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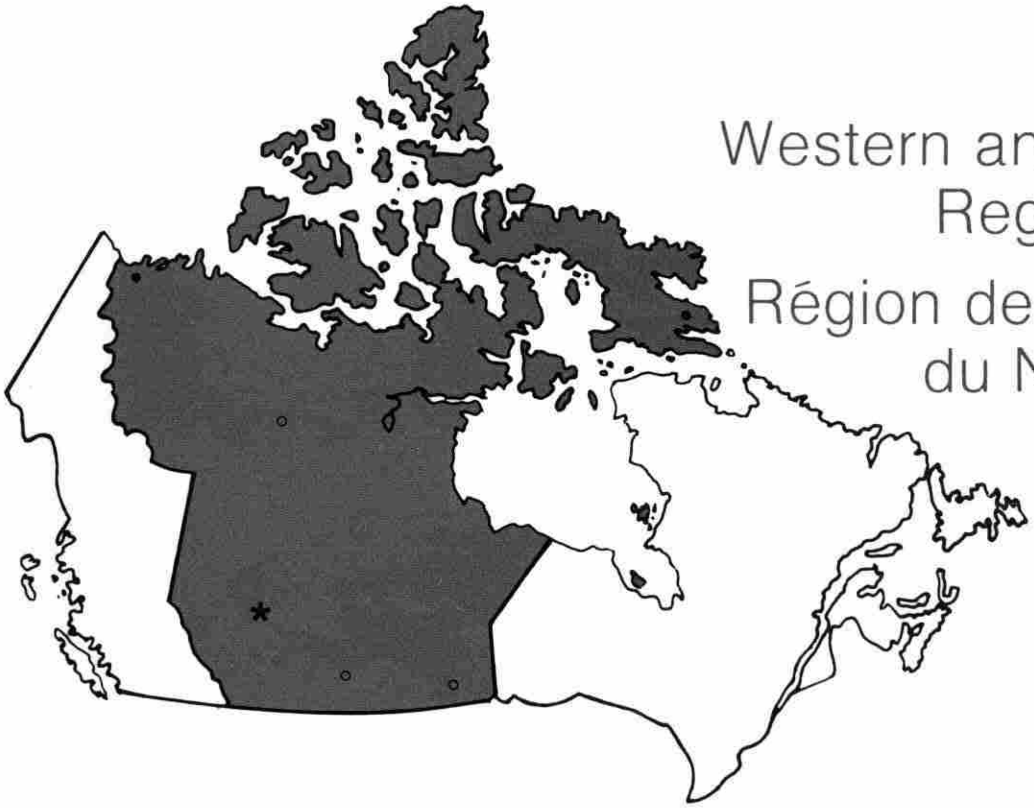

Western and Northern Region
Région de l'Ouest et du Nord

ASSESSMENT OF GOLD MINE IMPACTS ON THE BENTHIC ENVIRONMENT OF YELLOWKNIFE BAY, NWT

D. SUTHERLAND

MARCH 1989

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Environmental Protection

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Canada

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BY

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ABSTRACT

Environmental Protection carried out a study, from 1981 to 1984, of impacts of gold mine wastes on the benthic environment of Back Bay and Yellowknife Bay of Great Slave Lake. The study was done to determine the effects of sediment contaminated with arsenic, copper and other metals on benthic macroinvertebrate species composition and abundance, and to establish a quantitative baseline on sediment arsenic and metal concentrations and macroinvertebrates for future impact assessments. The Environment Canada National Water Research Institute collected and dated sediment cores to assess historical contamination trends. It was determined that sediment concentrations of arsenic, copper, mercury, lead and zinc have been enriched from two to twenty-fold by gold mine wastes deposited in the two sediment accumulation areas sampled. Based on the sediment core dating, the contamination in these areas appeared to have resulted primarily from tailings effluent discharged from the Giant Mine. Benthic macroinvertebrate abundance and species numbers have been greatly reduced in Back Bay. The sediment contaminant profiles indicated that arsenic concentrations have decreased since treatment of the Giant Mine tailings effluent started in 1981. Continued monitoring to determine the rate and nature of benthic macroinvertebrate community response to decreased contamination is recommended.

RESUME

La Protection de l'Environnement a étudié de 1981 á 1984 les effets des résidus de mine d'or sur le milieu benthique des baies Back et Yellowknife dans le Grand lac des Esclaves. Des échantillons ont été prélevés afin de déterminer les effets des sédiments contaminés par l'arsenic, le cuivre et d'autres métaux sur la composition et l'abondance des populations de macroinvertébrés benthiques, d'une part, et d'établir des donnes de base quantitatives sur les concentrations d'arsenic et de métaux dans les sédiments et sur les macroinvertébrés, d'autre part, afin de faire l'évaluation ultérieure des effets. L'Institut national de recherche sur les eaux d'Environnement Canada a recueilli des carottes de sédiments et en a fait la datation afin de dégager les tendances antérieures de contamination. Ainsi, il a été établi que les concentrations d'arsenic, de cuivre, de mercure, de plomb et de zinc dans les sédiments ont été multipliées, selon le cas, de deux á vingt fois par les résidues de mines d'or qui ont été déposés dans les deux secteurs de sédimentation oú des échantillons ont été prélevés. D'aprés la datation des carottes de sédiments, tout semble indiquer que la contamination est principalement attribuable aux effluents chargés qui sont produits par la mine Giant. L'abondance des macroinvertébrés benthiques et le nombre d'espéces ont beaucoup diminué dans la baie Back. Toutefois, les profils de contamination dans les sédiments laissent voir une diminution des concentrations d'arsenic depuis que l'on a commencé á traiter les effluents chargés de la mine Giant en 1981. Il est recommandé de poursuivre les travaux de surveillance afin de déterminer l'ampleur et la nature de la réaction des macroinvertébrés benthique á la baisse de la contamination.

ACKNOWLEDGEMENTS

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1.0 INTRODUCTION

1.1 Purpose of the Study

This study was initiated in 1981 and completed in 1984. The purpose was to define the degree of contamination and effects from gold mining activities on the Back Bay benthic environment, and to provide a database on which to assess the response of this environment to reductions in contaminant loading from local gold mines.

1.2 Description of the Study Area

Yellowknife Bay receives drainage from the Yellowknife River at its north end, and extends for 18 kilometres before opening into Great Slave Lake (Figure 1). Two operating mines, the Giant and CON Mines, and the abandoned Negus Mine are located on the western shore of the Bay. Immediately southeast of Giant Mine, Latham Island separates a small bay, locally known as Back Bay, from the main part of Yellowknife Bay (Figure 2).

1.3 History and Description of Mine Waste Disposal at Yellowknife

1.3.1 Negus and Con Mines

The Negus Mine began gold production in 1939. This operation continued until 1952, milling up to 200 tonnes of ore per day (Cominco Ltd., 1982). About 450,000 tonnes of tailings solids were deposited in a 6.5 hectare area, and liquid effluent drained into Yellowknife Bay (Figure 2).

In 1938, the CON Mine began roasting and milling 100 tonnes per day of gold bearing ore. This operation continues at a milling rate of 640 tonnes per day. All tailings solids from the milling process have been deposited into Pud Lake, with the liquid portion draining through three small lakes (Meg, Peg and Keg) before reaching Great Slave Lake at the mouth of Yellowknife Bay (Figure 2).

In the early years at CON Mine, roasting of the ore was necessary to remove arsenic and sulphur complexes from the gold. Until the Giant Mine began operations in 1948, air emissions of arsenic, sulphur, and possibly other metals were the primary source of contaminants entering Back Bay and Yellowknife Bay. Although the rate of ore processing at CON Mine has increased since 1938, installation of a wet scrubber in 1949 to recover arsenic, later improvements to the efficiency of emission controls, and a decrease in the quantity of sulphur in the ore produced reductions in the total quantities of arsenic released by roasting (Cominco Ltd., 1982).

Roasting was discontinued in 1969 when a change in the ore mineralogy allowed gold to be recovered directly in the mill process. Arsenic oxides recovered from the roasting process and stored in dry, surface impoundments, however, remain a source of fugitive emissions (Hazra and Prokopuk, 1977).

1.3.2 Giant Mine

With the initiation of gold production in 1948, Giant Mine began depositing tailings onto the land east of the mill (Figure 2). In 1951, tailings from the operation were deposited into a small lake to the north of the mine. The liquid portion of the tailings drained both into Baker Creek, which discharges into Back Bay, and northeastward into the head of Yellowknife Bay until 1968, when this latter flow of waste was stopped.

Prior to 1981, non-degradable contaminants in the tailings effluent (e.g. arsenic and metals) were removed through the physical settling of solids and by the precipitation of soluble metal hydroxides in the primary tailings pond. In 1981, Giant began treating the overflow from this pond in a chemical treatment plant (Connell, 1980) in order to comply with the requirements of a licence issued under the **Northern Inland Waters Act**. From 1981 to 1985, treatment of the liquid tailings effluent significantly reduced contaminant concentrations.

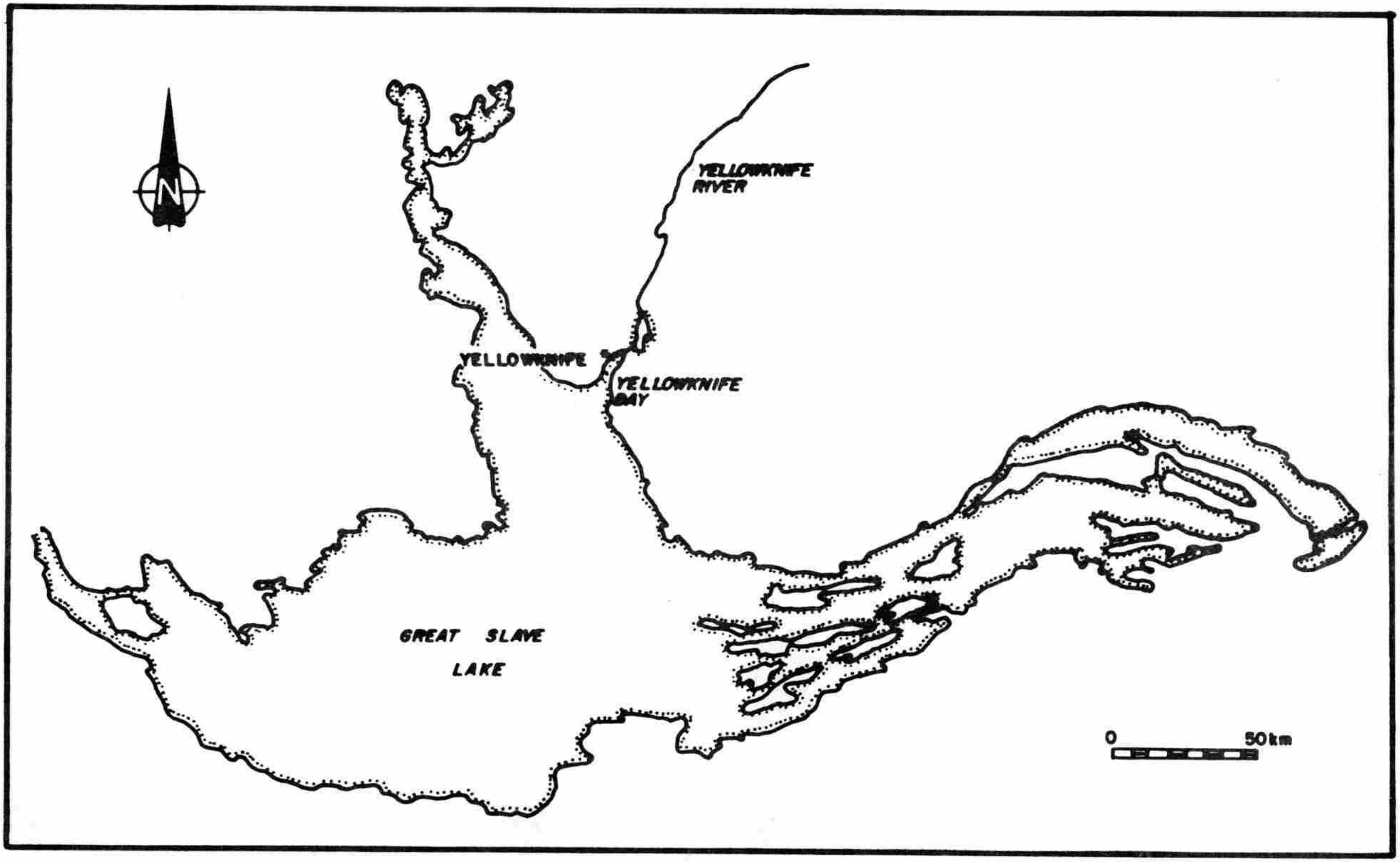

Figure 1 LOCATION OF YELLOWKNIFE BAY OF GREAT SLAVE LAKE.

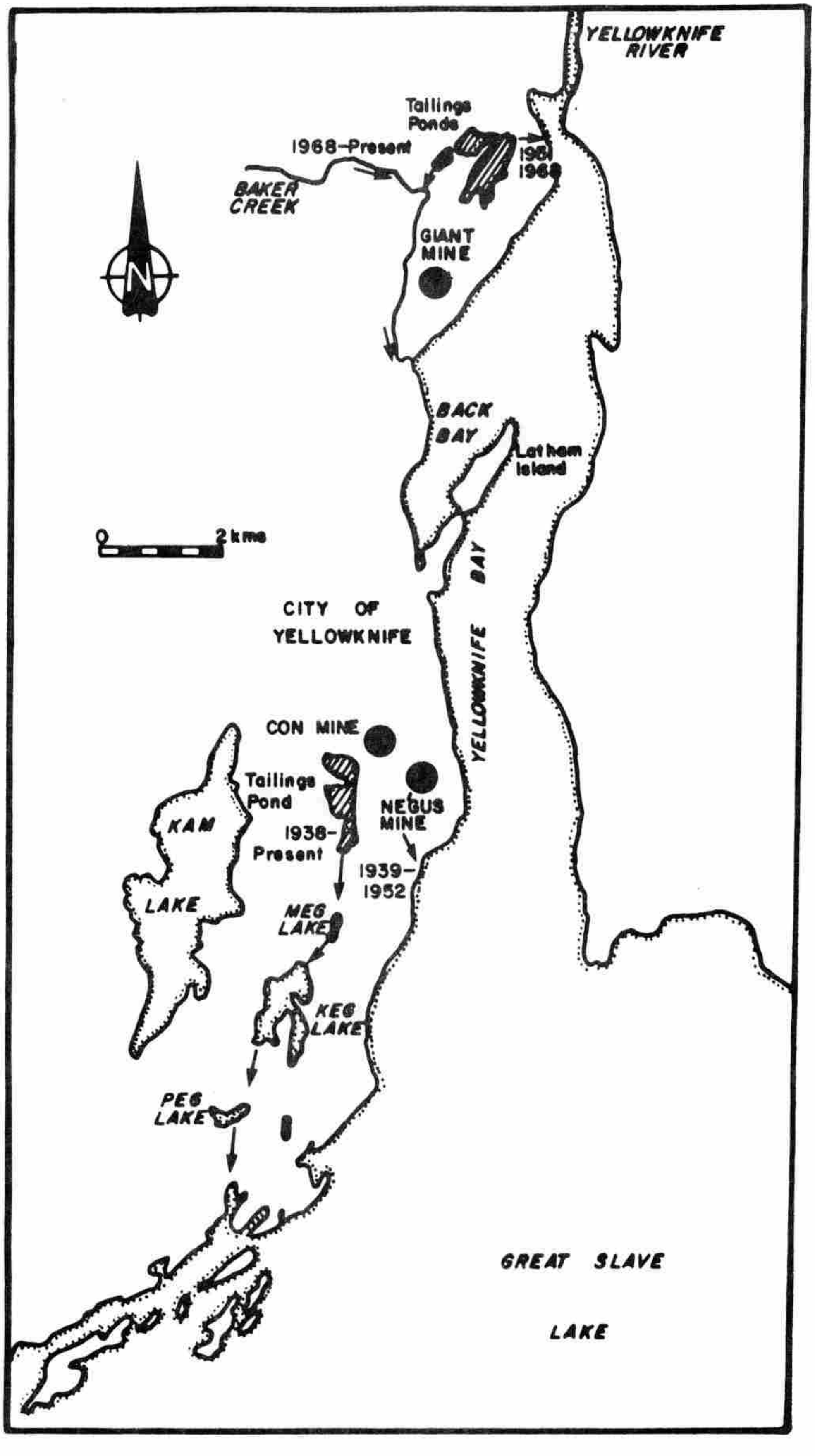

Figure 2 LOCATIONS OF GOLD MINES AT YELLOWKNIFE, SHOWING TAILINGS EFFLUENT DISCHARGE ROUTES

Giant began roasting of arsenopyritic ore in 1948. Despite increased quantities of material being roasted, air emissions of particulates and arsenic have been reduced through the installation of emission control technology (Edwards and Kent, 1979).

1.4 Results Of Previous Aquatic Impact Studies

Prior to 1972, evaluation of the impacts of wastes generated by Con Mine and Giant Mine was limited to water quality sampling in Back Bay and Yellowknife Bay. Grainge and Slupsky (1967) reported arsenic concentrations in these areas above the recommended guideline for drinking water quality (Department of National Health and Welfare, 1962). They recommended that the water intake for the City of Yellowknife be moved from Yellowknife Bay to the Yellowknife River, and that Giant Mine divert all its liquid tailings effluent into Baker Creek in order to protect the new drinking water source. Since 1968, the Giant Mine effluent has been discharged to Back Bay through Baker Creek.

A 1972 study of the effects of the Giant Mine liquid effluent on water quality, fish and benthic macroinvertebrates in Back Bay concluded that "a large portion of Yellowknife Bay was moderately polluted" (Falk *et al.*, 1973).

A second study of Back Bay and Yellowknife Bay, from 1974 to 1977, concluded that benthic community abundance was greatly reduced in the central portion of Back Bay as a result of sediment contamination from the Giant Mine liquid wastes (Moore *et al.*, 1978). Concentrations of arsenic, copper, lead and zinc in Back Bay water were occasionally found to exceed water quality objectives for the protection of aquatic life (Environment Canada, 1979; U.S.E.P.A., 1976).

These studies did not quantify the extent of sediment contamination relative to background levels nor the impacts on benthic macroinvertebrate communities relative to controls areas. With the implementation of effective tailings effluent treatment technology in 1981, Environmental Protection began the collection of a benthic database designed to permit quantitative assessment of biological response to reduced contaminant loading.

1.5 Objectives of the Present Study

1.5.1 General Objectives

The general objectives of the study were to:

(i) determine the significance of impacts on benthic macroinvertebrates from contamination of Back Bay sediment;

(ii) establish a database on sediment element levels and macroinvertebrate community parameters that could be used to monitor the response of the Back Bay benthic environment to reductions in element loading from Giant Mine; and

(iii) attempt to estimate the period of time required for recovery of affected benthic macroinvertebrate communities in Back Bay.

1.5.2 Study Phases

To quantitatively assess changes in benthic macroinvertebrate abundance in response to reduced contaminant loadings in Back Bay, it was first necessary to select the area of the Bay where this could be accomplished with a practical number of samples. The results of previous macroinvertebrate surveys had demonstrated that variability in abundance was high throughout the Bay. Thus, it was recognized that sampling of the entire Bay to provide a monitoring database would require either unrealistically large numbers of samples or produce such high data variability that only gross changes in mean abundance could be detected. It was decided that production of a relatively sensitive database in a limited area of Back Bay would provide the most useful indicator of benthic macroinvertebrate response to reduced contaminant loading. To select such an area it was necessary to conduct a preliminary survey of macroinvertebrate abundance in the Bay.

1.5.2.1 1981 Sampling Program

Sampling in 1981 was carried out to examine the effect of three factors on total macroinvertebrate abundance: water depth, distance from the mouth of Baker Creek, and direction from the mouth of the Creek. Water depth was chosen because it is a natural factor controlling macroinvertebrate habitat choice. All three factors were expected to influence the distribution of contaminants entering Back Bay through Baker Creek, and thus macroinvertebrate abundance. Sampling was done in June and October to determine seasonal effects on abundance in the area selected for future monitoring.

1.5.2.2 1983 Sampling Program

Following the analysis of the macroinvertebrate data from 1981, an area of Back Bay and a control area in Yellowknife Bay were selected, and follow-up sampling was carried out in 1983 to compare contaminant concentrations in surficial sediment with macroinvertebrate abundance and species composition. Sediment cores were also taken to establish the degree to which concentrations of arsenic and metals had been enriched by the various sources of mine waste.

1.5.2.3 1984 Sampling Program

The objectives of this program were to:

(i) determine the degree to which reduced contaminant loadings in Back Bay would reduce contaminant levels in the new sediment being deposited there; and

(ii) determine the rates of accumulation of sediment in Back Bay, and to estimate the time required for recovery of affected macroinvertebrate communities. The estimated recovery time could then be verified by future monitoring.

2.0 MATERIALS AND METHODS

2.1 Field Methods

2.1.1 Benthic Macroinvertebrates - 1981

Samples of macroinvertebrates were collected in June and October, 1981 in Back Bay. The sampling scheme is illustrated in Table 1.0. Sampling locations are shown in Figure 3. The sampling sites were located by travelling between landmarks while measuring water depths with a Furuno Model F17-21/22 echo sounder. When the appropriate water depth was found, the boat was anchored and three bottom samples were taken, from the bow, starboard and port sides, with a 15 cm by 15 cm by 23 cm Ekman grab sampler. The Ekman sampler contents were sieved through a 500 um mesh sieve for enumeration and identification of macroinvertebrates.

2.1.2 Bottom Sediment and Macroinvertebrates - 1983

Following the analysis of the macroinvertebrate data collected in 1981, sampling was repeated in August, 1983 in the 12 m area of Back Bay and in an area of similar water depth in Yellowknife Bay (Figure 4).

Ten, randomly allocated, sampling points were established in each area by triangulation, using survey transits, and the sites were marked with plastic buoys. The boat was anchored to the marker buoys and individual sediment samples were obtained concurrently for chemical, particle size and macroinvertebrate analysis.

Table 1.0 **Back Bay Benthic Macroinvertebrate Sampling Scheme in June and October, 1981**

	Distance from Baker Creek					Direction from Baker Creek	
Water Depth	300m	600m	900m	1200m	1500m	Northeast	Southeast
2m	X	X	X	X	X		X
6m	X	X	X	X	X	X	X
8m		X	X	X	X	X	X
12m		X	X	X		X	X

Samples of the top 5 cm of sediment were obtained with a Wildco KB corer fitted with a 5 cm internal diameter acrylic core tube. The corer was lowered slowly into the substrate by hand winching, which enabled retrieval of the cores with the fine, uncompacted surface particles undisturbed. The clear water on the top of the core was carefully decanted by pushing the core up the tube with a PVC plastic plunger. The surface floc was then poured into a plastic Whirl-pac bag (Fisher Scientific Co. Ltd.). The solid core was extruded into a PVC plastic measuring trough, cut with a section of PVC plastic, and the surface section was placed in the plastic bag with the floc. Samples for chemical analysis were placed into storage at -20° C on the day of collection. Samples for particle size analysis were refrigerated.

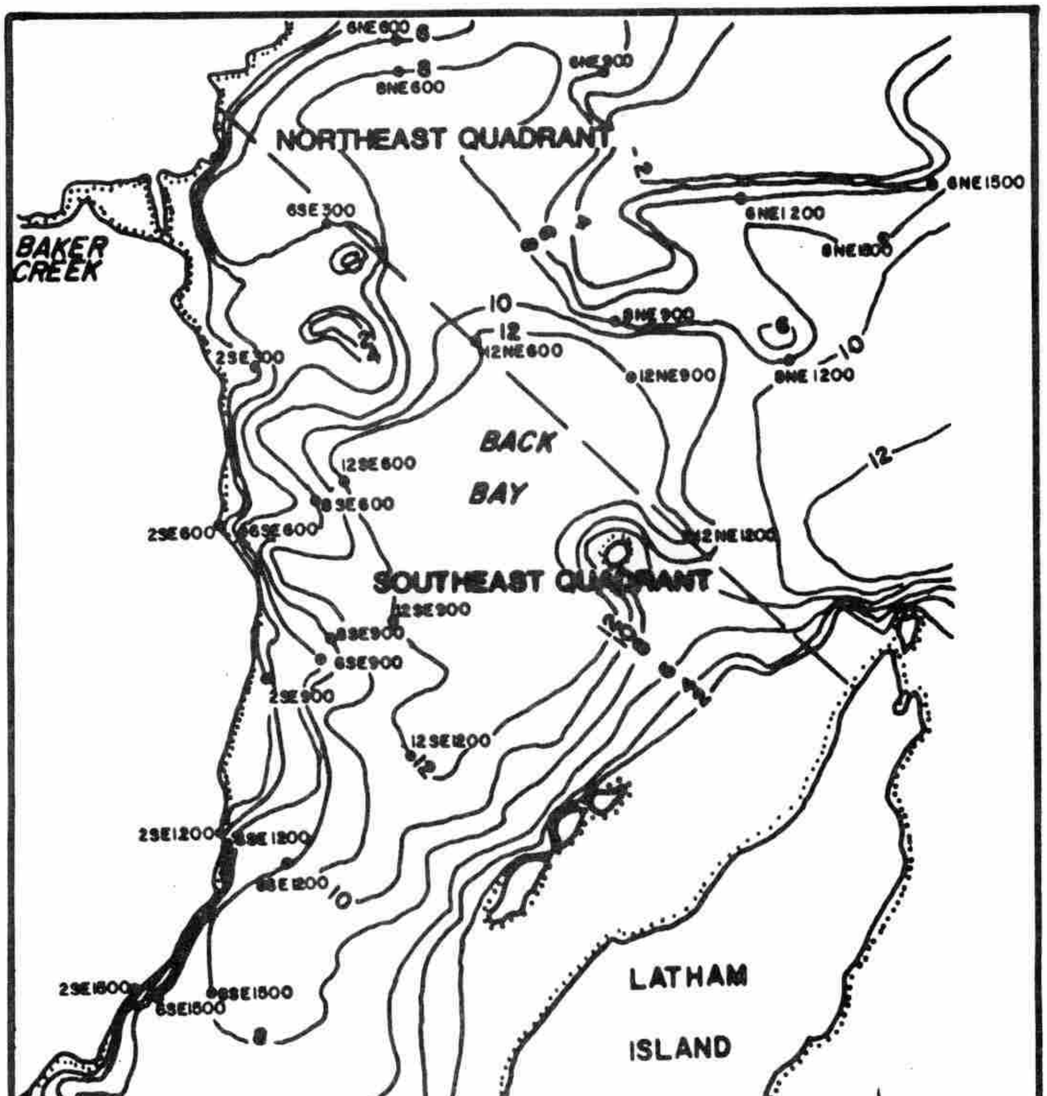

Figure 3 LOCATIONS OF BENTHIC MACROINVERTEBRATE SAMPLING POINTS IN BACK BAY IN 1981.

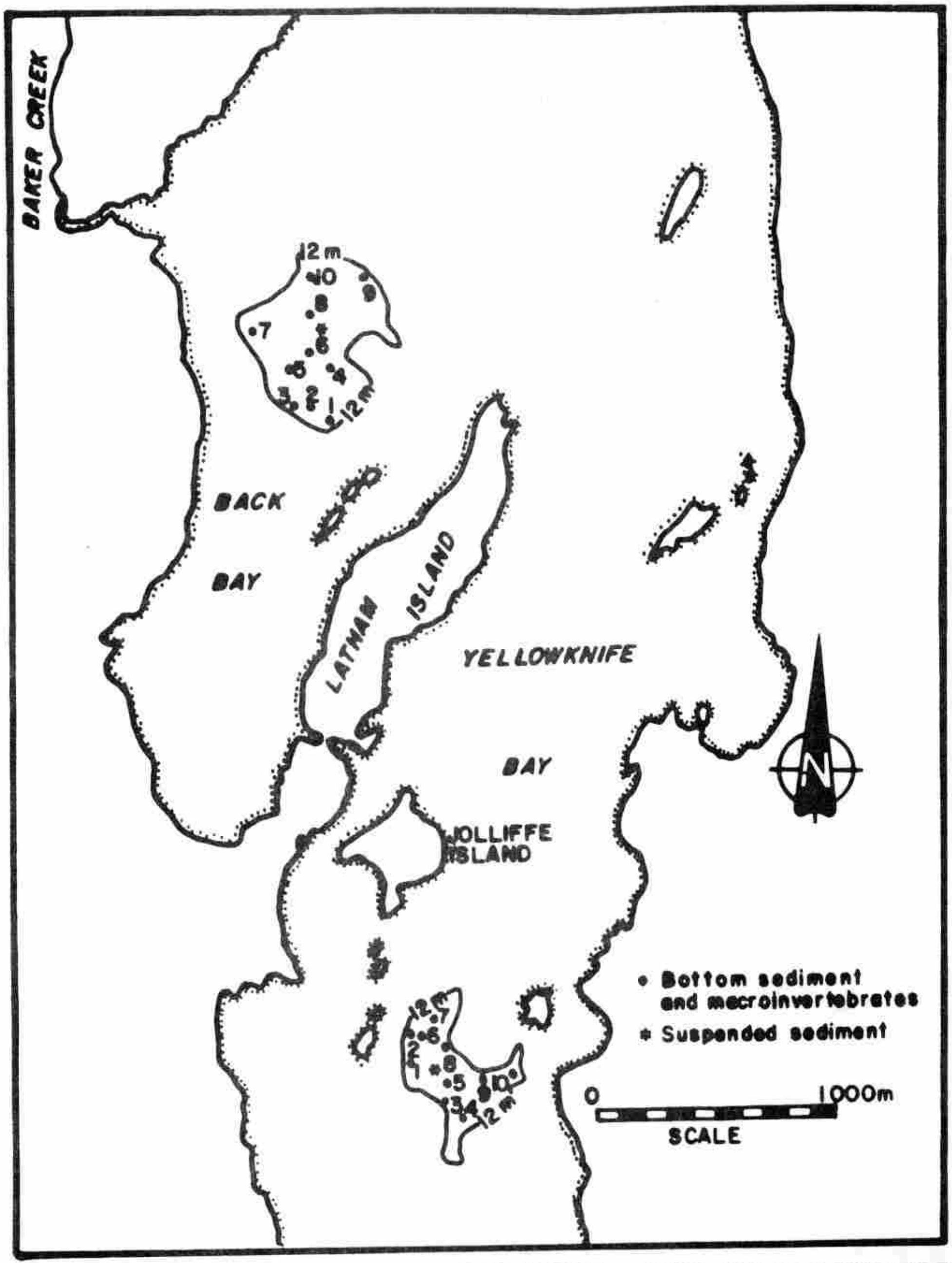

Figure 4 LOCATION OF BOTTOM SEDIMENT AND MACROINVERTEBRATE SAMPLING POINTS IN BACK BAY AND YELLOWKNIFE BAY IN 1983, AND SUSPENDED SEDIMENT SAMPLING POINTS IN 1984.

In addition to the ten, 5 cm core sections taken from each area, cores were obtained from each of three, randomly selected points in each area, subdivided into 5 cm sections and analyzed to establish element concentration profiles.

Samples for macroinvertebrate analysis were collected with an Ekman sampler at the same sites. Only those samples which filled at least 75 % of the sampler volume were retained for analysis. After field sieving through a 500 um mesh sieve, samples were delivered to the laboratory for sorting and enumeration.

2.1.3 Suspended and Bottom Sediment - 1984

Sediment traps were used to collect samples of particulates from the water column, for chemical analysis, over two periods in 1984 (July 24 to August 16, and September 8 to October 10). The traps were constructed from ABS plastic pipe (76 cm long; 10 cm internal diameter).

Three sediment traps were deployed at mid-depth in each of the Back Bay and Yellowknife Bay areas sampled in 1983 (Figure 4). Floats were placed at two positions between the samplers and the water surface to keep the samplers in a vertical position. Samples of sediment were handled and stored as described for the bottom sediment collected in 1983.

Sediment cores were collected at the two suspended sediment sampling locations for Lead-210 and Cesium-137 dating, and for chemical analysis of one cm sections by Environment Canada's National Water Research Institute (NWRI), in Burlington, Ontario. Samples were refrigerated during transport (Mudroch *et al.*, 1987).

2.2 Laboratory Methods

2.2.1 Sediment

2.2.1.1 Particle Size Analysis

The 1983 samples were oven dried and wet sieved to separate the size fractions defined by the Wentworth Scale. The <63 um fraction was further classified into particles smaller than 16 um and 4 um based on settling time in water, in accordance with the pipette method described by Buchanan and Kain (1971).

2.2.1.2 Element and Loss-on-Ignition Analysis

The sediment samples collected in 1983 were analyzed by the Environmental Protection Laboratory in Edmonton, Alberta. Samples were freeze-dried at -50° C and the fraction passing through a 63 um mesh stainless steel sieve was retained for element analysis.

Cadmium, copper, lead, manganese, nickel and zinc concentrations were determined using atomic absorption spectrophotometry (U.S.E.P.A., 1979) following sample digestion in acid solution ($HF:H_20_2:HNO_3$). Arsenic concentrations were determined by graphite furnace analysis (U.S.E.P.A., 1979), following the same digestion procedure.

Mercury was analyzed by the cold vapour atomic absorption technique (U.S.E.P.A., 1979 - Method 245.5), following digestion in aqua regia (3:1 $HCL:HNO_3$) and $K_2Cr_2O_7$.

Organic matter was measured by loss-on-ignition at 550°C, in accordance with the APHA Method 208 E (1974).

2.2.1.3 Quality Assurance on Element Analysis

To assess precision, three random samples were chosen from the ten taken from each area in 1983 and analyzed in triplicate. To assess the accuracy of the analysis, triplicate analysis of certified U.S. National Bureau of Standards 1645 River Sediment samples was conducted once during the analytical run for the same elements.

To assess both the precision and accuracy of the analysis of the 1984 suspended sediment samples, triplicate analysis of the 1645 River Sediment was conducted once during the analysis run. Insufficient material was available for an analysis of precision on the sample material.

2.2.2 Benthic Macroinvertebrates

The sieved samples for benthic macroinvertebrate analysis were kept refrigerated to facilitate live sorting over a one to three day period following collection. Organisms were identified to order, counted, and preserved in 70 percent ethanol. Identification to genus, or species (where possible), was carried out under contract by the Environmental Applications Group Limited of Toronto.

2.3 Statistical Methods

2.3.1 Benthic Macroinvertebrates - 1981 Results

Benthic macroinvertebrate abundance data from the 1981 survey were analyzed by a three-level nested ANOVA (Sokal and Rohlf, 1969) to assess the significance of the variance associated with water depth, distance from the effluent source and direction from the effluent source. Since pairing of stations in the northeast and southwest quadrants was necessary to assess the effect of direction, data from the 2 m water depth (obtained from the southeast quadrant only) and from the 300 m and 1500 m distances were eliminated from the nested ANOVA. Thus, community abundance and Chironimid abundance at 600 m, 900 m and 1200 m from the effluent source, at each of the 6 m, 8 m and 12 m isobaths in the two quadrants, were analyzed for the June and October data sets. Abundance data from only the 6 and 8 m water depths were analyzed for Amphipods, Oligochaetes, and Molluscs because of the preponderance of zero values in samples from the 12 meter isobath.

Prior to analysis, all values were transformed using the common logarithm to improve the normality of the data. The logarithmic transformation was chosen because accurate estimation of the distribution of the data could not be obtained from three replicates and because the logarithmic transformation is commonly applied to macroinvertebrate data (Elliott, 1977). The mean and variance were calculated from the triplicate analyses from each sample point. Occasional missing values were approximated by substituting the mean value for the other two replicates.

Wherever significant variances between the northeast and southeast quadrants were indicated by the nested ANOVA, the null hypothesis that abundance was similar was tested. Where neither depth nor distance was a significant source of variance, mean values for each sample were compared between the northeast and southeast quadrants using a t-test for small samples (Sokal and Rohlf, 1969). If the variance for either water depth or distance was significant, then a two-way ANOVA (Sokal and Rohlf, 1969) was conducted using direction and either depth or distance as the independent variables.

Although macroinvertebrate abundance from the 2 m isobath could not be compared between the northeast and southeast quadrants, the effect of distance from the effluent source along the 2 m isobath was assessed using a one-way ANOVA (Sokal and Rohlf, 1969). When distance was found to be a significant factor, the Newman-Keuls Multiple Comparison Test was used to determine the specific locations at which the significant differences occurred. This analysis was not carried out on June Amphipod or Mollusc data due to insufficient data.

2.3.2 Benthic Macroinvertebrates - 1983 Results

The number of samples collected from each of the two areas in 1983 was established from the 1981 results from the 12 m area of Back Bay, based on the formula for calculating optimal sample size recommended by Elliott (1977). The level of sensitivity adopted by Elliott (1977) was also applied in this calculation (i.e. a standard deviation of not greater than 20 % of the mean).

Prior to assessing the significance of differences in total macroinvertebrate abundance in Back Bay and Yellowknife Bay, frequency distributions were calculated for both sample sets and checked for fit using a Chi-square test (Elliott, 1977). The data were then transformed with the common logarithm, and the appropriateness of the transformation was confirmed using the F-test for the homogeneity of variance (Snedecor and Cochran, 1980). Mean abundance and species numbers from the two areas were then compared using a t-test (Snedecor and Cochran, 1980).

3.0 RESULTS

3.1 Bottom Sediment

3.1.1 Particle Size Distribution

Sediment in the Back Bay sampling area was composed of finer particulates (mean = 84.7% silt/clay) than sediment in Yellowknife Bay (mean = 55.4% silt/clay) (Appendix 1.1 and Table 2.0). This difference was primarily due to the higher clay content of Back Bay sediment (41% versus 17%).

3.1.2 Element Concentrations

3.1.2.1 Quality Assurance Results

Laboratory precision, as measured by triplicate analysis of 3 randomly selected samples of surface sediment from the two areas, ranged from 29% to 0% relative standard deviation (Appendix 1.2). The mean values were 10% or lower, and were considered acceptable (Table 3.0). One individual precision estimate of 29% on nickel was found to be due to an abnormally high analysis on one of the sub-samples (YK Bay St'n. 10, sub-sample A) and, since re-analysis had not been done, this value was rejected as an outlier.

Mean values for mercury, copper, manganese and zinc, from triplicate analyses of a certified sediment sample, were within the 95% confidence interval of the certified value, and accuracy was thus considered acceptable for quantitative assessment of these parameters. The mean lead and nickel values were marginally above and below the certified values (2% and 7%, respectively). The arsenic value was not certified; however, the values were considered acceptable for the qualitative assessment undertaken.

Table 2.0 **Sediment Particle Size Distributions from Back Bay and Yellowknife Bay**

(percentage mean ± standard deviation of 10 replicates)

Particle Size	Back Bay	Yellowknife Bay
Sand and Coarser Material (>63 um)	15.4 ± 5.0	44.8 ± 12.0
Silt (63 um - 4 um)	43.6 ± 16.3	38.2 ± 6.8
Clay (<4 um)	41.1 ± 17.5	17.2 ± 6.8

Table 3.0 **Laboratory Precision and Accuracy of 1983 Bottom Sediment Analyses**

Precision (expressed as coefficient of variation (C.V.) = 100 X S.D./Mean on 3 sub-samples of each of 6 samples)

	Element							
	As	Hg	Cu	Zn	Mn	Pb	Ni	C
Area								
BB	4	8	1	2	0.3	0.3	1	1
YKB	4	ND	1	3	1	2	10	1

ND - non detectable

Accuracy (based on triplicate analysis of National Bureau of Standards 1645 River Sediment)

	Element (ug/g)						
	As	Hg	Cu	Zn	Mn	Pb	Ni
Mean Value Obtained	68	0.78	116	1630	803	755	40
Mean Certified Value*	66	1.1	109	1720	785	714	46
Confidence Interval	-	0.5	19	170	97	28	3

* Certified arsenic value not available.

3.1.2.2 Element Concentration Profiles

The results of element analysis of the 1983 bottom sediment samples are presented in Appendix 1.3 and summarized in Table 4.0.

Although particle size composition varied from Back Bay to Yellowknife Bay, element concentrations were measured only on the silt/clay fraction (< 63 um), and therefore, can be directly compared.

The highest concentrations of arsenic, mercury, copper, lead and zinc were present in the top 10 cm of Back Bay sediment. Arsenic, copper, manganese and zinc in surface sediment from Yellowknife Bay were also enriched relative to concentrations in deeper sediment. A comparison of enrichment factors (mean value from 0-5 cm/mean value from 15-20 cm) shows that arsenic and copper concentrations in Back Bay surficial sediment were about 20 times the values in the deeper sediment (Table 5.0). Enrichment of recent Yellowknife Bay sediment was about 7 and 5 times for arsenic and copper, respectively.

Since these elements were not monitored in the study area prior to the commencement of mining operations, it was necessary to use an inferred baseline in deriving enrichment factors. Thus, the enrichment factors presented are approximations, based on the assumption that element levels in surface sediment were not substantially different from those in deeper sediment prior to the start of mining.

Table 4.0 **Element Concentrations of Back Bay and Yellowknife Bay Bottom Sediment**

[ug/g, dry weight, except LOI (%), in < 63 um fraction]
Core Increment

		0-5 cm[a]		5-10 cm[b]		10-15 cm[b]		15-20 cm[b]	
Element		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
As	BB	1868	552	967	725	200	44	110	10
	YKB	633	147	227	35	79	3	85	6
Hg	BB	0.12	0.15	0.12	0	<0.08	-	<0.08	-
	YKB	<0.08	-	<0.08	-	<0.08	-	<0.08	-
Cu	BB	810	120	333	132	34	2	35	2
	YKB	164	13	56	11	33	1	36	2
Ni	BB	61	4	59	3	36	2	38	3
	YKB	46	2	40	0	40	0	41	3
Mn	BB	583	172	723	246	737	220	713	176
	YKB	1497	164	650	223	420	26	427	15
Pb	BB	102	18	91	11	26	0	25	1
	YKB	47	4	34	3	27	2	29	5
Zn	BB	264	68	340	80	73	3	80	1
	YKB	134	11	100	10	73	6	80	0
LOI (%)	BB	5.1	0.3	4.0	0.1	4.1	0.6	4.2	0.6
	YKB	5.9	0.3	4.4	0.6	4.3	0.4	4.6	0.1

[a] N=10; [b] N=3

LOI - Loss-on-Ignition

Table 5.0 **Element Enrichment Factors in Back Bay and Yellowknife Bay Bottom Sediment**

(mean value in 0-5 cm / mean value in 15-20 cm)

	Arsenic	Mercury	Copper	Zinc	Manganese	Lead
Back Bay	17	1.5	23	3.3	0	4.1
Yellowknife Bay	7.4	0	4.6	1.7	3.5	1.6

The variability in contaminant concentrations in the ten, 0-5 cm samples from each area was high for the most enriched elements, with coefficients of variability (standard deviation/mean x 100) of 30% and 23% for arsenic in Back Bay and Yellowknife Bay, respectively. Variability in arsenic in the 15-20 cm core increment was lower, with 9% and 7% relative standard deviation for the two areas, respectively. Thus, increased contamination has substantially increased the heterogeneity of element concentrations in these two areas.

A more detailed record of historical arsenic concentrations in Back Bay and Yellowknife Bay bottom sediment was produced with the National Water Research Institute (NWRI) cores collected in 1984 (Mudroch *et al.*, 1987) (Table 6.0). Three of four cores showed arsenic concentrations decreasing in the most recent sediment in Back Bay, although considerable variability between cores was evident.

The trend toward decreasing arsenic concentrations clearly evident in the top 2 cm of the NWRI cores from Yellowknife Bay was not shown in the larger core increments analyzed by Environmental Protection (EP). The EP values were generally higher than NWRI's, which is likely due to the finer particle size fraction analyzed by EP (i.e. < 63 um versus < 189 um), and possibly to the use of different analytical methods (atomic absorption spectrometry and x-ray fluorescence spectrometry).

Table 6.0 **Historical Accumulation of Arsenic in Back Bay and Yellowknife Bay Bottom Sediment**

Core Increment (cm)		Arsenic Concentration (mean ± S.D. in ug/g, dry weight)			
		Back Bay		Yellowknife Bay	
NWRI	EP	NWRI[a]	EP	NWRI	EP
0-1	0-5	1294 ± 1021	1868 ± 522[b]	453 ± 118	617 ± 31[b]
1-2		893 ± 195		676 ± 154	
2-3		1073 ± 169		420 ± 248	
3-4		933 ± 232		74 ± 24	
4-5		618 ± 130		25 ± 20	
5-6	5-10	264 ± 221	967 ± 725[c]	21 ± 6	227 ± 35[c]
6-7		123 ± 60		20 ± 3	
7-8		116 ± 71		18 ± 5	
8-9		110 ± 58		21 ± 3	
9-10		105 ± 44		24 ± 8	
25-26	15-20	22 ± 3	110 ± 10[c]		85 ± 6[c]
27-28				16 ± 2	

[a] N=4; [b] N=10; [c] N=3

Arsenic enrichment of about 10-fold was evident at about the 6 cm increment in the NWRI Back Bay cores, whereas enrichment to this degree occurred at about the 3-4 cm increment in Yellowknife Bay sediment. This discrepancy in historical arsenic accumulation in the two areas can be attributed to a lower sediment depositional rate in Yellowknife Bay. Average depositional rates were calculated to be 0.24 cm per year in Yellowknife Bay and 0.37 cm per year in Back Bay, based on Lead-210 and Cesium-137 dating of NWRI cores (Mudroch *et al.*, 1987). Thus, an approximate 10-fold increase in arsenic accumulation occurred about 1968-9 in both locations. This enrichment corresponded with the date when Giant began discharging all tailings effluent to Back Bay through Baker Creek (Figure 2), which suggests that the major portion of this effluent was not entering Baker Creek prior to 1968. The relationship between sediment contamination and waste disposal events cannot be established conclusively, however, due to the lack of data on effluent flow rates and quality prior to the 1970's. The patterns of arsenic and zinc accumulation in Back Bay and Yellowknife Bay have been demonstrated to be statistically similar (Mudroch *et al.*, 1987), indicating that both areas responded similarly to increased contamination about 1968. The relationship between arsenic accumulation and major waste disposal events is illustrated in Figures 5 and 6, based upon data for individual NWRI cores.

The arsenic accumulation pattern demonstrated by the NWRI cores provides general evidence that the use of the inferred baseline is valid for the assessment of enrichment. The correlation between arsenic concentrations and waste disposal events, including decreased levels in the most recent sediment, indicates that the surface sediment was not enriched with this element to the same degree prior to the start of mining.

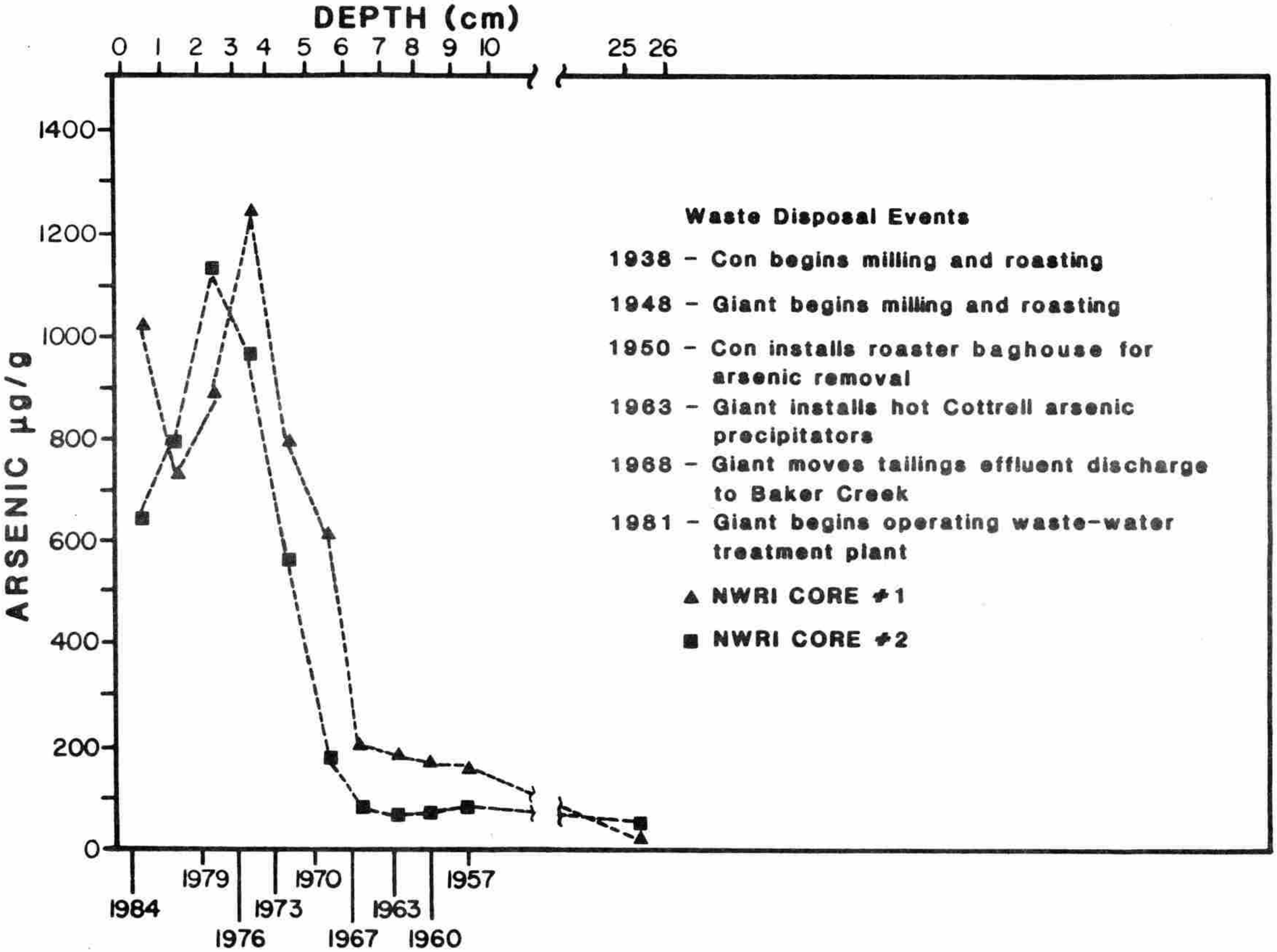

Figure 5 RELATIONSHIP BETWEEN MAJOR MINE WASTE DISPOSAL EVENTS AND SEDIMENT ARSENIC LEVELS IN BACK BAY BOTTOM SEDIMENT (BASED ON DATA FROM MUDROCH ET.AL,1987)

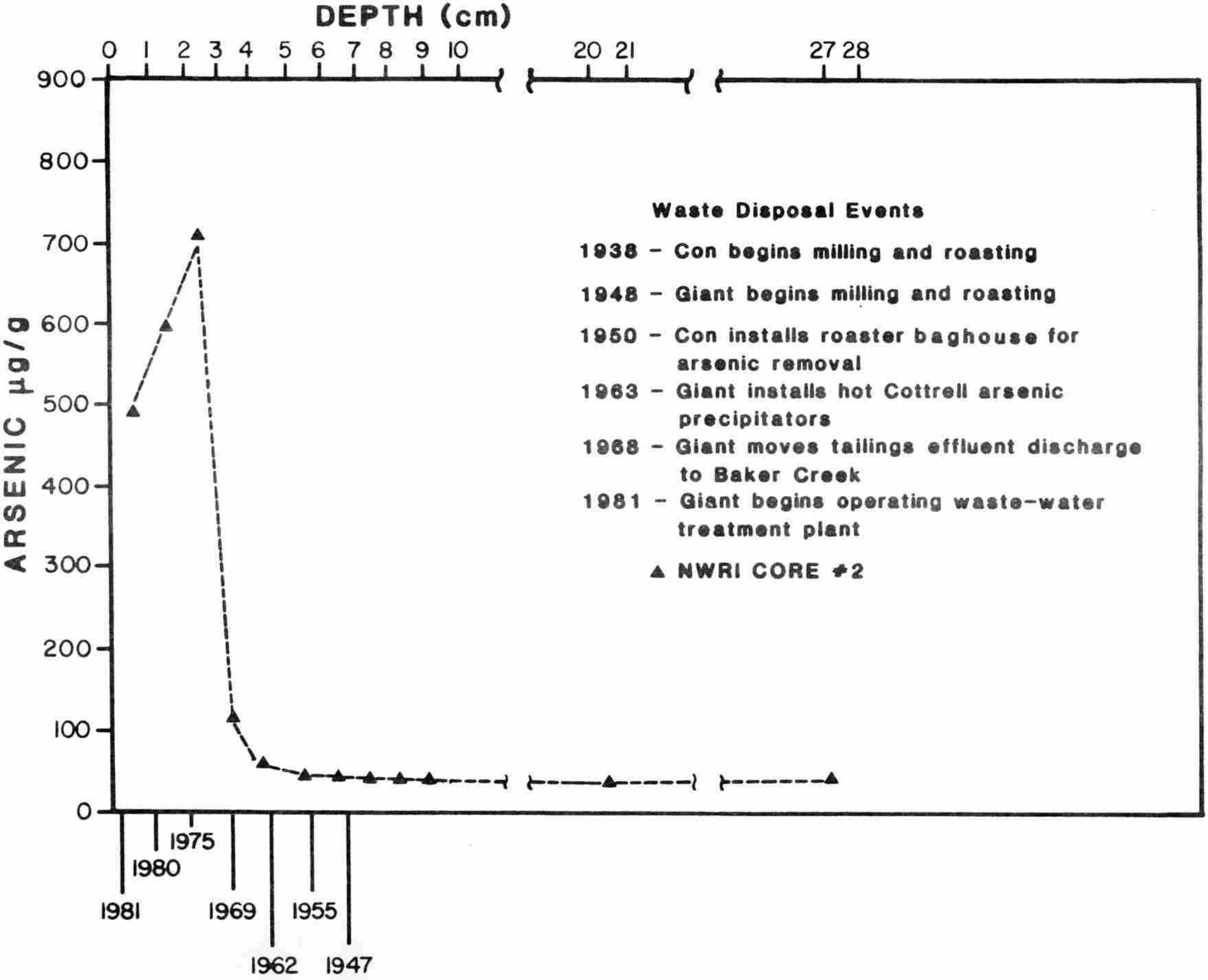

Figure 6 RELATIONSHIP BETWEEN MAJOR MINE WASTE DISPOSAL EVENTS AND SEDIMENT ARSENIC LEVELS IN YELLOWKNIFE BAY BOTTOM SEDIMENT (BASED ON DATA FROM MUDROCH ET.AL, 1987)

3.2 Suspended Sediment

3.2.1 Quality Assurance on Element Analysis

Precision, as measured on triplicate analyses of NBS River Sediment, varied from 0 % to 13 % relative standard deviation, and was considered acceptable (Appendix 1.4).

The accuracy of all metals analyzed on the reference material was also acceptable, as defined by the certified analysis.

3.2.2 Element Concentrations

The results of analysis of suspended sediment samples collected in sediment traps in Back Bay and Yellowknife Bay in 1984 are presented in Table 7.0 and Appendix 1.5. Analyses were carried out on unsieved sediment, rather than on the silt/clay fraction, because of the small amount of material collected.

When compared with the analyses of the top 5 cm of bottom sediment from both areas (Table 6.0), the suspended sediment was substantially less contaminated with arsenic (mean of approximately 300 ug/g versus 1800 ug/g in surficial bottom sediment) and copper (mean of 80 ug/g versus 800 ug/g).

Table 7.0 **Element Concentrations in Back Bay and Yellowknife Bay Suspended Sediment**

(mean± S.D.ug/g, dry weight, in unsieved sediment)

			Element			
Area	Arsenic	Mercury	Copper	Nickel	Lead	Zinc
BB[a]	310±156	0.15±0.06	78±8	49±3	56±9	160±14
YKB[a]	138±18	0.08,<0.01	75±14	54±8	43±7	165±7

[a] N=2

Mercury values were essentially the same as those found in the surficial sediment of Back Bay (i.e. 0.15 ug/g versus 0.12 ug/g), indicating continuing enrichment relative to the inferred baseline of <0.08 ug/g. Cadmium levels in both areas were below the limit of analytical detection of 4 ug/g.

3.3 Benthic Macroinvertebrates

3.3.1 Results of 1981 Sampling Program

A summary of the abundance data for the major taxonomic groupings collected in 1981 from Back Bay are presented in Appendix 2.1. The species composition of these samples is presented in Appendix 2.2, based on analysis by the Environmental Applications Group Limited (1983).

The results of statistical analysis of the effects of three environmental factors (i.e. water depth, distance from the waste source, and direction from the waste source) on the abundance of the total macroinvertebrate community and of four major taxonomic groups are presented in Table 8.0. The conclusions drawn from this analysis were:

(i) Total community abundance and chironomid abundance showed the same pattern of distribution (i.e. significantly decreased abundance with increasing water depth; no consistent differences between abundance in the northeast and southeast quadrants; and no significant influence of distance from Baker Creek) (Figures 7 and 8);

Table 8.0 **The Effect of Three Environmental Factors on Macroinvertebrate Abundance in Back Bay in 1983**

(based on Nested ANOVA of abundance)

Taxonomic Group	Date	Depth	Distance	Direction	Comments
Total	June	($p<.01$)	N.S.	($p<.001$)[a]	See Notes[b]
Community	October	($p<.001$)	N.S.	($p<.001$)[a]	See Notes[b]
Chironomids	June	($p<.005$)	N.S.	($p<.05$)[a]	See Notes[b]
	October	($p<.001$)	N.S.	($p<.001$)[a]	See Notes[b]
Amphipods	June	N.S.*	N.S.	($p<.001$)[a]	
	October	N.S.*	($p<.001$)	N.S.	See Notes[c]
Oligochaetes	June	N.S.*	($p<.05$)	N.S.	See Notes[c]
	October	($p<.005$)*	N.S.	N.S.	See Notes[c]
Molluscs	June	N.S.*	N.S.	($p<.005$)[a']	
	October	N.S.*	N.S.	N.S.	

Notes: * 6 m and 8 m only analyzed - too many zero values at 12 m

[a] neither northeast nor southeast quadrant consistently greater
[a'] abundance in northeast quadrant significantly greater than southeast quadrant
[b] decreased abundance related to increased water depth
[c] decreased abundance related to decreased distance

N.S. - non-significant difference

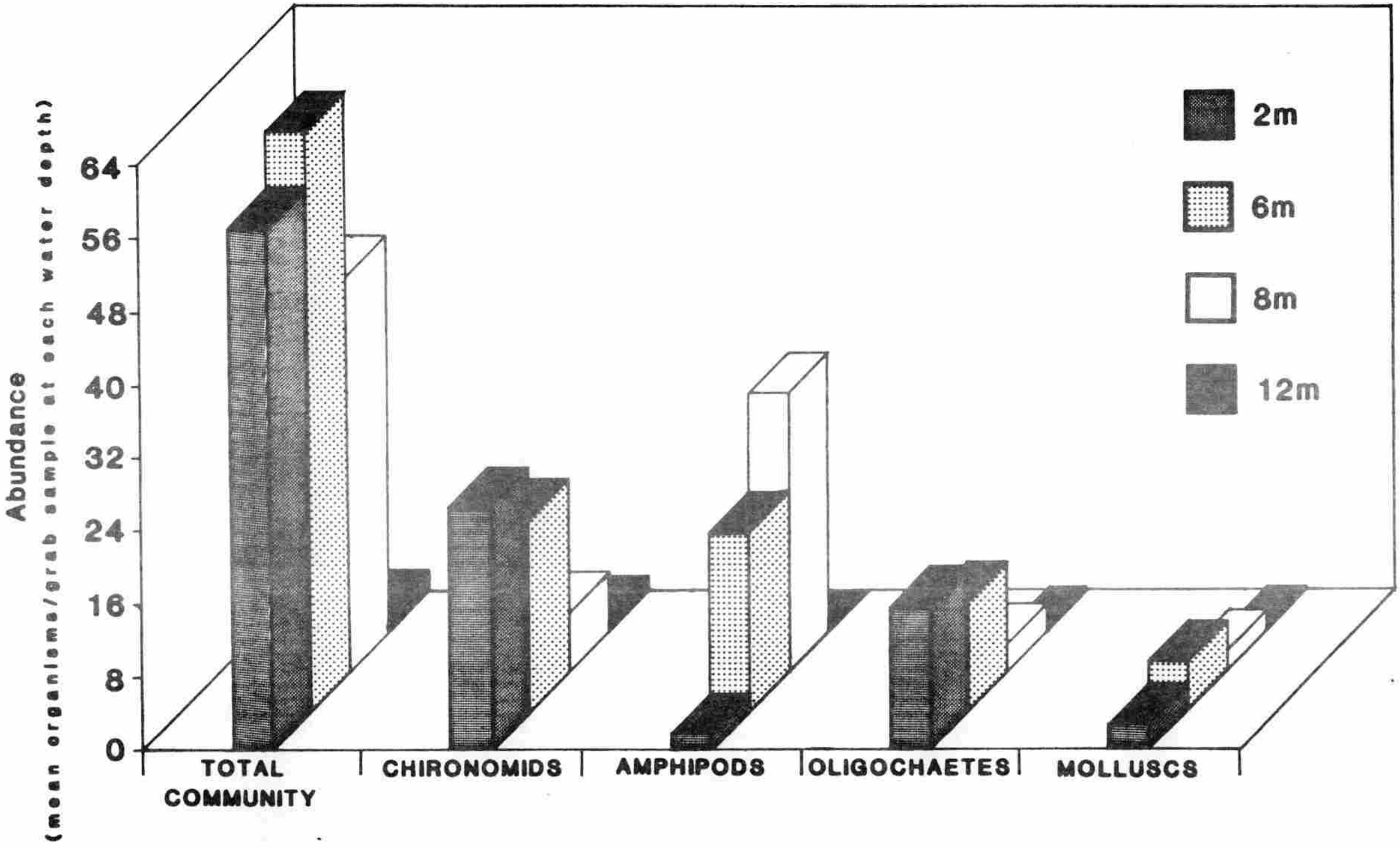

Figure 7 RELATIONSHIP BETWEEN MACROINVERTEBRATE ABUNDANCE AND WATER DEPTH IN BACK BAY IN JUNE, 1981

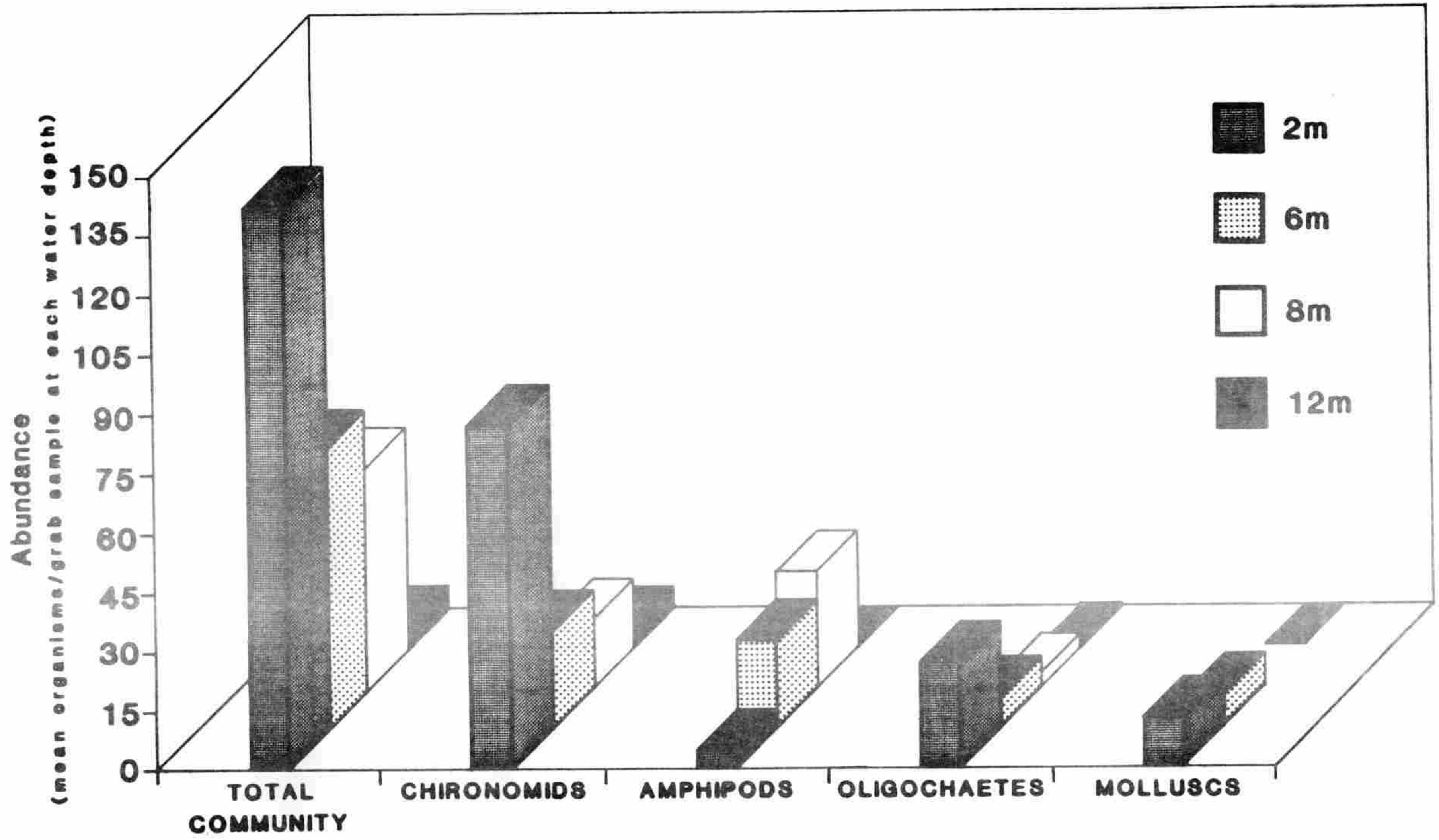

Figure 8 RELATIONSHIP BETWEEN MACROINVERTEBRATE ABUNDANCE AND WATER DEPTH IN BACK BAY IN OCTOBER, 1981

(ii) The abundance of amphipods, oligochaetes and molluscs did not show a statistically significant relationship with water depth. If data from the 12 m water depth could have been included in the analysis, the relationship would likely have been significant, since abundances were substantially lower at the 12 m depth (Figures 7 and 8); and

(iii) Overall, distance from the mouth of Baker Creek did not have a significant influence on the abundance of major groups. The exceptions were amphipod abundance in October and oligochaete abundance in June.

Since abundance data from the 2 m water depth were available only from the southeast quadrant, they could not be included in the nested ANOVA. Analysis of community and group abundance along the 2 m contour by one-way ANOVA, followed by the Student Newman-Keuls test for significance, did not show a consistent pattern of increased abundance with increased distance from Baker Creek (Table 9.0).

The influence of water depth, and of distance and direction from Baker Creek was generally similar between the two sampling periods (Table 8.0).

A seasonal effect on total community abundance was not evident in the 12 m area of Back Bay, although abundance varied between sampling periods at other water depths (Appendix 2.1).

Table 9.0 **The Effect of Distance from Baker Creek on Macroinvertebrate Abundance at the 2 m Water Depth in Back Bay (Southeast Quadrant)**

(based on one-way ANOVA of abundance, followed by Student Newman-Keuls Test-of-Significance)

Taxonomic Group	Date	Distance	Sampling Point Distance from Baker Creek (m)
Total Community	June	(p<.001)	300 < 900 < 1200 < 600 < 1500
	October	(p<.001)	900 < 300 < 1500 < 1200 < 600
Chironomids	June	(p<.005)	300 < 900 < 1200 < 600 < 1500
	October	(p<.005)	900 < 300 < 1500 < 1200 < 600
Amphipods	June	--------------data insufficient--------------	
	October	(p<.001)	300 = 600 < 900 < 1500 < 1200
Oligochaetes	June	(p<.005)	300 < 1200 < 900 < 1500 < 600
	October	(p<.01)	900 < 300 < 1200 < 600 < 1500
Molluscs	June	--------------data insufficient--------------	
	October	(p<.01)	900 < 300 < 600 < 1200 < 1500

Note: Numbers sharing an underscore do not differ statistically.

The strong influence of water depth on macroinvertebrate abundance could have been due to either natural or anthropogenic causes, or the interaction of both. Finer sediment particles are found in deeper water and, therefore, macroinvertebrate habitats would also be expected to change with increasing water depth. Changes in habitat would result in changes to macroinvertebrate abundance and species composition. At the same time, the finer particles provide increased surface area for binding of metals and other contaminants. Regardless of the causes, the demonstration of a relationship between water depth and macroinvertebrate abundance provided the information needed to design a sampling program to monitor biological response to reductions of contaminant loading in Back Bay.

The 12 m water depth was chosen for the 1983 macroinvertebrate and sediment sampling program for the following reasons:

(i) The effect of water depth on abundance was consistent for the major macroinvertebrate groups at the 12 m depth;

(ii) Since the 12 m area is the deepest area in Back Bay, fine particles would be expected to be deposited there, making it more homogeneous as a macroinvertebrate habitat and as a contaminant depositional area. Thus, changes in macroinvertebrate abundance and sediment element concentrations could be monitored with smaller numbers of samples than might be required in other depth strata; and

(iii) As a contaminant depositional area, it would provide the best location to assess benthic biological response to reduced contaminant loading from the Giant Mine.

3.3.2 Results of 1983 Sampling Program

3.3.2.1 Comparison of Macroinvertebrate Abundance

The abundance data for benthic macroinvertebrates collected in early August, 1983 are presented in Appendix 2.3 and summarized by major taxonomic groups in Table 10.0.

The mean abundance of the macroinvertebrate communities in Back Bay was significantly lower (3 organisms per sample) than in Yellowknife Bay (148 organisms per sample), based on a t-test ($P<0.001$).

The significant difference in abundance was primarily due to the near-absence of the amphipod, *Pontoporeia hoyi*, in Back Bay. Since this species was found in greater abundance in the 12 m area of Yellowknife Bay, it would be reasonable to expect that it would be present in 12 m of water in Back Bay under natural conditions. Rawson (1953) found *Pontoporeia* sp to be the most abundant benthic group in Great Slave Lake, comprising 63% of the total density. Densities of this amphipod throughout the Lake were relatively constant to a depth of 60 m at that time. Since Yellowknife Bay was also found to support the greatest biomass of benthic macroinvertebrates of any area of the Lake surveyed by Rawson in 1953, including the delta of the Slave River, the absence of *Pontoporeia* in Back Bay cannot be reasonably explained on natural biological grounds. Although low dissolved oxygen concentrations in Back Bay (1-3 mg/l) have been detected under ice cover in late winter (Environmental Protection, 1981-1983 unpublished data), these conditions should not affect the presence of this organism in mid-summer, when oxygen levels were not depressed. *Pontoporeia* is relatively mobile compared to other benthic residents (e.g. molluscs, oligochaetes and insects). The abundance of amphipods in shallower water of Back Bay in 1981 (Figures 7 and 8) indicates the availability of this macroinvertebrate for recolonization following restoration of higher oxygen levels. Occasionally low oxygen concentrations could have an indirect effect, however, on benthic biota, due to enhanced availability and therefore toxicity of metals and arsenic. Concentrations of soluble metals can be substantially greater in anaerobic sediment (Forstner and Wittmann, 1981).

Table 10.0 **Comparison of Abundance of Benthic Macroinvertebrates in Back Bay and Yellowknife Bay, August, 1983**

(mean±standard deviation of organisms per grab sample - 10 replicates per area)

Group	Back Bay	Yellowknife Bay
Amphipods	0.6±0.7	120±45
Chironomids	2.4±1.8	4.6±2.5
Molluscs	0	11.4±7.9
Oligochaetes	0	11.9±6.5
Water Mites	0	0.2±0.4
Total Community	3.1+1.7	148+57

The absence of oligochaetes from the 12 m area of Back Bay in 1981 and 1983 also provides evidence that oxygen depletion was not the main factor limiting macroinvertebrate abundance, since the two species found in Yellowknife Bay, *Limnodrilus hoffmeisteri* and *Peloscolex multisetosus*, have been described as being tolerant of organic pollution (Brinkhurst, 1980), and *Limnodrilus hoffmeisteri* is very tolerant of low oxygen concentrations (Milbrink, 1980). Thus, neither organic enrichment (e.g. from sewage disposal) nor oxygen depletion would, in themselves, account for the absence of these two species in Back Bay.

3.3.2.2 Comparison of Macroinvertebrate Community Composition

A comparison of the species composition of the Back Bay and Yellowknife Bay macroinvertebrate communities is presented in Table 11.0 and in Appendix 2.3. The mean number of species in Yellowknife Bay (6.0) significantly exceeded the number in Back Bay (2.1) ($P < 0.001$), with molluscs and oligochaetes absent from the Back Bay samples. Both locations had a similar number of chironomid species (5 and 6, respectively), only 2 of which were common to both areas.

Since the sediment in Yellowknife Bay was coarser than sediment in Back Bay (55% silt/clay versus 85% silt/clay), some differences in species composition may be expected under natural conditions. This difference alone cannot, however, explain the absence of oligochaetes and molluscs in Back Bay, since species in both groups of macroinvertebrates thrive in finer grained, more organically enriched sediment, and would be expected to occur in Back Bay. Thus, it is concluded that sediment contamination in Back Bay has had an adverse effect on macroinvertebrate species composition, as well as the effect on abundance discussed earlier. The combination of periodic oxygen depletion and contamination with arsenic and metals may have altered species composition as well as abundance.

Table 11.0 **Comparison of Species Composition of Benthic Macroinvertebrate Communities in Back Bay and Yellowknife Bay in August, 1983**

Species/Other Taxa	Frequency of Occurrence (%) Back Bay	 Yellowknife Bay	Common Species
Amphipoda			1
Pontoporeia hoyi	50	100	
Diptera			2
Chironomidae			
Procladius sp	40	100	
Monodiamesa sp	0	30	
Microspectra sp	50	30	
Heterotrissocladius sp	0	30	
Demicryptochironomus sp	0	10	
Zalutschia sp	20	0	
Cladotanytarsus sp	10	0	
Cryptochironomus sp	10	0	
Demicryptochironomus sp	0	10	
Empididae Chelifera sp	0	30	
Oligochaeta			
Tubificidae			
Peloscolex multisetosus	0	90	
Limnodrilus hoffmeisteri	0	20	
Lumbriculidae	0	30	
Mollusca			
Pelycypoda			
Sphaeriidae			
Pisidium nitidum	0	100	
Gastropoda			
Valvatidae			
Valvata sincera helicoidea	0	20	
Acarina			1
Oxidae			
Oxus sp	10	20	
Total Species:	7	13	4
Mean no. per sample ± S.D.:	2.1±1.3	6.6±1.1	-

4.0 DISCUSSION

The degree of enrichment, and the historical accumulation profiles of arsenic and copper in Yellowknife Bay demonstrate the mobility of these elements relative to other elements which were enriched in Back Bay sediment.

Installation of the wastewater treatment plant at Giant Mine in 1981 achieved a reduction of arsenic concentrations in the tailings effluent from 20-30 mg/l to an average of 0.3 mg/l from 1982 to 1986 (Giant Yellowknife Mines Ltd., 1975 - 1986). These reductions have resulted in decreased arsenic concentrations in Yellowknife Bay bottom sediment and a similar trend appears to be occurring in Back Bay. This conclusion is also supported by the results of suspended sediment sampling in 1984, which show lower concentrations of arsenic and copper in particles settling into both areas (Table 7.0).

Although metal contaminated sediment has been shown to reduce benthic macroinvertebrate abundance (e.g. Moore *et al.*, 1979a and 1979b; Wentsal *et al.*, 1977 and 1978; Maleug *et al.*, 1984; Reynoldson, 1987), predicting the response of a community to the mixture of elements present in a mine effluent, or even a single contaminant, cannot be done simply by measuring concentrations in water and sediment. The physical and chemical conditions of the substrate and the types of organisms present will affect the nature of community responses (Forstner and Wittmann, 1981; Allan, 1986). The availability of any particular metal to bottom-dwelling organisms depends on the chemical form, the properties of the particles to which it is attached, and the physical and chemical properties of the overlying water and sediment pore water. Factors such as oxidation-reduction potential and element speciation were not measured in this study. Thus, reliable predictions cannot be made on when benthic communities in Back Bay will begin to show recovery, even though arsenic concentrations appear to be declining in Back Bay surface sediment. Measurement of metal concentrations in a common invertebrate (e.g. *Procladius sp*) would provide the most direct comparison of metal bioavailability in the two areas and an indication of how resident organisms may respond to decreased contaminant loading.

Even with substantially reduced loadings of arsenic and copper, reduction of contamination in the top 5 cm of bottom sediment will take about 14 years in Back Bay and 21 years in Yellowknife Bay, based on calculated sedimentation rates.

The rate of biological recovery is also controlled by the depth of new, less contaminated sediment which must accumulate to permit enhanced survival of macroinvertebrates. Although burial of Back Bay sediment with new sediment may lower element concentrations substantially, the time required to produce a layer of sufficient thickness to support a more diverse and abundant community is affected by various physical, chemical and biological processes. These include the mixing of old and new sediment by the biota, recirculation of metals through benthic and planktonic food chains, resuspension, diffusion, and adsorption and desorption of contaminants (Allan, 1986). Thus, the 30 years required to accumulate the 10 cm of sediment commonly occupied by the macroinvertebrates may be the minimum time required to produce measurable recovery.

Assessment of the rate and nature of macroinvertebrate recovery would be useful in determining the response of Back Bay and Yellowknife Bay benthic environments to reduced contaminant loading. Such studies may also provide useful information for assessing the potential effects of new mining operations on lake benthic environments.

4.1 Future Monitoring and Research

4.1.1 Monitoring of Changes in Sediment Contamination and Macroinvertebrate Communities

Monitoring of sediment chemistry and macroinvertebrate abundance and species composition should be carried out to directly assess benthic biological recovery in Back Bay. Similar monitoring should be done in Yellowknife Bay to confirm that contaminant levels are dropping and to assess the biological response.

With such high variability in element concentrations, particularly arsenic, in Back Bay surficial sediment, significantly reduced concentrations will likely not be apparent for some time, possibly 10 years. Within this period, samples of the top one cm should be taken, either randomly or from fixed sampling points in the 12 m area. Samples of the top 5 cm should also be taken and the concentrations of elements not measured on the NWRI cores should be compared to the 1983 data.

If random sampling of the 12 m areas of Back Bay and Yellowknife Bay is to be done, the number of samples required to achieve a specified sensitivity in detecting statistically significant change can be estimated using the present data. Similarly, an estimate can be obtained of the number of samples required to detect a significant change in arsenic at the fixed points sampled by NWRI in 1984.

Assuming that the values of each element are normally distributed, the number of samples required to achieve a given sensitivity (or relative variability) may be obtained from the formula (Snedecor & Cochran, 1980):

$$n = t^2 s^2 / D^2$$

where: t = the two-tailed Student's t value at the level of significance, at n-1 degrees of freedom;

s^2 = sample variance;

D = desired precision or sensitivity (e.g. relative standard deviation or confidence limits) (in concentration units).

The sensitivity at which significant change in element concentrations can be detected can, therefore, be estimated by:

$$D = t\, s / \sqrt{n}$$

The number of samples required is calculated by initially substituting the values for t and s^2 from the previous database, and then replacing the t-value each time a new estimate of n is calculated, until a stable n is reached. The sensitivity of the EP and NWRI databases for each parameter and the number of samples required to achieve specific sensitivities are presented in Table 12.0. The element data were first tested for normality, using the Shapiro-Wilk w-test for small data sets (Shapiro and Wilk, 1965), and it was found that most elements were normally distributed. Since calculation of sample numbers on transformed data produced lower estimates than use of the untransformed data, the estimates in Table 12.0 are based on use of the untransformed data.

Table 12.0 **Sensitivity with which Changes in Element Concentrations Can Be Detected in Samples of Bottom Sediment**

		Sensitivity Achieved with Existing Samples(%)[a]	
Parameter		EP, 1983 (n = 10)	NWRI, 1984 (n = 4)
Arsenic	BB	21	125
	YKB	17	41
Mercury	BB	6	NA
	YKB	NA	NA
Copper	BB	11	NA
	YKB	6	NA
Nickel	BB	5	NA
	YKB	3	NA
Mang.	BB	21	NA
	YKB	8	NA
Lead	BB	13	NA
	YKB	7	NA
Zinc	BB	18	NA
	YKB	6	NA
L.O.I.	BB	4	NA
	YKB	4	NA

NA - not available: not analyzed (NWRI) or values < limit of analytical detection

[a] (95% confidence limit/mean) x 100

With 10 samples of the top 5 cm of sediment, significant changes in element concentrations, at the 95% level of confidence, can be detected with an approximate 20% increase in the mean value of any parameter. If monitoring of the top one cm is done to detect changes in arsenic concentrations, 10 samples would enable a 60% change to be detected, based on the results from the 4 NWRI samples taken in 1984. Thus, the increased sensitivity which could be gained with sampling the top one cm is reduced somewhat by the relatively higher variability at the fixed point sampled by NWRI. It may be reasonably expected, however, that variability will decrease as the number of samples taken increases, so that ten samples may produce a substantially lower variance than predicted from the NWRI data.

The macroinvertebrate data from the 1983 survey provide a basis for assessing the response of benthic communities to reduced contamination. Since the amphipods occupy the uppermost stratum of bottom sediment, near the sediment/water interface, it is hypothesized that these organisms will recover most quickly. Sampling should take place in early August for comparison with the 1983 data. The Yellowknife Bay area should also be sampled to determine biological response to reduced contamination.

Based on the 1983 data, approximately 10 samples from Back Bay and 6 samples from Yellowknife Bay are required to detect a significant change in total abundance of greater than 40% at the 95% level of confidence (i.e. as recommended by Elliott, 1977). Given the magnitude of the impact on benthic macroinvertebrates in Back Bay, the ability to detect change at 40% of the mean abundance value should be more than adequate. Thus, collection of 10 random samples from the Back Bay and Yellowknife Bay 12 m areas should be adequate to monitor the response of the benthic biota to reductions in contaminant loading from Giant Mine.

The species composition of the chironomid community should also be monitored as an indicator of response to the predominant contaminants: arsenic, copper and zinc. Since different species were present in the two locations in August, shifts in species composition may provide a good indicator of response to reduced concentrations of these metals.

4.1.2 Recommended Research

At present our knowledge of the toxicity and bio-availability of a mixture of elements, such as arsenic and metals, in sediment is insufficient to predict direct effects on benthic biota or indirect effects on benthic food chains. To predict the effects of element loading of sediment, it is necessary to directly monitor chemical and biological components of benthic and pelagic environments. It will be necessary to measure the most important factors controlling biological effects in order to improve our capability to predict impacts from new sources of mine waste. These factors include sediment oxidation-reduction potential, element speciation in sediment pore water, biological accumulation of contaminants, and structural and functional biological response to contaminants, acting either individually or in combinations. Mine wastes have been discharged to different areas of Back Bay and Yellowknife Bay, and these areas provide an opportunity to determine how macroinvertebrates have responded to decreased contamination.

The sediment element accumulation profiles from the 12 m areas of Back Bay and Yellowknife Bay demonstrate that tailings contaminants discharged prior to 1969 have been deposited in other locations of Yellowknife Bay. Thus, other sediment accumulation areas of the Bay may provide an indication of macroinvertebrate response to reduced contamination over varying periods. Depositional areas further out in Yellowknife Bay or beyond may contain different relative element concentrations due to differing rates of dispersion, providing the opportunity to examine element-specific effects on the biota.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1. Discharge of tailings effluent from the Giant Mine has increased the concentrations of elements such as arsenic, copper, mercury, lead and zinc in the bottom sediment of accumulation areas in Back Bay and Yellowknife Bay.

2. Enrichment of these elements in the two, 12 m depositional areas was shown, by sediment dating, to be due to discharge of tailings effluent through Baker Creek since 1968, indicating that contaminants from earlier mine operations have been deposited in other areas of Yellowknife Bay.

3. The similarity of element accumulation profiles in the Back Bay and Yellowknife Bay areas studied demonstrate the mobility of arsenic and some metals, and indicate the potential for contaminant spreading.

4. Arsenic concentrations in surficial bottom sediment in the two areas studied have decreased since treatment of tailings effluent started in 1981, indicating that the benthic environment is improving in response to waste treatment at Giant Mine. Accumulation of new, cleaner sediment will proceed slowly, however, at a rate of approximately 0.40 cm per year in Back Bay and 0.25 cm per year in Yellowknife Bay.

5. The abundance and number of benthic macroinvertebrate species in the 12 m area of Back Bay have been significantly reduced as a result of contamination from Giant Mine, as compared to an area of Yellowknife Bay.

6. The rate and nature of recovery of affected benthic macroinvertebrate communities cannot be accurately predicted from the existing database. Reductions in the major source of contaminants for the two areas studied provides an opportunity, however, to evaluate the response of benthic biota to decreasing contaminant loadings.

5.2 Recommendations

1. Concentrations of arsenic, mercury, copper, lead and zinc in surficial bottom sediment should be monitored periodically, and compared to the present baseline, in order to confirm the trend towards reduced contamination. The top one cm should be sampled, either randomly throughout the areas studied, or at the fixed points established by NWRI in 1984.

2. Abundance and species composition of benthic macroinvertebrate communities in the 12 m areas of Back Bay and Yellowknife Bay should be monitored periodically in order to evaluate biological response to reduced contaminant loadings in these areas. Random sampling at 10 points in each area should provide an adequate database on which to assess change.

3. The relationship between the biologically available forms of elements such as arsenic, mercury, copper, lead and zinc, and benthic macroinvertebrate community structural and functional parameters should be investigated in Back Bay and Yellowknife Bay in order to improve our capability to predict and control the effects of mine waste disposal. These studies should start with the monitoring of element concentrations in other sediment accumulation areas in Yellowknife Bay which have been contaminated through previous waste disposal practices at Giant Mine.

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APPENDIX 1.0

RESULTS OF ANALYSIS OF BOTTOM AND SUSPENDED SEDIMENT FROM BACK BAY AND YELLOWKNIFE BAY

APPENDIX 1.1

PARTICLE SIZE COMPOSITION OF BOTTOM SEDIMENT SAMPLED IN AUGUST, 1983

Appendix 1.1 Particle Size Composition of Bottom Sediment Sampled in August, 1983

(expressed as percentage of the total sample dry weight)

Back Bay Particle Size Category (um)

Sample	>500	>250	>125	>63	>16	>4	<4
1	0.0	0.42	9.42	6.87	30.76	48.46	4.06
2	0.31	1.57	6.13	10.49	13.32	9.29	58.87
3	1.41	8.09	9.99	4.03	39.76	14.14	22.54
4	0.00	0.39	4.21	8.81	10.33	14.67	61.64
5	0.53	1.79	5.14	9.61	13.86	32.46	36.60
6	0.04	0.66	3.39	6.67	23.52	29.58	36.11
7	0.01	0.46	2.71	4.56	13.53	26.60	52.11
8	0.32	0.90	3.87	6.76	33.87	1.74	52.54
9	0.00	2.42	11.97	7.21	14.56	20.81	43.01
10	0.04	0.48	4.27	7.69	12.14	32.24	43.13
Mean:	0.27	1.72	6.11	7.27	20.57	23.00	41.06
St'd. Dev.:	0.44	2.34	3.20	2.03	10.63	13.63	17.51

Appendix 1.1, Cont'd.

Yellowknife Bay	Particle Size Category (um)						
Sample	>500	>250	>125	>63	>16	>4	<4
1	0.09	0.29	23.31	25.61	21.27	17.40	11.99
2	4.18	9.38	29.89	17.09	15.11	11.77	12.56
3	0.00	1.24	21.23	21.48	28.22	14.11	13.69
4	2.54	6.29	28.67	18.59	15.68	14.11	14.11
5	0.95	4.05	25.28	19.21	20.51	13.41	16.57
6	0.01	1.97	14.34	12.63	41.37	6.29	23.38
7	0.02	1.04	13.03	15.26	24.75	19.56	26.36
8	1.53	0.45	12.68	17.32	18.52	22.75	28.78
9	0.55	3.52	31.66	23.10	20.91	12.54	7.71
10	0.02	0.84	16.55	21.84	23.55	19.95	17.27
Mean:	0.99	2.91	21.66	19.21	22.99	13.19	17.24
St'd. Dev.:	1.40	2.97	7.21	3.88	7.58	5.42	6.81

APPENDIX 1.2

QUALITY ASSURANCE RESULTS FOR ELEMENT ANALYSIS OF BOTTOM SEDIMENT SAMPLED IN AUGUST, 1983

Appendix 1.2 Quality Assurance Results for Element Analysis of Bottom Sediment Sampled in August, 1983

Appendix 1.2.1 Precision

[expressed as percentage relative standard deviation (% R.S.D.)]

Back Bay

Element
[ug/g, except Loss-on-Ignition (%)]

Sample	Sub-sample	Arsenic	Mercury	Copper	Nickel	Managanese	Lead	Zinc	Cadmium[a]	Loss-on-Ignition
1	A	2300	0.12	670	53	850	91	210	(1	5.0
	B	2000	0.14	670	53	850	91	200	(1	5.1
	C	2000	0.16	670	55	850	91	210	(1	5.1
Mean		2100	0.14	670	54	850	91	207	NA	5.1
Standard Deviation		173	0.02	0	1	0	0	6	NA	0.0
% R.S.D.		8	14	0	2	0	0	3	NA	1
5	A	1400	0.14	810	63	500	115	270	(1	4.8
	B	1300	0.12	800	63	500	113	270	(1	4.9
	C	1300	0.12	760	61	500	112	260	(1	4.8
Mean		1333	0.13	790	62	500	113	267	NA	4.8
Standard Deviation		58	0.01	26	1	0	2	6	NA	0.1
% R.S.D.		4	9	3	0	0	1	2	NA	1
10	A	2300	0.10	880	60	480	82	230	(1	5.6
	B	2300	0.10	880	59	470	80	230	(1	5.5
	C	2300	0.10	870	60	470	81	230	(1	5.5
Mean		2300	0.10	877	60	473	81	230	NA	5.5
Standard Deviation		0	0.01	6	1	6	1	0	NA	0.1
% R.S.D.		0	0	1	1	1	1	0	NA	1
Mean % R.S.D.		4	8	1	1	0.3	0.3	2	NA	1

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[a] ((less-than) indicates a value below the limit of analytical detection.

NA - not applicable: One or more values below the limit of analytical detection.

Appendix 1.2.1, cont'd.

Yellowknife Bay		Element [ug/g, except Loss-on-Ignition (%)]								
Sample	Sub-sample	Arsenic	Mercury[a]	Copper	Nickel	Manganese	Lead	Zinc	Cadmium	Loss-on-Ignition
2	A	950	<0.08	190	47	1800	55	150	<1	6.0
	B	930	<0.08	190	46	1700	52	150	<1	6.1
	C	950	<0.08	190	47	1700	54	150	<1	6.0
Mean		943	NA	190	47	1733	54	150	NA	6.0
Standard Deviation		12	NA	0	1	58	2	0	NA	0.1
% R.S.D.		1	NA	0	1	3	3	0	NA	1
7	A	750	<0.08	160	44	1400	47	130	<1	6.1
	B	720	<0.08	160	44	1400	48	130	<1	6.1
	C	790	<0.08	170	45	1400	46	140	<1	6.1
Mean		753	NA	163	44	1400	47	133	NA	6.1
Standard Deviation		35	NA	6	1	0	1	6	NA	0.0
% R.S.D.		5	NA	4	1	0	2	4	NA	0
10	A	580	<0.08	150	70	1300	43	140	<1	5.5
	B	620	<0.08	150	44	1300	42	130	<1	5.4
	C	560	<0.08	150	43	1300	41	130	<1	5.5
Mean		587	NA	150	52	1300	42	133	NA	5.5
Standard Deviation		31	NA	0	15	0	1	6	NA	0.1
% R.S.D.		5	NA	0	29	0	2	4	NA	1
Mean % R.S.D.		4	NA	1	10	1	2	3	NA	1

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[a] < (less-than) indicates a value below the limit of analytical detection.

NA - not applicable: One or more values below the limit of analytical detection.

Appendix 1.2, cont'd.

Appendix 1.2.2 Accuracy

(Based on analysis of NBS 1645 River Sediment)

Element
(ug/g)

Sub-sample	Arsenic	Mercury	Copper	Nickel	Manganese	Lead	Zinc	Cadmium
A	71	0.73	118	40	820	767	1700	9
B	64	0.72	113	39	780	739	1620	8
C	68	0.88	116	40	810	758	1600	8
Mean Obtained	68	0.78	116	40	803	755	1630	8
Certified Mean	NA	1.1	109	46	785	714	1720	10.2
95% Confidence Limits	NA	0.6-1.6	90-128	43-49	688-882	686-742	1550-1890	8.7-11.7

NA - not applicable: arsenic analysis not certified.

APPENDIX 1.3

RESULTS OF ELEMENT ANALYSIS OF BOTTOM SEDIMENT SAMPLED IN AUGUST, 1983

Appendix 1.3

Results of Element Analysis of Bottom Sediment Sampled in August, 1983

Back Bay

Element
[ug/g, except Loss-on-Ignition (%), on (63 um fraction]

Sample [a]	Core Increment (cm)	Arsenic	Mercury	Copper	Nickel	Manganese	Lead	Zinc	Cadmium [c]	Loss-on-Ignition
1A	0 - 5	2300	0.12	670	53	850	91	210	(1	5.0
1B	0 - 5	2000 (2100)[b]	0.14 (0.14)	670 (670)	53 (54)	850 (850)	91 (91)	200 (207)	(1 (NA)	5.1 (5.1)
1C	0 - 5	2000	0.16	670	55	850	91	210	(1	5.1
1	5 - 10	480	0.12	190	56	700	78	260	(1	3.9
1	10 - 15	180	(0.08	32	37	730	26	70	(1	3.7
1	15 - 20	100	(0.08	33	40	730	26	79	(1	3.6
2	0 - 5	1900	0.12	640	60	580	99	210	(1	5.2
3	0 - 5	850	0.12	760	58	530	100	230	(1	4.9
3	5 - 10	620	0.12	360	58	490	100	420	(1	4.0
3	10 - 15	170	(0.08	36	34	520	26	74	(1	3.9
3	15 - 20	110	(0.08	34	34	530	25	80	(1	4.1
4	0 - 5	1700	0.14	890	64	500	100	300	(1	5.0
5A	0 - 5	1400	0.14	810	63	500	115	270	(1	4.8
5B	0 - 5	1300 (1323)	0.12 (0.13)	800 (790)	63 (62)	500 (500)	113 (113)	270 (267)	(1 (NA)	4.9 (4.8)
5C	0 - 5	1300	0.12	760	61	500	112	260	(1	4.8
6	0 - 5	1000	0.14	820	67	500	140	420	1	4.6
7	0 - 5	1700	0.12	700	62	480	110	260	(1	5.2
8	0 - 5	2900	0.12	1000	65	460	110	300	(1	5.2
9	0 - 5	2100	0.10	950	56	950	77	200	(1	5.3
9	5 - 10	1800	0.12	450	62	980	94	340	(1	4.0
9	10 - 15	250	(0.08	34	38	960	26	75	(1	4.8
9	15 - 20	120	(0.08	37	40	880	24	80	(1	4.8
10A	0 - 5	2200	0.10	880	60	480	82	230	(1	5.6
10B	0 - 5	2300 (2300)	0.10 (0.10)	880 (877)	59 (60)	470 (473)	80 (81)	230 (230)	(1 (NA)	5.5 (5.5)
10C	0 - 5	2300	0.10	870	60	470	81	230	(1	5.5
Mean:	0 - 5 (N=10)	1060	0.12	810	61	583	102	264	NA	5.1
	5 - 10 (N=3)	967	0.12	333	59	723	91	340	NA	4.0
	10 - 15 (N=3)	200	NA	34	36	737	26	73	NA	4.1
	15 - 20 (N=3)	110	NA	35	38	713	25	80	NA	4.2

Appendix 1.3, cont'd.

Yellowknife Bay

		Element [ug/g, except Loss-on-Ignition (%), on < 63 um fraction]								
Sample	Core Increment (cm)	Arsenic	Mercury	Copper	Nickel	Manganese	Lead	Zinc	Cadmium	Loss-on-Ignition
1	0 - 5	590	<0.08c	170	49	1500	49	130	<1	5.8
1	5 - 10	260	<0.08	53	40	610	37	100	<1	4.9
1	10 - 15	80	<0.08	32	40	390	30	70	<1	4.2
1	15 - 20	79	<0.08	34	41	410	28	80	<1	4.5
2Aa	0 - 5	950	<0.08	190	47	1800	55	150	<1	6.0
2B	0 - 5	930 (943)b	<0.08 (NA)	190 (190)	46 (47)	1700 (1733)	52 (54)	150 (150)	<1 (NA)	6.1 (6.0)
2C	0 - 5	950	<0.08	190	47	1700	54	150	<1	6.0
3	0 - 5	610	<0.08	170	48	1600	50	140	<1	6.2
3	5 - 10	190	<0.08	44	40	450	32	90	<1	4.5
3	10 - 15	76	<0.08	33	40	430	26	70	<1	3.9
3	15 - 20	85	<0.08	38	44	430	34	80	<1	4.7
4	0 - 5	640	<0.08	160	46	1500	52	140	<1	5.9
5	0 - 5	360	<0.08	180	48	1500	50	130	<1	5.8
6	0 - 5	570	<0.08	160	47	1600	47	140	<1	6.2
7A	0 - 5	750	<0.08	160	44	1400	47	130	<1	6.1
7B	0 - 5	720 (753)	<0.08 (NA)	160 (163)	44 (44)	1400 (1400)	48 (47)	130 (133)	<1 (NA)	6.1 (6.1)
7C	0 - 5	790	<0.08	170	45	1400	46	140	<1	6.1
8	0 - 5	630	<0.08	150	43	1200	40	110	<1	5.8
9	0 - 5	650	<0.08	150	47	1600	44	130	<1	5.6
9	5 - 10	230	<0.08	62	40	890	33	110	<1	3.8
9	10 - 15	82	<0.08	34	40	440	26	80	<1	4.6
9	15 - 20	90	<0.08	36	39	440	24	80	<1	4.5
10A	0 - 5	580	<0.06	150	70	1300	43	140	<1	5.5
10B	0 - 5	620 (587)	<0.08 (NA)	150 (150)	44 (44)d	1300 (1300)	42 (42)	130 (133)	<1 (NA)	5.4 (5.5)
10C	0 - 5	560	<0.06	150	43	1300	41	130	NA	5.5
Mean:	0 - 5 (N=10)	633	NA	164	46	1497	47	134	NA	5.9
	5 - 10 (N=3)	227	NA	56	40	650	34	100	NA	4.4
	10 - 15 (N=3)	79	NA	33	40	420	27	73	NA	4.3
	15 - 20 (N=3)	85	NA	36	41	427	29	80	NA	4.6

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[a] A, B and C denote sub-samples used to determine analytical precision.

[b] Mean of three sub-samples.

[c] < (less-than) indicates a value below the limit of analytical detection.

[d] Mean of sub-samples 10B and 10C only: 10A value rejected as an outlier.

NA - not applicable: All values below the limit of analytical detection.

APPENDIX 1.4

QUALITY ASSURANCE RESULTS FOR ELEMENT ANALYSIS OF SUSPENDED SEDIMENT SAMPLED FROM JULY TO OCTOBER, 1984

Appendix 1.4 Quality Assurance Results for Element Analysis of Suspended Sediment Sampled from July to October, 1984

(Based on analysis of NBS 1645 River Sediment)

Appendix 1.4.1 Precision

[expressed as percentage relative standard deviation (% R.S.D.)]

Element
(ug/g)

Sub-sample	Arsenic	Mercury	Copper	Nickel	Lead	Zinc	Cadmium
A	66	0.76	114	50	727	1680	9
B	65	0.95	113	40	722	1650	9
C	67	0.81	113	41	734	1640	9
Mean	66	0.84	113	44	728	1657	9
Standard Deviation	1	0.10	1	6	6	21	0
% R.S.D.	2	12	1	13	1	1	0

Appendix 1.4.2 Accuracy

	Arsenic	Mercury	Copper	Nickel	Lead	Zinc	Cadmium
Certified Mean	NA	1.1	109	45.8	714	1720	10.2
95% Confidence Limits	NA	0.6-1.6	90-128	42.9-48.7	686-742	1550-1890	8.7-11.4
Mean Obtained	66	0.84	113	44	728	1657	9

NA - not applicable: arsenic value not certified.

APPENDIX 1.5

RESULTS OF ELEMENT ANALYSIS OF SUSPENDED SEDIMENT SAMPLED FROM JULY TO OCTOBER, 1984

Appendix 1.5 Results of Element Analysis of Suspended Sediment Sampled from July to October, 1984

Location	Sediment Trapping Period (1984)	Element (ug/g, dry weight, in unsieved sediment) Arsenic	Mercury	Copper	Nickel	Lead	Zinc	Cadmium
Back Bay	Jul. 24 to Aug. 16	200	0.19	72	51	62	170	<4
	Sept. 8 to Oct. 10	420	0.10	83	47	49	150	<4
Mean:		310	0.15	78	49	56	160	NA
Standard Deviation:		156	0.06	8	3	9	14	NA
Yellowknife Bay	Jul. 24 to Aug. 16	120 130 (125)a	0.09 0.08 (0.09)	63 61 (52)	45 55 (50)	49 47 (48)	160 160 (160)	<4 <4 (NA)
	Sept. 8 to Oct. 10	150	<0.08	87	61	38	170	<4
Mean:		138	NA	75	56	43	165	NA
Standard Deviation:		18	NA	18	8	7	7	NA

[a] Mean of duplicate analysis.

NA - not applicable: One or more values below the limit of analytical detection.

APPENDIX 2.0

RESULTS OF ANALYSIS OF BENTHIC MACROINVERTEBRATES SAMPLED FROM BACK BAY AND YELLOWKNIFE BAY

APPENDIX 2.1

ABUNDANCE OF BENTHIC MACROINVERTEBRATES SAMPLED FROM BACK BAY IN JUNE AND OCTOBER, 1981

Appendix 2.1

Abundance of Benthic Macroinvertebrates Sampled from Back Bay in June and October, 1981

[Number of organisms per grab sample (mean and standard deviation of triplicate samples)]

Water Depth (m)		2					6										8										12									
Distance (m)[a]		300	600	300	1200	1500	300		600		900		1200		1500		300		600		900		1200		1500		300		600		900		1200		1500	
Direction[b]		SE	SE	SE	SE	SE	SE	NE	SE	NE	SE	NE	SE	NE	SE	NE	SE	NE	SE	NE	SE	NE	SE	NE	SE	NE	SE	NE	SE	NE	SE	NE	SE	NE	SE	NE
Total Abundance	June	12.0 7.9	90.0 1.4	33.3 4.2	41.0 15.7	110.0 53.2	7.0 0.0	NA NA	26.7 14.4	56.0 22.9	50.0 10.0	59.3 21.2	48.7 20.2	135.0 38.3	52.0 12.7	125.3 26.6	NA NA	NA NA	6.7 4.2	5.7 1.5	7.3 4.7	73.0 6.2	46.3 44.7	87.3 30.2	12.3 5.0	100.1 10.1	NA NA	NA NA	0.7 0.6	1.7 2.1	0.3 0.6	0.7 1.2	8.7 4.9	2.3 2.5	NA NA	NA NA
	Oct.	55.3 31.6	204.3 39.8	23.0 4.6	210.3 35.0	218.3 138.6	NA NA	42.7 5.0	96.3 28.0	47.3 10.6	78.7 6.0	95.7 15.9	49.3 10.0	78.3 12.7	89.3 16.7	59.3 17.3	NA NA	NA NA	37.7 5.1	34.0 4.6	NA NA	50.3 10.2	52.0 26.6	38.3 21.0	76.3 12.4	52.3 8.6	NA NA	NA NA	10.0 1.4	0.7 1.2	7.0 2.6	3.3 2.9	12.7 9.1	0.3 0.6	NA NA	NA NA
Chironomids.	June	4.7 6.4	33.0 7.1	18.7 4.7	19.7 6.1	57.3 30.2	4.0 1.0	NA NA	15.7 6.7	34.7 16.9	29.0 2.6	31.3 6.4	9.3 4.0	35.3 13.5	2.7 2.5	26.0 4.4	NA NA	NA NA	4.3 4.0	4.7 2.1	6.7 4.2	2.7 1.2	8.7 7.5	17.3 3.1	1.3 0.6	6.0 5.6	NA NA	NA NA	0.6 0.6	1.3 2.3	0.3 0.6	0.0 0.0	5.7 3.1	2.0 2.0	NA NA	NA NA
	Oct.	41.3 22.0	150.0 48.6	16.7 6.5	119.7 11.7	100.3 109.3	NA NA	37.7 5.5	61.0 15.1	38.3 7.6	14.3 5.5	27.3 6.7	13.0 4.4	11.3 7.2	12.7 5.9	10.0 2.0	NA NA	NA NA	30.7 3.1	29.0 2.7	NA NA	13.7 3.1	10.0 2.6	21.0 14.2	16.0 2.6	3.0 1.0	NA NA	NA NA	10.0 1.4	0.7 1.2	7.0 2.6	3.0 2.6	11.0 7.8	0.3 0.6	NA NA	NA NA
Amphipods	June	0.0 0.0	0.0 0.0	0.0 0.0	0.7 0.6	3.0 2.6	0.0 0.0	NA NA	0.3 0.6	3.0 2.0	2.3 4.0	0.0 0.0	17.0 11.5	59.7 31.5	17.7 18.0	75.3 21.1	NA NA	NA NA	0.0 0.0	0.0 0.0	0.0 0.0	67.7 7.0	31.3 40.0	54.3 26.1	5.3 5.8	86.3 3.8	NA NA	NA NA	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.3 0.6	NA NA	NA NA
	Oct.	0.0 0.0	0.0 0.0	1.3 0.6	17.3 5.8	5.7 4.9	NA NA	0.0 0.0	0.7 0.6	0.3 0.6	20.7 22.4	25.3 5.5	21.0 1.0	49.7 4.0	46.3 10.5	39.0 6.1	NA NA	NA NA	1.3 1.5	0.7 1.2	NA NA	29.7 3.5	36.7 22.0	57.0 0.0	35.7 12.7	44.7 4.5	NA NA	NA NA	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	NA NA	NA NA
Oligochaetes	June	1.3 1.1	53.5 7.8	5.3 6.8	5.0 8.7	14.0 2.0	0.0 0.0	NA NA	5.0 6.1	9.7 6.7	14.0 9.5	21.0 22.0	11.0 10.1	18.0 2.6	8.0 7.2	20.7 1.2	NA NA	NA NA	0.0 0.0	0.3 0.6	0.0 0.0	0.7 1.2	5.3 3.1	6.0 3.5	4.0 4.4	7.0 4.6	NA NA	NA NA	0.0 0.0	0.3 0.6	0.0 0.0	0.0 0.0	1.7 2.1	0.0 0.0	NA NA	NA NA
	Oct.	6.3 9.3	41.7 15.0	0.3 0.6	29.3 43.0	57.3 33.9	NA NA	0.0 0.0	8.3 2.5	3.0 1.7	9.7 3.2	8.3 7.6	9.0 6.6	4.3 4.0	20.0 11.3	5.0 7.8	NA NA	NA NA	2.0 2.0	0.3 0.6	NA NA	0.0 0.0	0.7 1.2	3.0 3.0	15.3 7.2	1.0 1.0	NA NA	NA NA	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	1.7	0.0	NA	NA
Molluscs	June	0.0 0.0	1.5 0.7	0.3 0.6	0.7 0.6	12.3 9.2	3.0 0.3	NA NA	0.7 0.6	11.0 8.9	2.0 3.5	3.3 4.9	3.0 4.4	20.0 6.0	2.0 2.0	3.7 0.6	NA NA	NA NA	0.0 0.0	0.7 0.6	0.0 0.0	0.7 1.2	1.0 0.0	9.7 5.7	0.3 0.6	7.3 9.2	NA NA	NA NA	0.0 0.0	0.0 0.0	0.0 0.0	0.7 1.2	1.7 2.1	0.0 0.0	NA NA	NA NA
	Oct.	1.0 0.0	3.0 3.0	0.0 0.0	33.0 46.7	26.2 20.1	NA NA	1.0 0.0	7.7 5.1	3.3 2.3	26.7 18.1	15.3 11.6	0.7 1.2	9.0 9.8	6.3 7.5	4.3 7.5	NA NA	NA NA	0.7 1.2	1.0 1.7	NA NA	4.7 4.7	3.0 2.6	3.3 1.5	2.3 2.5	2.7 4.6	NA NA	NA NA	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	NA NA	NA NA
Trichopterans	June	1.3 2.3	1.0 1.4	4.0 1.0	4.7 3.2	4.7 5.0	0.0 0.0	NA NA	3.7 3.2	0.0 0.0	0.0 0.0	2.3 4.0	3.0 4.4	0.0 0.0	6.0 0.0	0.0 0.0	NA NA	NA NA	0.0 0.0	0.0 0.0	0.3 0.6	0.3 0.6	0.0 0.0	0.0 0.0	0.7 1.2	1.0 1.7	NA NA	NA NA	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	NA NA	NA NA
	Oct.	0.3 0.6	3.3 2.1	2.7 2.9	2.3 3.2	1.0 1.7	NA NA	0.0 0.0	0.3 0.6	0.0 0.0	0.0 0.0	1.7 0.6	0.3 0.6	0.0 0.0	0.0 0.0	0.0 0.0	NA NA	NA NA	0.0 0.0	0.0 0.0	NA NA	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	NA NA	NA NA	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	NA NA	NA NA
Nematodes	June	4.0 1.7	0.0 0.0	4.0 3.6	12.3 9.1	9.3 14.5	0.0 0.0	NA NA	0.3 0.6	0.0 0.0	0.3 0.5	0.0 0.0	0.0 0.0	0.3 0.6	0.0 0.0	0.0 0.0	NA NA	NA NA	0.0 0.0	0.0 0.0	0.0 0.0	0.3 0.6	0.0 0.0	0.3 0.3	0.0 0.0	0.0 0.0	NA NA	NA NA	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	NA NA	NA NA
	Oct	0.0 0.0	2.0 2.0	1.3 1.2	0.0 0.0	6.7 4.6	NA NA	0.0 0.0	0.0 0.0	0.0 0.0	0.3 0.6	1.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	NA NA	NA NA	0.0 0.0	0.0 0.0	NA NA	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	NA NA	NA NA	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	NA NA	NA NA
Mites	June	0.7 1.1	0.5 0.7	0.0 0.0	0.0 0.0	4.0 2.0	0.0 0.0	NA NA	0.0 0.0	1.7 1.1	1.0 1.0	0.3 0.6	0.3 0.6	1.0 1.7	0.3 0.6	1.7 1.5	NA NA	NA NA	0.0 0.0	0.0 0.0	0.0 0.0	0.7 0.6	0.0 0.0	0.7 1.2	0.0 0.0	0.0 0.0	NA NA	NA NA	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	NA NA	NA NA
	Oct.	0.7 0.6	0.0 0.0	0.0 0.0	3.3 4.2	2.0 2.6	NA NA	2.7 1.2	10.3 9.3	2.0 2.0	8.7 3.2	17.3 17.9	2.0 1.7	3.3 2.9	1.0 1.7	0.7 1.2	NA NA	NA NA	1.3 1.5	1.0 1.7	NA NA	1.3 0.6	2.0 1.0	8.7 10.3	4.7 3.5	1.0 1.0	NA NA	NA NA	0.0 0.0	0.0 0.0	0.0 0.0	0.3 0.6	0.0 0.0	0.0 0.0	NA NA	NA NA
Leeches	June	0.0 0.0	0.0 0.0	0.3 0.6	0.0 0.0	0.0 0.0	0.0 0.0	NA NA	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	NA NA	NA NA	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	NA NA	NA NA	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	NA NA	NA NA
	Oct.	0.0 0.0	0.0 0.0	0.0 0.0	0.3 0.6	0.0 0.0	NA NA	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	NA NA	NA NA	0.0 0.0	0.0 0.0	NA NA	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	NA NA	NA NA	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	NA NA	NA NA
Other	June	0.0 0.0	0.3 0.6	0.7 0.6	1.3 2.3	5.3 5.8	0.0 0.0	NA NA	1.0 1.7	6.0 1.0	1.3 1.5	1.0 1.7	1.3 1.1	0.7 0.6	0.0 0.0	0.0 0.0	NA NA	NA NA	0.3 0.6	0.0 0.0	0.3 0.6	0.0 0.0	0.0 0.0	0.0 0.0	0.7 1.1	0.0 0.0	NA NA	NA NA	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	NA NA	NA NA
	Oct	0.3 0.6	4.0 1.0	0.7 0.6	9.3 5.5	11.7 13.6	NA NA	1.3 0.6	0.3 0.5	0.0 0.0	1.7 2.1	0.3 0.6	3.0 3.5	0.7 0.6	3.0 2.6	0.0 0.0	NA NA	NA NA	1.3 0.6	1.3 0.5	NA NA	0.3 0.6	0.0 0.0	0.3 0.5	1.7 1.2	0.0 0.0	NA NA	NA NA	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	NA NA	NA NA

a Distance from the mouth of Baker Creek.

b Direction from the mouth of Baker Creek (i.e. southeast and northeast quadrants). NA - not available

APPENDIX 2.2

SPECIES COMPOSITION OF BENTHIC MACROINVERTEBRATE COMMUNITIES SAMPLED FROM BACK BAY IN JUNE AND OCTOBER, 1981

Appendix 2.3 Species Composition of Benthic Macroinvertebrate Communities Sampled from Back Bay in June and October, 1981

Acarina

- Arrenurus sp
- Lebertia sp
- Neumania sp
- Oxus sp
- Piona sp
- Sperchon sp
- Unionicola sp

Amphipoda

- Gammarus lacustris lacustris
- Hyalella azteca
- Pontoporeia hoyi

Diptera

- Chironomidae
  - Ablabesmyia sp
  - Brillia sp
  - Chironomus anthracimus grp
  - Chrionomus plumosus grp
  - Chironomus sp
  - Cladotanytarsus sp
  - Cricotopus sp
  - Cricotopus festivellus grp
  - Cricotopus tremulus grp
  - Cricotopus sylvestris grp
  - Cryptochironomus sp
  - Cryptotendipes sp
  - Demicryptochironomus sp
  - Dicrotendipes sp
  - Endochironomus sp
  - Glyptotendipes sp
  - Harnischia cf curtilamellata
  - Heterotrissocladius sp
  - Heterotrissocladius cf changi
  - Heterotrissocladius cf oliveri
  - Monodiamesa sp
  - Nanocladius cf distinctus
  - Nanocladius sp
  - Nilotanypus sp
  - Cladopelma sp
  - Orthocladiinae

Diptera, Chironomidae, cont'd.

- Parachironomus T1
- Parachironomus T2
- Paracladopelma nr nais
- Paracladopelma galaptera
- Paracladopelma sp
- Pagastiella ostansa
- Paralauterborniella cf nigrohalterallis
- Larsia sp
- Psectrocladius sp
- Parakiefferiella sp
- Phaenopsectra sp
- Potthastia sp
- Polypedilum cf nubeculosum
- Polypedilum (Tripodura) sp
- Procladius sp
- Protanypus sp
- Psectrocladius T4
- Psectrocladius nr simulans
- Pseudochironomus sp
- Stictochironomus sp
- Tanytarsus sp
- Thienemannimyia grp
- Zalutschia sp

Ephemeroptera

- Baetidae
  - Pseudocloeon sp
- Caenidae
  - Caenis
- Ephemerellidae
  - Ephemerella sp
- Ephemeridae
  - Hexagenia sp
  - Ephemera prob simulans

Hemiptera

- Corixidae
  - Sigara sp
  - Sigara trilineata

Empidae

- Chelifera sp

Diptera, cont'd.

- Trichoptera
  - Leptoceridae
    - Mystacides sp
    - Oecetis sp
    - Triaenodes sp
  - Molannidae
    - Molanna prob flavicornis
  - Phryganeidae
    - Agrypnia sp
    - Phryganea sp
    - Phryganea prob cinera
  - Polycentropodidae

Hirudinea

- Helobdella stagnalis
- Dina sp
- Piscicola prob geometra

Mollusca

- Lymnaeidae
  - Lymnaea prob stagnalis
  - Fossaria prob modicella
  - Stagnicola arctica
- Physidae
  - Physa gyrina
- Planorbidae
  - Gyraulus parvus
  - Promenetus exacuous exacuous
- Sphaeriidae
  - Sphaerium nitidum
  - Sphaerium securis
  - Pisidium casertanum
  - Pisidum casertanum
  - Pisidum compressum
  - Pisidum lilljeborgi cristatum
  - Pisidum idahoense
  - Pisidum nitidum
  - Pisidum sp
  - Pisidum variable
  - Valvitadae
  - Valvata sincera helicoides

Mollusca, Valvatidae, cont'd.

- Valvata tricarinata

Oligochaeta

- Lumbriculidae
- Tubifidicae
  - Limnodrilus hoffmeisteri
  - Limnodrilus profundicola
  - Limnodrilus sp
  - Pelescolex sp

Nematoda

APPENDIX 2.3

ABUNDANCE AND SPECIES COMPOSITION OF BENTHIC MACROINVERTEBRATE COMMUNITIES SAMPLED FROM BACK BAY AND YELLOWKNIFE BAY IN AUGUST, 1983

Appendix 2.3 Abundance and Species Composition of Benthic Macroinvertebrates Sampled from Back Bay and Yellowknife Bay in August, 1983

Abundance/Species Composition
[organisms per grab sample; presence (x) or absence (-)]

Area	Back Bay												Yellowknife Bay											
Taxonomic Group / Station	1	2	3	4	5	6	7	8	9	10	Mean	St'd. Dev.	1	2	3	4	5	6	7	8	9	10	Mean	St'd. Dev.
Amphipoda	2	1	1	1	0	0	0	0	1	0	0.6	0.7	241	97	95	116	132	116	85	119	101	93	119.5	45.1
Haustoriidae																								
Pontoporeia hoyi	x	x	x	x	-	-	-	-	x	-			x	x	x	x	x	x	x	x	x	x		
Diptera																								
Chironomidae	1	2	1	3	2	3	1	7	3	1	2.4	1.8	7	1	1	7	3	8	5	4	4	6	4.6	2.5
Orthocladiinae	-	-	-	-	-	-	-	x	-	x														
Heterotrissocladius sp													-	-	-	-	-	x	x	-	-	x		
Zalutschia sp	-	-	-	x	-	-	-	x	-	-														
Tanytarsini																								
Microspectra sp	-	-	x	-	x	x	x	x	-	-			-	-	-	x	-	x	-	-	x	-		
Cladotanytarsus sp	-	-	-	x	-	-	-	-	-	-														
Tanypodinae																								
Procladius sp	x	x	-	-	-	-	-	x	x	-			x	x	x	x	x	x	x	x	x	x		
Prodiamesinae																								
Monodiamesa sp													-	-	-	-	x	-	-	-	x	x		
Chironomini																								
Cryptochironomus sp	-	-	-	-	-	-	-	x	-	-														
Demicryptochironomus sp													-	-	-	-	-	-	x	-	-	-		
Empidae	0	0	0	0	0	0	0	0	0	0	0.0	0.0	0	0	0	0	0	1	1	1	0	0	0.3	0.5
Chalifera sp													-	-	-	-	-	x	x	x	-	-		
Mollusca	0	0	0	0	0	0	0	0	0	0	0.0	0.0	32	15	7	5	12	9	11	8	10	5	11.4	7.9
Gastropoda																								
Valvatidae																								
Valvata sincera helicoidea													x	-	-	-	-	-	x	-	-	-		
Pelecypoda																								
Sphaeriidae																								
Pisidium nitidum													x	x	x	x	x	x	x	x	x	x		
Oligochaeta	0	0	0	0	0	0	0	0	0	0	0.0	0.0	23	7	5	7	12	10	11	8	24	12	11.9	6.5
Tubificidae																								
Peloscolex multisetosus													x	x	x	x	x	x	x	-	x	x		
Limnodrilus hoffmeisteri													-	x	-	-	-	-	-	-	x	-		
Lumbriculidae													x	-	x	-	x	-	-	-	-	-		
Acarina	0	0	1	0	0	0	0	0	0	0	0.1	0.3	0	0	1	0	0	0	0	1	0	0	0.2	0.4
Oxidae																								
Oxus sp	-	-	x	-	-	-	-	-	-	-			-	-	x	-	-	-	-	x	-	-		
Total Community Abundance	3	3	3	4	2	3	1	7	4	1	3.1	1.7	303	120	109	135	159	144	113	141	139	116	147.9	55.8
Number of Species/Other Taxa	2	2	3	3	1	1	1	5	2	1	2.1	1.3	6	5	6	5	5	7	9	5	7	5	6.0	1.3

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