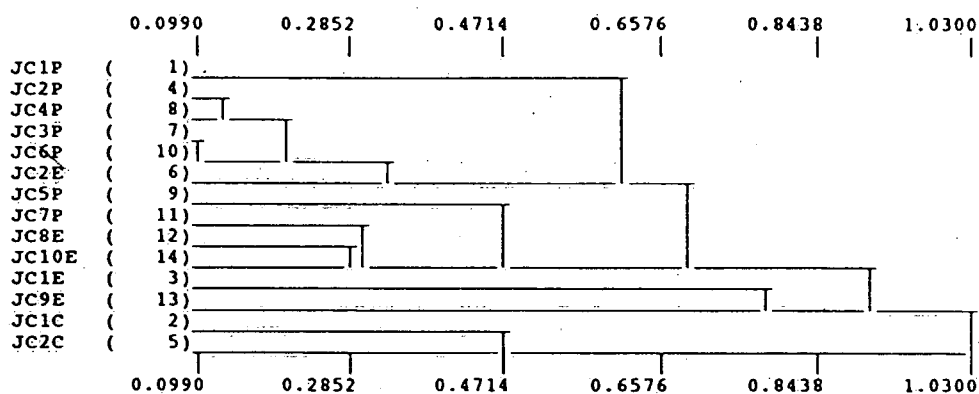
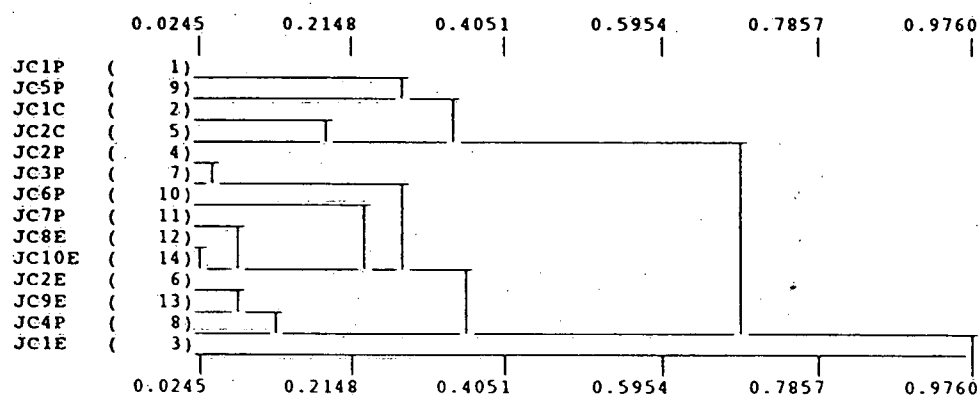


Figure 3.31. Overall abundance of the four most abundant taxa

02/02/93 10:36:56.82 DEND Jack of Clubs - mean no/sample 1992



02/02/93 10:41:38.71 DEND Jack of Clubs - mean no/100cm2 1992



02/02/93 10:51:29.04 DEND Jack of Clubs - percent 1992

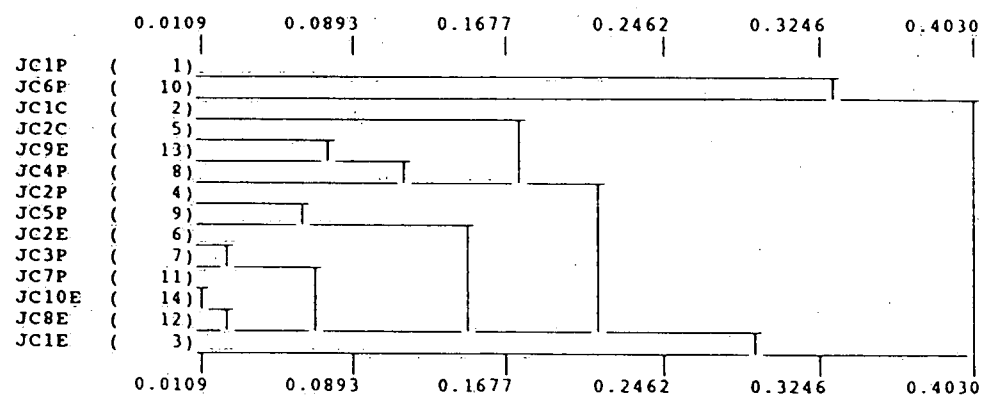


Figure 3.32. Cluster analysis of the different sampling stations of Jack of Clubs Lake

Bivalves

This group appears to be more strongly affected by the tailings, comprising the lowest proportion of the community at stations 4 and 5. Overall they make up 19% of the benthic community but are only 6.5 and 10% at stations 4 and 5 respectively, and their abundance is markedly reduced, particularly at station 5.

Oligochaeta

The oligochaete usually form a major component of the benthic fauna, but in JCL they only comprise 3.9% of the benthic community overall. Moreover, their distribution and abundance are highly variable, ranging from approx. 10% of the community at station 9 to less than 1% at station 7, and at three stations (3, 4 and 6) none were found. This group is particularly sensitive to metals, which may explain their low numbers.

Diptera

The Diptera (except chironomids) were only found at station 1. This station was unlike the other stations in that the sediment was highly organic with large amounts of vegetable debris. This is probably typical of much of the littoral zone of the lake, and arguably could be the natural condition of stations at the tailings area.

Initial Observations - Sediment Toxicity Tests

Four sediment toxicity tests were performed on samples from the ten sites as well as a clean reference sediment (Long Point - Lake Erie). The tests used and endpoints measured were (1) growth and survival in *Chironomus riparius* (midge), *Hyalella azteca* (scud) and *Hexagenia limbata* (mayfly) and (2) survival and reproduction in *Tubifex tubifex* (worm). The results are summarized in Figure 3.33 and are presented with increasing distance from the tailings toward the left of the figure. There is no evidence of acute toxicity (reduced survival) due to tailings in three of the four species, either with proximity to the tailings or in comparison with the reference material.

There is no evidence for impaired reproduction in *T. tubifex* either between sites in the lake or in comparison to the reference sediment. This is strong evidence that metals are not a concern, as this species is particularly sensitive to metal contamination. Furthermore, it addresses the absence of oligochaetes in the lake community suggesting either a geographical mechanism for their absence or interaction (competition or predation) from other organisms.

Chironomus riparius shows no evidence of acute toxicity, which is in agreement with the relative importance of this family in JCL. Nor was there any indication of reduced growth in the

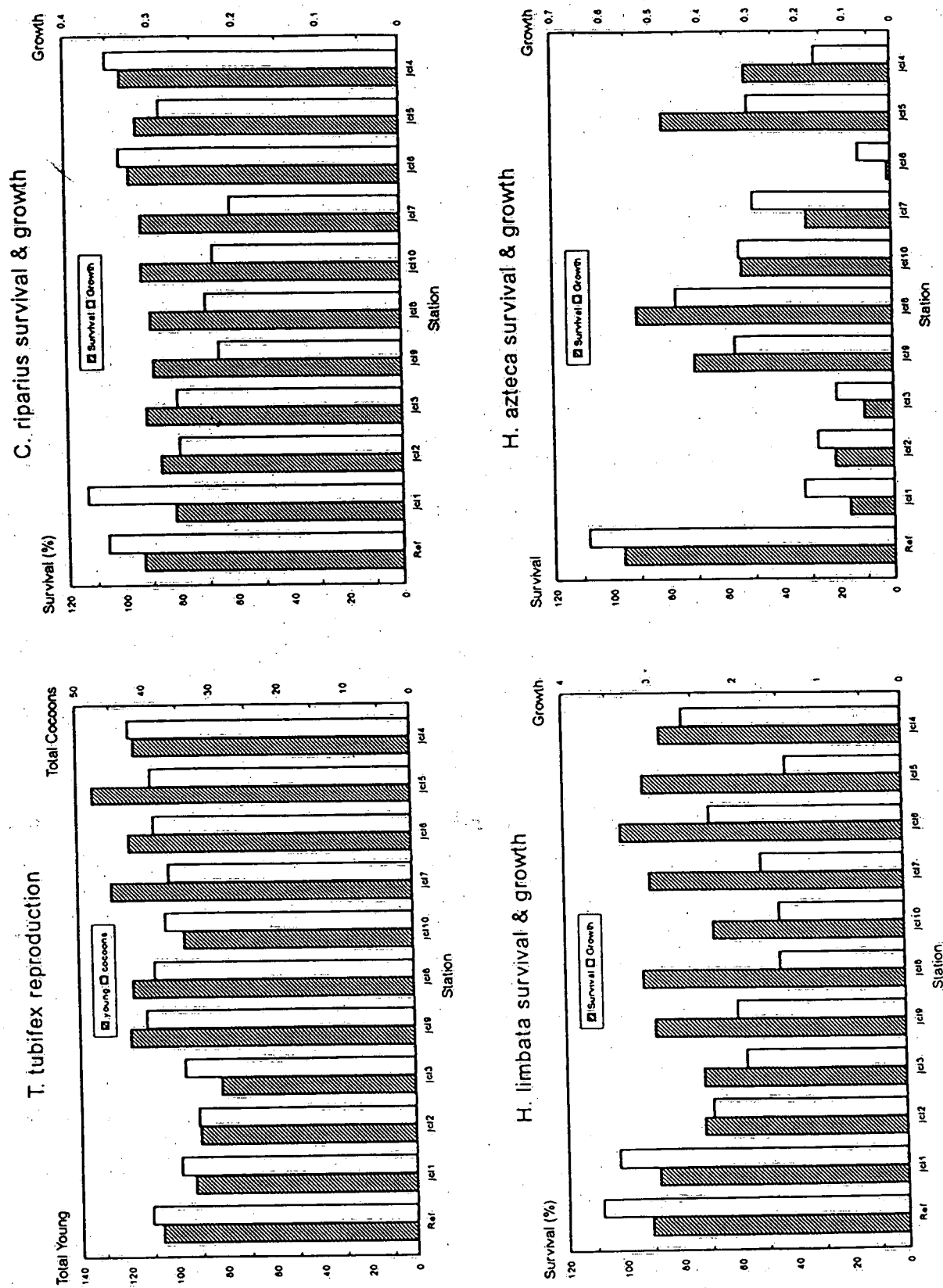


Figure 3.33. Bioassay test response in four invertebrate species

vicinity of the tailings (sites 4,5 and 6), where growth was similar to the reference sediment. The only sites indicating reduced growth were 7, 8 , 9 and 10 all deeper stations. Further examination of the sediment characteristics may explain this observation.

As is the case with the other two species, *Hexagenia limbata* shows no evidence of toxicity. Survival is well within the expected range for clean sediments and growth while more variable, which is normal for this test species, shows no apparent pattern in response to proximity to the tailings.

The last species tested was the amphipod *Hyaella azteca*. The data from this species showed the greatest variation, and both survival and growth were affected at sites within the lake. The test results also showed a marked reduction in survival and growth compared with the reference sediment. Sites 1,2 , 3 and 6 were the most affected. Of these four sites 1,2 and 3 are located furthest from the tailings and only site 6 is in the vicinity of the tailings. Site 5 which is closest to the tailings is one of the least toxic sites. It is difficult to interpret these results as demonstrating an impact due to tailings as there is little spatial consistency in the results, and no spatial signal can be seen. *Hyaella* is the most sensitive of the species tested and is also responsive to sediment characteristics such as particle size. This may account for the observed results.

3.3.3. Lower Vegetation

During the past decade natural vegetation has started to cover part of the exposed surface area of the tailings. Certain plants are known to be very resistant to high metal concentrations. Consequently, effects of metals on the terrestrial vegetation in the vicinity of JCL were studied. Eleven different plant species growing on the surface of the mine tailings on the shore of JCL and along surrounding creeks were analyzed for metals (Table 3.17).

In the plants sampled the concentrations of Co, Cu, Ni and Zn were similar to the reported typical values for terrestrial vegetation (Thompson and Walsh, 1988). However, all the other elements were present in considerably greater concentrations than natural levels. Metal concentrations in some of the plant species showed very good correlations with the metal distributions in the tailings and soils. For example, concentrations of trace elements in red clover (*Trifolium pratense*) were one order of magnitude greater in plants sampled from the tailings, than those in plants sampled west shore of the lake (opposite from the tailings).

The metal concentrations in some of the plants suggest preferential accumulation of certain elements. In beaked sedge (*Carex rostrata*) the concentrations of As, Fe and Pb concentrations were considerably higher on the tailings than on the shore of the lake and the banks of the surrounding creeks. However, the

Table 3.17. Major and trace element concentrations (mg/kg) in lower vegetation at the tailings and adjacent areas

		As	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Red clover	Trifolium pratense	10.95	1.22	d.l.	28.0	12.4	1846	57	12.8	d.l.	41.4
Red clover	Trifolium pratense	1.86	0.24	d.l.	1.8	5.9	135	20	0.7	d.l.	11.8
Horsetails	Equisetum variegatum	9.93	1.75	1.71	14.6	6.0	508	274	7.4	8.52	80.4
Horsetails	Equisetum variegatum	18.65	2.63	1.34	9.9	7.8	1478	87	4.6	16.30	57.77
Horsetails	Equisetum variegatum	8.43	1.70	1.02	10.9	7.0	414	479	6.3	6.87	30.5
Red paintbrush	Castilleja miniata	5.27	1.47	0.27	4.7	8.3	128	169	4.2	3.04	78.8
Northern aster	Aster modestus	7.60	1.32	0.56	10.7	9.6	310	112	4.8	4.44	35.8
Tall blue bell	Mertensia paniculata	2.24	0.31	d.l.	6.4	7.2	222	80	4.8	d.l.	35.2
Sunflower	Crysanthemum leucanthemum	10.30	1.40	0.63	14.7	7.6	456	26	4.3	4.69	17.1
Pearly everlasting	Anaphalis margaritacea	10.91	2.27	0.92	18.1	10.7	843	104	4.8	8.91	51.1
Pearly everlasting	Anaphalis margaritacea	4.45	1.59	0.08	6.9	7.9	358	61	3.0	d.l.	37.83
Fuzzy-spiked	Elymus innovatus	6.03	1.07	0.12	16.2	8.3	1371	376	3.7	3.34	39.4
Fuzzy-spiked	Elymus innovatus	7.07	1.50	0.48	10.1	5.3	1027	65	2.1	5.44	51.1
Fuzzy-spiked	Elymus innovatus	8.53	d.l.	d.l.	5.1	3.0	531	81	0.8	d.l.	33.22
Fuzzy-spiked	Elymus innovatus	2.15	0.46	d.l.	24.1	3.8	638	287	8.4	d.l.	12.9
Fuzzy-spiked	Elymus innovatus	5.50	1.08	0.80	5.3	5.4	477	154	2.3	4.14	119.55
Willow	Salix drummondiana	54.00	4.08	1.92	12.1	8.9	3042	424	6.5	27.60	138.83
Beaked sedge	Carex rostrata	36.83	2.05	0.87	8.1	6.8	3249	107	4.5	15.25	220.11
Beaked sedge	Carex rostrata	17.52	1.38	0.72	12.1	5.0	1224	229	5.2	14.76	227.41
Beaked sedge	Carex rostrata	27.18	1.71	0.79	10.1	5.9	2236	168	4.8	15.01	223.77
Beaked sedge	Carex rostrata	2.73	1.22	0.29	15.3	4.8	237	118	4.1	2.55	22.3
Tufted hairgrass	Deschampsia caespitosa	3.66	0.84	0.24	50.1	5.6	416	32	16.0	1.14	25.3
Tufted hairgrass	Deschampsia caespitosa	3.20	0.96	0.64	49.1	6.3	568	57	17.9	3.84	22.9
Tufted hairgrass	Deschampsia caespitosa	6.02	1.54	0.90	25.2	18.1	556	250	10.5	6.02	35.1
Typical natural concentration (Thompson and Walsh, 1988)		0.2	0.6	0.5	0.23	14	140	630	3	2.7	100
Detection limits		0.008	0.002	0.003	0.002	0.002	0.001	0.001	0.005	0.009	0.001

d.l. = below detection limit

concentrations of the other elements in the same plant species do not show significant correlation with metal concentrations in the associated tailings. In general, the deep-rooted species (willow and beaked sedge) accumulated higher concentrations of metals .

3.3.4. Higher Vegetation

The INAA results for 35 elements are listed in Appendix C; Table 3.18 shows the excellent precision obtained, firstly for two control samples (CLV-1 and V-6) inserted randomly in the batch, and secondly for 'blind' (separated after preparation) and field duplicates. Mercury is seen to be very low in all samples, the only exception being $0.5 \mu\text{g/g}$ in the bark of Engelmann spruce at the edge of the lake at site 7. Clearly, the spruce shows the greatest response for Au, with bark as the most sensitive plant part, reaching a maximum of 103 ng/g (dry weight) at site 7 where the maximum Hg level is also seen (Figure 3.34). The highest value for Au (30 ng/g) in spruce twigs is at site 5, just uphill from the metal enriched seep designated 05 in the water series. The distribution of Au in spruce twigs around JCL is illustrated in Figure 3.34. Evidently willow does not take up Au to any great extent: the mean content in 17 twig samples, in areas where the metal would be high in solution, is low at $1.5 \pm 0.9 \text{ ng/g Au}$. The spruce at site 15 is anomalous in Au; this sample is uphill from the lake and receives drainage from the slopes on the opposite side of Hwy. 26.

The highest As contents occur in the spruce collected at sites 5, 6 and 7 on a traverse just uphill of the gulley running southwest down to the lake from the old Cariboo Gold operations. The bark and twigs of the spruce at site 5, closest to the seepage, contain greater than $40 \mu\text{g/g}$ As, with the twigs of a nearby fir containing as much as $10 \mu\text{g/g}$ As. The twigs of the willow at site 5 however contain only $0.8 \mu\text{g/g}$ As, showing little uptake as in the case of Au. The rapid decrease in As along the Willow River from the tailings shown by the water data (Figure 3.13) is reflected in the spruce twigs (Figure 3.35) where, for example, those at site 13 contain only $0.5 \mu\text{g/g}$ As. This pattern is also in evidence for As in willow twigs, though the magnitude is much lower than that of spruce (Figure 3.36). Perhaps not surprisingly, the spruce of site 5 is anomalous in this data set in Fe, Hf, Co, Sb, Sc, Th, W, Zn and the rare earth elements, as well as in Au and As. Interestingly, the spruce at site 15 is also enriched in most of these elements in addition to Na (very high at $>250 \mu\text{g/g}$), Br, Cr, Ni, Th and U. Both water and vegetation results indicate mineralisation on the slopes near site 15. Willow twigs showing one of the few reportable values for Se are located at site 2 where Se in the water data set was maximum (1810 ng/L).

08 Wt. TW	1.4	<0.3	0.16	8	0.86	0.61	0.2	<0.3	<0.05	0.005	<0.05	<0.05	<0.1	0.06	<0.05	11.9	<2	6
	1.4	<0.3	0.20	8	0.90	0.44	0.1	<0.3	<0.05	0.005	<0.05	<0.05	<0.1	0.57	<0.05	10.9	<2	6
13b Wt. TW	1.8	<0.3	0.38	8	0.25	0.38	0.3	<0.3	<0.05	0.005	<0.05	<0.05	<0.1	0.49	<0.05	9.9	<2	3
	1.6	<0.3	0.42	11	0.25	0.37	0.3	<0.3	<0.05	0.005	<0.05	<0.05	<0.1	0.52	<0.05	8.3	<2	4

	Au ng/L	Ag μg/g	As μg/g	Ba μg/g	Br μg/g	Ce %	Co μg/g	Cr μg/g	Cs μg/g	Pb %	Hf μg/g	Hg μg/g	Ir ng/L	K %	Mn μg/g	Na μg/g	Ni μg/g	Pb μg/g
FIELD DUPLICATES																		
01 DF.TW	1.0	<0.3	0.04	36	0.38	0.51	0.3	0.6	<0.05	0.008	<0.06	<0.06	<0.1	0.47	<0.06	23.8	<2	4
	0.6	<0.3	0.04	38	0.38	0.52	0.3	0.5	<0.05	0.008	<0.06	<0.06	<0.1	0.46	<0.06	23.8	<2	3
11 W1.TW	0.08	<0.3	0.12	8	0.17	0.60	0.3	<0.3	<0.05	<0.006	<0.06	<0.06	<0.1	0.42	<0.06	12.8	<2	6
	1.1	<0.3	0.10	<6	0.40	0.36	<0.1	<0.3	<0.05	<0.006	<0.06	<0.06	<0.1	0.28	0.06	12.8	<2	4
13 W1.TW	0.9	<0.3	0.07	10	0.18	0.38	<0.1	<0.3	<0.05	0.007	<0.06	<0.06	<0.1	0.48	<0.06	9.9	<2	3
	1.8	<0.3	0.38	9	0.26	0.38	0.3	<0.3	<0.05	0.006	<0.06	<0.06	<0.1	0.49	<0.06	9.3	<2	4
15 W1.TW	2.4	<0.3	0.06	28	0.18	0.60	0.3	<0.3	<0.05	0.006	<0.06	<0.06	<0.1	0.63	<0.06	10.1	3	6
	1.0	<0.3	0.03	16	0.19	0.47	0.2	<0.3	<0.05	0.006	<0.06	<0.06	<0.1	0.36	<0.06	23.6	<2	4

	Sb	Se	Sc	Sr	Te	Th	U	W	Zn	La	Ce	Nd	Sm	Eu	Tb	Yb	Lu
	$\mu\text{g/g}$	$\mu\text{g/g}$	$\mu\text{g/g}$	$\mu\text{g/g}$	$\mu\text{g/g}$	$\mu\text{g/g}$	$\mu\text{g/g}$	$\mu\text{g/g}$	$\mu\text{g/g}$	$\mu\text{g/g}$	$\mu\text{g/g}$	$\mu\text{g/g}$	$\mu\text{g/g}$	$\mu\text{g/g}$	$\mu\text{g/g}$	$\mu\text{g/g}$	$\mu\text{g/g}$
CLV-1	0.230	0.26	3.2	30	<0.05	0.5	87	0.87	77	2.7	INT	7.1	INT	0.08	<0.1	0.093	<0.003
	0.270	0.29	3.8	64	<0.05	0.6	90	1.0	80	3.2	INT	8.8	INT	<0.05	<0.1	0.092	<0.003
	0.260	0.32	4.1	32	<0.05	0.5	90	0.74	80	3.4	INT	8.8	INT	0.09	<0.1	0.096	<0.003
BUND DUPLICATES																	
V-4	0.073	0.23	<0.1	36	<0.05	0.2	0.08	<0.05	32	0.85	1.7	0.7	0.13	<0.05	<0.1	0.078	0.011
	0.078	0.28	<0.01	48	<0.05	0.2	0.09	<0.05	38	1.1	1.8	0.7	0.16	<0.05	<0.1	0.090	0.013
	0.062	0.20	<0.1	43	<0.05	0.1	0.06	<0.05	26	0.86	1.4	0.6	0.12	<0.05	<0.1	0.080	0.008
	0.076	0.19	<0.1	26	<0.05	0.1	0.07	<0.05	28	0.86	1.6	0.7	0.12	<0.05	<0.1	0.068	0.012
BUND DUPLICATES																	
01 ES TW	0.028	0.08	0.1	70	<0.05	<0.1	0.02	<0.05	78	0.21	0.4	<0.5	0.02	<0.05	<0.1	0.016	0.002
	0.032	0.07	<0.1	55	<0.05	<0.1	<0.01	<0.05	77	0.15	0.3	<0.5	0.02	<0.05	<0.1	0.013	0.002
BUND DUPLICATES																	
02 ES TW	0.022	0.04	<0.1	78	<0.05	<0.1	0.01	0.06	64	0.18	0.5	<0.5	0.01	<0.05	<0.1	0.008	0.002
	0.026	0.04	<0.1	86	<0.05	<0.1	<0.01	<0.05	69	0.10	0.3	<0.5	0.01	<0.05	<0.1	0.007	0.001
BUND DUPLICATES																	
15 ES BK	0.078	0.41	0.1	37	<0.05	0.4	0.13	0.20	87	1.6	2.4	<0.5	0.20	<0.05	<0.1	0.114	0.018
	0.078	0.40	0.1	63	0.08	0.4	0.14	0.24	87	1.6	2.6	<0.5	0.20	<0.05	<0.1	0.086	0.016
BUND DUPLICATES																	
06 ES TW	0.066	0.06	<0.1	23	<0.05	<0.1	0.01	0.28	61	0.18	0.4	<0.5	0.02	<0.05	<0.1	0.013	0.002
	0.072	0.06	<0.1	21	<0.05	<0.1	<0.01	0.36	80	0.22	0.5	<0.5	0.03	<0.05	<0.1	0.011	0.002
BUND DUPLICATES																	
02 DF TW	0.020	0.02	<0.1	38	<0.05	<0.1	<0.01	<0.05	26	0.08	<0.3	<0.5	<0.01	<0.05	<0.1	<0.005	<0.001
	0.021	0.03	<0.1	34	<0.05	<0.1	<0.01	<0.05	28	0.08	<0.3	<0.5	<0.01	<0.05	<0.1	<0.005	<0.001
BUND DUPLICATES																	
08 WL TW	0.014	0.01	<0.1	28	<0.05	<0.1	<0.01	<0.05	180	0.03	<0.3	<0.5	<0.01	<0.05	<0.1	<0.005	<0.001

	0.013	0.01	<0.1	29	<0.06	<0.1	<0.01	<0.06	140	0.04	<0.3	<0.5	<0.01	<0.06	<0.1	<0.006	<0.001
13b WJ TW	0.016	0.01	0.1	26	<0.06	<0.1	<0.01	<0.06	130	0.06	<0.3	<0.5	<0.01	<0.06	<0.1	<0.006	<0.001
	0.016	0.01	<0.1	21	<0.06	<0.1	<0.01	<0.06	130	0.06	<0.3	<0.5	<0.01	<0.06	<0.1	<0.006	<0.001

	Sb $\mu\text{g/g}$	Sr $\mu\text{g/g}$	Sr $\mu\text{g/g}$	Ta $\mu\text{g/g}$	Th $\mu\text{g/g}$	U $\mu\text{g/g}$	W $\mu\text{g/g}$	Zn $\mu\text{g/g}$	La $\mu\text{g/g}$	Ce $\mu\text{g/g}$	Nd $\mu\text{g/g}$	Sm $\mu\text{g/g}$	Eu $\mu\text{g/g}$	Tb $\mu\text{g/g}$	Yb $\mu\text{g/g}$	Lu $\mu\text{g/g}$
FIELD DUPLICATES																
01 DF, TW	0.021	0.03	<0.1	19	<0.06	<0.1	<0.01	<0.06	33	0.08	<0.3	<0.01	<0.06	<0.1	<0.006	<0.001
	0.018	0.03	<0.1	23	<0.06	<0.1	<0.01	<0.06	37	0.08	<0.3	<0.01	<0.06	<0.1	<0.006	<0.001
11 WI, TW	0.008	<0.01	<0.1	17	<0.06	<0.1	<0.01	<0.06	48	0.04	<0.3	<0.01	<0.06	<0.1	<0.006	<0.001
	0.008	<0.01	<0.1	16	<0.06	<0.1	<0.01	<0.06	17	0.03	<0.3	<0.01	<0.06	<0.1	<0.006	<0.001
13 WI, TW	0.012	0.02	<0.1	20	<0.06	<0.1	<0.01	<0.06	85	0.06	<0.3	<0.01	<0.06	<0.1	<0.006	<0.001
	0.016	0.01	0.1	26	<0.06	<0.1	<0.01	<0.06	130	0.06	<0.3	<0.01	<0.06	<0.1	<0.006	<0.001
15 WI, TW	0.014	<0.01	0.1	64	<0.06	<0.1	<0.01	<0.06	96	0.03	<0.3	<0.01	<0.06	<0.1	<0.006	<0.001
	0.014	0.01	0.2	40	<0.06	<0.1	<0.01	<0.06	130	0.04	<0.3	<0.01	<0.06	<0.1	<0.006	<0.001

* ES = Engelmann spruce; WI = Willow; LP = Lodgepole pine; SF = Subalpine fir; TW = twigs and BK = bark.

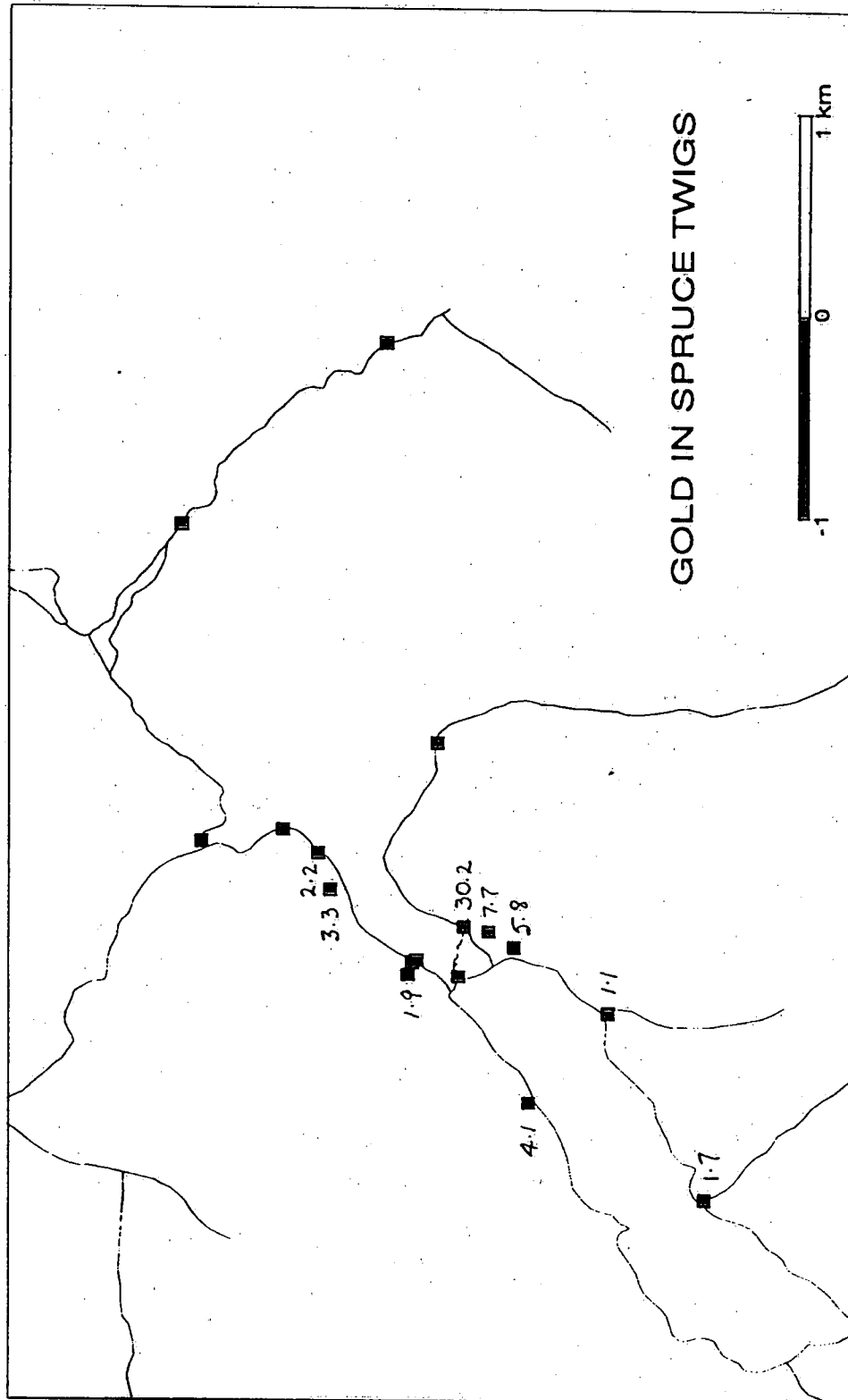


Figure 3.34. Gold in spruce twigs (ng/g)

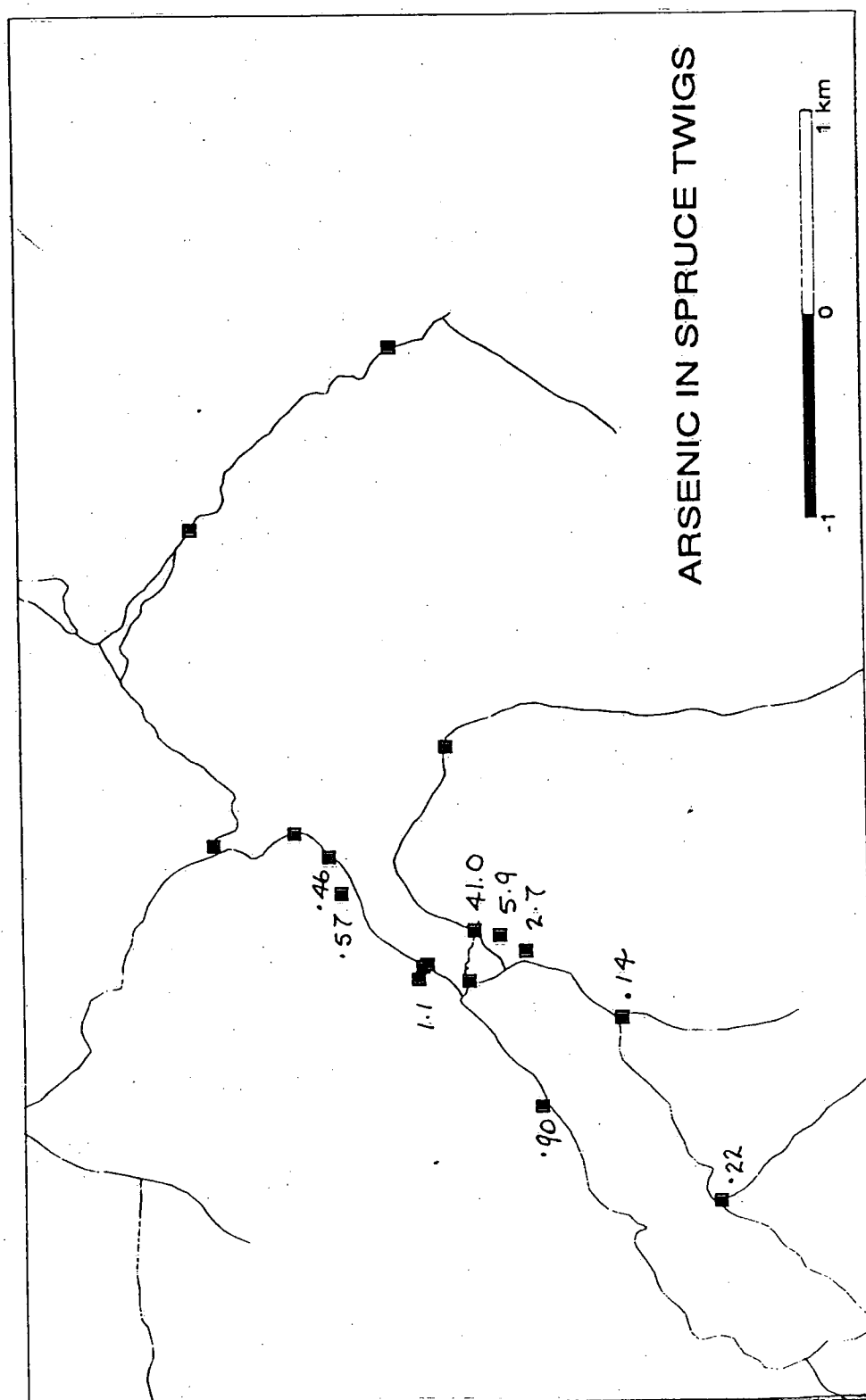


Figure 3.35. Arsenic in spruce twigs ($\mu\text{g/g}$)

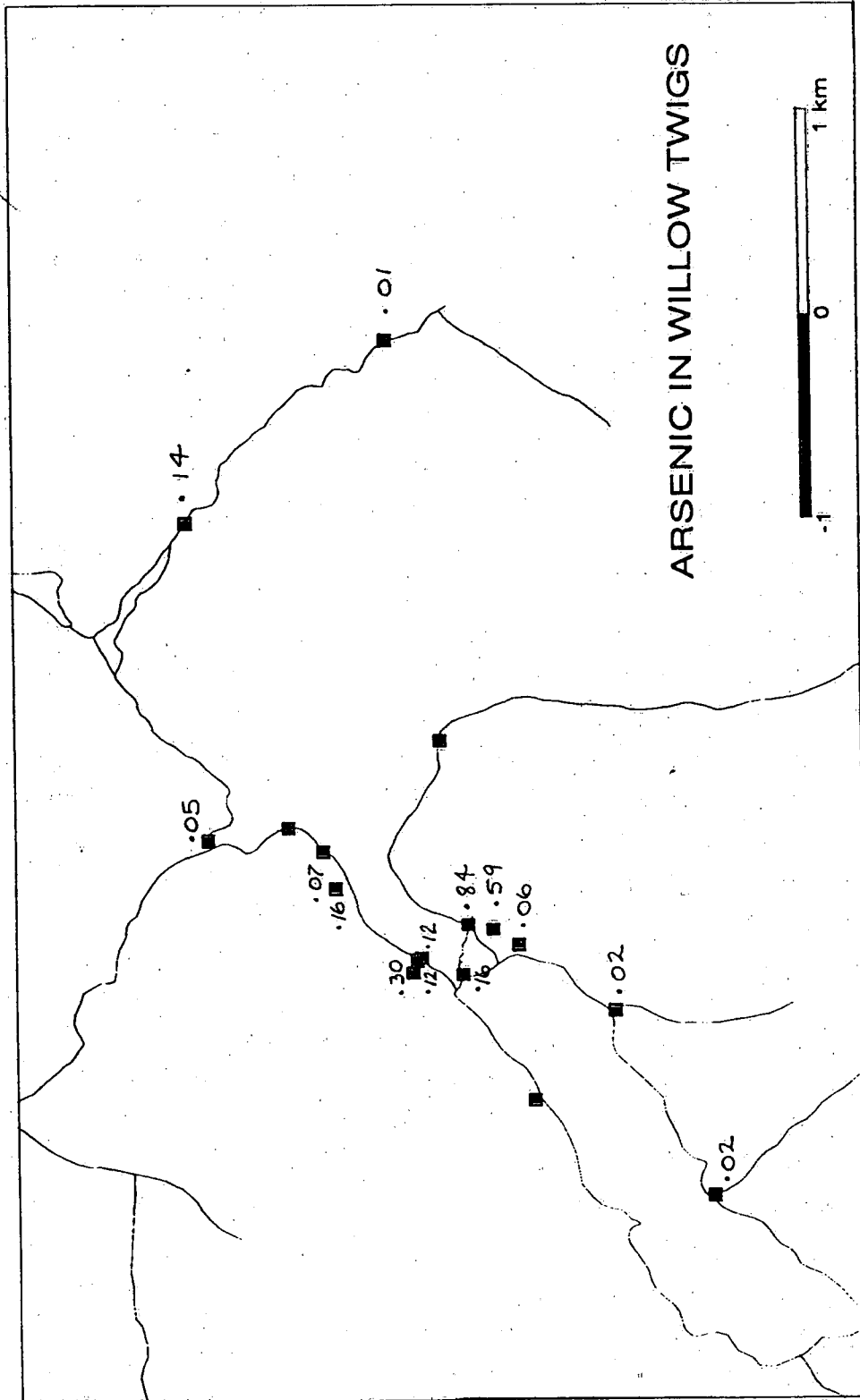


Figure 3.36. Arsenic in willow twigs ($\mu\text{g/g}$)

4. REFERENCES

- Adriano, D.G. 1986. Trace Elements in the Terrestrial Environment. Springer-Verlag, Berlin.
- Aller, R.C. and J.Y. Yingst. 1985. Effects of marine deposit-feeders *Heteromastus filiformis* (Polychaeta), *Macoma balthica* (Bivalva), and *Tellina texana* (Bivalva) on averaged sedimentary solute transport, reaction rates, and microbial distributions. *J. Mar. Res.* 43: 615-645.
- Andrews, K.I. 1989. A Preliminary Investigation of Public Health and Environmental Impacts of Abandoned mine tailings at Wells, B.C. Willimas Lake, Ministry of Environment, Province of British Columbia.
- Azcue, J.M. and Nriagu, J.O. 1993. Arsenic forms in mine-polluted sediments of Moira Lake, Ontario. *Environm. Intern.* 19: 405-415.
- Besser, J.M. and Rabeni, C.F. 1987. Bioavailability and toxicity of metals leached from lead-mine tailings to aquatic invertebrates. *Environ. Toxicol. Chem.* 6: 879-890.
- Bondar-Clegg. 1992. Bondar-Clegg & Company Ltd. 5420 Canotek Rd., Ottawa, ON K1J 9G2.
- Burrows, I.G. and Whitton, B.A. 1983. Heavy metals in water, sediment and invertebrates from a metal-contaminated river free of organic pollution. *Hydrobiologia* 106: 263-273.
- Day, K.E. and Reynoldson, T.B. 1991. Standard operating procedures (cultures and sediment bioassays methods) for: *T. tubifex*, *C. riparius*, *H. limbata* and *H. azteca*. NWRI report (in press).
- Dixit, S.S. and Witcomb, D. 1983. Heavy metal burden in water, substrate, and macroinvertebrate body tissue of a polluted river Irwell (England). *Environ. Poll.* (Series B) 6: 161-172.
- Duncan, G.A. and LaHaie, G.G. 1979. Size analysis procedures used in the sedimentology laboratory, NWRI, CCIW, Hydraulics Division, Manual, September 1979.
- Finch, C., Hall, G. and G. McConnel. 1992. Current Research, New Fowland Department of Mines and Energy. 92: 297-307.
- Folk, R.L. 1974. Petrology of sedimentary rocks. Hemphill Publishing Co., Austin, Texas, pp.182.
- Folk, R.L. and Ward, W.C. 1957. Brazos River Bar: a study in the significance of grain size parameters. *J. Sed. Petrol.* 27: 3-26.

Forstner, U. 1982. Accumulation phases for heavy metals in limnic sediments. *Hydrobiologia* 91: 269-284.

Frithsen, J.B. 1984. Metal incorporation by benthic fauna: relationships to sediment inventory. *Estuarine Coastal Shelf Sci.*, 19: 523-539.

Galbraith, D.M. 1991. Reclamation assessment - Wells tailings. MEMPR, Resources Management Branch.

Harris, L. 1984. Barkerville. The Town that Gold Built. Hancock House Publishers, Ltd.

Jackson, T.A., 1978a. A biogeochemical study of heavy metals in lakes and streams, and a proposed method for limiting heavy-metal pollution of natural waters. *Verhandl. Internat. Verein. f. Theoretische u. Angewandte Limnol.* 20: 1945-1946.

Jackson, T.A., 1978b. The biogeochemistry of heavy metals in polluted lakes and streams at Flin Flon, Canada, and a proposed method for limiting heavy-metal pollution of natural waters. *Environ. Geol.* 2: 173-189.

Jackson, T.A., 1984. Effects of inorganic cadmium, zinc, copper, and mercury on methyl mercury production in polluted lake sediments - evidence for selective inhibition and stimulation of microbial species based on variations in heavy metal tolerance. In Nriagu, J.O. (ed.), *Environmental Impacts of Smelters*, p. 551-578. John Wiley & Sons, New York, Toronto, Chichester, Brisbane, Singapore.

Jackson, T.A., 1991. Effects of heavy metals and selenium on mercury methylation and other microbial activities in freshwater sediments. In Vernet, J.-P. (ed.), *Heavy Metals in the Environment*, p. 191-217, Elsevier, Amsterdam, London, New York, Tokyo.

Jackson, T.A., J.F. Klaverkamp, and M.D. Dutton, 1993. Heavy metal speciation and its biological consequences in a group of lakes polluted by a smelter, Flin Flon, Manitoba, Canada. *Appl. Geochem.* 2: 285-289.

Kalil E. K., and M. Goldhaber, 1973. A sediment squeezer for removal of pore water without air contact. *J. Sediment Petrol.* 43: 553-557.

Langston, W.J. 1980. Arsenic in UK sediments and its availability to benthic organisms. *J. Mar. Biol. Assoc. U.K.*, 60: 869-881.

Ludditt, F.W. 1980. Barkerville Days. Mitchell Press Ltd.

Lynch, J. 1990. *Geostand. News* 14: 153-167.

MacKinnon, A., Pojar, J. and Coupe, R. 1992. Plants of Northern British Columbia. B.C. Ministry of Forests and Lone Pine Publishing, Canada.

McNeely, R.N., Neimanis, V.P.. and L. Dwyer. 1979. Water Quality Source Book: A Guide to Water Quality Parameters. Inland Waters Directorate, Water Quality Branch, Ottawa, Canada.

Molot, L.A. and Dillon, P.J. 1991. Nitrogen/phosphorus ratios and the prediction of chlorophyll in phosphorus limited lakes in Central Ontario. *Can. J. Fish. Aquat. Sci.* 48: 140-145.

Mudroch, A. 1985. Geochemistry of the Detroit River sediments. *J. Great Lakes Res.* 11: 193-200.

Mudroch, A. and Duncan, G.A. 1986. Distribution of Metals in different size fractions of sediment from Niagara River. *J. Great Lakes Res.* 12: 117-126.

Nagy, E., Carey, J.H., Hart, J.H., Ongley, E. and Tisdale, J. 1986. Hydrocarbons in Mackenzie River suspended sediments. NWRI Contribution n° 86-65.

Philbert, F.J. and Traversy, W.J. 1974. Methods of sample treatment and analysis of lake waters and precipitated samples. In Proc. 16th Conf. Great Lakes Res. pp.,294-310. Int. Assoc. Great Lakes Res.

Rescan, 1990. Tailings site investigation and remediation planning at Wells, British Columbia. Rescan Environmental Services, Ltd., Vancouver, B.C.

Reynoldson, T.B. 1992. Factors influencing the distribution of benthic fauna of Lake Superior: establishing long term monitoring sites. NWRI, Environment Canada.

Reynoldson, T.B., Thompson, S.P. and Bamsey, J.L. 1991. A sediment bioassay using the turbificid oligochaete worm *Tubifex tubifex*. *Environ. Toxicol. Chem.* 10: 1061-1072.

Riedel, G.F., Sanders, J.G. and Osman, R.W. 1989. The role of three species of benthic invertebrates in the transport of arsenic from contaminated estuarine sediment. *J. Exp. Mar. Biol. Ecol.* 134: 143-155.

Robert, F. and Taylor, B.E. 1989. Structure and mineralization at the Mosquito Creek gold mine Cariboo district, B.C. Geological Association of Canada, Cordillera Section, Short Course n°14.

Rosa, F., Bloesch, J., and Rathke, D. E., 1991. Sampling the settling and suspended particulate matter (SPM), In: Handbook of techniques for aquatic sediment sampling, Chapter 5; A. Mudroch and S. MacKnight, editors, CRC Incorporated, publishers.

Shepard, F.P. 1954. Nomenclature based on sand-silt ratios. *J. Sed. Petrol.* 24: 151-158.

Smee, B.W., Hall, G.E.M. and Koop, D.J. 1978. Analysis of fluoride, chloride, nitrate, and sulphate in natural waters using chromatography. *J. Geochem. Explor.* 10: 257-265.

Struik, L.C. 1988. Structural Geology of the Cariboo Gold Mining District, east-Central British Columbia; Geological Survey of Canada, Memoir 421, 100p.

Taylor, G.W. 1978. Mining. The History of Mining in British Columbia. Hancock House Publishers, Ltd.

Thompson, M. and Walsh, J.N. 1988. Handbook of Inductively Coupled Plasma Spectrometry. Blackie and Son, Ltd. London.

Wentsel, R., McIntosh, A. and Anderson, V. 1977. Sediment contamination and benthic macroinvertebrate distribution in a metal-impacted lake. *Environ. Poll.* 14: 187-193.

APPENDICES

APPENDIX A

SEQUENTIAL LEACHES OF CORES (ug/g)

155

	Zn PHASE 1	Zn PHASE 2	Zn PHASE 3	Zn PHASE 4	Zn PHASE 5	Zn PHASE 6	LOD
Bowron Lake 0-1	4	26	19	7	15	71	59.46
Bowron Lake 1-2	6	35	27	8	21	97	58.26
Bowron Lake 2-3	6	32	24	9	22	93	55.16
Bowron Lake 3-4	7	35	28	7	22	99	56.04
Bowron Lake 4-5	8	37	26	10	22	103	55.54
Bowron Lake 5-6	7	39	29	9	22	106	54.89
Bowron Lake 6-7	7	42	31	9	24	113	52.43
Bowron Lake 7-8	7	38	30	10	22	107	51.95
Bowron Lake 8-9	8	44	35	9	22	118	53.37
Bowron Lake 9-10	10	40	34	10	23	117	52.03
Bowron Lake 10-11	12	42	32	10	20	116	50.46
Bowron Lake 11-12	10	40	33	10	25	118	52.08
Bowron Lake 12-13	9	43	29	7	23	111	51.03
Bowron Lake 13-14	8	39	29	10	23	109	51.73
Bowron Lake 14-15	8	39	26	9	22	104	52.46
Bowron Lake 0-2	10	41	27	10	20	108	60.57
Bowron Lake 2-4	12	42	31	10	23	118	59.00
Bowron Lake 4-6	12	44	40	11	27	134	57.93
Bowron Lake 6-8	14	45	39	10	27	135	56.41
Bowron Lake 8-10	17	47	40	9	26	139	56.74
Bowron Lake 10-12	17	43	34	10	27	131	57.83
Bowron Lake 12-14	18	46	33	12	32	141	59.02
Bowron Lake 14-16	11	45	63	11	26	156	60.23
JC #10 0-2	29	79	82	13	25	228	53.72
JC #10 2-4	28	89	93	15	29	254	40.38
JC #10 4-6	119	85	118	25	41	388	62.78
JC #10 6-8	132	60	49	13	23	277	42.30
JC #10 8-10	109	61	44	16	24	254	42.72
JC #10 10-12	95	56	44	15	25	235	49.69
JC #10 12-14	167	98	54	26	20	365	37.86
JC #10 14-16	217	84	55	21	20	397	36.70
JC #10 16-18	135	87	61	17	37	337	38.76
JC #3 0-2	22	72	72	9	24	199	55.23
JC #3 2-4	158	105	95	14	27	399	47.58
JC #3 4-6	252	146	110	14	22	544	50.00
JC #3 6-8	136	94	71	14	20	335	44.39
JC #3 8-10	119	127	69	16	22	353	40.27
JC #3 10-12	124	119	81	17	24	365	46.61
JC #3 12-14	165	153	86	14	27	445	45.57
JC #3 14-16	117	147	80	16	29	389	45.45
JC #3 16-18	117	134	84	16	28	379	43.06
JC #3 18-20	91	113	94	15	30	343	46.76
TILL-2	3	33	44	16	25	121	
TILL-2	3	34	43	13	22	115	
TILL-2	3	35	45	14	24	121	
TILL-2	3	34	43	14	23	117	
TILL-2	3	36	44	17	25	125	
LKSD-4	75	73	14	13	13	188	
LKSD-4	74	72	16	10	11	183	
LKSD-4	69	81	18	10	12	190	

APPENDIX A

SEQUENTIAL LEACHES OF CORES (ug/g)

156

	Cu PHASE 1	Cu PHASE 2	Cu PHASE 3	Cu PHASE 4	Cu PHASE 5	Cu PHASE 6	LOD
Bowron Lake 0-1	4	15	7	0	2	28	59.46
Bowron Lake 1-2	6	18	8	2	2	36	58.26
Bowron Lake 2-3	6	17	9	2	2	36	55.16
Bowron Lake 3-4	6	18	7	2	2	35	56.04
Bowron Lake 4-5	6	18	8	2	2	36	55.54
Bowron Lake 5-6	8	19	9	2	2	40	54.89
Bowron Lake 6-7	9	20	9	2	2	42	52.43
Bowron Lake 7-8	9	20	8	2	2	41	51.95
Bowron Lake 8-9	11	20	9	2	2	44	53.37
Bowron Lake 9-10	12	21	10	2	2	47	52.03
Bowron Lake 10-11	12	22	9	2	2	47	50.46
Bowron Lake 11-12	12	21	10	2	2	47	52.08
Bowron Lake 12-13	11	22	9	2	2	46	51.03
Bowron Lake 13-14	12	21	8	2	2	45	51.73
Bowron Lake 14-15	11	20	7	2	2	42	52.46
Bowron Lake 0-2	8	20	22	2	2	54	60.57
Bowron Lake 2-4	8	21	21	2	2	54	59.00
Bowron Lake 4-6	7	26	20	2	2	57	57.93
Bowron Lake 6-8	6	29	22	2	2	61	56.41
Bowron Lake 8-10	8	30	23	4	2	67	56.74
Bowron Lake 10-12	8	28	20	2	2	60	57.83
Bowron Lake 12-14	9	27	21	4	2	63	59.02
Bowron Lake 14-16	11	22	19	9	2	63	60.23
JC #10 0-2	8	18	37	5	2	70	53.72
JC #10 2-4	16	21	33	6	3	79	40.38
JC #10 4-6	24	33	47	17	4	125	62.78
JC #10 6-8	12	28	20	6	1	67	42.30
JC #10 8-10	12	25	20	8	2	67	42.72
JC #10 10-12	5	31	22	7	2	67	49.69
JC #10 12-14	16	20	18	11	2	67	37.86
JC #10 14-16	18	19	21	9	2	69	36.70
JC #10 16-18	19	22	22	6	2	71	38.76
JC #3 0-2	4	17	36	2	2	61	55.23
JC #3 2-4	18	28	35	4	3	88	47.58
JC #3 4-6	27	27	34	6	3	97	50.00
JC #3 6-8	21	22	26	6	2	77	44.39
JC #3 8-10	28	29	28	8	3	96	40.27
JC #3 10-12	27	35	29	6	5	102	46.61
JC #3 12-14	32	36	31	5	4	108	45.57
JC #3 14-16	32	39	29	4	4	108	45.45
JC #3 16-18	28	40	27	5	5	105	43.06
JC #3 18-20	18	52	31	4	4	109	46.76
TILL-2	12	54	46	9	26	147	
TILL-2	12	56	46	8	22	144	
TILL-2	12	55	47	9	23	146	
TILL-2	12	55	45	9	22	143	
TILL-2	13	57	49	10	24	153	
LKSD-4	-1	9	6	13	2	29	
LKSD-4	0	8	7	11	4	30	
LKSD-4	1	9	6	10	2	28	

APPENDIX A

SEQUENTIAL LEACHES OF CORES (ug/g)

157

	Pb PHASE 1	Pb PHASE 2	Pb PHASE 3	Pb PHASE 4	Pb PHASE 5	Pb PHASE 6	LOD
Bowron Lake 0-1	-2	11	-2	0	2	9	59.46
Bowron Lake 1-2	0	14	-4	0	2	12	58.26
Bowron Lake 2-3	2	11	-2	0	2	13	55.16
Bowron Lake 3-4	6	11	-2	0	2	17	56.04
Bowron Lake 4-5	8	10	-2	2	2	20	55.54
Bowron Lake 5-6	5	14	-4	2	2	19	54.89
Bowron Lake 6-7	8	14	-8	0	2	16	52.43
Bowron Lake 7-8	2	14	-3	2	3	18	51.95
Bowron Lake 8-9	4	15	-2	0	4	15	53.37
Bowron Lake 9-10	4	15	-2	0	2	13	52.03
Bowron Lake 10-11	5	15	-4	0	3	19	50.46
Bowron Lake 11-12	4	15	-6	0	4	17	52.08
Bowron Lake 12-13	4	9	-2	0	4	8	51.03
Bowron Lake 13-14	4	10	-2	0	4	8	51.73
Bowron Lake 14-15	4	9	-4	0	4	13	52.46
Bowron Lake 0-2	0	14	-6	10	4	22	60.57
Bowron Lake 2-4	8	10	-4	10	6	30	59.00
Bowron Lake 4-6	11	6	-5	8	6	26	57.93
Bowron Lake 6-8	12	6	-4	8	6	28	56.41
Bowron Lake 8-10	11	8	-4	9	4	28	56.74
Bowron Lake 10-12	11	6	0	9	9	35	57.83
Bowron Lake 12-14	9	15	-4	0	5	25	59.02
Bowron Lake 14-16	4	13	-6	2	6	19	60.23
JC #10 0-2	8	101	6	6	5	126	53.72
JC #10 2-4	34	46	3	9	3	95	40.38
JC #10 4-6	131	49	4	12	6	202	62.78
JC #10 6-8	115	30	1	8	3	157	42.30
JC #10 8-10	118	39	0	10	2	169	42.72
JC #10 10-12	64	24	-4	15	3	102	49.69
JC #10 12-14	182	90	3	9	3	287	37.86
JC #10 14-16	225	58	2	8	3	296	36.70
JC #10 16-18	166	68	-3	1	4	236	38.76
JC #3 0-2	4	65	-2	2	2	71	55.23
JC #3 2-4	93	62	-4	-1	5	155	47.58
JC #3 4-6	183	87	3	5	3	281	50.00
JC #3 6-8	171	80	0	0	3	254	44.39
JC #3 8-10	173	98	4	0	3	278	40.27
JC #3 10-12	130	67	-2	0	2	197	46.61
JC #3 12-14	167	73	1	-1	3	243	45.57
JC #3 14-16	95	52	4	-4	3	150	45.45
JC #3 16-18	87	40	3	0	3	133	43.06
JC #3 18-20	47	35	2	4	4	92	46.76
TILL-2	5	10	-1	0	8	22	
TILL-2	5	10	-1	-1	7	20	
TILL-2	5	11	-1	0	9	24	
TILL-2	5	10	2	-3	8	22	
TILL-2	5	10	-3	3	9	24	
LKSD-4	52	38	-2	0	3	91	
LKSD-4	52	40	-2	-3	3	90	
LKSD-4	48	40	-2	-1	2	87	

APPENDIX A

SEQUENTIAL LEACHES OF CORES (ug/g)

158

	NI PHASE 1	NI PHASE 2	NI PHASE 3	NI PHASE 4	NI PHASE 5	NI PHASE 6	LOD
Bowron Lake 0-1	6	17	13	2	7	45	59.46
Bowron Lake 1-2	4	19	10	4	10	47	58.26
Bowron Lake 2-3	9	20	13	4	9	55	55.16
Bowron Lake 3-4	9	20	13	2	11	55	56.04
Bowron Lake 4-5	10	20	14	6	10	60	55.54
Bowron Lake 5-6	11	22	14	7	10	64	54.89
Bowron Lake 6-7	11	20	15	7	11	64	52.43
Bowron Lake 7-8	12	20	16	5	10	63	51.95
Bowron Lake 8-9	11	20	15	7	11	64	53.37
Bowron Lake 9-10	12	21	15	4	10	62	52.03
Bowron Lake 10-11	12	21	17	5	12	67	50.46
Bowron Lake 11-12	12	23	15	6	13	69	52.08
Bowron Lake 12-13	11	20	18	4	12	65	51.03
Bowron Lake 13-14	12	23	12	8	14	69	51.73
Bowron Lake 14-15	13	22	13	6	11	65	52.46
Bowron Lake 0-2	12	20	18	10	10	70	60.57
Bowron Lake 2-4	15	21	21	10	11	78	59.00
Bowron Lake 4-6	11	20	23	8	12	74	57.93
Bowron Lake 6-8	12	22	26	10	14	84	56.41
Bowron Lake 8-10	13	21	21	13	13	81	56.74
Bowron Lake 10-12	13	22	26	10	14	85	57.83
Bowron Lake 12-14	15	23	25	35	16	114	59.02
Bowron Lake 14-16	13	21	19	209	19	281	60.23
JC #10 0-2	9	27	44	66	13	159	53.72
JC #10 2-4	12	31	45	131	16	235	40.38
JC #10 4-6	19	27	52	305	23	426	62.78
JC #10 6-8	17	18	26	11	11	83	42.30
JC #10 8-10	17	18	21	13	10	79	42.72
JC #10 10-12	28	20	23	41	15	127	49.69
JC #10 12-14	12	18	22	15	9	76	37.86
JC #10 14-16	15	17	23	30	11	96	36.70
JC #10 16-18	13	21	30	12	11	87	38.76
JC #3 0-2	4	32	33	9	11	89	55.23
JC #3 2-4	18	28	44	11	15	116	47.58
JC #3 4-6	25	29	46	11	12	123	50.00
JC #3 6-8	20	26	34	11	11	102	44.39
JC #3 8-10	16	29	33	14	13	105	40.27
JC #3 10-12	17	26	40	14	16	113	46.61
JC #3 12-14	14	28	39	12	16	109	45.57
JC #3 14-16	13	33	42	14	20	122	45.45
JC #3 16-18	11	31	40	16	19	117	43.06
JC #3 18-20	13	32	44	12	20	121	46.76
TILL-2	0	9	13	7	9	38	
TILL-2	2	9	11	7	8	37	
TILL-2	0	8	14	9	10	41	
TILL-2	1	8	15	9	9	42	
TILL-2	1	8	16	9	9	43	
LKSD-4	6	14	6	9	7	42	
LKSD-4	6	14	5	9	27	61	
LKSD-4	6	16	3	6	6	37	
::							
	Co PHASE 1	Co PHASE 2	Co PHASE 3	Co PHASE 4	Co PHASE 5	Co PHASE 6	LOD
Bowron Lake 0-1	-2	11	2	0	2	13	59.46
Bowron Lake 1-2	0	16	2	0	4	22	58.26
Bowron Lake 2-3	2	9	2	0	2	15	55.16
Bowron Lake 3-4	2	9	5	0	4	20	56.04
Bowron Lake 4-5	2	12	6	0	4	24	55.54

APPENDIX A

SEQUENTIAL LEACHES OF CORES (ug/g)

159

	Co PHASE 1	Co PHASE 2	Co PHASE 3	Co PHASE 4	Co PHASE 5	Co PHASE 6	LOD
Bowron Lake 0-1	-2	11	2	0	2	13	59.46
Bowron Lake 1-2	0	16	2	0	4	22	58.26
Bowron Lake 2-3	2	9	2	0	2	15	55.16
Bowron Lake 3-4	2	9	5	0	4	20	56.04
Bowron Lake 4-5	2	12	6	0	4	24	55.54
Bowron Lake 5-6	0	16	5	0	3	24	54.89
Bowron Lake 6-7	2	14	5	0	4	25	52.43
Bowron Lake 7-8	0	15	5	2	3	25	51.95
Bowron Lake 8-9	2	17	6	0	4	29	53.37
Bowron Lake 9-10	2	13	6	0	4	25	52.03
Bowron Lake 10-11	4	14	3	0	3	24	50.46
Bowron Lake 11-12	4	15	4	0	4	27	52.08
Bowron Lake 12-13	2	16	4	2	4	28	51.03
Bowron Lake 13-14	2	14	4	0	4	24	51.73
Bowron Lake 14-15	2	15	2	2	4	25	52.46
Bowron Lake 0-2	4	27	2	2	4	39	60.57
Bowron Lake 2-4	6	21	2	0	4	33	59.00
Bowron Lake 4-6	8	18	5	2	5	38	57.93
Bowron Lake 6-8	10	20	4	2	4	40	56.41
Bowron Lake 8-10	10	19	4	2	4	39	56.74
Bowron Lake 10-12	11	17	7	2	5	42	57.83
Bowron Lake 12-14	11	19	5	2	4	41	59.02
Bowron Lake 14-16	6	24	2	6	4	42	60.23
JC #10 0-2	2	28	6	2	3	41	53.72
JC #10 2-4	7	19	7	4	3	40	40.38
JC #10 4-6	12	12	8	10	4	46	62.78
JC #10 6-8	5	8	5	3	3	24	42.30
JC #10 8-10	5	8	3	5	3	24	42.72
JC #10 10-12	7	8	3	5	3	26	49.69
JC #10 12-14	3	6	4	5	3	21	37.86
JC #10 14-16	3	6	5	6	2	22	36.70
JC #10 16-18	4	7	5	5	1	22	38.76
JC #3 0-2	-2	18	6	2	2	26	55.23
JC #3 2-4	8	8	7	3	3	29	47.58
JC #3 4-6	10	9	6	3	2	30	50.00
JC #3 6-8	8	8	6	2	2	26	44.39
JC #3 8-10	5	9	6	3	2	25	40.27
JC #3 10-12	8	10	8	2	3	31	46.61
JC #3 12-14	5	11	8	1	4	29	45.57
JC #3 14-16	5	12	7	3	3	30	45.45
JC #3 16-18	5	11	10	2	2	30	43.06
JC #3 18-20	5	11	10	1	5	32	46.76
TILL-2	1	6	3	2	2	14	
TILL-2	1	6	5	2	2	16	
TILL-2	2	5	4	1	2	14	
TILL-2	2	4	4	1	2	13	
TILL-2	1	4	3	2	3	13	
LKSD-4	3	3	2	1	2	11	
LKSD-4	2	2	1	2	2	9	
LKSD-4	3	3	1	1	2	10	

APPENDIX A

SEQUENTIAL LEACHES OF CORES (ug/g)

160

	Mn PHASE 1	Mn PHASE 2	Mn PHASE 3	Mn PHASE 4	Mn PHASE 5	Mn PHASE 6	LOD
Bowron Lake 0-1	842	9860	73	15	48	10838	59.46
Bowron Lake 1-2	1477	3521	111	17	68	5194	58.26
Bowron Lake 2-3	2961	880	102	20	67	4030	55.16
Bowron Lake 3-4	2758	798	100	15	69	3740	56.04
Bowron Lake 4-5	2116	959	96	22	67	3260	55.54
Bowron Lake 5-6	1219	1494	102	22	71	2908	54.89
Bowron Lake 6-7	868	1724	107	25	71	2795	52.43
Bowron Lake 7-8	916	1745	109	22	67	2859	51.95
Bowron Lake 8-9	1154	1784	114	24	68	3144	53.37
Bowron Lake 9-10	1086	1256	113	25	70	2550	52.03
Bowron Lake 10-11	1027	953	111	22	61	2174	50.46
Bowron Lake 11-12	974	1017	109	21	78	2199	52.08
Bowron Lake 12-13	997	1222	102	16	73	2410	51.03
Bowron Lake 13-14	1092	1314	101	21	73	2601	51.73
Bowron Lake 14-15	1128	1143	94	24	72	2461	52.46
Bowron Lake 0-2	2066	2096	127	25	70	4384	60.57
Bowron Lake 2-4	2761	888	126	25	74	3874	59.00
Bowron Lake 4-6	2326	656	137	27	78	3224	57.93
Bowron Lake 6-8	2036	551	139	27	76	2829	56.41
Bowron Lake 8-10	2102	541	139	23	73	2878	56.74
Bowron Lake 10-12	1935	511	137	26	82	2691	57.83
Bowron Lake 12-14	2284	652	135	30	88	3189	59.02
Bowron Lake 14-16	1770	1181	113	60	84	3208	60.23
JC #10 0-2	513	4055	227	27	39	4861	53.72
JC #10 2-4	638	318	175	44	58	1233	40.38
JC #10 4-6	1284	265	232	95	73	1949	62.78
JC #10 6-8	1409	245	118	10	37	1819	42.30
JC #10 8-10	1714	330	109	10	38	2201	42.72
JC #10 10-12	2579	482	119	20	39	3239	49.69
JC #10 12-14	1753	334	119	10	27	2243	37.86
JC #10 14-16	1763	278	121	14	27	2203	36.70
JC #10 16-18	765	212	127	11	30	1145	38.76
JC #3 0-2	214	7610	144	11	35	8014	55.23
JC #3 2-4	1821	372	200	20	41	2454	47.58
JC #3 4-6	1426	242	179	9	22	1878	50.00
JC #3 6-8	2099	389	117	8	22	2635	44.39
JC #3 8-10	1429	303	145	14	28	1919	40.27
JC #3 10-12	687	173	169	22	33	1084	46.61
JC #3 12-14	824	225	180	18	28	1275	45.57
JC #3 14-16	816	220	161	23	43	1263	45.45
JC #3 16-18	839	212	156	25	43	1275	43.06
JC #3 18-20	1769	289	200	22	37	2317	46.76
TILL-2	73	304	118	50	131	676	
TILL-2	72	300	118	43	114	647	
TILL-2	91	279	122	44	147	683	
TILL-2	91	278	121	45	138	674	
TILL-2	92	289	121	47	156	705	
LKSD-4	230	67	41	13	85	436	
LKSD-4	225	64	40	9	75	413	
LKSD-4	259	72	42	11	82	466	

APPENDIX A

SEQUENTIAL LEACHES OF CORES (ug/g)

161

	Fe PHASE 1	Fe PHASE 2	Fe PHASE 3	Fe PHASE 4	Fe PHASE 5	Fe PHASE 6	LOD
Bowron Lake 0-1	2805	47088	11275	2647	6248	70063	59.46
Bowron Lake 1-2	4396	42527	15428	3410	8628	74387	58.26
Bowron Lake 2-3	6359	35709	14600	3489	8930	69087	55.16
Bowron Lake 3-4	6584	36398	14843	2516	9411	69752	56.04
Bowron Lake 4-5	6062	35452	14206	3847	9429	68996	55.54
Bowron Lake 5-6	5716	34847	15190	3847	9510	69110	54.89
Bowron Lake 6-7	5394	34698	16435	4106	9804	70437	52.43
Bowron Lake 7-8	5523	32489	16257	3800	8947	67016	51.95
Bowron Lake 8-9	5566	36085	17517	3893	8982	72043	53.37
Bowron Lake 9-10	5215	34427	17136	3813	9053	69644	52.03
Bowron Lake 10-11	4613	31424	16289	4075	7945	64346	50.46
Bowron Lake 11-12	4862	31268	16527	3956	10319	66932	52.08
Bowron Lake 12-13	4920	33147	15239	2686	9535	65527	51.03
Bowron Lake 13-14	5456	33676	15006	3894	9354	67386	51.73
Bowron Lake 14-15	4657	33406	14063	3853	8886	64865	52.46
Bowron Lake 0-2	10185	40702	17083	3804	8948	80722	60.57
Bowron Lake 2-4	13662	41729	17357	3992	10022	86762	59.00
Bowron Lake 4-6	15580	33034	19291	4566	10373	82844	57.93
Bowron Lake 6-8	13216	34291	19024	4444	10466	81441	56.41
Bowron Lake 8-10	14271	32853	19565	3327	9895	79911	56.74
Bowron Lake 10-12	11753	33253	19284	4536	10438	79264	57.83
Bowron Lake 12-14	10834	35888	18853	4732	12088	82395	59.02
Bowron Lake 14-16	9325	35170	15472	5727	10495	76189	60.23
JC #10 0-2	2054	30541	31275	5702	7531	77103	53.72
JC #10 2-4	2336	14916	25974	7197	8423	58846	40.38
JC #10 4-6	6541	18927	37198	16304	14670	93640	62.78
JC #10 6-8	7080	14622	17443	9716	9404	58265	42.30
JC #10 8-10	6703	16638	17336	12204	7544	60425	42.72
JC #10 10-12	10350	19342	17133	7582	7639	62046	49.69
JC #10 12-14	5407	17471	19225	18494	6298	66895	37.86
JC #10 14-16	7000	15949	19585	17256	6851	66641	36.70
JC #10 16-18	6072	16541	26077	14182	7911	70783	38.76
JC #3 0-2	1949	25631	31391	2944	8943	70858	55.23
JC #3 2-4	6198	19766	36498	5662	8851	76975	47.58
JC #3 4-6	7525	22335	37206	7504	5814	80384	50.00
JC #3 6-8	5934	18010	24755	9836	5732	64267	44.39
JC #3 8-10	5525	20333	29339	11257	7940	74394	40.27
JC #3 10-12	5414	18687	34689	7770	7723	74283	46.61
JC #3 12-14	4150	19164	38098	8058	7051	76521	45.57
JC #3 14-16	4311	19436	33183	7496	9309	73735	45.45
JC #3 16-18	4765	19136	33186	7160	9082	73329	43.06
JC #3 18-20	7326	20992	46277	5948	11019	91562	46.76
TILL-2	326	9720	13868	5090	5740	34744	
TILL-2	319	9588	14288	4240	5020	33455	
TILL-2	444	10437	14625	4025	6595	36126	
TILL-2	443	10116	14988	4065	6300	35912	
TILL-2	461	10767	14810	4310	6520	36868	
LKSD-4	560	7535	8243	4890	5280	26508	
LKSD-4	571	7326	8357	3760	4705	24719	
LKSD-4	501	7386	7337	5010	5060	25294	

APPENDIX A

SEQUENTIAL LEACHES OF CORES (ug/g)

162

	As PHASE 1	As PHASE 2	As PHASE 3	As PHASE 4	As PHASE 5	As PHASE 6	LOD
Bowron Lake 0-1	295	8346	6625	883	351	16500	59.46
Bowron Lake 1-2	762	12958	10093	1123	550	25486	58.26
Bowron Lake 2-3	1148	10902	8347	1170	553	22120	55.16
Bowron Lake 3-4	812	7087	7142	1026	649	16716	56.04
Bowron Lake 4-5	625	4384	6125	1233	482	12849	55.54
Bowron Lake 5-6	395	3564	5583	1221	571	11334	54.89
Bowron Lake 6-7	351	3313	5710	1225	590	11189	52.43
Bowron Lake 7-8	381	3367	6541	1084	569	11942	51.95
Bowron Lake 8-9	491	3895	7235	902	580	13103	53.37
Bowron Lake 9-10	420	3956	6510	1019	557	12462	52.03
Bowron Lake 10-11	369	2994	6139	955	472	10929	50.46
Bowron Lake 11-12	466	3077	5676	919	591	10729	52.08
Bowron Lake 12-13	395	3282	5316	715	514	10222	51.03
Bowron Lake 13-14	477	3626	5342	761	435	10641	51.73
Bowron Lake 14-15	326	3138	4290	666	417	8837	52.46
Bowron Lake 0-2	1162	8478	11784	671	839	22934	60.57
Bowron Lake 2-4	1265	6166	8916	617	911	17875	59.00
Bowron Lake 4-6	1690	4083	8697	629	966	16065	57.93
Bowron Lake 6-8	1364	4123	7445	549	911	14392	56.41
Bowron Lake 8-10	1624	3974	8003	492	866	14959	56.74
Bowron Lake 10-12	1244	4124	7474	620	959	14421	57.83
Bowron Lake 12-14	872	3344	7079	602	837	12734	59.02
Bowron Lake 14-16	804	3762	6418	592	693	12269	60.23
JC #10 0-2	1410	49414	110319	21938	2552	185633	53.72
JC #10 2-4	4011	23307	61788	25987	2717	117810	40.38
JC #10 4-6	15519	342334	96177	116105	4432	574567	62.78
JC #10 6-8	10445	19865	38303	84117	2471	155201	42.30
JC #10 8-10	3552	17606	32964	86625	1885	142632	42.72
JC #10 10-12	8643	14212	24172	44755	1935	93717	49.69
JC #10 12-14	7954	22904	55265	158952	2541	247616	37.86
JC #10 14-16	13169	32166	49894	140587	2608	238424	36.70
JC #10 16-18	8895	23951	70135	110593	3327	216901	38.76
JC #3 0-2	869	26881	62676	2861	1460	94747	55.23
JC #3 2-4	9831	36477	104962	23950	3797	179017	47.58
JC #3 4-6	10986	47320	115809	51636	3736	229487	50.00
JC #3 6-8	6083	28540	70160	64566	2597	171946	44.39
JC #3 8-10	4242	18679	73557	71217	3670	171365	40.27
JC #3 10-12	3900	10870	61118	31416	4281	111585	46.61
JC #3 12-14	3593	11865	60752	39169	4109	119488	45.57
JC #3 14-16	2188	7705	46702	29116	4403	90114	45.45
JC #3 16-18	2647	7073	40028	24111	4790	78649	43.06
JC #3 18-20	3520	9334	49935	18693	3440	84922	46.76
TILL-2	183	3065	11377	5796	3218	23639	
TILL-2	177	2940	11723	4336	2800	21976	
TILL-2	237	3044	12394	3700	3531	22906	
TILL-2	214	3079	12069	3731	3356	22449	
TILL-2	221	2962	12174	4155	3588	23100	
LKSD-4	1483	2744	4234	3039	1334	12834	
LKSD-4	1569	3115	4376	2442	1182	12684	
LKSD-4	1208	3376	3733	2961	1126	12404	

APPENDIX B STREAM WATER DATA

163

Element Unit Det Lim	PH UNI .01	CONDUCT UMO 5	NA mg/L .1	K mg/L .1	CA mg/L .1	MG mg/L .1	AS ug/L .2	NO2 ug/L 50	NO3 ug/L 50	F ug/L 50	PO4 ug/L 50	BR ug/L 50	SO4 mg/L .05	CL mg/L .05
01	7.25	151.	0.42	0.27	26.32	4.83	-0.20	-50.	-50.	80.	-50.	-50.	5.55	0.29
01 D5			0.42	0.24	29.54	5.41	-0.20							
02	7.49	206.	0.45	0.30	26.44	13.58	-0.20	-50.	569.	129.	-50.	-50.	15.3	0.26
02 D5			0.50	0.27	29.13	15.47	-0.20							
04	7.52	202.	0.50	0.24	33.94	6.46	0.21	164.	78.	92.	-50.	-50.	10.3	0.62
04 D3			0.36	0.24	22.71	4.08	0.38							
05	2.67	1701.	0.58	0.66	75.60	9.20	556.47	-50.	-50.	-50.	-50.	-50.	640.	0.11
06	6.90	663.	0.94	0.47	122.25	32.85	0.51	-50.	-50.	66.	-50.	-50.	308.	0.17
08 D3			0.84	0.56	127.80	30.75	-0.20							
09	7.13	108.	0.50	0.16	13.59	5.19	0.29	-50.	-50.	60.	-50.	-50.	16.0	0.48
09 D3			0.94	0.14	14.25	4.66	1.66							
09 D4			0.36	0.12	11.79	4.47	0.20							
09 D5			0.38	0.12	12.02	4.43	0.26							
09bD4			0.43	0.14	13.95	5.22	0.49							
10	8.10	1630.	9.40	3.27	269.10	188.10	2.08	-50.	-50.	-50.	-50.	-50.	1000.	4.06
10 D4			12.03	3.01	251.55	172.20	2.21							
11	7.84	415.	0.60	0.47	97.50	17.10	0.89	-50.	-50.	133.	-50.	-50.	93.4	0.35
12	7.77	1497.	9.55	2.96	238.40	167.25	1.39	-50.	-50.	-50.	-50.	-50.	916.	2.30
13	7.23	211.	0.93	0.33	27.93	9.73	0.54	-50.	-50.	77.	-50.	-50.	54.2	0.76
13 D4			0.54	0.15	18.08	6.36	0.43							
13 D5			0.50	0.16	19.59	6.99	0.49							
14	7.17	228.	1.19	0.42	32.35	9.21	0.85	-50.	-50.	72.	-50.	-50.	57.8	2.41
15	7.26	225.	0.60	0.48	24.97	15.61	0.33	-50.	-50.	169.	-50.	-50.	51.8	0.25
16	2.76	1757.	0.52	0.47	171.90	49.05	7.52	-50.	-50.	-50.	-50.	-50.	810.	1.71
17	7.37	148.	0.42	0.23	25.23	4.82	0.31	-50.	-50.	113.	-50.	-50.	7.82	0.13
18			0.57	0.18	18.89	7.21	0.57							
19	7.18	135.	0.70	0.26	19.58	5.88	0.32	-50.	-50.	-50.	-50.	-50.	4.05	0.44
20	7.43	228.	0.83	0.26	38.58	6.14	0.41	-50.	-50.	124.	-50.	-50.	8.11	1.05
21	7.17	108.	0.42	0.14	16.30	4.53	0.22	-50.	-50.	65.	-50.	-50.	7.16	0.19
22	7.53	221.	0.97	0.26	39.56	6.11	0.39	-50.	-50.	115.	-50.	-50.	7.33	1.36
0	7.07	165.	0.66	0.19	22.91	7.02	0.57	-50.	-50.	69.	-50.	-50.	36.5	0.68
24			0.72	0.27	3.74	0.33	0.22							
25			4.65	0.47	24.53	11.57	0.20							
26			7.55	5.16	316.35	74.10	7.18							
27	7.36	203.	2.14	0.23	22.42	11.95	-0.20	-50.	-50.	-50.	-50.	-50.	16.5	4.53
28	6.83	209.	1.20	0.54	18.59	8.89	0.35	-50.	4581.	-50.	-50.	-50.	7.24	16.4
29	7.28	119.	1.51	0.52	18.39	3.72	0.21	-50.	-50.	-50.	-50.	-50.	3.62	0.53
30	7.39	176.	0.76	0.31	28.67	6.20	0.58	-50.	-50.	-50.	-50.	-50.	16.8	0.73
31			0.54	0.15	18.15	6.26	0.39							
32	7.03	138.	0.41	0.16	20.70	4.17	1.23	-50.	-50.	87.	-50.	-50.	31.4	0.07
BL 01			0.54	0.26	9.96	2.64	-0.20							

APPENDIX B

STREAM WATER DATA

164

Element	Se 78	Te 130	Bi 209	Sb 121	Al	Ti	V	Co	Ni	Cu	Zn	Y	Cd	In
Unit	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Det Lim	0.002	0.002	0.002	0.003	10	0.05	0.01	0.005	0.1	0.1	0.1	0.01	0.01	0.001
01	0.063	-0.002	-0.002	0.013	25	0.25	0.04	0.138	0.6	0.8	0.3	0.05	-0.01	-0.001
01 D5	0.037	-0.002	0.002	0.015	-10	0.69	0.21	0.282	16.4	0.7	1.2	0.01	-0.01	-0.001
02	1.810	-0.002	0.004	0.008	31	0.38	0.05	0.194	0.6	0.8	0.8	0.03	-0.01	-0.001
02 D5	2.101	-0.002	-0.002	0.007	-10	0.07	0.02	0.036	0.4	0.4	0.2	-0.01	-0.01	-0.001
04	0.834	-0.002	-0.002	0.040	51	0.76	0.12	0.099	0.6	0.8	0.4	0.04	-0.01	-0.001
04 D3	0.471	-0.002	0.002	0.023	41	0.45	0.10	0.129	0.6	0.9	0.5	0.05	-0.01	-0.001
05	0.212	0.039	0.109	0.081	357	0.08	0.05	57.003	61.6	21.4	116.1	0.81	0.22	-0.001
08	0.023	-0.002	0.003	0.004	-10	-0.05	-0.01	5.238	6.3	3.9	7.3	0.03	0.27	-0.001
08 D3	0.019	-0.002	-0.002	0.005	-10	-0.05	0.01	7.343	8.9	0.4	10.7	0.03	0.16	-0.001
09	0.102	-0.002	0.008	0.012	-10	-0.05	-0.01	0.128	0.8	0.4	0.5	-0.01	-0.01	-0.001
09 D3	0.096	-0.002	0.045	0.018	13	0.13	0.02	0.346	1.2	0.6	1.4	0.03	0.01	-0.001
09 D4	0.103	-0.002	0.004	0.010	-10	-0.05	0.02	0.364	20.6	0.5	5.0	-0.01	0.01	-0.001
09 D5	0.100	-0.002	0.005	0.010	-10	-0.05	-0.01	0.045	0.6	1.0	0.5	-0.01	-0.01	-0.001
09bD4	0.094	-0.002	0.008	0.013	-10	-0.05	0.01	0.204	3.7	0.3	4.0	0.01	-0.01	-0.001
10	0.007	-0.002	-0.002	0.100	-10	-0.05	-0.01	0.578	1.9	0.8	3.4	-0.01	-0.01	-0.001
10 D4	0.012	-0.002	-0.002	0.026	-10	0.14	0.06	1.527	74.5	0.5	22.6	-0.01	0.01	-0.001
11	0.014	-0.002	0.012	0.017	-10	-0.05	-0.01	0.956	1.8	0.7	0.9	0.01	0.02	-0.001
12	0.023	-0.002	0.039	0.042	16	0.19	0.02	0.996	2.9	2.2	1.8	0.01	0.02	-0.001
13	0.081	-0.002	0.005	0.010	-10	0.05	-0.01	0.780	1.7	0.3	1.2	0.01	0.02	-0.001
13 D4	0.103	-0.002	0.005	0.011	-10	-0.05	-0.01	0.337	1.0	0.3	0.6	-0.01	0.01	-0.001
13 D5	0.118	-0.002	0.011	0.041	-10	0.05	0.02	0.303	2.2	1.4	0.7	-0.01	-0.01	-0.001
14	0.083	-0.002	0.012	0.017	12	0.18	0.01	1.568	3.1	0.5	4.8	0.03	0.04	-0.001
15	0.783	-0.002	0.005	0.017	52	2.22	0.20	0.363	4.9	1.2	2.9	0.08	0.02	-0.001
16	0.469	-0.002	0.022	0.009	468	-0.05	-0.01	21.175	22.3	6.3	99.7	4.06	1.36	0.015
17	0.539	-0.002	-0.002	0.026	28	0.30	0.07	0.110	0.7	0.7	0.2	0.05	-0.01	-0.001
18	0.110	-0.002	0.004	0.011	-10	-0.05	-0.01	0.400	1.1	0.3	0.7	-0.01	0.01	-0.001
19	0.145	-0.002	-0.002	0.016	-10	-0.05	0.03	0.175	0.9	0.5	0.6	0.02	0.01	-0.001
20	0.229	-0.002	-0.002	0.014	-10	-0.05	0.02	0.121	1.1	0.5	0.3	0.01	-0.01	-0.001
21	0.252	-0.002	-0.002	0.014	11	0.11	0.03	0.076	1.0	0.8	0.2	0.04	-0.01	-0.001
22	0.192	-0.002	-0.002	0.017	-10	0.05	0.02	0.117	0.8	0.5	0.2	0.01	-0.01	-0.001
23	0.099	-0.002	-0.002	0.009	-10	0.06	0.02	1.217	28.4	0.3	13.7	0.01	0.03	-0.001
24	0.052	-0.002	-0.002	0.065	41	0.81	0.43	0.341	1.0	2.1	9.5	0.03	0.03	-0.001
25	0.461	-0.002	-0.002	0.036	37	0.81	0.18	0.212	1.1	1.7	1.7	0.05	0.02	-0.001
26	0.101	-0.002	-0.002	0.011	-10	-0.05	-0.01	4.629	7.0	0.1	13.1	0.03	0.04	-0.001
27	0.465	-0.002	-0.002	0.004	-10	-0.05	-0.01	0.066	0.6	0.1	0.4	-0.01	-0.01	-0.001
28	0.278	-0.002	0.003	0.016	-10	0.13	0.03	3.036	4.2	1.4	1.8	0.06	0.11	-0.001
29	0.096	-0.002	-0.002	0.028	-10	0.08	0.17	0.149	1.0	2.7	1.7	0.03	0.12	-0.001
30	0.127	-0.002	-0.002	0.022	-10	-0.05	-0.01	0.265	1.2	1.6	16.3	0.01	0.08	-0.001
31	0.105	-0.002	0.008	0.011	-10	-0.05	-0.01	0.343	1.0	0.3	0.6	-0.01	0.01	-0.001
32	0.061	-0.002	0.008	0.038	10	0.09	0.01	1.261	2.4	2.4	6.1	0.04	0.04	-0.001
BL 01	0.027	-0.002	0.005	0.014	-10	0.06	0.04	0.037	0.8	0.6	-0.1	0.01	-0.01	-0.001

APPENDIX B

STREAM WATER DATA

165

Element	La	Ce	Pr	Nd	Sm	Eu	Tb	Gd	Dy	Ho	Er	Tm	Yb	Lu
Unit	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
Det Lim	0.01	0.01	0.005	0.01	0.005	0.001	0.001	0.005	0.005	0.001	0.001	0.001	0.001	0.001
01	0.05	0.06	0.010	0.043	0.008	0.002	0.002	0.012	0.008	0.001	0.005	-0.001	0.002	-0.001
01 D5	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
02	0.03	0.05	0.006	0.028	0.007	0.002	0.001	0.008	0.005	0.001	0.003	-0.001	0.002	-0.001
02 D5	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
04	0.04	0.08	0.009	0.037	0.008	0.003	0.001	0.008	0.008	0.001	0.004	-0.001	0.002	-0.001
04 D3	0.03	0.08	0.009	0.040	0.009	0.002	0.002	0.010	0.007	0.001	0.004	-0.001	0.003	-0.001
05	0.27	0.51	0.061	0.245	0.070	0.039	0.017	0.094	0.123	0.023	0.075	0.009	0.064	0.009
06	-0.01	0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
06 D3	-0.01	0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	0.001	-0.001	-0.001	-0.001
09	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
09 D3	0.02	0.04	0.005	0.023	0.007	0.002	0.001	0.007	0.006	-0.001	0.003	-0.001	0.002	-0.001
09 D4	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
09 D5	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
09bD4	-0.01	-0.01	-0.005	-0.01	-0.005	0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
10	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
10 D4	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
11	-0.01	-0.01	-0.005	-0.01	-0.005	0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
12	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
13	-0.01	0.01	-0.005	-0.01	-0.005	0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
13 D4	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	0.001	-0.001	-0.001	-0.001
13 D5	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
14	0.01	0.03	-0.005	0.016	-0.005	0.001	-0.001	0.006	-0.005	-0.001	0.002	-0.001	0.002	-0.001
15	0.03	0.06	0.009	0.044	0.011	0.005	0.002	0.016	0.011	0.002	0.007	-0.001	0.005	-0.001
16	0.49	1.13	0.150	0.717	0.268	0.161	0.088	0.461	0.587	0.114	0.360	0.046	0.311	0.044
17	0.03	0.06	0.008	0.033	0.008	0.003	0.001	0.009	0.006	0.002	0.004	-0.001	0.003	-0.001
18	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
19	-0.01	-0.01	-0.005	-0.01	-0.005	0.002	-0.001	-0.005	-0.005	-0.001	0.001	-0.001	0.001	-0.001
20	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	0.001	-0.001	-0.001	-0.001
21	0.01	0.02	-0.005	0.017	0.005	0.003	0.001	0.009	0.005	0.001	0.004	-0.001	0.003	-0.001
22	-0.01	-0.01	-0.005	-0.01	-0.005	0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	0.001	-0.001
23	-0.01	-0.01	-0.005	-0.01	-0.005	0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
24	0.02	0.04	0.006	0.024	0.007	0.002	0.001	0.008	0.006	0.001	0.003	-0.001	0.002	-0.001
25	0.02	0.05	0.007	0.034	0.008	0.003	0.002	0.009	0.008	0.002	0.005	-0.001	0.004	-0.001
26	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
27	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
28	0.01	0.02	-0.005	0.020	0.005	0.002	0.001	0.011	0.010	0.002	0.006	-0.001	0.006	0.001
29	0.01	0.02	-0.005	0.013	-0.005	0.001	-0.001	-0.005	-0.005	-0.001	0.003	-0.001	0.003	-0.001
30	-0.01	-0.01	-0.005	-0.01	-0.005	0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
31	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
32	0.01	0.02	-0.005	0.014	0.005	0.002	-0.001	0.005	0.007	0.001	0.003	-0.001	0.003	-0.001
BL 01	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001

APPENDIX B

STREAM WATER DATA

166

Element Unit Det Lim	Pb ug/L 0.02	U ug/L 0.005	Mn ug/L 2	Fe ug/L 5
01	0.04	0.233	2	55
01 D5	0.05	0.306	-2	140
02	0.10	0.438	3	76
02 D5	-0.02	0.698	-2	11
04	0.09	0.687	5	112
04 D3	0.07	0.343	12	70
05	144.70	0.320	2838	163828
08	0.03	0.167	2874	22803
08 D3	-0.02	0.027	2686	10102
09	0.10	0.073	28	331
09 D3	1.13	0.038	60	217
09 D4	0.09	0.054	17	71
09 D5	0.07	0.071	6	30
09bD4	0.18	0.078	57	338
10	0.03	5.843	212	127
10 D4	0.12	5.713	180	90
11	0.07	0.373	931	213
12	0.23	5.403	418	137
13	0.11	0.123	237	155
13 D4	0.09	0.087	96	129
13 D5	0.08	0.089	98	113
14	0.14	0.126	301	199
15	0.08	0.145	13	178
16	55.49	1.285	7937	126903
17	0.06	0.379	5	68
18	0.04	0.076	112	99
19	0.04	0.122	71	263
20	-0.02	0.292	49	120
21	0.05	0.123	14	23
22	-0.02	0.267	33	121
23	0.08	0.101	173	96
24	0.46	0.012	34	112
25	0.16	0.172	7	94
26	0.04	0.922	2087	81042
27	-0.02	0.394	18	53
28	0.07	1.128	3682	481
29	0.16	0.091	9	62
30	0.10	0.210	77	104
31	0.06	0.084	96	134
32	1.73	0.009	90	571
BL 01	-0.02	0.051	-2	33

167

Element	PH	CONDUCT	NA	K	CA	MG	AS	NO2	NO3	F	PO4	BR	SO4	CL
Unit	UNI	UMO	mg/L	mg/L	mg/L	mg/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	mg/L	mg/L
Det Lim	.01	5	.1	.1	.1	.1	.2	50	50	50	50	50	.05	.05
1 b		99.	0.39	0.14	12.90	4.65	0.40	-50.	-50.	-50.	-50.	-50.	14.4	0.23
1-4		84.	0.35	0.16	11.77	4.27	0.41	-50.	-50.	-50.	-50.	-50.	9.75	0.23
1 a		83.	0.35	0.14	11.10	4.10	-0.20	-50.	-50.	-50.	-50.	-50.	9.95	0.23
2 b		106.	0.47	0.18	15.55	5.38	-0.20	-50.	-50.	-50.	-50.	-50.	18.9	0.30
2-8		105.	0.42	0.18	13.99	4.95	0.34	-50.	-50.	75.	-50.	-50.	16.0	0.27
2 a		84.	0.35	0.15	10.76	4.24	-0.20	-50.	-50.	-50.	-50.	-50.	10.1	0.15
3 b		117.	0.48	0.19	15.33	5.45	0.33	-50.	-50.	-50.	-50.	-50.	19.3	0.36
3-8		99.	0.42	0.16	13.35	4.92	0.21	-50.	-50.	-50.	-50.	-50.	15.2	0.28
3-8 dup			0.42	0.18	13.32	4.86	0.26							
3 a		86.	0.35	0.16	11.28	4.30	0.26	-50.	-50.	-50.	-50.	-50.	10.2	0.19
4 b		154.	0.45	0.16	15.28	5.60	0.27	-50.	-50.	54.	76.	-50.	21.3	9.32
4-6		97.	0.39	0.14	11.30	4.37	-0.20	-50.	-50.	-50.	-50.	-50.	12.7	0.89
4 a		95.	0.38	0.14	11.52	4.40	0.30	-50.	-50.	-50.	-50.	-50.	10.4	2.01
5 b		114.	0.51	0.18	15.90	5.54	-0.20	-50.	-50.	72.	-50.	-50.	19.1	0.30
5-11		115.	0.50	0.18	15.97	5.51	0.23	-50.	-50.	77.	-50.	-50.	19.2	0.35
5-7		100.	0.45	0.16	13.42	4.89	-0.20	-50.	-50.	-50.	-50.	-50.	14.7	0.25
5-4		88.	0.39	0.15	11.85	4.46	-0.20	-50.	-50.	-50.	-50.	-50.	11.5	0.23
5 a		89.	0.38	0.14	11.63	4.34	0.29	-50.	-50.	69.	-50.	-50.	10.3	0.28
6 b		111.	0.48	0.16	14.85	5.25	-0.20	-50.	-50.	-50.	-50.	-50.	17.5	0.31
6-6		99.	0.43	0.15	13.11	4.86	0.31	-50.	-50.	75.	-50.	-50.	14.4	0.25
6 a		87.	0.38	0.14	11.55	4.35	0.25	-50.	-50.	80.	-50.	-50.	9.91	0.21
7 b		120.	0.51	0.18	16.08	5.60	0.22	-50.	-50.	74.	-50.	-50.	20.5	0.31
7-11		113.	0.48	0.18	15.20	5.38	0.24	-50.	-50.	72.	-50.	-50.	18.3	0.30
7-8		102.	0.45	0.16	13.53	4.90	0.23	-50.	-50.	75.	-50.	-50.	15.3	0.26
7-4		100.	0.38	0.14	11.45	4.34	0.39	-50.	-50.	65.	-50.	-50.	10.5	0.16
7 a		88.	0.38	0.14	11.52	4.30	0.27	-50.	-50.	75.	-50.	-50.	10.5	0.22
8 b		117.	0.51	0.18	15.90	5.51	0.30	-50.	-50.	76.	-50.	-50.	19.3	0.32
8-8		103.	0.45	0.16	13.82	4.95	0.27	-50.	-50.	70.	-50.	-50.	15.4	0.26
8 a		119.	0.38	0.12	11.63	4.30	-0.20	-50.	-50.	68.	-50.	-50.	19.1	0.34
9 b		119.	0.50	0.19	15.77	5.45	0.24	-50.	-50.	77.	-50.	-50.	19.0	0.31
9-12		115.	0.50	0.18	15.73	5.41	0.36	-50.	-50.	84.	-50.	-50.	18.3	0.30
9-8		104.	0.43	0.15	13.58	4.89	-0.20	-50.	-50.	66.	-50.	-50.	14.7	0.21
9-4		88.	0.38	0.14	11.46	4.27	0.28	-50.	-50.	57.	-50.	-50.	9.65	0.16
9 a		87.	0.36	0.14	11.48	4.30	0.30	-50.	-50.	60.	-50.	-50.	9.54	0.13
10 b		124.	0.50	0.16	15.66	5.48	-0.20	-50.	-50.	61.	-50.	-50.	19.6	0.33
10-8		98.	0.42	0.14	12.84	4.70	0.31	-50.	-50.	53.	-50.	-50.	13.0	0.20
10 a		86.	0.38	0.11	11.54	4.29	0.25	-50.	-50.	67.	-50.	-50.	9.67	0.15
BL 01 b		75.	0.69	0.30	10.33	2.89	0.32	-50.	455.	-50.	-50.	-50.	2.05	0.01
BL 01 8m		73.						-50.	-50.	-50.	-50.	-50.	2.04	0.00
BL 01 a		65.	0.52	0.23	9.42	2.57	0.42	-50.	-50.	-50.	-50.	-50.	2.60	-0.00
BL 02 b		75.	0.70	0.31	10.99	2.97	0.27	-50.	487.	-50.	-50.	-50.	2.05	-0.00
BL 02 8m		70.	0.61	0.28	10.10	2.75	-0.20	-50.	170.	-50.	-50.	-50.	2.25	-0.00
BL 02 a		65.	0.56	0.27	9.72	2.61	0.31	-50.	-50.	-50.	-50.	-50.	2.68	-0.00

168

Element	CONDUCT	NA	K	CA	MG	AS	NO2	NO3	F	PO4	BR	SO4	CL
Unit	UMO	mg/L	mg/L	mg/L	mg/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	mg/L	mg/L
Det Lim	5	.1	.1	.1	.1	.2	50	50	50	50	50	.05	.05
1 b	99.	0.39	0.14	12.90	4.65	0.40	-50.	-50.	-50.	-50.	-50.	14.4	0.23
1-4	84.	0.35	0.16	11.77	4.27	0.41	-50.	-50.	-50.	-50.	-50.	9.75	0.23
1 a	83.	0.35	0.14	11.10	4.10	-0.20	-50.	-50.	-50.	-50.	-50.	9.95	0.23
2 b	106.	0.47	0.18	15.55	5.38	-0.20	-50.	-50.	-50.	-50.	-50.	18.9	0.30
2-8	105.	0.42	0.18	13.99	4.95	0.34	-50.	-50.	75.	-50.	-50.	16.0	0.27
2 a	84.	0.35	0.15	10.76	4.24	-0.20	-50.	-50.	-50.	-50.	-50.	10.1	0.15
3 b	117.	0.48	0.19	15.33	5.45	0.33	-50.	-50.	-50.	-50.	-50.	19.3	0.36
3-8	99.	0.42	0.16	13.35	4.92	0.21	-50.	-50.	-50.	-50.	-50.	15.2	0.28
3-8 dup		0.42	0.18	13.32	4.86	0.26							
3 a	86.	0.35	0.16	11.28	4.30	0.26	-50.	-50.	-50.	-50.	-50.	10.2	0.19
4 b	154.	0.45	0.16	15.28	5.60	0.27	-50.	-50.	54.	76.	-50.	21.3	9.32
4-6	97.	0.39	0.14	11.30	4.37	-0.20	-50.	-50.	-50.	-50.	-50.	12.7	0.89
4 a	95.	0.38	0.14	11.52	4.40	0.30	-50.	-50.	-50.	-50.	-50.	10.4	2.01
5 b	114.	0.51	0.18	15.90	5.54	-0.20	-50.	-50.	72.	-50.	-50.	19.1	0.30
5-11	115.	0.50	0.18	15.97	5.51	0.23	-50.	-50.	77.	-50.	-50.	19.2	0.35
5-7	100.	0.45	0.16	13.42	4.89	-0.20	-50.	-50.	-50.	-50.	-50.	14.7	0.25
5-4	88.	0.39	0.15	11.85	4.46	-0.20	-50.	-50.	-50.	-50.	-50.	11.5	0.23
5 a	89.	0.38	0.14	11.63	4.34	0.29	-50.	-50.	69.	-50.	-50.	10.3	0.28
6 b	111.	0.48	0.16	14.85	5.25	-0.20	-50.	-50.	-50.	-50.	-50.	17.5	0.31
6-6	99.	0.43	0.15	13.11	4.86	0.31	-50.	-50.	75.	-50.	-50.	14.4	0.25
6 a	87.	0.38	0.14	11.55	4.35	0.25	-50.	-50.	80.	-50.	-50.	9.91	0.21
7 b	120.	0.51	0.18	16.08	5.60	0.22	-50.	-50.	74.	-50.	-50.	20.5	0.31
7-11	113.	0.48	0.18	15.20	5.38	0.24	-50.	-50.	72.	-50.	-50.	18.3	0.30
7-8	102.	0.45	0.16	13.53	4.90	0.23	-50.	-50.	75.	-50.	-50.	15.3	0.26
7-4	100.	0.38	0.14	11.45	4.34	0.39	-50.	-50.	65.	-50.	-50.	10.5	0.18
7 a	88.	0.38	0.14	11.52	4.30	0.27	-50.	-50.	75.	-50.	-50.	10.5	0.22
8 b	117.	0.51	0.18	15.90	5.51	0.30	-50.	-50.	76.	-50.	-50.	19.3	0.32
8-8	103.	0.45	0.16	13.82	4.95	0.27	-50.	-50.	70.	-50.	-50.	15.4	0.26
8 a	119.	0.38	0.12	11.63	4.30	-0.20	-50.	-50.	68.	-50.	-50.	19.1	0.30
9 b	119.	0.50	0.19	15.77	5.45	0.24	-50.	-50.	77.	-50.	-50.	19.0	0.31
9-12	115.	0.50	0.18	15.73	5.41	0.36	-50.	-50.	84.	-50.	-50.	18.3	0.33
9-8	104.	0.43	0.15	13.58	4.89	-0.20	-50.	-50.	66.	-50.	-50.	14.7	0.25
9-4	88.	0.38	0.14	11.46	4.27	0.28	-50.	-50.	57.	-50.	-50.	9.65	0.16
9 a	87.	0.36	0.14	11.48	4.30	0.30	-50.	-50.	60.	-50.	-50.	9.54	0.13
10 b	124.	0.50	0.16	15.66	5.48	-0.20	-50.	-50.	61.	-50.	-50.	19.6	0.32
10-8	98.	0.42	0.14	12.84	4.70	0.31	-50.	-50.	53.	-50.	-50.	13.0	0.20
10 a	86.	0.38	0.11	11.54	4.29	0.25	-50.	-50.	67.	-50.	-50.	9.67	0.18
BL 01 b	75.	0.69	0.30	10.33	2.89	0.32	-50.	455.	-50.	-50.	-50.	2.05	0.07
BL 01 8m	73.						-50.	-50.	-50.	-50.	-50.	2.04	0.06
BL 01 a	65.	0.52	0.23	9.42	2.57	0.42	-50.	-50.	-50.	-50.	-50.	2.60	-0.05
BL 02 b	75.	0.70	0.31	10.99	2.97	0.27	-50.	487.	-50.	-50.	-50.	2.05	-0.05
BL 02 8m	70.	0.61	0.28	10.10	2.75	-0.20	-50.	170.	-50.	-50.	-50.	2.25	-0.05
BL 02 a	65.	0.56	0.27	9.72	2.61	0.31	-50.	-50.	-50.	-50.	-50.	2.68	-0.05

APPENDIX B STREAM WATER DATA

169

Element Unit Det Lim	Se 78 ug/L 0.002	Te 130 ug/L 0.002	Bi 209 ug/L 0.002	Sb 121 ug/L 0.003	Al ug/L 10	Ti ug/L 0.05	V ug/L 0.01	Co ug/L 0.005	Ni ug/L 0.1	Cu ug/L 0.1	Zn ug/L 0.1	Y ug/L 0.01	Cd ug/L 0.01	In ug/L 0.001
1 b	0.107	-0.002	-0.002	0.009	-10	-0.05	0.01	0.099	0.7	0.4	2.8	0.02	0.02	-0.001
1-4	0.103	-0.002	-0.002	0.010	-10	-0.05	0.01	0.200	0.6	0.3	0.8	-0.01	-0.01	-0.001
1 s	0.099	-0.002	-0.002	0.010	-10	-0.05	0.01	0.110	0.7	0.4	1.7	-0.01	0.01	-0.001
2 b	0.110	-0.002	-0.002	0.011	-10	-0.05	0.01	0.048	0.7	0.6	1.2	0.01	-0.01	-0.001
2-8	0.107	-0.002	-0.002	0.010	-10	-0.05	-0.01	0.130	0.7	0.5	0.9	0.02	-0.01	-0.001
2 s	0.106	-0.002	-0.002	0.011	-10	-0.05	0.01	0.066	0.6	0.5	0.7	-0.01	-0.01	-0.001
3 b	0.107	-0.002	-0.002	0.025	-10	-0.05	0.01	0.025	0.8	0.6	1.2	0.01	0.01	-0.001
3-8	0.105	-0.002	-0.002	0.010	-10	-0.05	-0.01	0.082	0.7	0.4	0.7	0.02	-0.01	-0.001
3-8 dup	0.111	-0.002	-0.002	0.010	-10	-0.05	0.01	0.026	0.6	0.5	0.7	0.01	-0.01	-0.001
3 s	0.109	-0.002	-0.002	0.010	-10	-0.05	0.01	0.047	0.6	0.4	0.8	-0.01	-0.01	-0.001
4 b	0.103	-0.002	0.005	0.015	11	0.07	0.02	0.036	0.9	1.8	6.1	0.02	0.12	-0.001
4-6	0.109	-0.002	-0.002	0.013	-10	0.09	0.01	0.026	0.7	4.3	2.8	0.02	0.06	-0.001
4 s	0.109	-0.002	-0.002	0.010	-10	0.06	0.01	0.050	0.6	1.3	1.7	-0.01	0.05	-0.001
5 b	0.109	-0.002	0.004	0.012	-10	-0.05	0.01	0.024	0.7	1.7	2.1	0.01	-0.01	-0.001
5-11	0.112	-0.002	-0.002	0.012	-10	-0.05	-0.01	0.021	0.7	1.7	1.8	0.01	0.02	-0.001
5-7	0.111	-0.002	0.002	0.013	10	0.09	0.01	0.021	0.9	6.0	2.4	0.02	0.13	-0.001
5-4	0.107	-0.002	0.002	0.013	-10	-0.05	-0.01	0.020	0.7	0.6	1.2	0.01	-0.01	-0.001
5 s	0.106	-0.002	-0.002	0.012	-10	-0.05	0.01	0.042	0.6	0.8	0.9	-0.01	-0.01	-0.001
6 b	0.109	-0.002	-0.002	0.010	-10	-0.05	-0.01	0.024	0.7	1.0	1.2	0.01	-0.01	-0.001
6-6	0.097	-0.002	0.004	0.033	-10	-0.05	-0.01	0.078	0.7	0.6	1.1	0.02	-0.01	-0.001
6 s	0.105	-0.002	-0.002	0.008	-10	-0.05	-0.01	0.037	0.6	1.1	0.9	-0.01	-0.01	-0.001
7 b	0.108	-0.002	0.009	0.009	-10	0.05	-0.01	0.031	0.7	1.2	1.5	0.02	-0.01	-0.001
7-11	0.107	-0.002	0.004	0.011	-10	-0.05	-0.01	0.061	0.7	0.6	0.7	0.01	-0.01	-0.001
7-8	0.105	-0.002	-0.002	0.007	-10	-0.05	-0.01	0.050	0.6	0.3	0.7	0.01	-0.01	-0.001
7-4	0.104	-0.002	0.002	0.009	-10	-0.05	-0.01	0.034	0.6	0.4	0.6	-0.01	0.03	-0.001
7 s	0.104	-0.002	-0.002	0.017	-10	-0.05	-0.01	0.034	0.6	0.3	0.5	-0.01	-0.01	-0.001
8 b	0.105	-0.002	0.004	0.015	18	0.32	0.03	0.046	0.7	0.4	1.2	0.02	-0.01	-0.001
8-8	0.105	-0.002	-0.002	0.007	-10	-0.05	-0.01	0.060	0.7	0.3	1.2	0.02	-0.01	-0.001
8 s	0.106	-0.002	-0.002	0.008	-10	-0.05	-0.01	0.037	0.6	0.3	0.9	-0.01	-0.01	-0.001
9 b	0.104	-0.002	0.009	0.009	-10	-0.05	-0.01	0.024	0.8	2.3	3.0	0.01	0.02	-0.001
9-12	0.112	-0.002	0.065	0.010	19	1.20	0.36	0.468	31.4	13.8	6.1	0.01	-0.01	-0.001
9-8	0.117	-0.002	0.019	0.007	-10	-0.05	0.01	0.021	0.7	2.3	1.5	0.01	-0.01	-0.001
9-4	0.107	-0.002	0.016	0.009	-10	-0.05	-0.01	0.041	0.6	1.2	1.2	-0.01	-0.01	-0.001
9 s	0.107	-0.002	0.009	0.010	-10	-0.05	-0.01	0.042	0.6	1.6	1.6	-0.01	-0.01	-0.001
10 b	0.109	-0.002	-0.002	0.009	-10	-0.05	-0.01	0.021	0.6	0.4	0.8	0.01	-0.01	-0.001
10-8	0.111	-0.002	-0.002	0.008	-10	-0.05	-0.01	0.048	0.7	0.3	0.7	0.02	-0.01	-0.001
10 s	0.113	-0.002	-0.002	0.008	-10	-0.05	-0.01	0.031	0.5	0.3	0.6	-0.01	-0.01	-0.001
BL 01 b	0.025	-0.002	-0.002	0.015	-10	3.34	1.04	1.283	88.5	1.8	6.4	0.04	-0.01	-0.001
BL 01 6m														
BL 01 s	0.031	-0.002	0.002	0.023	-10	7.70	2.62	3.029	211.9	4.7	14.6	0.01	-0.01	-0.001
BL 02 b	0.029	-0.002	-0.002	0.016	-10	2.05	0.63	1.190	51.0	1.7	4.2	0.04	-0.01	-0.001
BL 02 8m	0.030	-0.002	-0.002	0.010	-10	0.09	0.03	0.100	1.1	0.5	0.5	0.03	0.01	-0.001
BL 02 s	0.032	-0.002	-0.002	0.008	-10	-0.05	0.03	0.053	0.7	0.5	0.5	0.01	-0.01	-0.001

APPENDIX B

STREAM WATER DATA

170

Element Unit Det Lim	La ug/L 0.01	Ce ug/L 0.01	Pr ug/L 0.005	Nd ug/L 0.01	Sm ug/L 0.005	Eu ug/L 0.001	Tb ug/L 0.001	Gd ug/L 0.005	Dy ug/L 0.005	Ho ug/L 0.001	Er ug/L 0.001	Tm ug/L 0.001	Yb ug/L 0.001	Lu ug/L 0.001
1 b	-0.01	-0.01	-0.005	-0.01	-0.005	0.001	-0.001	-0.005	-0.005	-0.001	0.002	-0.001	0.001	-0.001
1-4	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
1 s	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
2 b	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	0.001	-0.001	-0.001	-0.001
2-8	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	0.001	-0.001	0.001	-0.001
2 s	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
3 b	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
3-8	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	0.001	-0.001
3-8 dup	-0.01	-0.01	-0.005	-0.01	-0.005	0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	0.001	-0.001
3 s	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
4 b	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	0.001	-0.001	0.001	-0.001
4-6	0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	0.001	-0.001	0.002	-0.001
4 s	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
5 b	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	0.001	-0.001
5-11	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	0.001	-0.001
5-7	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	0.001	-0.001
5-4	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
5 s	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
6 b	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	0.001	-0.001	0.001	-0.001
6-6	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	0.001	-0.001	0.001	-0.001
6 s	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
7 b	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	0.001	-0.001	0.001	-0.001
7-11	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	0.001	-0.001
7-8	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	0.001	-0.001	0.001	-0.001
7-4	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
7 s	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
8 b	0.01	0.02	-0.005	0.016	-0.005	0.001	-0.001	-0.005	-0.005	-0.001	0.002	-0.001	0.001	-0.001
8-8	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	0.001	-0.001	0.002	-0.001
8 s	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
9 b	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	0.001	-0.001
9-12	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	0.001	-0.001	0.001	-0.001
9-8	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	0.001	-0.001	0.002	-0.001
9-4	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
9 s	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
10 b	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	0.001	-0.001	-0.001	-0.001
10-8	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	0.002	-0.001	0.002	-0.001
10 s	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	0.002	-0.001
BL 01 b	0.04	0.02	0.008	0.036	0.007	0.002	-0.001	0.009	0.006	0.001	0.003	-0.001	0.002	-0.001
BL 01 8m														
BL 01 s	-0.01	-0.01	-0.005	-0.01	0.020	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001
BL 02 b	0.03	0.02	0.007	0.032	0.007	0.001	0.001	0.008	-0.005	0.001	0.003	-0.001	0.002	-0.001
BL 02 8m	0.02	0.02	-0.005	0.022	-0.005	0.001	-0.001	0.006	-0.005	-0.001	0.002	-0.001	0.001	-0.001
BL 02 s	-0.01	-0.01	-0.005	-0.01	-0.005	-0.001	-0.001	-0.005	-0.005	-0.001	-0.001	-0.001	-0.001	-0.001

APPENDIX B

STREAM WATER DATA

171

Element Unit Det Lim	Pb ug/L 0.02	U ug/L 0.005	Mn ug/L 2	Fe ug/L 5
1 b	0.20	0.095	7	108
1-4	-0.02	0.077	4	39
1 s	0.05	0.069	-2	27
2 b	0.02	0.132	-2	39
2-8	0.03	0.106	-2	26
2 s	0.02	0.068	2	24
3 b	0.08	0.134	-2	40
3-8	0.03	0.110	-2	22
3-8 dup	0.02	0.111	-2	23
3 s	-0.02	0.072	-2	20
4 b	0.22	0.135	10	37
4-6	0.45	0.088	-2	28
4 s	0.11	0.073	2	21
5 b	0.06	0.142	-2	41
5-11	0.07	0.135	-2	38
5-7	0.25	0.100	-2	30
5-4	0.06	0.083	-2	24
5 s	0.04	0.073	-2	23
6 b	0.08	0.123	-2	33
6-6	0.04	0.099	2	27
6 s	0.06	0.073	-2	9
7 b	0.05	0.139	-2	28
7-11	0.02	0.125	-2	32
7-8	-0.02	0.108	-2	20
7-4	0.02	0.074	-2	22
7 s	0.02	0.075	-2	23
8 b	0.08	0.150	2	77
8-8	0.02	0.109	-2	26
8 s	0.02	0.070	-2	26
9 b	0.09	0.135	-2	42
9-12	0.31	0.132	3	300
9-8	0.06	0.105	-2	24
9-4	0.04	0.072	-2	21
9 s	0.05	0.072	-2	23
10 b	0.02	0.152	-2	38
10-8	0.03	0.102	-2	22
10 s	0.03	0.073	-2	24
BL 01 b	0.24	0.050	11	803
BL 01 8m				
BL 01 s	0.48	0.047	23	1781
BL 02 b	0.16	0.045	6	476
BL 02 8m	0.03	0.042	-2	38
BL 02 s	0.05	0.045	-2	25

APPENDIX C

VEGETATION DATA

172

Sample Name Units Detection Limit	Au ng/g 0.1	Ag ug/g 0.3	As ug/g 0.01	Ba ug/g 5	Br ug/g 0.01	Ca % 0.01	Co ug/g 0.1	Cr ug/g 0.3	Cu ug/g 0.05	Fe % 0.005	Hf ug/g 0.05	Hg ug/g 0.05	Ir ng/g 0.1
01 DF.TW	1	-0.3	0.04	36	0.38	0.51	0.3	0.6	-0.05	0.008	-0.05	-0.05	-0.1
01 ES.BK	7.5	-0.3	0.33	44	3.5	1	0.2	0.5	-0.05	0.018	-0.05	0.12	-0.1
01 ES.TW	1.7	-0.3	0.22	53	1.9	0.81	0.2	0.7	-0.05	0.024	-0.05	0.07	-0.1
01 WL.TW	1.9	-0.3	0.02	-5	0.23	0.68	0.6	1.5	-0.05	0.006	-0.05	-0.05	-0.1
02 DF.TW	2.1	-0.3	0.05	48	0.62	0.44	0.2	0.3	-0.05	0.008	-0.05	-0.05	-0.1
02 ES.BK	17.7	-0.3	0.26	76	2.5	0.77	0.2	0.3	0.09	0.01	-0.05	0.11	-0.1
02 ES.TW	1.1	-0.3	0.14	76	1	0.63	0.2	0.6	0.18	0.013	-0.05	0.06	-0.1
02 WL.TW	1	-0.3	0.02	8	0.64	0.38	0.3	0.4	-0.05	-0.005	-0.05	-0.05	-0.1
03 DF.TW	2.4	-0.3	0.6	55	0.54	0.41	0.5	1.3	-0.05	0.05	-0.05	-0.05	-0.1
03 ES.BK	12.3	-0.3	2.3	160	5.7	0.89	1	2.9	0.13	0.127	0.14	-0.05	-0.1
03 ES.TW	3.3	-0.3	0.57	64	1.3	0.51	0.7	1.9	0.07	0.064	0.09	-0.05	-0.1
03 LP.BK	6.7	-0.3	1.8	47	1.7	0.17	0.8	3.1	0.14	0.151	0.17	-0.05	-0.1
03 LP.TW	1.3	-0.3	0.55	12	0.97	0.3	0.4	1.5	-0.05	0.043	0.06	-0.05	-0.1
03 WL.TW	2.9	-0.3	0.16	52	0.45	1	0.8	0.7	-0.05	0.009	-0.05	-0.05	-0.1
04 DF.TW	1	-0.3	0.08	60	0.31	0.44	0.2	0.4	-0.05	0.009	-0.05	-0.05	-0.1
04 WL.TW	1.5	-0.3	0.02	30	0.21	0.88	0.3	-0.3	-0.05	-0.005	-0.05	-0.05	-0.1
05 DF.TW	24.3	-0.3	10	54	1	0.46	0.5	1	-0.05	0.112	-0.05	-0.05	-0.1
05 ES.BK	29.7	-0.3	43	33	1.6	0.92	1.5	1.6	-0.05	0.495	0.12	-0.05	-0.1
05 ES.TW	30.2	-0.3	41	31	1.4	0.78	1.7	2.4	0.05	0.446	0.15	-0.05	-0.1
05 WL.TW	2.2	-0.3	0.84	92	1	0.77	0.3	0.5	-0.05	0.013	-0.05	-0.05	-0.1
06 DF.TW	4.6	-0.3	2.2	52	0.94	0.39	0.3	0.8	0.06	0.032	-0.05	-0.05	-0.1
06 ES.TW	7.7	-0.3	5.9	64	0.86	0.61	0.4	0.6	0.15	0.068	-0.05	-0.05	-0.1
06 WL.TW	1.7	-0.3	0.59	23	3.3	0.27	0.2	-0.3	-0.05	0.009	-0.05	-0.05	-0.1
07 DF.TW	2.5	-0.3	0.97	70	0.67	0.52	0.3	0.8	0.05	0.022	-0.05	-0.05	-0.1
07 ES.BK	103	-0.3	9.2	130	7.8	1.3	0.5	1.6	0.09	0.143	0.11	0.53	-0.1
07 ES.TW	5.8	-0.3	2.7	160	1.1	0.74	0.4	0.9	0.06	0.046	-0.05	-0.05	-0.1
07 WL.TW	1.3	-0.3	0.06	8	0.44	0.44	0.3	-0.3	-0.05	-0.005	-0.05	-0.05	-0.1
08 WL.TW	1.4	-0.3	0.16	8	0.96	0.51	0.2	-0.3	-0.05	0.005	-0.05	-0.05	-0.1
10 LP.TW	1.8	-0.3	0.34	7	1.1	0.29	0.2	0.8	0.07	0.018	-0.05	-0.05	-0.1
10 WL.TW	1.3	-0.3	0.3	-5	0.22	0.37	0.2	-0.3	-0.05	0.008	-0.05	-0.05	-0.1
11 LP.TW	0.9	-0.3	0.15	-5	0.7	0.21	0.3	0.4	0.06	0.008	-0.05	-0.05	-0.1
11 WL.TW	0.9	-0.3	0.12	8	0.17	0.5	0.3	-0.3	-0.05	-0.005	-0.05	-0.05	-0.1
12 ES.TW	1.9	-0.3	1.1	66	2.7	0.57	1	2.2	0.08	0.086	0.14	-0.05	-0.1
12 LP.TW	3.8	-0.3	0.28	11	0.5	0.16	0.5	1.3	-0.05	0.042	0.06	-0.05	-0.1
12 WL.TW	0.8	-0.3	0.12	-5	0.29	0.4	0.3	-0.3	-0.05	0.01	-0.05	-0.05	-0.1
13 ES.TW	2.2	-0.3	0.46	58	0.66	0.61	0.4	1.3	0.05	0.042	0.05	-0.05	-0.1
13 WL.TW	0.9	-0.3	0.07	10	0.19	0.38	-0.1	-0.3	-0.05	0.007	-0.05	-0.05	-0.1
14 LP.TW	3.9	-0.3	0.15	5	0.62	0.21	0.3	0.8	-0.05	0.017	-0.05	-0.05	-0.1
15 ES.BK	11.7	-0.3	1.8	160	9.6	0.98	1.7	3.1	0.12	0.165	0.14	0.12	-0.1
15 ES.TW	4.1	-0.3	0.9	140	3.3	0.8	1.5	2.8	0.14	0.138	0.15	0.05	-0.1
15 WL.TW	1	-0.3	0.03	16	0.19	0.47	0.2	-0.3	-0.05	0.005	-0.05	-0.05	-0.1
19 ES.TW	3.9	-0.3	0.18	99	0.24	0.39	0.1	-0.3	-0.05	0.006	-0.05	-0.05	-0.1
19 LP.TW	0.4	-0.3	0.02	5	0.85	0.2	0.2	0.3	-0.05	-0.005	-0.05	-0.05	-0.1
19 WL.TW	0.9	-0.3	-0.01	27	0.31	0.59	0.2	-0.3	-0.05	-0.005	-0.05	-0.05	-0.1
20 WL.TW	1.1	-0.3	0.14	11	0.22	0.61	-0.1	-0.3	-0.05	-0.005	-0.05	-0.05	-0.1
21 WL.TW	0.6	-0.3	0.01	5	0.16	0.41	0.2	-0.3	-0.05	-0.005	-0.05	-0.05	-0.1
22 WL.TW	4.4	-0.3	0.05	23	0.34	0.75	0.3	-0.3	-0.05	-0.005	-0.05	-0.05	-0.1

APPENDIX C

VEGETATION DATA

173

Sample Name	K	Mo	Na	Ni	Rb	Sb	Sc	Se	Sr	Ta	Th	U	W
Units	%	ug/g	ug/g	ug/g	ug/g	ug/g	ug/g	ug/g	ug/g	ug/g	ug/g	ug/g	ug/g
Detection Limit	0.05	0.05	0.5	2	1	0.005	0.01	0.1	10	0.05	0.1	0.01	0.05
01 DF.TW	0.47	-0.05	23.9	-2	3	0.021	0.03	-0.1	19	-0.05	-0.1	-0.01	-0.05
01 ES.BK	0.3	-0.05	39.8	-2	2	0.028	0.05	-0.1	48	-0.05	-0.1	-0.01	-0.05
01 ES.TW	0.64	-0.05	64	-2	4	0.028	0.08	0.1	70	-0.05	-0.1	0.02	-0.05
01 WL.TW	0.43	0.07	13.1	-2	4	0.016	0.01	-0.1	38	-0.05	-0.1	-0.01	-0.05
02 DF.TW	0.52	-0.05	22.9	-2	4	0.02	0.02	-0.1	38	-0.05	-0.1	-0.01	-0.05
02 ES.BK	0.16	-0.05	26.2	-2	1	0.023	0.03	-0.1	77	-0.05	-0.1	0.03	0.06
02 ES.TW	0.5	-0.05	36.8	-2	4	0.022	0.04	-0.1	78	-0.05	-0.1	0.01	0.06
02 WL.TW	0.62	0.07	12.4	-2	6	0.016	-0.01	0.2	41	-0.05	-0.1	-0.01	-0.05
03 DF.TW	0.67	-0.05	73.9	4	7	0.033	0.13	-0.1	15	-0.05	0.1	0.04	0.19
03 ES.BK	0.41	0.14	232	-2	8	0.12	0.4	-0.1	24	-0.05	0.3	0.11	0.3
03 ES.TW	0.71	0.08	92.3	5	7	0.041	0.16	-0.1	25	-0.05	0.2	0.04	0.34
03 LP.BK	0.23	-0.05	201	-2	6	0.085	0.44	-0.1	-10	-0.05	0.4	0.08	0.27
03 LP.TW	0.32	0.05	52.5	2	4	0.029	0.1	-0.1	-10	-0.05	0.1	0.04	0.19
03 WL.TW	0.78	0.09	24.5	3	6	0.022	0.02	-0.1	49	-0.05	-0.1	-0.01	-0.05
04 DF.TW	0.4	-0.05	22.5	-2	2	0.017	0.03	-0.1	14	-0.05	-0.1	-0.01	-0.05
04 WL.TW	0.51	-0.05	11	-2	1	0.016	0.01	-0.1	35	-0.05	-0.1	-0.01	-0.05
05 DF.TW	0.56	-0.05	38.2	2	2	0.087	0.07	-0.1	14	-0.05	-0.1	0.02	0.34
05 ES.BK	0.35	-0.05	49.6	-2	4	0.34	0.22	-0.1	-10	-0.05	0.4	0.1	2.3
05 ES.TW	0.78	-0.05	74	4	5	0.35	0.25	-0.1	31	0.06	0.4	0.06	1.9
05 WL.TW	0.84	-0.05	13.1	4	7	0.025	0.01	-0.1	32	-0.05	-0.1	-0.01	0.12
06 DF.TW	0.57	-0.05	27.1	-2	3	0.043	0.04	-0.1	19	-0.05	-0.1	-0.01	0.12
06 ES.TW	0.72	-0.05	32.3	-2	7	0.066	0.06	-0.1	23	-0.05	-0.1	0.01	0.28
06 WL.TW	0.43	-0.05	13.9	-2	5	0.019	0.01	-0.1	10	-0.05	-0.1	-0.01	-0.05
07 DF.TW	0.51	-0.05	30.9	2	4	0.031	0.05	0.1	19	-0.05	-0.1	-0.01	0.06
07 ES.BK	0.27	-0.05	77.5	-2	4	0.12	0.19	-0.1	17	-0.05	0.2	0.06	0.7
07 ES.TW	0.59	0.13	55.4	3	4	0.061	0.08	-0.1	30	-0.05	-0.1	0.02	0.19
07 WL.TW	0.44	-0.05	8.8	-2	4	0.014	-0.01	-0.1	24	-0.05	-0.1	-0.01	-0.05
08 WL.TW	0.6	-0.05	11.9	-2	6	0.014	0.01	-0.1	29	-0.05	-0.1	-0.01	-0.05
10 LP.TW	0.58	-0.05	37	4	7	0.029	0.05	-0.1	-10	-0.05	-0.1	-0.01	0.09
10 WL.TW	0.32	-0.05	22.7	2	2	0.015	0.01	-0.1	29	-0.05	-0.1	-0.01	-0.05
11 LP.TW	0.83	-0.05	20.7	3	7	0.023	0.02	-0.1	-10	-0.05	-0.1	-0.01	-0.05
11 WL.TW	0.42	-0.05	12.9	-2	5	0.009	-0.01	-0.1	17	-0.05	-0.1	-0.01	-0.05
12 ES.TW	0.95	0.06	168	3	5	0.046	0.22	-0.1	45	-0.05	0.3	0.06	0.57
12 LP.TW	0.32	0.08	108	3	2	0.031	0.1	-0.1	-10	-0.05	0.1	0.02	0.24
12 WL.TW	0.39	0.05	85.3	-2	2	0.016	0.02	-0.1	25	-0.05	-0.1	0.01	-0.05
13 ES.TW	0.67	-0.05	68.2	2	4	0.037	0.11	-0.1	30	-0.05	0.1	0.03	0.08
13 WL.TW	0.48	-0.05	16.3	-2	5	0.012	0.02	-0.1	20	-0.05	-0.1	-0.01	-0.05
14 LP.TW	0.36	0.07	30.6	3	3	0.021	0.05	-0.1	-10	-0.05	-0.1	-0.01	-0.05
15 ES.BK	0.32	-0.05	287	8	4	0.078	0.41	0.1	37	-0.05	0.4	0.13	0.2
15 ES.TW	0.66	0.08	259	9	6	0.064	0.31	-0.1	46	-0.05	0.4	0.09	0.9
15 WL.TW	0.36	-0.05	23.6	-2	4	0.014	0.01	0.2	40	-0.05	-0.1	-0.01	-0.05
19 ES.TW	0.98	-0.05	12.2	2	5	0.012	0.01	-0.1	25	-0.05	-0.1	-0.01	-0.05
19 LP.TW	0.38	-0.05	10.1	-2	1	0.016	0.01	-0.1	-10	-0.05	-0.1	-0.01	-0.05
19 WL.TW	0.47	-0.05	8.4	-2	3	0.011	-0.01	-0.1	26	-0.05	-0.1	-0.01	-0.05
20 WL.TW	0.46	-0.05	9.1	-2	7	0.012	-0.01	0.2	33	-0.05	-0.1	-0.01	-0.05
21 WL.TW	0.46	-0.05	9.9	-2	4	0.012	-0.01	0.1	23	-0.05	-0.1	-0.01	-0.05
22 WL.TW	0.52	0.06	47	2	4	0.01	-0.01	-0.1	42	-0.05	-0.1	-0.01	-0.05

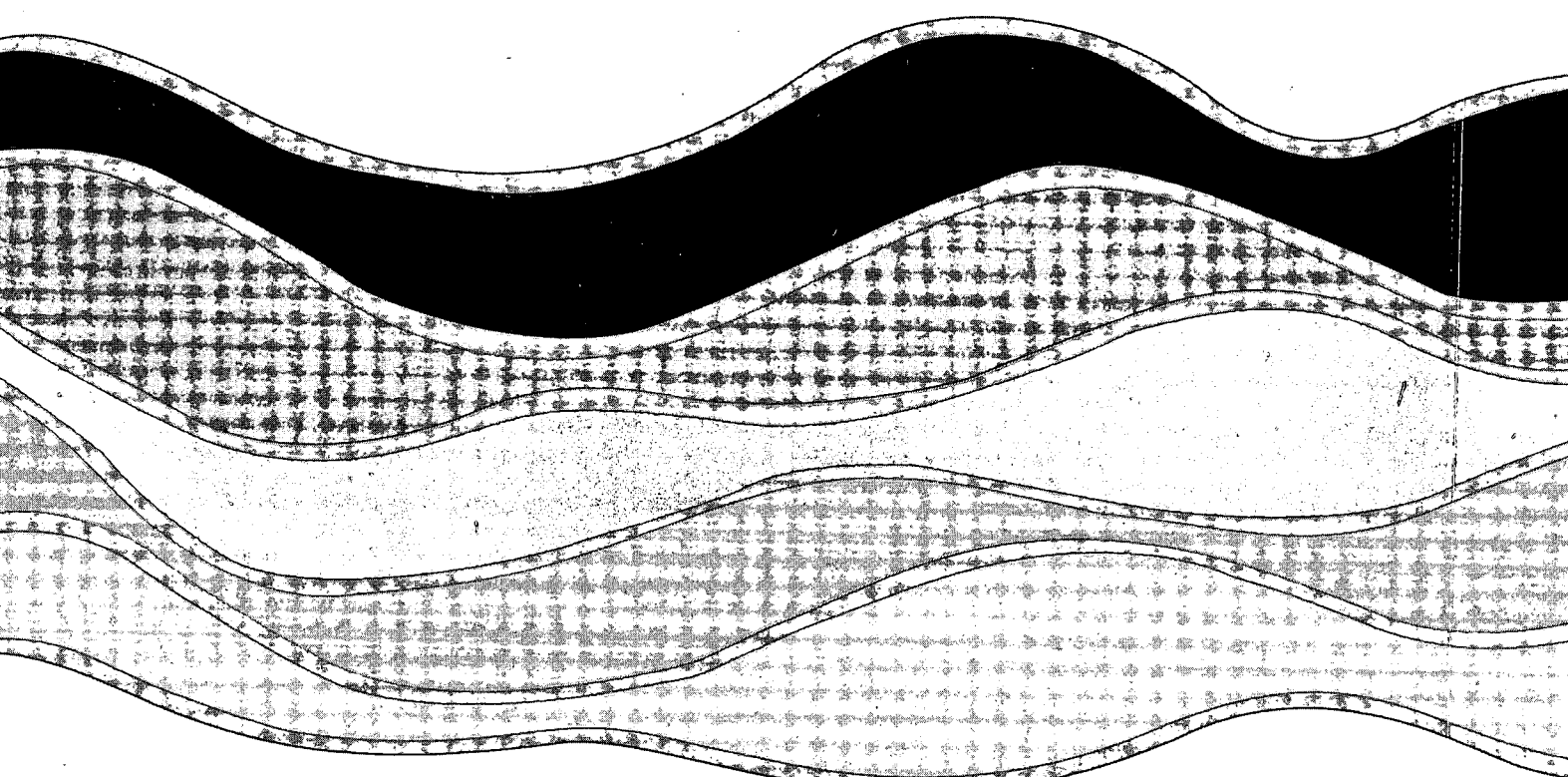
APPENDIX C

VEGETATION DATA

174

Sample Name	Zn	La	Ce	Nd	Sm	Eu	Tb	Yb	Lu	Mass
Units	ug/g	ug/g	ug/g	ug/g	ug/g	ug/g	ug/g	ug/g	ug/g	g
Detection Limit	2	0.01	0.3	0.5	0.01	0.05	0.1	0.005	0.001	0
01 DF.TW	33	0.09	-0.3	-0.5	-0.01	-0.05	-0.1	-0.005	-0.001	15.5
01 ES.BK	44	0.18	0.3	-0.5	0.02	-0.05	-0.1	0.01	0.001	15.62
01 ES.TW	78	0.21	0.4	-0.5	0.02	-0.05	-0.1	0.015	0.002	15.64
01 WL.TW	105	0.02	-0.3	-0.5	-0.01	-0.05	-0.1	-0.005	-0.001	15.3
02 DF.TW	26	0.08	-0.3	-0.5	-0.01	-0.05	-0.1	-0.005	-0.001	15.32
02 ES.BK	56	0.13	0.3	-0.5	0.01	-0.05	-0.1	0.006	-0.001	15.67
02 ES.TW	64	0.18	0.5	-0.5	0.01	-0.05	-0.1	0.009	0.002	15.68
02 WL.TW	38	0.02	-0.3	-0.5	-0.01	-0.05	-0.1	-0.005	-0.001	15.48
03 DF.TW	50	0.66	1.3	-0.5	0.07	-0.05	-0.1	0.033	0.005	15.62
03 ES.BK	54	1.3	2.1	1	0.16	-0.05	-0.1	0.08	0.013	15.74
03 ES.TW	100	0.71	1.3	-0.5	0.09	-0.05	-0.1	0.047	0.007	13.3
03 LP.BK	32	1.6	2.9	0.9	0.2	-0.05	-0.1	0.094	0.014	15.34
03 LP.TW	36	0.49	0.9	-0.5	0.06	-0.05	-0.1	0.034	0.005	15.48
03 WL.TW	120	0.23	-0.3	-0.5	0.02	-0.05	-0.1	0.006	-0.001	14.22
04 DF.TW	30	0.09	-0.3	-0.5	0.01	-0.05	-0.1	0.006	0.001	14.78
04 WL.TW	120	0.03	-0.3	-0.5	-0.01	-0.05	-0.1	-0.005	-0.001	15.72
05 DF.TW	32	0.39	0.7	-0.5	0.04	-0.05	-0.1	0.016	0.003	15.51
05 ES.BK	54	1.2	2.1	0.7	0.16	0.06	-0.1	0.079	0.012	15.31
05 ES.TW	64	1.1	2	0.6	0.15	-0.05	-0.1	0.083	0.011	14.06
05 WL.TW	67	0.29	-0.3	-0.5	0.01	-0.05	-0.1	0.005	-0.001	15.12
06 DF.TW	34	0.14	-0.3	-0.5	0.02	-0.05	-0.1	0.008	0.001	15.7
06 ES.TW	61	0.18	0.4	-0.5	0.02	-0.05	-0.1	0.013	0.002	15.27
06 WL.TW	33	0.04	-0.3	-0.5	-0.01	-0.05	-0.1	-0.005	-0.001	15.5
07 DF.TW	37	0.13	-0.3	-0.5	0.02	-0.05	-0.1	0.009	0.002	15.55
07 ES.BK	80	0.7	1.2	-0.5	0.09	-0.05	-0.1	0.042	0.008	15.51
07 ES.TW	89	0.23	0.5	-0.5	0.03	-0.05	-0.1	0.019	0.002	15.36
07 WL.TW	100	0.02	-0.3	-0.5	-0.01	-0.05	-0.1	-0.005	-0.001	15.62
08 WL.TW	160	0.03	-0.3	-0.5	-0.01	-0.05	-0.1	-0.005	-0.001	15.47
10 LP.TW	30	0.18	0.3	-0.5	0.03	-0.05	-0.1	0.014	0.001	15.32
10 WL.TW	88	0.05	-0.3	-0.5	-0.01	-0.05	-0.1	-0.005	-0.001	15.54
11 LP.TW	30	0.07	-0.3	-0.5	-0.01	-0.05	-0.1	0.005	-0.001	15.38
11 WL.TW	48	0.04	-0.3	-0.5	-0.01	-0.05	-0.1	-0.005	-0.001	15.59
12 ES.TW	87	0.94	1.8	0.6	0.12	-0.05	-0.1	0.066	0.01	15.22
12 LP.TW	30	0.46	0.8	-0.5	0.06	-0.05	-0.1	0.029	0.004	15.56
12 WL.TW	75	0.08	-0.3	-0.5	0.01	-0.05	-0.1	0.005	0.001	15.82
13 ES.TW	71	0.43	0.8	-0.5	0.06	-0.05	-0.1	0.03	0.005	15.24
13 WL.TW	95	0.06	-0.3	-0.5	-0.01	-0.05	-0.1	-0.005	-0.001	15.53
14 LP.TW	25	0.19	0.3	-0.5	0.03	-0.05	-0.1	0.01	0.002	15.73
15 ES.BK	97	1.5	2.4	-0.5	0.2	-0.05	-0.1	0.114	0.016	15.62
15 ES.TW	93	1.3	2.3	0.8	0.17	-0.05	-0.1	0.096	0.013	15.31
15 WL.TW	130	0.04	-0.3	-0.5	-0.01	-0.05	-0.1	-0.005	-0.001	15.45
19 ES.TW	58	0.04	-0.3	-0.5	-0.01	-0.05	-0.1	-0.005	-0.001	15.7
19 LP.TW	17	0.04	-0.3	-0.5	-0.01	-0.05	-0.1	-0.005	-0.001	15.52
19 WL.TW	85	0.02	-0.3	-0.5	-0.01	-0.05	-0.1	-0.005	-0.001	15.57
20 WL.TW	67	0.02	-0.3	-0.5	-0.01	-0.05	-0.1	-0.005	-0.001	15.48
21 WL.TW	46	0.02	-0.3	-0.5	-0.01	-0.05	-0.1	-0.005	-0.001	15.65
22 WL.TW	100	0.04	-0.3	-0.5	-0.01	-0.05	-0.1	-0.005	-0.001	15.71

R8456



NATIONAL WATER RESEARCH INSTITUTE
P.O. BOX 5050, BURLINGTON, ONTARIO L7R 4A6

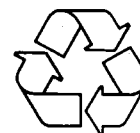


Environment Canada
Environnement Canada

Canada

INSTITUT NATIONAL DE RECHERCHE SUR LES EAUX
C.P. 5050, BURLINGTON (ONTARIO) L7R 4A6

Think Recycling!



Pensez à recycler!

Environment Canada Library, Burlington



3 9055 1017 0187 7