INVESTIGATIONS OF THE SPANISH RIVER AREA

OF THE NORTH CHANNEL OF LAKE HURON

III. SUSPENDED SEDIMENT TRANSPORT, SEDIMENT POREWATER AND WATER CHEMISTRY CHARACTERIZATION

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ABSTRACT

The results for porewater, water column and suspended-trapped sediments chemistry in the Spanish Harbour/Whalesback Channel and North Channel, are summarized. Sediment porewater nutrients are found to be enriched by a factor of 30 to 2600 when compared to lake water levels. The highest increase was found for ammonia at the station closest to the river mouth. Total metal concentrations in porewater are highest at a depth of 8 cm, which corresponds to peak loading between 1950 and 1960, based on sedimentation rates reported for this area. Total metal concentrations in water in the Whalesback Channel are 50 to 60% higher than in the North Channel, however the concentrations meet the federal guidelines for the protection of aquatic life. The mean current speed and direction in the Whalesback Channel is 3.8 cm/sec in a southerly direction into the North Channel. This research clearly indicates that at least during the study period (May to September), there is trace metal and nutrient transport occurring from the Spanish Harbour/Whalesback Channel to the North Channel of Lake Huron. Metal concentrations in the suspended sediments are above the Lowest Effect Level given by the Ontario Ministry of the Environment and Energy sediment guidelines. Remediation of the water and sediment quality in the Whalesback Channel would considerably decrease contaminant loadings to the open water of Lake Huron.

1. INTRODUCTION

The Spanish River is located on the Canadian Shield with the majority of the Spanish River watershed located in the geographic District of Sudbury (Figure 1a).
The bedrock geology of the Spanish River drainage basin is comprised of two major lithological units. The upper part of the watershed is characterized by Precambrian igneous rocks, including the Sudbury Irruptive, while the lower part is underlain by sedimentary, volcanic and derived metamorphic rocks. Surficial deposits are typically thin layers of undifferentiated silts, clays and sands interspersed with swamps and bogs between bedrock ridges. The mean annual flow for the river is 132.6 $m^3 \cdot sec^{-1}$ with a 20-year flood flow of 1,100 $m^3 \cdot sec^{-1}$ (MacLaren Plansearch, 1984).

In 1985, the Spanish Harbour was designated by the International Joint Commission as one of the 42 Areas of Concern (AoC) in the Great Lakes Basin, based on an assessment undertaken in 1980. Problems identified included: tainting of fish, impaired benthic communities, and indications of nutrient and metal enrichment in the adjacent near shore waters. Concentrations of polychlorinated biphenyls (PCBs) and some metals in the sediments were found to exceed provincial guidelines for the open water disposal of dredge spoils. Other impaired uses included domestic water-taking, livestock watering and fish habitat losses. Use impairments in the AoC to that date were largely attributed to the waste loadings from a pulp and paper mill located 52 km upstream at Espanola (Ross, 1975). Chronology of operations is reported below.

Dymond and Delaporte (1952) were the first to report on the degradation of the

Spanish River. Subsequent studies carried out by Swabey (1965) and Conroy and McGrath (1967) documented the biological impacts associated with the waste discharges from this facility. From 1947 until approximately 1980, commercial fishermen fishing the Whalesback Channel could not market walleye due to the tainting problems (Swabey, 1965; Loftus, 1980). The taste of the fish was described as being "like fuel oil and turpentine" (Loftus, 1980) and was attributed to tainting by phenolic substances from the upstream pulp and paper mill (Swabey, 1965; MOEE, 1983). A 1972 water quality survey carried out by the Ministry of the Environment and Energy (MOEE) found that due to high loadings of

BOD_5, dissolved oxygen levels were as low as 4.2 $mg \cdot L^{-1}$ 40 km downstream of the mill (MOEE, 1972). Bacteriological counts exceeded body-contact recreation objectives with fecal coliforms ranging from 500-900 counts/100 mL at Espanola, to 68-400 counts/100 mL near the river mouth. In 1980, the Spanish Harbour was included in the 1980 Great Lakes International Surveillance Plan. The results of the study documented eutrophication problems in the harbour (Hayman, 1980).

Chronology of Espanola Mill.

Date	Event (Source: E.B. Eddy, 1987 and 1990 annual reports)
1905	- startup as groundwood facility.
1912	- first two paper machines on-line.
1914	- two additional paper machines brought on-line.
1920s	- fifth and sixth paper machines brought on-line.
1927	- ownership changes to Abitibi Power and Paper.
1932	- facility shutdown.
1943	- converted to Kraft production (265 tons/day); facility owned by Kalamazoo Vegetable Parchment (KVP) Co.
1965	- production expanded to 625 tons/day.
1966	- facility purchased by Brown Forest Industries Ltd.
1969	- facility purchased by George Weston Ltd.; given present name E.B. Eddy Forest Products Ltd.
1970	- spill recovery and primary treatment installed.
1977	- oxygen bleaching installed on softwood line.
1980	- hardwood line converted to oxygen bleaching.
1983	- secondary treatment implemented.

1988 - chlorine dioxide substitution implemented.
1989 - switch to dry debarking;
all effluents diverted to secondary treatment.
1990 - chlorine dioxide substitution increased on hardwood line;
in-plant modifications continued.

A harbour is often considered to be one of the final sinks for all types of soluble and particulate contaminants released to the environment and for materials produced in the water body itself. Near shore areas, in particular, are often characterized by wide variations in concentrations of contaminants due to localized inputs and as a result of near shore mixing processes. Contaminants entering a water body in soluble form eventually associate with particulate matter either by adsorption, chemical association, or biological uptake. This association can occur in the water column and/or in the bottom sediment compartments. The material in the water column settles to the bottom, but may be recycled back into the water column through resuspension induced by physical mixing processes. The most important process by which particulate matter is removed from the water column is through sedimentation.

The purpose of this study was to measure sediment porewater profiles at three sites in the Whalesback Channel of the North Channel, lake Huron; and one control site to determine concentrations of trace elements and nutrients in the sediment porewater. The concentration of soluble and particulate nutrients and total metals in the water column were to be measured, and related to those in porewater and sediment. However the most important task was to measure the sedimentation rates of suspended particulates and associated contaminants in Lake Huron at four limnologically different sites. Sedimentation rates were to be observed at two levels in the water column; at 10 metres below surface, and 2 metres above the lake bottom. Since contaminants have a high affinity for particulate matter, conclusions were to be drawn concerning the pathway and eventual fate of contaminants, from the Spanish Harbour/Whalesback Channel, out into the North Channel waters. Studies to achieve the above goals were initiated in 1988, with the measurements of contaminants and nutrients in sediment porewater. A study to assess the transport of contaminated sediment from the Whalesback Channel, out to the open waters of the North Channel, was initiated in 1990 and completed in 1992. Sediment traps were deployed from April to September (1990 to 1992) at four stations to measure sedimentation rates at two levels in the water column, inside the Whalesback Channel and outside in the North Channel waters. Current meters were deployed at 3 stations (110, 111, and 112, Figure 1b), at a depth of 10 m to measure water temperature, current speed and direction. Water column physico-chemical measurements were carried out at selected stations along two transects in the Whalesback channel in July 1991.

ABBREVIATION TABLE

Abbreviation	Description
TSM	Total Suspended Matter
ISM	Inorganic Suspended Matter
OSM	Organic Suspended Matter
TTM	Total Trapped Matter
ITM	Inorganic Trapped Matter
OTM	Organic Trapped Matter
LOI	Loss on Ignition
CHLA	Chlorophyll *a*
CHLA.U	Chlorophyll *a* (uncorrected)
CHLA.C	Chlorophyll *a* (corrected)
POC	Particulate Organic Carbon
PN	Particulate Nitrogen
TP	Total Phosphorus
TPP	Total Particulate Phosphorus
NH_3	Ammonia
SRP	Soluble Reactive Phosphorus
$NO_3 + NO_2$	Nitrate plus Nitrite
TRANS	Light Transmission

2. MATERIALS AND METHODS

Study Area

Location

The Spanish River is located on the Canadian Shield with the majority of the Spanish River watershed located in the geographic District of Sudbury (Figure 1a). From its headwaters, the river flows in a southerly direction towards the North Channel of Lake Huron and discharges south of the Village of Spanish in the District of Shedden. Its drainage area encompasses approximately 14,000 km^2. The Spanish River watershed consists of a network of lakes and rivers which are regulated by twenty-two control structures. The average slope of the Spanish River from its headwaters to the town of Espanola is approximately 1.1 m/km.

The bedrock geology of the Spanish River drainage basin is comprised of two major lithological units. The upper part of the watershed is characterized by Precambrian igneous rocks, including the Sudbury Irruptive, while the lower part is underlain by sedimentary, volcanic and derived metamorphic rocks. Surficial deposits are typically thin layers of undifferentiated silts, clays and sands interspersed with swamps and bogs between bedrock ridges.

The surficial geology of the river and the adjacent nearshore area originated during the Wisconsin glaciation. The location of the north shore of the glacial Lake Algonquin near Massey resulted in the deposition of varved clays. When the glacial lake level dropped, lacustrine and beach sands were deposited in the area, as well as varved clays and silts. These deposits now form the streambanks and riverbed of the Spanish River downstream of Espanola.

Significant tributaries include Wakonassin, Vermilion and Aux Sables Rivers. The Wakonassin and Aux Sables Rivers are essentially pristine waterways, although historically they were used to transport red and white pine to mills located at the mouth of Spanish River. For the first 30 years of this century, major sawmills operated at the mouth of the Spanish River at Spanish Mills and Moyles Mills (Brown, 1983). The Aux Sables River joins the Spanish River at the town of Massey. It contributes approximately 15 % of the baseflow of the lower Spanish River (Beak, 1980).

The Vermilion River drains the greater part of the Sudbury Basin, including INCO and Falconbridge metal mining properties at Levack/Opaning and INCO smelting/refining facilities at Copper Cliff. The Vermilion River merges with the Spanish River just upstream of the town of Espanola.

The lower reaches of the Spanish River have been impacted since the turn of the century by log driving operations and subsequent waste discharges from a pulp and paper mill facility at Espanola. Mining, milling and smelting operations in the Sudbury Basin have been a major source of heavy metals for the river and have resulted in an extensive area of contaminated sediments in both the nearshore zone of the AoC and the Whalesback Channel. Problems identified at the time included: tainting of fish, impaired benthic communities and indications of nutrient and metal enrichment in the adjacent nearshore waters. Concentrations of PCBs and some metals in sediments were found to exceed provincial guidelines for the open water disposal of dredge spoils. Other impaired uses included domestic water-taking and livestock watering.

Sampling, Sample Preparation and Analytical Methods

Water

Sampling stations were established in the Spanish Harbour study area for collecting water, sediment and other *in situ* measurements, Reynoldson *et al*, (1995). Additional sampling stations were located along two transects; one from the Spanish River mouth, westward past John's Island out to North Channel waters, the other from Aird Bay, towards the south to the North Channel. The East-West and the North-South transects were established to detect any spatial gradients due to riverine and other local inputs. These stations were

labelled with the "T" notation, (Figure 1b).

At most sampling stations, surface to bottom profiles of temperature and light transmissions in water were recorded, using a combined transmissometer-electronic-bathythermograph (TEBT) system. A YSI oxygen meter was used to measure *in situ* DO. In addition, pH was measured at selected stations in the two transects, at 4 m below the water surface. Collected samples were analyzed for pH at laboratory temperature, using the Cole Palmer Analyzer, Model 5800-05.

Water samples for particulate and soluble nutrient, and trace elements analysis were collected by Van Dorn bottle (Rosa *et al*, 1991) from selected stations in the study area. At these stations one sample was collected at 4 m below water surface. Particulate organic carbon and nitrogen (POC, PN), chlorophyll a (CHLA), corrected and uncorrected (CHLA.C, CHLA.U) for phyophyten, and total phosphorus (TP) were determined according to (EC 1992, V.1). For the determination of total suspended matter (TSM), the samples were filtered, using precombusted (500°C) and pre-weighed Whatman GF/C glass fibre filters (approximate pore size 1-2 μm). The filters were dried at 100°C for 3 hours to obtain the dry weight of the TSM. The inorganic suspended matter (ISM), was gravimetrically measured after the sample was combusted at 500°C for 2.5 hours. Organic suspended matter (OSM) was calculated from the difference between TSM and ISM.

At these stations, one water sample was collected and filtered for the determination of dissolved elements. The filtration of the samples was carried out in the field within a few hours of collection using Millipore glass filtration apparatus, with 0.45 μm cellulose acetate filters. The samples were acidified with 50 μl of Ultrex HNO_3. All samples were stored at 4°C until analyzed.

Sediment porewater

The samples of sediment pore water were collected at three sampling stations (1,2, and 8) in the harbour area and at one station (14) just outside the harbour toward the offshore. One dialysis sampler, "peeper" (Hesslein, 1976), was used at each of the four stations in this study, to recover *in situ* porewater at 1cm intervals. To remove any O_2 stored in the samplers' acrylic material, the peepers were bubbled with N_2 for two days before assembling them (Carignan *et al.*, 1994). Each peeper has a sequence of 60 cells. A few days prior to sampling, the cells were filled with oxygen-free deionized, doubly distilled water (DDW) and the open side was covered with a 0.45 μm cellulose membrane (Gelman Scientific, Inc.) (Rosa and Azcue, 1993). Subsamples of the water used in the assembling and storage of the peepers were kept as blanks for further analysis to monitor any possible contamination. The peepers were kept in bubbling chambers with oxygen-free DDW until divers installed them vertically in relatively flat areas at the lake bottom. The peepers were left inserted in the bottom sediments for four weeks to allow the water in the cells to equilibrate with the ambient sediment pore water. At retrieval, the peepers were quickly rinsed with lake water to dislodge adhering sediment particles. The porewater from each cell was immediately removed, by using disposable syringes. The samples were collected in 6 mL polystyrene vials and acidified with Ultrapure Seastar concentrated acid and stored at 4°C until analyzed. Trace metal and major ions samples were acidified with 50 μL of HNO_3, and those for nutrients were acidified with 50 μL of H_2SO_4. All the vials were previously acid washed following the method recommended by Nriagu *et al.* (1993). The samples were analyzed for trace elements by inductively coupled plasma atomic emission spectroscopy (ICP-AES) using a Jobin Ivon Model 74. The standard solutions consisted of high purity concentrations of the trace elements in a solution of 2% HNO_3 (Delta Scientific Laboratory Products, Canada).

<u>Trapped sediments</u>

From April to September 1990 to 1992, cylindrical sediment traps (aspect ratio of 14:1) arranged in sets of five in a sedimentation trap frame assembly (Rosa, 1985), were deployed at two levels in the water column at four locations (stations 110, 111, 112, and 113) (Figure 1b), in Lake Huron. The surface traps were set at 10 m below surface. The bottom traps were installed and kept at 2 m above the lake bottom. Each summer, the sediment traps were refurbished once at the middle of the study period, and then removed in September.

The validity in the collection efficiency of these traps has been proven by experiments conducted by Bloesch and Burns (1980). The traps were carefully retrieved so as to minimize resuspension of settled material. The supernatant was drained off through drain holes (Rosa, 1985), and the sediment samples were taken from the remaining 0.60 L of each of the five replicate traps, and combined into one sample. The variability among the replicate traps was found to be between 5 and 10%.

The combined sample was homogenized and subsampled for the required chemical analyses. Subsamples were filtered through precombusted (500°C) and pre-weighed Whatman GF/C glass fibre filters (approximate. pore size 1-2 μ) for total trapped matter (TTM). The TTM was gravimetrically measured after the sample was dried at 100°C. The inorganic trapped matter (ITM) was gravimetrically measured after the samples were combusted at 550°C. The organic trapped matter (OTM) were calculated by difference (TSM-ISM) and (TTM-ITM), respectively. The particulate phosphorus (PP) was measured by filtering a subsample through a Sartorius SM 11106, 0.45-μ filter and digesting the sample filter in 50 mL of acidified water (0.5 mL 30% H_2SO_4/50 mL of sample). The determination of phosphorus and other chemical constituents was caried out according to Environment Canada (1992, vol 1).

Chemical analyses were carried out on the water samples collected at discrete depths each time the traps were removed, emptied, and replaced. The samples were analyzed for TSM, ISM, OSM, particulate organic carbon and nitrogen (POC, PN), and chlorophyll. During each sampling time, an electronic bathythermograph (EBT) was taken to register *in situ* surface to bottom, water temperature and depth profile.

3. RESULTS AND DISCUSSION

Water Chemistry

Temperature structure, light transmission and thermal stratification depths

From the onset of thermal stratification to fall overturn, there are many physical processes/mechanisms that influence the distribution of biological and chemical parameters in lakes. Special caution must be exercised when correlating chemical and biological data, with the variability of thermal stratification depths, and water temperatures, since they may both directly or indirectly affect ambient nutrient concentrations. The thermal

stratification of the Spanish Harbour and North Channel is typical of dimictic lakes. Thermal layers were well established in July, with light transmission decreasing slightly toward the lake bottom at the deeper stations (Figure 2). The mean light transmission in surface waters (epilimnion) was about 10% higher than that in the hypolimnion at deeper stations. In contrast, in the shallow stations in the harbour (T18 to T14), the light transmission decreased substantially toward the surface (Figure 2). This was due to the greater quantities of suspended matter in the water column (Figure 3), due to dredging activities in the area along the North Shore. Regression analysis between TSM (y) and % transmission (x) for all the transect stations with TSM data, shows a high statistically significant negative relationship between these two parameters:

$$\text{TSM } (\text{mg} \cdot \text{L}^{-1}) = 8.0 - 0.09 \text{ \% Transmission}$$

$$(P < 0.001,\ n = 15,\ r = 0.87)$$

Both the Whalesback Channel and the North Channel stations were thermally stratified during the sampling period. The thermal layers were typical of a well stratified temperate lake, with epilimnion and thermocline thickness between 8 to 12 m, and 2 to 10 m, respectively, and surface water temperatures between 17.0 and 21.0°C. The remainder of the water column consisted of a cold, 7-9°C, hypolimnion.

The suspended particulate matter in a lake sinks through the water column. The portion of organic matter, which does not decay, and the inorganic matter in the water column eventually may settle on the lake bottom. Decaying organic matter in the water column and at the sediment surface can consume a considerable amount of oxygen. In the Spanish Harbour this consumption was substantial, especially at stations 2 and 8 (see below).

Nutrients

Water quality problems may arise in any water-body, if the nutrient concentrations exceed certain levels which promote excessive algal production. Generally, increased levels of phosphorus, nitrogen, and carbon in the lake water, have been inextricably related to biological productivity. Although many elements and compounds are required for biosynthesis, nitrogen and phosphorus have long been considered to be the principal limiting nutrients for primary production. In addition, there was evidence that organic carbon may also limit production in some situations.

The spatial distribution in the concentration of nutrients and suspended matter in the epilimnion, at selected transect sites "T", are reported in Table 1. Total and inorganic suspended matter show different spatial patterns at the shallow and deep stations. The shallow stations (Table 2) had the highest concentrations of TSM and ISM and the lowest % LOI. In the shallow areas winds can mix the water column down to the bottom thus causing previously sedimented material to resuspend and redistribute throughout the water column. However, in deep areas the water column is stratified, and the thermocline acts as a barrier between the epilimnion and hypolimnion, because of temperature and density gradients, and confines resuspended material to the hypolimnion, thus resulting in lower inorganic content at the deep stations as shown on Table 2.

Table 1. Water Column Suspended Matter Concentrations ($mg \cdot L^{-1}$) at Stations Along Two Transects

Station	TSM	ISM	OSM	LOI %	TP ($\mu g \cdot L^{-1}$)
T1	1.43	0.80	0.63	44.2	8.6
T3	1.07	0.47	0.60	56.3	8.2
T5	0.97	0.43	0.53	55.2	8.5
T7	0.70	0.07	0.63	90.5	11.5
T9	1.23	0.53	0.70	56.8	10.0
T11	1.20	0.60	0.60	50.0	11.6
T13	1.75	0.70	1.05	60.0	14.2
T15	2.60	1.45	1.15	44.2	15.2
T17	6.40	4.40	2.00	31.3	20.5
T19	1.30	0.60	0.70	53.8	11.5
T21	1.10	0.30	0.80	72.7	11.5
T22	1.24	0.68	0.56	45.2	13.1
T25	0.87	0.23	0.63	73.1	10.9
T27	0.80	0.17	0.63	79.2	8.8
T29	0.67	0.07	0.60	90.0	6.7

Physico-chemical parameters for the transect stations are reported in Table 2. Particulate nutrients in the water column decrease in a westerly direction from the Harbour (T17) to the western end of the Whalesback Channel (T5) (Table 1, and Figure 1b). This is due to river loadings and resuspension increasing the suspended load in the Harbour. As distance increases towards the Whalesback Channel the suspended load decreases, due to less resuspension in the deeper areas, (Table 2) and greater net sedimentation. Some spatial trend exists for the North-South transect (Aird Bay to John's Island), with the exception that the suspended load in the shallow area (T19 and T21 Table 1), is much less than in the Harbour area T17. The difference in TSM concentrations between T17 (6.4 $mg \cdot L^{-1}$), and T19 (1.3 $mg.L^{-1}$), may be due to the net loading from the Spanish River.

Table 2. Water Depth, Surface Temperature, Surface pH and % Transmission at Stations Along Two Transects

Station*	Surface		Transmission (%)		Station Depth (m)
	pH	Temperature (°C)	Surface	Bottom	
T1	8.07	16.9	76.5	67.0	27.9
T2	7.93	16.4	72.0	58.3	31.0
T3	8.09	17.4	70.0	64.0	42.5
T4	7.94	18.7	77.9	60.0	39.5
T5	7.94	19.0	78.0	66.0	18.8
T6	7.96	18.9	79.0	73.0	29.8
T7	7.95	19.2	79.0	80.0	25.1
T8	7.83	20.3	79.0	79.5	34.8
T9	7.77	20.0	79.3	78.5	23.8
T10	7.75	20.7	77.5	76.5	17.0
T11	7.55	21.0	70.0	73.5	8.2
T12	7.49	21.3	65.0	75.0	7.2
T13	7.60	21.3	60.0	50.0	9.2
T14	7.68	21.3	50.0	58.0	10.0
T15	7.67	21.7	45.8	58.0	7.2
T16	7.35	22.4	36.0	59.0	7.8
T17	7.39	22.8	35.5	54.3	11.4
T18	7.45	22.6	35.8	47.0	8.0
T19	7.82	20.7	62.0	51.0	6.0
T20	7.8	20.5	66.0	64.0	8.2
T21	7.87	20.5	73.0	56.0	10.6
T22	7.87	20.3	79.5	73.3	10.6
T23	7.82	20.3	79.3	78.0	25.2
T24	7.88	20.1	80.0	78.0	32.8
T25	7.67	20.2	75.0	78.0	35.0
T26	7.8	18.9	59.8	74.0	10.5
T27	8.13	17.8	79.0	65.3	15.0
T28	8.22	17.4	78.0	76.0	7.0
T29	8.31	17.7	77.3	71.0	30.1

Dissolved oxygen measurements were also aken at each station, at 4 m below surface and at 1 m above the bottom. Lowest bottom DO concentration was 6.65 at station T17.

***T1 to T18 - West to East transect**
T19 to T29 - North to South transect

Trace metals

Metal loadings originate in the Sudbury Basin and are related to the historical mining, milling and smelting operations and to active point sources. Metals are transported from the upstream watershed via the Vermilion and Spanish Rivers. The input of metals has resulted in an extensive area of contaminated sediments in the Spanish Harbour and Whalesback Channel. Total trace metal concentrations in water along two transects, West-East and North-South, are shown in Table 3. The East-West Transect (Figure 4) shows a decreasing metal concentration from the Harbour (station T17) through the Whalesback Channel out to the North Channel (station T1). Trends are much more pronounced for nickel and copper than lead and zinc. Water at stations T3, west of station T7 (Figure 1), in the North Channel, contains the lowest trace metal concentrations (Table 3). Not too far west of T3, water at station T1 showed increasing concentrations of copper and zinc. The nearest main tributary to this area is the Serpent River. This increase indicated that the Serpent River may be a possible source of copper and zinc to the North Channel. The greatest decrease (50%) in concentrations of nickel copper and zinc were found from inside the Whalesback Channel out to the North Channel on an East-West direction (Figure 4 top). Thus the Spanish River could still be a source of copper and nickel to the Spanish Harbour-North Channel system. There is also the possibility that the higher metal concentrations in water could be partially due to higher sediment resuspension and diffusion processes in the shallow Harbour area, resulting from greater turbulence in shallow environments. The North-South transect from Aird Bay and South through the Whalesback Channel, and out to the North Channel, also showed a high, but constant spatial trend in metal concentrations (Figure 4, bottom), for all trace metals, particularly for nickel and copper. However, there is a 50% decrease in concentrations between the

Whalesback Channel (station T19 to T25), and station T27, which is in the North Channel waters.

Table 3. Water Column Trace Metal Concentrations ($\mu g \cdot L^{-1}$) at Stations Along Two Transects

Station	Co	Cr	Cu	Ni	Pb	Zn
T1	0.5	0.6	2.9	4.6	0.7	6.2
T3	0.5	0.4	1.1	5.5	0.7	2.1
T7	0.5	0.4	2.7	10.5	0.7	2.9
T8	0.5	0.4	2.0	10.8	0.7	2.3
T9	0.5	0.5	1.9	10.9	0.7	3.4
T13	0.5	0.4	1.7	11.7	0.8	10.9
T17	0.5	0.7	2.3	13.2	0.7	3.1
T19	0.5	0.6	2.3	12.1	0.8	3.8
T21	0.5	0.6	2.0	10.7	5.1	5.7
T22	0.5	0.5	2.2	11.4	0.7	2.8
T24	0.5	0.4	2.0	10.8	0.7	2.3
T25	0.5	0.6	2.4	11.5	0.7	2.6
T27	0.5	0.4	1.0	5.1	0.7	1.6

Regression analysis was performed between different fractions of suspended matter (TSM, ISM, OSM AND TP; Table 1) and metal concentrations (Table 3) in the water column. The data was arranged in three different sets; station T1 to T17; stations T19 to T27; and stations T1 to T27. Statistically significant (>90%) correlation was found only for zinc and lead, (Table 4) in the organic fraction of suspended matter (OSM), in the transect T1 to T17 only. Copper and nickel show higher correlations with the ISM than OSM, although the correlation is not significant (<90%). These correlations indicate that zinc and lead have a greater affinity for the suspended organic fraction, where Ni and Cu associate preferably with the inorganic fraction. These results contradict findings of metal association in the bottom sediments in this area (Mudroch *et al*, 1995). The disagreement may be due to the difference in organic compositions of suspended sediments (30-90%, Table 1), and bottom sediments (3.2 - 9.8 %, Reynoldson *et al*, 1995).

Table 4. Regression Between Organic Suspended Matter (mg·L^{-1}) and Total Metal Concentrations (µg·L^{-1}) in the Water Column

Parameter(x) OSM	North - South Transects Parameter (y) Cu	Zn	Ni	Pb
R	0.05	* 0.85	0.13	* 0.85
Slope	0.32	14.52	4.28	18.29
Y-intercept	1.77	-6.34	7.32	-10.5
	5	5	5	5

* Level of significance > 90%

The effect of mining and smelting operations in the Sudbury Basin, on the metal loadings to the Harbour and the Whalesback Channel is clearly identified by results shown in Table (5). The concentration of six metals in water (Table 5), sampled in three sections of the study area shows considerable decrease (47%) in metal concentrations from the impacted areas (Harbour and Whalesback Channel) to the North Channel waters. The greatest decrease (57%) was in the concentration of nickel. Total phosphorus (TP) shows similar decrease as nickel.

Table 5. Total Metal and Phosphorus Concentrations in Water (µg·L^{-1}) in Three Compartments of the Study Area

	Whalesback Channel						North Channel		
	Shallow (< 15m)			Deep (> 15m)					
	Average	Std.Dev.	n	Average	Std.Dev.	n	Average	Std.Dev.	n
Co	0.5	0.0	5	0.5	0.0	5	0.5	0.0	3
Cr	0.6	0.1	5	0.5	0.1	5	0.5	0.1	3
Cu	2.1	0.2	5	2.2	0.3	5	1.7	0.9	3
Ni	11.8	0.8	5	10.9	0.3	5	5.1	0.4	3
Pb	1.6	1.7	5	0.7	0.0	5	0.7	0.0	3
Zn	5.3	3.0	5	2.7	0.4	5	3.3	2.1	3
Sum	21.9	-	6	16.6	-	6	11.7	-	6
% Ni	54	-	-	66	-	-	44	-	-
% Zn	24	-	-	16	-	-	28	-	-
TP	18.2	7.1	7	10.2	1.1	4	8.1	0.8	4

Sum = Sum of 6 metals

Regression analysis between total phosphorus and total nickel in the water column show a significant correlation (Table 6), in the West - East, and the combined transects. Most likely nickel is associated with the inorganic fraction of the TP, since nickel has no correlation with the organic suspended matter (OSM), (Table 4). This may be due to the soluble nickel and adsorption of phosphorus onto clay particles.

Table 6. Regression Between Total Phosphorus ($mg \cdot L^{-1}$) and Total Metal Concentrations ($\mu g \cdot L^{-1}$) in the Water Column

Statistics	West - East Transects Parameter (y)			
	Cu	Zn	Ni	Pb
TP R	0.13	0.11	**0.80	0.22
Slope	0.02	0.08	0.61	0.002
Y-intercept	1.87	3.83	2.03	0.69
n	6	6	6	6

Statistics	North-South & West-East Transects Parameter (y)			
	Cu	Zn	Ni	Pb
TP R	0.17	0.03	**0.51	0.30
Slope	0.01	0.01	0.20	0.05
Y-intercept	1.86	3.94	6.80	0.36
n	11	11	11	11

Porewater

Peepers were deployed at the beginning of June and retrieved in mid-July 1988. One double peeper (Figure 5), was deployed at each of the four stations studied (Figure 6), to obtain sediment porewater profiles of nutrients, trace and major elements. Concentration profiles of major and trace metals obtained from sediment cores at these stations were discussed by Mudroch *et al*, (1995).

Sediment porewater concentration profiles, of selected nutrients, trace metals and

major ions to a depth of 10 cm,are shown in Tables 7 to 10, for the four sampling stations. The whole concentration-depth profiles for nutrients, and trace elements are reported in Appendix A. In general, elevated concentrations of most parameters, were found in the sediment porewater collected at the three stations in the harbour when compared to the control station outside the Spanish Harbour. The maximum concentration of different parameters in the sediment porewater profile occur at different depths at each station. This is related to the distance of the respective station to the river mouth, and to the accumulation of different fractions of organic and inorganic suspended sediments on the lake bottom. Within the sediment column, the formation of dissolved chemical species, depends upon biochemical processes, mainly the bacterial decomposition of organic matter and physico-chemical processes, such as desorption of soluble species from the particulate fraction.

Ammonium and phosphorus concentrations in the bottom few centimetres (-5 to 0 cm depth, Tables 7 to 10) of lake water are generally low (0.025 and 0.007 mg.L^{-1}, respectively), increasing to maximum concentrations in the sediment porewater at different depths in the sediments. The concentration profile of these two parameters is different at all four stations, and indicates a possible relationship with distance from the source (Spanish River) for ammonia, and to water depth for phosphorus (Figure 7). The concentrations of ammonia in the sediment porewater were greatest at station 8 which is closest to the river mouth, for all four stations. The concentrations at this station are 10 times greater than at station 2, downstream of station 8, and about 60 times greater than at station 14, furthest from river mouth, and the control station(1). This trend in ammonia concentrations is possibly due to the sediment organic matter being decomposed mainly by sulfate-reducing bacteria.

Sediment Porewater Concentrations (mg/L)

TABLE 7. Stn. 1

Depth	Ni	Zn	Cu	Pb	NH3	SRP	NO3+NO2
−5	0.004	0.023	0.004	0.000	0.025	0.003	0.230
−4	0.003	0.006	0.004	0.000	0.025	0.006	0.240
−3	0.002	0.004	0.002	0.000	0.025	0.005	0.240
−2	0.002	0.010	0.003	0.000	0.030	0.005	0.230
−1	0.006	0.005	0.002	0.000	0.025	0.014	0.210
0	0.013	0.006	0.003	0.000	0.030	0.143	0.040
1	0.024	0.017	0.006	0.001	0.200	0.376	0.000
2	0.027	0.013	0.005	0.006	0.200	0.536	0.000
3	0.033	0.018	0.006	0.006	0.200	0.700	0.000
4	0.031	0.018	0.005	0.029	0.200	0.732	0.000
5	0.030	0.011	0.004	0.006	0.200	0.684	0.000
6	0.037	0.014	0.005	0.002	0.200	0.916	0.000
7	0.039	0.021	0.004	0.003	0.200	1.236	0.000
8	0.036	0.015	0.005	0.003	0.200	1.132	0.000
9	0.043	0.013	0.004	0.004	0.200	1.140	0.000
10	0.057	0.019	0.004	0.057	0.240	1.328	0.000

TABLE 8. Stn. 2

Depth	Ni	Zn	Cu	Pb	NH3	SRP	NO3+NO2
−2	0.018	0.005	0.009	0.011	0.025	0.057	0.275
−1	0.019	0.006	0.008	0.012	0.025	0.063	0.310
0	0.020	0.009	0.008	0.013	0.025	0.086	0.265
1	0.022	0.008	0.008	0.015	0.200	0.240	0.265
2	0.025	0.008	0.009	0.012	0.200	0.412	0.169
3	0.042	0.011	0.009	0.018	0.200	0.548	0.000
4	0.051	0.013	0.011	0.025	0.200	0.608	0.000
5	0.055	0.005	0.010	0.022	0.200	0.612	0.000
6	0.051	0.004	0.010	0.020	0.200	0.592	0.000
7	0.054	0.010	0.011	0.022	0.400	0.684	0.000
8	0.046	0.003	0.011	0.020	0.600	1.136	0.000
9	0.058	0.006	0.011	0.023	1.120	1.152	0.000
10	0.096	0.009	0.023	0.058	1.280	1.288	0.000

TABLE 9. Stn. 8

Depth	Ni	Zn	Cu	Pb	NH3	SRP	NO3+NO2
−4	0.026	0.008	0.002	0.000	0.455	0.011	0.000
−3	0.025	0.003	0.001	0.000	0.480	0.011	0.000
−2	0.026	0.006	0.001	0.000	0.510	0.016	0.000
−1	0.028	0.005	0.001	0.000	0.530	0.015	0.000
0	0.034	0.004	0.001	0.000	0.680	0.284	0.000
1	0.085	0.008	0.005	0.000	0.800	0.252	0.000
2	0.060	0.008	0.006	0.003	1.640	0.496	0.000
3	0.084	0.005	0.004	0.003	2.400	0.804	0.000
4	0.091	0.003	0.001	0.000	3.000	1.288	0.000
5	0.123	0.003	0.005	0.000	3.480	1.604	0.000
6	0.141	0.002	0.002	0.000	3.680	1.616	0.000
7	0.115	0.001	0.001	0.000	3.720	1.756	0.000
8	0.114	0.005	0.001	0.000	3.320	1.696	0.000
9	0.107	0.014	0.002	0.000	4.520	1.576	0.000
10	0.112	0.009	0.001	0.002	5.200	1.680	0.000

TABLE 10. Stn. 14

Depth	Ni	Zn	Cu	Pb	NH3	SRP	NO3+NO2
−6	0.024	0.01	0.012	0.008	0.025	0.007	0.240
−5	0.023	0.01	0.010	0.004	0.025	0.007	0.000
−4	0.026	0.01	0.011	0.007	0.025	0.009	0.000
−3	0.031	0.03	0.011	0.008	0.025	0.008	0.000
−2	0.030	0.02	0.013	0.017	0.025	0.008	0.000
−1	0.095	0.03	0.023	0.024	0.025	0.007	0.000
0	0.094	0.03	0.030	0.033	0.050	0.042	0.000
1	0.093	0.02	0.039	0.038	0.200	0.151	0.000
2	0.094	0.04	0.037	0.038	0.200	0.892	0.000
3	0.120	0.05	0.046	0.056	0.200	1.696	0.000
4	0.152	0.04	0.050	0.066	0.280	1.736	0.000
5	0.180	0.08	0.058	0.076	0.320	2.024	0.000
6	0.284	0.10	0.071	0.086	0.240	1.900	0.000
7	0.311	0.12	0.074	0.095	0.280	2.264	0.000
8	0.903	0.37	0.164	0.211	0.320	2.448	0.000
9	0.431	0.17	0.089	0.124	0.360	2.600	0.000
10	0.242	0.08	0.059	0.077	0.480	2.800	0.000

Sediment Depth = cm

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Phosphorous concentration maximas in the sediment porewater occur at different depths in the sediments, and appear to be related to water depth. Station 8, which is the neareast to the Spanish River mouth and the shallowest (6 m water depth) has maximum concentrations of phosphorus deeper in the sediment profile (at about 40 cm) than at station 2 (8 m water depth) and station 14 (12 m water depth) (Figure 7). These results also indicate that station 8 receives greater loading of organic material than stations 2 and 14. Since maximum concentrations of phosphorus are within the same range (2.5 - 3.0 $mg \cdot L^{-1}$) at these three stations, the composition of organic material at these depths, where maximas occur, must be similar. In order to compare the impact of nutrient loadings at each station, a ratio between the maximum concentration in the profile and concentration in the lake water was calculated. For ammonia, the ratios at stations 1, 2, 8, and 14 are 50, 200, 2600, and 30, respectively. For phosphorus, these ratios for stations 1, 2, 8, and 14 are 300, 500, 400, and 600, respectively. The high ammonia ratios at station 2 and particularly at station 8, can be the result of historical river loadings to the harbour from the upstream pulp and paper mill, sewage treatment plant effluents, and decomposition of organic matter.

The results indicated reduced conditions (absence of NO_3 + NO_2) (Figure 8) in the bottom waters at station 8. Increased diffusion caused by anoxic regeneration due to reduced conditions, increase concentrations of ammonia in lake water between 0.5 and 0.6 $mg.L^{-1}$, (Table 9); this is 20 times greater than ambient concentrations. Similar levels of regeneration has been reported by Bonanni *et al* (1992) for a highly eutrophic system. No phosphorus regeneration was apparent at any of the stations. The lowest concentrations NH_3 similar to those at the control station 1 were found at station 14, which is the furthest from the river mouth at the eastern end of the Whalesback Channel. A unique concentration profile with maximum concentrations between 5 and 10 cm depth, peeking at 8 cm, was also found at this station for all the parameters measured with the exception of NH_3, Sr, and Mn. Station 14 is the only station that exhibits any noticeable soluble Fe concentrations in the sediment. Low concentrations of soluble iron were found at the sediment-water interface at all other stations. The results indicated that most of the Fe is in the particulate fraction in this area, since Fe concentrations were lower than the detection limit in the sediment porewater.

At station 8, the concentration profiles of Ca, Ni, NH_3, Sr, Ba and Ti in porewater showed similar and increasing quasi-linear concentration gradients, with increasing depth, to the maximum sampled sediment depth (50 cm). The results indicated regeneration of soluble Mn and Fe at station 8 most likely due to anoxic conditions in the bottom waters (Table 9 and Figure 9). The concentration profile of Na was constant (Figure 10), at all stations with lowest concentration at station 1 and highest at station 8. Copper concentrations, in the sediment porewater (Figure 11) were considerably greater at stations 2 and 14 (factor of 15-20) than those at stations 1 and 8. Lead showed the same spatial variability as Cu, (Figure 12). The concentration profiles of nutrients, trace and major elements which are not reported in the text above, are shown in Appendix A.

SEDIMENTATION RATES (DOWN-FLUX)

Sedimentation data can be obtained by using properly designed sediment traps (Hargrave and Burns, 1979; Bloesch and Burns, 1980). A well designed trap avoids overtrapping as well as undertrapping of particulate material. However sediment traps do not solve the problem of resuspension of bottom sediments or mineralization within the trap (Bloesch and Burns, 1980). This study was planned to further understand different sedimentation processes, and how these processes can be used to aid in understanding contaminant pathways and transport in the North Channel of Lake Huron.

From April to September 1990 to 1992, the sediment traps at the four stations (110 to 113, Figure 1b), were refurbished twice with a mean exposure time of 56 days. Mean summer sedimentation rates of suspended material at each station at 10 m below surface and 2 m above the lake bottom were measured for the summer periods.

Neil Brown current meters were deployed at three stations (110, 111, and 112, Figure 13), at a depth of 10 m , from 1990 to 1992. Hourly water temperature, current speed, and direction was measured over the same time period that sediment traps were deployed, i.e. April to September 1990 to 1992. The daily mean current meter data is shown in Figures 14 to 16. The greatest variability in the current speed was recorded at station 112, with a range of speed between 2 and 20 $cm \cdot sec^{-1}$. The seasonal temperature, speed, and direction are shown in Table 11)

Table 11. North Channel Average Summer Current Meter Data, at 10 m Below Surface

Stn.	1990			1991			1992		
	D (degrees)	S ($cm \cdot s^{-1}$)	T (°C)	D (degrees)	S ($cm \cdot s^{-1}$)	T (°C)	D (degrees)	S ($cm \cdot s^{-1}$)	T (°C)
110	183	3.8	15.2	185	3.8	15.6	N.A.	N.A.	N.A.
111	183	2.5	10.7	174	3.5	14.3	177	2.0	12.7
112	175	5.1	12.4	165	5.2	12.8	172	3.0	10.5
Mean	180	3.8	12.8	175	4.2	14.2	174	2.5	11.6

D = direction; S = speed; T = temperature; N.A. = current meter failed.

Results for the study period show that the mean 1990 and 1991 current velocity and direction at the study site in the Harbour is 3.8 $cm \cdot sec^{-1}$, in a southerly direction (184°) into the North Channel. The relationship in speed and direction among the three stations are shown in Figures 13 to 16. The arrows indicate direction and relative magnitude of the water current speed. All three stations have similar current speed and direction (approximately 4 cm·sec^{-1} in the South direction). Based on these results there can be a considerable volume of water transferred from the Whalesback Channel to the North Channel, through the two channels formed by Klots, Rainboth and Aikens Islands. The particulate downflux of Total Trapped Matter (TTM) at 10 m below the water surface, ranges from 1.5 to 3.0 g·m^{-2}d^{-1}. For all parameters, fluxes in the bottom traps are consistently greater than the fluxes at the 10 m water depth. Metal concentrations associated with suspended and trapped sediments are greater than the Lowest Effect Level (LEL) given in the OMEE guidelines (Table 12).

Table 12. Trace Element Concentrations in Trapped Material, Surface and Bottom traps 1990 - 1992, Number of Cases Exceeding LEL and LoT

	LEL (μg·g^{-1})	LoT (μg·g^{-1})
Ni	> 31	> 90
Ni (station 113)	> 31	> 90
As	> 6	< 33
As (station 113)	> 6	< 33
Zn	> 120	< 820
Zn (station 113)	> 120	< 820
Cu	> 25	30% > 114
Cu (station 113)	> 25	< 114
Pb	> 31	< 250
Pb (station 113)	> 31	< 250

LEL = Lowest Effective Level; LoT = Limit of Tolerance.

The highest downflux and metal concentrations were found at the study site in the Harbour. Trace element concentrations in the trapped matter were greater in the hypolimnion than the epilimnion traps. The greater concentrations near the bottom indicated some degree of resuspension, (Table 13c), in both the Harbour and the North

Channel sites. In order to easily compare concentrations at the three study sites, a metal index was calculated. The metal concentrations in the surface (10 m) traps were divided by the Lowest Effect Level concentrations. In 1991, copper had the greatest metal index (eight times above the LEL Guidelines) of the three metals. All metals show a decreasing spatial trend from inside to the outside of the harbour. The 1991 trace elements concentrations at all trap sites were greater than those in 1990 and 1992, particularly for cadmium at the Harbour site (station 110). These data indicated that Cu, Cd and Zn loadings to the North Channel mainly occur through surface waters, based on water current direction (see above) and suspended sediment concentrations. Although the results suggested some bottom transport, it was not as important as surface transport due to the bottom depth of the sill (7-10 m), between the Harbour and the North Channel. Year-to-year differences in the trace element indices show greater variability in the Harbour site (station 110), with some fluctuations in the North Channel sampling stations. Trace element indices for 1991 were greater than those in 1990 and 1992 at all the stations except station 112. Cadmium showed the greatest change of all trace elements. The results clearly indicate that, at least during the summer months, there is trace element transport occurring from the Spanish Harbour into the North Channel waters. Contaminant loading from the Harbour into the North Channel could be estimated during the study periods, but not for a whole year since current meter and sediment trap data are not available from September to April, for the three years.

Table 13a. Gross Sedimentation Rates ($g \cdot m^{-2} d^{-1}$) for Three Stations in the North Channel, 1990 to 1992.

(Bottom Traps were not deployed at station 113.)

1. April 30 - August 28, 1990 Means

Station	TTM	ITM	OTM	POC	PN	TPP
110	2.61	2.22	0.39	0.141	0.019	0.0045
111	1.51	1.28	0.23	0.081	0.011	0.0027
112	2.87	2.42	0.45	0.175	0.026	0.0026

2. May 7 - August 28, 1991 Means

Station	TTM	ITM	OTM	POC	PN	TPP
110	2.87	2.31	0.56	0.211	0.031	0.0066
111	2.35	2.04	0.31	0.120	0.019	0.0048
112	3.68	3.06	0.62	0.222	0.026	0.0048

3. May 5 - September 3, 1992 Means

Station	TTM	ITM	OTM	POC	PN	TPP
110	2.01	1.60	0.41	0.121	0.015	0.0022
111	2.38	2.02	0.36	0.117	0.015	0.0022
112	3.32	2.71	0.61	0.158	0.024	0.0021

4. North Channel 1990-92 Mean Gross Sedimentation ($g \cdot m^{-2} d^{-1}$)

Station	TTM	ITM	OTM	POC	PN	TPP
110	2.50	2.04	0.45	0.158	0.022	0.0044
111	2.08	1.78	0.30	0.106	0.015	0.0032
112	3.29	2.73	0.56	0.185	0.025	0.0032

Table 13b. Net Nutrient Sedimentation Rates ($g \cdot m^{-2}d^{-1}$) for Four Stations in the North Channel, 1990 to 1992

1. April 30 - August 28, 1990 Means

Station	TTM	ITM	OTM	POC	PN	TPP
110	1.31	1.08	0.23	0.171	0.023	0.0034
111	1.40	1.07	0.33	0.153	0.022	0.0026
112	2.04	1.61	0.43	0.174	0.027	0.0031
113	1.47	1.18	0.29	0.114	0.016	0.0016
Average	1.55	1.23	0.32	0.153	0.022	0.0027

2. May 7 - August 28, 1991 Means

Station	TTM	ITM	OTM	POC	PN	TPP
110	1.46	1.11	0.36	0.103	0.018	0.0047
111	1.42	1.08	0.34	0.126	0.020	0.0063
112	1.49	1.02	0.47	0.175	0.024	0.0055
113	1.07	0.75	0.33	0.081	0.014	0.0029
Average	1.36	0.99	0.37	0.121	0.019	0.0048

3. May 5 - September 3, 1992 Means

Station	TTM	ITM	OTM	POC	PN	TPP
110	1.14	0.89	0.25	0.067	0.010	0.0017
111	1.60	1.36	0.24	0.084	0.010	0.0018
112	1.25	0.99	0.26	0.082	0.011	0.0013
113	1.21	0.96	0.25	0.090	0.013	0.0012
Average	1.30	1.05	0.25	0.081	0.011	0.0015

4. North Channel 1990-92 Mean Net Sedimentation Rates ($g \cdot m^{-2}d^{-1}$)

Station	TTM	ITM	OTM	POC	PN	TPP
110	1.30	1.03	0.28	0.114	0.017	0.0033
111	1.47	1.17	0.30	0.121	0.017	0.0036
112	1.59	1.21	0.39	0.144	0.021	0.0033
113	1.25	0.96	0.29	0.095	0.014	0.0019
Average	1.41	1.09	0.32	0.118	0.017	0.0030

Table 13c. North Channel Resuspension Rates ($g \cdot m^{-2} d^{-1}$) for Three Stations 1990 to 1992

(The resuspension rates were calculated by subtracting the near bottom trap rates from the 10 m below surface trap rates.)

1. For April 30 - August 28, 1990

Station	TTM	ITM	OTM	POC	PN	TPP
110	-1.30	-1.14	-0.16	-0.071	-0.010	-0.0011
111	-0.11	-0.21	0.10	-0.007	-0.001	-0.0001
112	-0.83	-0.81	-0.02	-0.001	0.001	0.0005

2. For May 7 - August 28, 1991

Station	TTM	ITM	OTM	POC	PN	TPP
110	-1.41	-1.20	-0.20	-0.108	-0.013	-0.0019
111	-0.93	-0.96	0.03	0.006	0.001	0.0015
112	-2.19	-2.04	-0.16	-0.047	-0.002	0.0006

3. For May 5 - September 3, 1992

Station	TTM	ITM	OTM	POC	PN	TPP
110	-0.87	-0.71	-0.16	-0.054	-0.005	-0.0005
111	-0.78	-0.66	-0.12	-0.033	-0.005	-0.0004
112	-2.07	-1.72	-0.35	-0.077	-0.013	-0.0008

4. Resuspension Rate Means ($g \cdot m^{-2} d^{-1}$) For 3 Seasons, 1990-1992

Station	TTM	ITM	OTM	POC	PN	TPP
110	-1.19	-1.02	-0.17	-0.078	-0.009	-0.0012
111	-0.61	-0.61	0.00	-0.011	-0.002	0.0003
112	-1.70	-1.52	-0.17	-0.042	-0.005	0.0001
Average	-1.16	-1.05	-0.11	-0.044	-0.005	-0.0002
Standard Deviation	0.55	0.46	0.10	0.033	0.004	0.0008

BOTTOM SEDIMENT RESUSPENSION CALCULATIONS (UP-FLUX)

Resuspension of bottom sediments is known to interfere with flux measurement close to the lake bottom. A simple procedure used here to calculate bottom resuspension, is based on the summer epilimnetic concentrations of TSM which are proportional to the TTM flux out of the epilimnion (see regression below). This procedure is similar to the procedure used by Rosa (1985).

Such a correction procedure was used in this study to calculate the resuspension for the study sites. The mean summer flux measured at 2 m above the bottom (gross flux, Table 13a) was subtracted from flux measured at 10 m below the water surface (net flux, Table 13b). The results show that total and inorganic suspended matter have the highest contribution to resuspension (Table 14). The TTM flux out of the epilimnion (10 m water depth) is related to the mean epilimnion TSM concentration (5 m water depth) by the expression:

$$y = 0.67\,x + 0.80 \qquad (P = 0.100) \quad (r = 0.55)$$

y = flux out of the epilimnion ($g \cdot m^{-2}\ d^{-1}$)

x = epilimnion mean concentration ($g \cdot m^{-3}$)

The calculated slope of 0.67 $m \cdot d^{-1}$ is the mean settling velocity of TTM during the summer period. Settling velocities of 0.76 $m \cdot d^{-1}$, were reported by Rosa (1985), in the Eastern Basin of Lake Ontario.

TABLE 14. Mean Upward Flux at 2.0 m Above the Lake Bottom for Three Seasons.

	Whalesback Channel (Station 110)		North Channel (Station 112)		All Stations (Stns. 110,111 & 112)	
	Upward Flux	Up-flux as a % of Total Flux	Upward Flux	Up-flux as a % of Total Flux	Upward Flux	Up-flux as a % of Total Flux
Nutrients ($g \cdot m^{-2}d^{-1}$)						
TTM	-1.19	47	-1.70	51	-1.16	42
ITM	-1.02	49	-1.52	57	-1.05	46
OTM	-0.17	44	-0.17	33	-0.11	37
POC	-0.078	46	-0.042	39	-0.044	35
PN	-0.009	50	-0.005	37	-0.005	36
PP	-0.0012	39	0.0001	41	-0.0002	32
Metals ($\mu g \cdot m^{-2}d^{-1}$)						
Cu	-256.6	59	-126.2	47	-164.2	54
Zn	-535	45	-174	29	-263	32
Ni	-357.6	51	-309.7	54	-282.5	50
Pb	-55.0	41	-100.2	46	-24.6	31
Mean		49		44		42

Upward Flux = Resuspension

The calculated upward flux of total suspended matter at 2 m above the bottom is 1.2 and 1.7 $g \cdot m^{-2} d^{-1}$, or 47 and 51 % of the gross flux for stations 110 and 112, respectively (Table 14). From these results, assuming constant flux, particulate concentration per unit area, and from the measured downward flux of TTM in the epilimnion (Table 13a), the turnover times of TSM at 2 m above the bottom are estimated for the Whalesback Channel and North Channel. Since sediments can be recycled many more times in shallow areas than deep areas, it follows that the consistency and stability of the sediment-water interface is dependent on the intensity of physical mixing processes and water depth.

In a lake, especially in shallow zones where most of the resuspension occurs, the main cause of resuspension is oscillatory wave action at the sediment-water interface (Lee *et al.* 1981). The upward flux may also be due to migration of phytoplankton and

zooplankton. This migration occurs mostly around the thermocline and epilimnion region and contributes less than 2% of the total downward flux (Burns and Rosa, 1980). Resuspension close to the lake bottom is mainly the result of currents and major storm events, particularly during the spring and fall.

The mean resuspension rates for nutrients at 2 m above the lake bottom for each season are shown on Table 13c. The greatest resuspension rates for TTM and ITM were observed at station 112 in the North Channel during 1991 and 1992. The mean resuspension rates for TTM and ITM at this station for the three seasons, (Table 13c) are a factor of 2, greater than the means for stations 110 and 111. This is due to the fact that station 112 is in the open waters of the North Channel, and is exposed to higher water currents than stations 110 and 111 (Table 11). The mean current speed for the three sampling periods at station 112 ($4.5\ cm \cdot sec^{-1}$) is 50% greater than that at the other two stations ($2.9\ cm \cdot sec^{-1}$), (Table 11). The inorganic fraction of the trapped matter (ITM) shows the highest resuspension (57%) of all the nutrients measured (Table 14). The calculated upward flux for Cu, Ni, Zn, and Pb is shown in Table 14. The greatest resuspension was found for Cu at station 110 (59%) and the lowest for Zn at station 112 (29%).

CONCLUSIONS

The lower reaches of the Spanish River have been impacted since the turn of the century by log driving operations and subsequent waste discharges from a pulp and paper mill facility at Espanola. Mining, milling and smelting operations in the Sudbury Basin have been a major source of heavy metals for the river and have resulted in an extensive area of contaminated sediments in both the nearshore zone of the AoC and the Whalesback

Channel. The results of of the geochemical composition of sediment porewater, water column and suspended-trapped sediments in the Spanish Harbour/Whalesback Channel and North Channel are summarized.

Total trace element concentrations in water along two transects, West-East and North-South in the study area, show a decreasing trace element concentration from the Harbour through the Whalesback Channel and out to the North Channel waters. Spatial trends in trace element concentration are much more significant for nickel and copper, than lead and zinc. The greatest decrease (50%) in concentrations of trace elements in the water column, from inside the Whalesback Channel out to the North Channel on an East-West direction was found for nickel and copper. Thus the Spanish River still appears to be a source of copper and nickel to the Spanish Harbour - North Channel system. A high constant spatial trend in trace elment concentrations was also found along the North-South Transect from Aird Bay through the Whalesback Channel, and out to the North Channel, particularly for nickel and copper. However, a 50% decrease in concentrations of these two elements was observed between the Whalesback Channel and the North Channel waters.

Sediment porewater nutrients were found to be greater by a factor of 30 to 2600 when compared to lthe nutrient concentrations in the lake water. The concentrations of nutrients and trace elements in the sediment porewater also show a spatial trend. The concentrations of ammonia were also found to be greatest at station 8 which is the closest station to the river mouth. Concentrations at this station were 10 times greater than those at station 2 (downstream of station 8) and about 60 times greater than those at station 14 (furthest from river mouth) and station 1 (control).

The maximum concentrations of phosphorous occurred at different depths ni the sediment and appeared to be related to water depth in the study area. The maximum

concentrations of phosphorus at station 8 which is the closest to the river mouth and the shallowest (6 m) existed deeper in the sediment profile (40 cm) than those at station 2 (8 m water depth) and those at station 14 (12 m water depth). Concentration ratios (water/sediment porewater) for ammonia, at stations 1, 2, 8, and 14 were 50, 200, 2600, and 30, respectively. For phosphorus, the ratios for stations 1, 2, 8, and 14 were 300, 500, 400, and 600, respectively. These high ammonia ratios at station 2 and particularly station 8, are most likely a result of historical river loadings to the Harbour from the upstream pulp & paper mill, sewage treatment plants effluent, and decomposition of organic matter. Station 14 is the only station where soluble Fe concentrations were foundin the sediment. At the other stations, low concentrations occurred at the sediment-water interface. At these stations soluble Fe concentrations were lower than the e detection limit, below the sediment-water interface. At station 8, porewater concentration profiles for Ca, Ni, NH_3, Sr, Ba and Ti showed similar and increasing quasi-linear concentration gradients, with increasing depth, to the bottom of the collected sediment profile (50 cm sediment depth). Copper concentrations in the sediment porewater, at stations 2 and 14, were greater (factor of 15-20) than those at stations 1 and 8.

The greatest variability in the current speed was recorded at station 112, with a range of speed between 2 and 20 $cm \cdot sec^{-1}$. This is due to the fact that station 112 is in the open waters of the North Channel, and is not sheltered by land like the other stations. Results for the study period show that the mean 1990 and 1991 current velocity and direction at the study area in the Harbour is 3.8 $cm \cdot sec^{-1}$ in a southerly direction (184°) into the North Channel. The relationship among the speed and direction at the three stations is very consistent for the three summer study periods.

The particulate downflux of Total Trapped Matter (TTM) at 10 m below the water surface ranged from 1.5 to 3.0 $g \cdot m^{-2} d^{-1}$. For all parameters, fluxes in the bottom traps

weree consistently greater than the fluxes at the 10 m trap depth. Trace element concentrations associated with suspended and trapped sediments were greater than the Lowest Effect Level (LEL) given in the OMEE guidelines. The concentration of trace elements showed a decreasing spatial trend from inside to outside of the Spanish Harbour/North Channel system. The 1991 trace element concentrations at all trap sites were greater than those measured in 1990 and 1992, particularly for cadmium at the Harbour site. Results of the study showed that cupper, cadmium and zinc loadings to the North Channel mainly occur by transport through surface waters, based on water current direction (see above) and the concentration of suspended sediments. Although some transport along the bottom seemed to occurr, it was considered not as important as the surface transport due to the depth of the sill
(7-10 m), between the Whalesback Channel and the North Channel. Our results clearly indicated that, at least during the summer months, trace element transport occurs from the Spanish Harbour-Whalesback Channel system into the North Channel waters.

Year-to-year differences in the trace element indices in the trapped matter, show higher variability in the Harbour site (station 110), with some minor fluctuations at the North Channel sites. Trace element metal indices for 1991 were greater than those for 1990 and 1992, at all the sampling stations except station 112. Cadmium showed the highest degree of change. The calculated upward flux of total suspended matter at 2m above the bottom was 1.2 and 1.7 $g \cdot m^{-2} d^{-1}$, or 47 and 51 % of the gross flux, for stations 110 and 112 respectively. From these results, assuming constant flux and particulate concentration per unit area, and from the measured downward flux of TTM in the epilimnion, the turnover times of TSM at 2 m above the bottom are estimated to be two to three days. Since sediments can be recycled many more times in shallow than deep areas, it appears that the consistency and stability of the sediment-water interface in shallow areas is fairly low. Thus these sediments are much more capable to contribute greater diffusion and regeneration of contaminants in sediment porewater into the overlying water column.

The results of the study clearly indicate that, at least during the summer months, there is trace element transport from the Spanish Harbour/Whalesback Channel into the North Channel waters. Contaminant loading from the Harbour into the North Channel could be estimated for the study periods but not for a whole year since current meter and sediment trap data are not available from September to April, for the three study years. Loading reductions from the Spanish River to the Spanish Harbour/Whalesback Channel system will utimately result in loading reductions to the North Channel waters. However this reduction may be masked by the resuspension of contaminated sediments with subsequent release of the contaminants into the overlying water, as shown by the results of this study.

Detection limits

Parameter	Detection Limit in Water	Detection Limit in Sediment
As	0.1 $\mu g \cdot L^{-1}$	5 $\mu g \cdot g^{-1}$
Zn	1 $\mu g \cdot L^{-1}$	1 $\mu g \cdot g^{-1}$
Cu	1 $\mu g \cdot L^{-1}$	1 $\mu g \cdot g^{-1}$
Ni	2 $\mu g \cdot L^{-1}$	1 $\mu g \cdot g^{-1}$
Fe	1 $\mu g \cdot L^{-1}$	0.01 %
Cd	1 $\mu g \cdot L^{-1}$	0.2 $\mu g \cdot g^{-1}$
Co	1 $\mu g \cdot L^{-1}$	1 $\mu g \cdot g^{-1}$
Mn	0.5 $\mu g \cdot L^{-1}$	1 $\mu g \cdot g^{-1}$
Pb	5 $\mu g \cdot L^{-1}$	2 $\mu g \cdot g^{-1}$
Cr	1 $\mu g \cdot L^{-1}$	1 $\mu g \cdot g^{-1}$
TSM	10 $\mu g \cdot L^{-1}$	
ISM	10 $\mu g \cdot L^{-1}$	
OSM	10 $\mu g \cdot L^{-1}$	
TTM	10 $\mu g \cdot L^{-1}$	
ITM	10 $\mu g \cdot L^{-1}$	
OTM	10 $\mu g \cdot L^{-1}$	
LOI	0.1 %	
CHLA	0.1 $\mu g \cdot L^{-1}$	
CHLA.U	0.1 $\mu g \cdot L^{-1}$	
CHLA.C	0.1 $\mu g \cdot L^{-1}$	
POC	10 $\mu g \cdot L^{-1}$	
PN	2 $\mu g \cdot L^{-1}$	
TP	0.2 $\mu g \cdot L^{-1}$	
TPP	0.1 $\mu g \cdot L^{-1}$	
SRP	0.2 $\mu g \cdot L^{-1}$	
NH_3	5 $\mu g \cdot L^{-1}$	
$NO_3 + NO_2$	10 $\mu g \cdot L^{-1}$	
TRANS	1%	

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Appendix A

Table A1

Spanish River Harbour Pore Water (mg/l)
Station 1

[illegible]	Mn	Ca	Mg	Ba	Ti	Fe	As	Zn	Cu	Ni	Na	Sr	Pb
-5	0.000	15	3.3	0.02	0.09	0.02	0.007	0.023	0.004	0.004	2.3	0.077	0.000
-4	0.000	15	3.2	0.02	0.09	0.01	0.007	0.006	0.004	0.003	2.3	0.082	0.000
-3	0.000	14	3.3	0.02	0.08	0.00	0.007	0.004	0.002	0.002	2.3	0.077	0.000
-2	0.000	14	3.4	0.02	0.08	0.04	0.007	0.010	0.003	0.002	2.3	0.074	0.000
-1	0.060	15	3.4	0.04	0.08	0.10	0.007	0.005	0.002	0.006	2.3	0.079	0.000
0	0.341	14	3.5	0.05	0.08	0.90	0.009	0.006	0.003	0.013	2.4	0.078	0.000
1	0.689	15	3.5	0.08	0.09	0.17	0.011	0.017	0.006	0.024	2.4	0.082	0.001
2	0.914	15	3.6	0.12	0.09	0.03	0.011	0.013	0.005	0.027	2.4	0.083	0.006
3	1.055	16	3.6	0.13	0.09	0.00	0.015	0.018	0.006	0.033	2.5	0.095	0.006
4	1.015	15	3.5	0.12	0.09	0.00	0.016	0.018	0.005	0.031	2.3	0.088	0.029
5	1.023	16	3.6	0.11	0.09	0.00	0.016	0.011	0.004	0.030	2.4	0.091	0.006
6	1.075	16	3.6	0.11	0.09	0.00	0.018	0.014	0.005	0.037	2.4	0.094	0.002
7	0.610	16	3.4	0.10	0.10	0.00	0.020	0.021	0.004	0.039	2.4	0.102	0.003
8	0.520	17	3.6	0.10	0.10	0.00	0.020	0.015	0.005	0.036	2.4	0.105	0.003
9	0.710	17	3.6	0.10	0.10	0.00	0.021	0.013	0.004	0.043	2.4	0.109	0.004
10	0.804	19	3.7	0.13	0.11	0.00	0.026	0.019	0.004	0.057	2.6	0.125	0.057
11	1.064	17	3.9	0.11	0.10	0.00	0.025	0.022	0.004	0.050	2.5	0.105	0.002
12	1.054	17	3.9	0.11	0.10	0.00	0.023	0.010	0.002	0.046	2.5	0.107	0.001
13	1.037	17	3.8	0.11	0.10	0.00	0.026	0.011	0.003	0.051	2.5	0.106	0.003
14	1.102	17	3.9	0.11	0.10	0.00	0.026	0.011	0.003	0.050	2.5	0.105	0.003
15	0.986	23	3.6	0.17	0.14	0.00	0.030	0.079	0.006	0.060	2.8	0.163	0.005
16	0.547	31	2.5	0.26	0.21	0.00	0.041	0.025	0.008	0.081	2.6	0.147	0.052
17	1.206	17	4.1	0.11	0.10	0.00	0.022	0.009	0.002	0.034	2.5	0.105	0.012
18	1.222	17	4.1	0.11	0.10	0.00	0.023	0.007	0.002	0.032	2.4	0.104	0.002
19	1.121	17	4.0	0.11	0.10	0.00	0.023	0.010	0.003	0.048	2.4	0.105	0.003
20	1.067	18	4.1	0.13	0.11	0.00	0.026	0.009	0.003	0.038	2.5	0.116	0.003
21	1.064	17	4.2	0.12	0.10	0.00	0.026	0.008	0.003	0.038	2.5	0.108	0.003
22	0.949	18	4.1	0.13	0.11	0.00	0.028	0.010	0.004	0.042	2.5	0.111	0.006
23	0.984	17	4.1	0.13	0.10	0.00	0.027	0.006	0.002	0.038	2.5	0.110	0.081
24	1.014	17	4.2	0.13	0.10	0.00	0.026	0.008	0.003	0.039	2.5	0.108	0.005
25	1.045	17	4.2	0.13	0.10	0.00	0.023	0.015	0.003	0.037	2.5	0.106	0.004
26	1.000	18	4.2	0.14	0.11	0.00	0.024	0.014	0.004	0.045	2.6	0.110	0.005
27	0.723	21	4.2	0.17	0.13	0.00	0.026	0.013	0.005	0.050	2.9	0.139	0.007
28	1.178	17	4.3	0.13	0.10	0.00	0.022	0.010	0.003	0.042	2.5	0.101	0.017
[illegible]	1.134	19	4.4	0.16	0.11	0.00	0.025	0.016	0.004	0.048	2.7	0.121	0.006
[illegible]	1.180	16	4.2	0.14	0.10	0.00	0.021	0.010	0.002	0.040	2.5	0.101	0.006
31	1.265	16	4.2	0.13	0.09	0.00	0.021	0.010	0.005	0.043	2.5	0.094	0.018
32	1.300	16	4.2	0.14	0.09	0.00	0.021	0.008	0.002	0.040	2.5	0.095	0.004
33	1.304	16	4.3	0.15	0.09	0.00	0.023	0.008	0.003	0.045	2.5	0.095	0.006
34	1.350	16	4.4	0.16	0.10	0.00	0.023	0.007	0.002	0.043	2.6	0.099	0.007
35	0.857	25	4.5	0.31	0.16	0.00	0.036	0.017	0.006	0.074	3.2	0.177	0.029
36	1.361	15	4.3	0.16	0.09	0.00	0.020	0.009	0.003	0.044	2.4	0.092	0.006
37	1.323	16	4.2	0.16	0.09	0.00	0.018	0.005	0.002	0.041	2.4	0.091	0.005
38	1.350	15	4.1	0.17	0.08	0.00	0.016	0.005	0.002	0.040	2.4	0.086	0.013
39	1.365	14	4.1	0.16	0.08	0.00	0.014	0.008	0.003	0.038	2.4	0.083	0.007
40	1.356	15	4.1	0.18	0.09	0.00	0.013	0.006	0.003	0.038	2.4	0.084	0.009
41	1.404	14	4.2	0.18	0.08	0.00	0.011	0.005	0.002	0.037	2.4	0.083	0.007
42	1.322	16	4.3	0.21	0.09	0.00	0.008	0.009	0.002	0.038	2.6	0.096	0.008
43	1.408	14	4.2	0.19	0.09	0.00	0.009	0.029	0.004	0.039	2.5	0.082	0.032
44	1.463	15	4.3	0.20	0.09	0.00	0.009	0.013	0.003	0.040	2.5	0.088	0.016
45	1.468	14	4.2	0.20	0.09	0.00	0.008	0.056	0.003	0.038	2.5	0.082	0.013
46	1.517	14	4.3	0.20	0.09	0.00	0.009	0.008	0.003	0.038	2.5	0.084	0.010
47	1.537	14	4.4	0.22	0.09	0.00	0.008	0.012	0.004	0.042	2.5	0.087	0.012
48	1.549	14	4.3	0.22	0.09	0.00	0.009	0.013	0.004	0.041	2.5	0.085	0.012
49	1.511	15	4.5	0.24	0.10	0.00	0.010	0.015	0.005	0.049	2.6	0.094	0.014
50	1.537	14	4.3	0.22	0.09	0.00	0.008	0.015	0.004	0.043	2.5	0.088	0.012

Table A2 Spanish River Harbour Pore Water (mg/l)
Station 2

I.D	Mn	Ca	Mg	Ba	Ti	Fe	As	Zn	Cu	Ni	Na	Sr	Pb
-2	0.013	11.6	3.23	0.02	0.059	0.07	0.002	0.005	0.009	0.018	3.7	0.048	0.011
-1	0.027	11.0	2.99	0.02	0.057	0.43	0.002	0.006	0.008	0.019	3.2	0.046	0.012
0	0.050	11.5	3.00	0.02	0.058	0.70	0.002	0.009	0.008	0.020	3.5	0.047	0.013
1	0.102	11.7	3.26	0.02	0.059	0.80	0.002	0.008	0.008	0.022	3.7	0.049	0.015
2	0.244	11.9	3.29	0.03	0.060	1.12	0.002	0.008	0.009	0.025	3.7	0.050	0.012
3	1.431	12.3	3.44	0.07	0.063	2.12	0.004	0.011	0.009	0.042	3.7	0.051	0.018
4	1.625	12.4	3.48	0.08	0.066	1.30	0.006	0.013	0.011	0.051	3.8	0.052	0.025
5	1.894	13.6	3.78	0.09	0.071	0.80	0.007	0.005	0.010	0.055	4.0	0.059	0.022
6	1.874	12.7	3.59	0.08	0.065	0.88	0.006	0.004	0.010	0.051	3.8	0.055	0.020
7	1.856	14.0	3.95	0.09	0.072	0.42	0.007	0.010	0.011	0.054	4.2	0.061	0.022
8	1.801	13.1	3.68	0.08	0.067	0.77	0.006	0.003	0.011	0.046	4.0	0.057	0.020
9	1.979	16.5	4.52	0.11	0.086	0.07	0.007	0.006	0.011	0.058	4.8	0.075	0.023
10	1.966	20.6	5.49	0.18	0.108	0.00	0.009	0.009	0.023	0.096	5.5	0.097	0.058
11	2.006	13.0	3.61	0.09	0.067	0.15	0.005	0.005	0.015	0.060	4.1	0.059	0.036
12	2.053	13.0	3.56	0.09	0.068	0.00	0.004	0.005	0.018	0.059	4.1	0.061	0.044
13	2.163	14.3	3.89	0.10	0.074	0.00	0.004	0.008	0.026	0.068	4.5	0.067	0.064
14	2.184	13.8	3.71	0.10	0.072	0.00	0.004	0.015	0.024	0.069	4.4	0.067	0.061
15	1.447	21.1	5.48	0.19	0.111	0.00	0.007	0.009	0.051	0.114	5.8	0.113	0.111
16	1.453	19.8	5.17	0.19	0.108	0.00	0.007	0.006	0.035	0.110	5.7	0.108	0.111
17	2.064	13.6	3.67	0.13	0.071	0.00	0.005	0.003	0.024	0.078	4.4	0.074	0.074
18	2.062	13.9	3.73	0.15	0.073	0.00	0.004	0.002	0.025	0.081	4.5	0.076	0.073
19	1.789	14.6	3.92	0.16	0.077	0.00	0.004	0.003	0.025	0.089	4.5	0.080	0.070
20	1.789	14.8	3.96	0.18	0.077	0.00	0.005	0.004	0.024	0.094	4.5	0.083	0.076
21	1.627	14.8	3.99	0.20	0.082	0.00	0.005	0.007	0.027	0.100	4.5	0.084	0.113
22	1.326	15.5	4.18	0.23	0.091	0.00	0.005	0.007	0.031	0.110	4.5	0.090	0.111
23	1.242	15.4	4.12	0.24	0.083	0.00	0.006	0.012	0.031	0.112	4.4	0.090	0.116
24	0.691	18.9	4.96	0.32	0.099	0.00	0.008	0.004	0.042	0.142	5.1	0.112	0.144
25	0.963	16.7	4.46	0.27	0.088	0.00	0.006	0.005	0.039	0.128	4.5	0.093	0.121
26	0.941	17.1	4.57	0.30	0.089	0.00	0.007	0.004	0.038	0.135	4.4	0.098	0.121
27	0.491	19.5	5.12	0.37	0.101	0.00	0.009	0.006	0.044	0.158	4.7	0.113	0.133
28	0.516	17.8	4.70	0.33	0.096	0.00	0.008	0.003	0.041	0.147	4.2	0.101	0.130
29	0.168	22.6	5.87	0.46	0.120	0.00	0.011	0.007	0.051	0.195	5.1	0.133	0.167
30	0.396	18.8	4.99	0.38	0.099	0.00	0.009	0.006	0.035	0.165	4.2	0.110	0.122
31	0.224	19.7	5.18	0.40	0.101	0.00	0.009	0.001	0.035	0.172	4.3	0.112	0.115
32	0.235	19.3	5.13	0.41	0.099	0.00	0.009	0.001	0.049	0.173	4.1	0.111	0.110
33	0.009	31.2	7.80	0.69	0.162	0.00	0.015	0.006	0.059	0.282	5.9	0.185	0.170
34	0.105	22.6	5.92	0.48	0.119	0.00	0.010	0.006	0.037	0.203	4.4	0.127	0.127
35	0.110	22.4	5.85	0.48	0.116	0.00	0.011	0.008	0.039	0.204	4.3	0.125	0.114
36	0.028	27.0	6.90	0.59	0.142	0.00	0.012	0.006	0.044	0.248	5.1	0.153	0.157
37	0.124	22.5	5.93	0.47	0.120	0.00	0.010	0.009	0.035	0.202	4.6	0.123	0.109
38	0.262	19.9	5.31	0.42	0.106	0.00	0.009	0.012	0.031	0.177	4.3	0.108	0.093
39	0.385	19.4	5.19	0.40	0.103	0.00	0.009	0.005	0.029	0.168	4.5	0.105	0.091
40	0.441	18.8	5.04	0.38	0.103	0.00	0.009	0.016	0.028	0.159	4.6	0.100	0.085
41	0.584	18.2	4.83	0.35	0.099	0.00	0.008	0.037	0.023	0.150	4.7	0.096	0.073
42	0.954	16.9	4.50	0.32	0.094	0.00	0.007	0.009	0.025	0.134	4.7	0.089	0.075
43	1.048	16.4	4.39	0.29	0.092	0.00	0.006	0.008	0.026	0.123	4.9	0.084	0.079
44	1.509	15.3	4.09	0.27	0.089	0.00	0.006	0.010	0.024	0.112	5.0	0.077	0.087
45	1.512	18.4	4.85	0.31	0.106	0.00	0.007	0.020	0.030	0.123	6.3	0.093	0.092
46	2.363	13.8	3.65	0.21	0.081	0.00	0.005	0.024	0.020	0.088	5.3	0.068	0.063

Table A3

Spanish River Harbour Pore Water (mg/l)
Station 8

[illegible]	Mn	Ca	Mg	Ba	Ti	Fe	As	Zn	Cu	Ni	Na	Sr	Pb
-4	1.0229	10.0	2.6	0.038	0.050	0.28	0.002	0.008	0.002	0.026	4.1	0.039	0.000
-3	1.0489	10.2	2.6	0.038	0.048	0.28	0.002	0.003	0.001	0.025	4.1	0.040	0.000
-2	1.1712	10.5	2.7	0.045	0.050	0.29	0.002	0.006	0.001	0.026	4.1	0.041	0.000
-1	1.2669	10.9	2.8	0.049	0.052	0.36	0.002	0.005	0.001	0.028	4.2	0.043	0.000
0	1.6596	10.5	2.7	0.093	0.049	1.20	0.002	0.004	0.001	0.034	4.1	0.041	0.000
1	1.6950	11.7	2.9	0.103	0.058	0.41	0.010	0.008	0.005	0.085	4.2	0.048	0.000
2	1.6801	12.9	3.1	0.094	0.068	0.38	0.010	0.008	0.006	0.060	4.2	0.051	0.003
3	1.0195	17.3	3.7	0.120	0.087	0.00	0.021	0.005	0.004	0.084	4.3	0.069	0.003
4	0.8153	19.0	4.0	0.124	0.094	0.00	0.025	0.003	0.001	0.091	4.2	0.077	0.000
5	0.4917	21.6	4.4	0.177	0.107	0.00	0.025	0.003	0.005	0.123	4.4	0.088	0.000
6	0.4716	23.8	4.9	0.191	0.118	0.00	0.024	0.002	0.002	0.141	4.5	0.101	0.000
7	1.0769	21.7	4.6	0.167	0.107	0.00	0.012	0.001	0.001	0.115	4.4	0.092	0.000
8	1.3710	21.2	4.6	0.170	0.105	0.00	0.007	0.005	0.001	0.114	4.4	0.092	0.000
9	1.6633	17.6	4.0	0.145	0.087	0.00	0.004	0.014	0.002	0.107	4.3	0.076	0.000
10	1.6763	19.0	4.4	0.169	0.094	0.00	0.003	0.009	0.001	0.112	4.4	0.083	0.002
11	1.7089	20.5	4.8	0.180	0.100	0.00	0.002	0.010	0.002	0.112	4.7	0.088	0.000
12	1.6834	20.8	4.8	0.188	0.103	0.00	0.002	0.013	0.002	0.108	4.7	0.089	0.002
13	1.6741	21.5	5.0	0.206	0.107	0.00	0.002	0.014	0.001	0.112	4.7	0.093	0.000
14	1.7054	22.2	5.1	0.218	0.117	0.00	0.002	0.013	0.002	0.118	4.9	0.096	0.004
15	1.6888	20.1	4.7	0.200	0.100	0.00	0.001	0.015	0.001	0.113	4.7	0.087	0.003
16	1.6625	24.0	5.5	0.253	0.119	0.00	0.002	0.020	0.002	0.143	5.0	0.107	0.002
17	1.6291	24.0	5.5	0.255	0.119	0.00	0.002	0.019	0.001	0.154	5.0	0.105	0.001
18	1.6690	22.7	5.3	0.248	0.112	0.00	0.001	0.009	0.002	0.149	5.0	0.101	0.001
19	1.5389	26.1	5.9	0.305	0.128	0.00	0.002	0.007	0.001	0.179	5.2	0.118	0.000
20	1.4884	24.7	5.6	0.289	0.127	0.00	0.002	0.018	0.003	0.174	5.0	0.111	0.008
21	1.3537	26.5	5.9	0.321	0.131	0.00	0.001	0.010	0.001	0.193	5.0	0.120	0.001
22	1.0714	29.8	6.4	0.373	0.147	0.00	0.002	0.005	0.002	0.223	5.0	0.138	0.001
23	1.1535	29.2	6.4	0.359	0.142	0.00	0.002	0.004	0.002	0.220	5.1	0.134	0.016
24	0.8707	31.0	6.6	0.392	0.151	0.00	0.002	0.009	0.002	0.238	5.0	0.145	0.000
25	0.5563	36.4	7.2	0.478	0.179	0.00	0.002	0.007	0.002	0.287	5.0	0.174	0.000
26	0.7464	33.1	6.9	0.426	0.166	0.00	0.002	0.004	0.002	0.257	5.1	0.155	0.003
27	0.2211	35.5	7.9	0.419	0.159	0.00	0.003	0.003	0.003	0.246	5.0	0.151	0.007
28	0.3496	40.2	7.5	0.553	0.202	0.00	0.002	0.010	0.004	0.314	5.0	0.194	0.004
[illegible]	0.5136	37.2	7.4	0.511	0.187	0.00	0.003	0.012	0.007	0.284	5.2	0.177	0.007
[illegible]	0.4749	37.5	7.4	0.523	0.183	0.00	0.002	0.005	0.001	0.286	5.2	0.180	0.000
31	0.3929	38.7	7.4	0.546	0.190	0.00	0.001	0.005	0.001	0.293	5.1	0.188	0.000
32	0.2421	41.7	7.3	0.627	0.208	0.00	0.002	0.011	0.002	0.313	5.0	0.205	0.006
33	0.1938	44.0	7.2	0.625	0.221	0.00	0.002	0.007	0.003	0.339	5.0	0.221	0.002
34	0.2018	44.0	7.3	0.605	0.219	0.00	0.003	0.006	0.001	0.319	5.1	0.222	0.007
35	0.1799	44.6	7.1	0.594	0.220	0.00	0.001	0.007	0.001	0.317	5.0	0.225	0.000
36	0.1563	47.3	7.3	0.629	0.235	0.00	0.002	0.007	0.001	0.330	5.2	0.242	0.000
37	0.1981	45.8	7.4	0.595	0.227	0.00	0.002	0.025	0.003	0.314	5.2	0.232	0.001
38	0.0851	50.8	6.5	0.689	0.260	0.00	0.003	0.025	0.004	0.354	5.0	0.268	0.004
39	0.0850	50.1	6.4	0.672	0.255	0.00	0.002	0.024	0.001	0.343	4.9	0.267	0.000
40	0.0967	48.9	6.4	0.662	0.247	0.00	0.002	0.009	0.001	0.332	4.9	0.261	0.001
41	0.0552	52.9	5.6	0.727	0.276	0.00	0.003	0.009	0.002	0.360	4.8	0.290	0.008
42	0.0843	49.9	6.2	0.677	0.254	0.00	0.002	0.008	0.001	0.333	4.9	0.270	0.001
43	0.0461	54.8	5.5	0.780	0.283	0.00	0.002	0.006	0.001	0.368	5.0	0.309	0.002
44	0.0643	52.1	5.8	0.724	0.269	0.00	0.003	0.012	0.003	0.344	4.9	0.289	0.005
45	0.0652	52.9	5.7	0.737	0.272	0.00	0.002	0.010	0.002	0.349	5.0	0.295	0.001
46	0.0696	53.6	5.9	0.748	0.276	0.00	0.002	0.005	0.001	0.351	5.1	0.301	0.001
47	0.0437	54.2	5.0	0.781	0.285	0.00	0.002	0.023	0.003	0.358	4.8	0.319	0.006
48	0.0123	61.1	3.5	0.960	0.333	0.00	0.002	0.009	0.002	0.417	4.8	0.429	0.000
49	0.0903	50.0	5.6	0.709	0.254	0.00	0.001	0.006	0.001	0.323	4.6	0.328	0.000
50	0.0671	52.4	5.0	0.734	0.268	0.00	0.001	0.004	0.004	0.324	4.7	0.350	0.004

Table A4 Spanish River Harbour Pore Water (mg/l)
Station 14

Depth	Mn	Ca	Mg	Ba	Ti	Fe	As	Zn	Cu	Ni	Na	Sr	Pb
-6	0.009	11	2.9	0.04	0.059	0.000	0.005	0.01	0.012	0.024	4.1	0.049	0.008
-5	0.008	11	2.9	0.02	0.057	0.000	0.004	0.01	0.010	0.023	4.0	0.048	0.004
-4	0.012	12	3.2	0.02	0.061	0.015	0.005	0.01	0.011	0.026	4.3	0.051	0.007
-3	0.142	11	2.9	0.02	0.057	0.264	0.005	0.03	0.011	0.031	4.1	0.047	0.008
-2	0.624	11	3.0	0.04	0.059	1.087	0.007	0.02	0.013	0.030	4.2	0.049	0.017
-1	1.961	11	2.8	0.19	0.058	1.402	0.019	0.03	0.023	0.095	3.9	0.050	0.024
0	2.000	12	3.2	0.20	0.060	0.900	0.030	0.03	0.030	0.094	4.2	0.055	0.033
1	2.014	13	3.4	0.24	0.075	0.484	0.040	0.02	0.039	0.093	4.5	0.060	0.038
2	1.840	13	3.4	0.26	0.072	0.119	0.048	0.04	0.037	0.094	4.4	0.062	0.038
3	1.069	15	3.8	0.29	0.090	0.000	0.049	0.05	0.046	0.120	4.9	0.068	0.056
4	1.264	15	4.0	0.35	0.103	0.000	0.056	0.04	0.050	0.152	4.6	0.072	0.066
5	1.359	15	4.3	0.39	0.117	0.000	0.059	0.08	0.058	0.180	4.8	0.077	0.076
6	1.444	15	5.1	0.55	0.167	0.000	0.058	0.10	0.071	0.284	5.0	0.084	0.086
7	1.575	16	5.3	0.59	0.229	0.000	0.061	0.12	0.074	0.311	5.3	0.091	0.095
8	1.108	19	10.0	1.52	0.609	0.000	0.072	0.37	0.164	0.903	6.6	0.140	0.211
9	1.740	16	6.2	0.73	0.176	0.000	0.053	0.17	0.089	0.431	4.9	0.092	0.124
10	2.404	15	5.0	0.46	0.152	0.000	0.051	0.08	0.059	0.242	4.6	0.083	0.077
11	2.768	15	4.1	0.29	0.107	0.000	0.046	0.04	0.037	0.130	4.2	0.076	0.055
12	2.727	15	3.9	0.23	0.093	0.361	0.041	0.02	0.032	0.095	4.1	0.074	0.050
13	2.696	15	4.2	0.27	0.099	0.203	0.041	0.02	0.034	0.103	4.2	0.078	0.059
14	2.639	17	4.5	0.28	0.104	0.115	0.040	0.02	0.039	0.105	4.5	0.085	0.064
15	2.860	16	4.2	0.23	0.087	0.697	0.035	0.01	0.035	0.082	4.2	0.076	0.052
16	3.085	15	3.9	0.21	0.078	1.157	0.030	0.01	0.034	0.072	3.9	0.071	0.057
17	3.195	15	4.2	0.23	0.091	1.084	0.029	0.01	0.043	0.081	4.0	0.075	0.072
18	3.028	15	4.2	0.24	0.099	0.753	0.028	0.02	0.042	0.087	3.9	0.074	0.068
19	3.020	15	4.2	0.24	0.090	0.850	0.025	0.01	0.042	0.085	3.9	0.073	0.064
20	3.022	15	4.2	0.23	0.089	0.967	0.024	0.01	0.042	0.084	3.9	0.073	0.060
21	2.997	16	4.4	0.26	0.104	0.662	0.022	0.02	0.047	0.092	4.0	0.074	0.078
22	3.244	17	4.9	0.31	0.118	0.475	0.022	0.02	0.043	0.108	4.2	0.080	0.079
23	3.226	15	4.5	0.29	0.111	0.580	0.022	0.02	0.045	0.106	3.8	0.075	0.085
24	3.267	17	4.8	0.31	0.118	0.512	0.022	0.02	0.054	0.111	4.0	0.080	0.105
25	3.267	16	4.8	0.35	0.132	0.431	0.021	0.04	0.054	0.126	4.0	0.080	0.105
26	3.220	15	4.6	0.34	0.128	0.637	0.020	0.03	0.050	0.116	3.8	0.077	0.102
27	3.208	16	4.9	0.34	0.137	0.615	0.020	0.03	0.051	0.116	4.0	0.078	0.092
28	3.187	27	7.8	0.57	0.202	1.000	0.030	0.04	0.089	0.168	6.4	0.132	0.173
29	3.062	15	4.6	0.32	0.121	1.548	0.017	0.03	0.054	0.098	3.8	0.075	0.111
30	3.047	15	4.6	0.33	0.118	1.008	0.017	0.02	0.050	0.100	3.7	0.075	0.105
31	3.114	16	4.6	0.33	0.113	1.278	0.016	0.02	0.051	0.094	3.7	0.076	0.103
32	3.078	15	4.4	0.31	0.100	1.511	0.016	0.02	0.046	0.085	3.6	0.075	0.097
33	3.056	16	4.6	0.29	0.104	1.158	0.016	0.02	0.047	0.088	3.7	0.074	0.091
34	3.298	16	4.7	0.31	0.107	1.477	0.016	0.02	0.045	0.093	3.7	0.077	0.098
35	3.384	16	4.5	0.31	0.100	2.091	0.015	0.01	0.040	0.084	3.5	0.075	0.094
36	3.294	16	4.6	0.32	0.101	2.132	0.014	0.02	0.043	0.082	3.6	0.075	0.102
37	3.218	15	4.3	0.30	0.092	2.417	0.015	0.02	0.037	0.075	3.5	0.074	0.080
38	3.156	16	4.5	0.32	0.098	1.869	0.015	0.02	0.037	0.080	3.6	0.076	0.082
39	3.038	16	4.5	0.30	0.093	1.685	0.016	0.01	0.034	0.076	3.6	0.073	0.078
40	2.866	15	4.4	0.28	0.095	2.106	0.014	0.01	0.034	0.071	3.6	0.072	0.075
41	3.491	27	7.7	0.59	0.185	0.000	0.023	0.04	0.060	0.141	6.4	0.130	0.148
42	3.271	18	5.5	0.44	0.144	0.472	0.015	0.03	0.040	0.114	4.4	0.091	0.102
43	3.193	17	5.5	0.52	0.155	0.000	0.014	0.04	0.041	0.137	4.1	0.087	0.220
44	3.008	16	7.3	0.98	0.319	0.000	0.015	0.11	0.056	0.285	5.0	0.100	0.108
45	3.072	16	5.5	0.56	0.202	0.097	0.014	0.05	0.036	0.144	4.5	0.085	0.085
46	3.361	18	10.3	1.59	0.304	0.000	0.016	0.21	0.082	0.554	6.2	0.119	0.142

Table A5 Pore Water SRP ($mg.L^{-1}$)

Depth	Station 1	Station 2	Station 8	Station 14
-6	0.00	0.00	0.00	0.0065
-5	0.003	0.00	0.00	0.0071
-4	0.0055	0.00	0.011	0.0085
-3	0.0045	0.00	0.011	0.00
-2	0.0045	0.057	0.0155	0.008
-1	0.0135	0..063	0.015	0.0065
0	0.1425	0.055	0.284	0.0415
1	0.376	0.24	0.252	0.151
2	0.536	0.412	0.496	0.892
3	0.7	0.548	0.804	1.696
4	0.732	0.608	1.288	1.736
5	0.684	0.612	1.604	2.024
6	0.916	0.592	1.616	1.9
7	1.236	0.684	1.756	2.264
8	1.132	1.136	1.696	2.448
9	1.14	1.152	1.576	2.6
10	1.328	1.288	1.68	2.8
11	1.756	1.524	1.064	3.436
12	1.452	1.668	0.98	2.845
13	1.788	1.792	0.98	2.584
14	1.692	1.856	1.036	2.364
15	1.604	1.832	1.068	2.164
16	1.62	1.844	1.14	2.1
17	1.74	1.896	1.192	1.944
18	1.712	1.904	1.268	1.94
19	1.552	1.96	1.316	1.908
20	1.496	2.12	1.392	1.82
21	1.456	2.168	1.484	1.752
22	1.432	2.332	1.524	1.676
23	1.324	2.308	1.568	1.58
24	1.324	2.356	1.624	1.424
25	1.336	2.424	1.684	1.492
26	1.296	2.484	1.716	1.5
27	1.092	2.62	1.74	1.316
28	1.004	2.58	1.66	1.132
29	1.14	2.624	1.683	1.128
30	1.464	2.6	1.696	1.244
31	1.472	2.72	1.756	1.236
32	1.376	2.66	1.7	1.236
33	1.316	2.744	1.81	1.28
34	1.496	2.448	1.9	1..224
35	1.764	2.256	1.94	1.172
36	1.669	2.072	2.36	1.08
37	1.556	1.86	2.36	0.8932
38	1.556	1.648	2.02	0.696
39	1.592	1.476	2.31	0.652
40	1.64	1.272	2.51	0.78
41	1.532	1.104	2.31	0.852
42	1.552	0.996	2.32	0.944
43	1.688	0.776	1.99	0.94
44	1.44	0.648	1.97	0.864
45	1.54	0.648	2.23	0.844
46	1.568	0.000	2.2	0.916
47	1.552	0.00	2.014	0.00
48	1.568	0.00	2.014	0.00
49	1.748	0.00	2.014	0.00
50	1.912	0.00	2.014	0.00

Table A6 Pore water NH_4^+ (mg.L^{-1})

Depth	Station 1	Station 2	Station 8	Station 14
-6	0.00	0.00	0.00	0.025
-5	0.025	0.00	0.00	0.025
-4	0.025	0.00	0.455	0.025
-3	0.025	0.00	0.48	0.025
-2	0.03	0.025	0.51	0.025
-1	0.025	0.025	0.53	0.025
0	0.03	0.025	0.68	0.05
1	0.2	0.2	0.8	0.2
2	0.2	0.2	1.64	0.2
3	0.2	0.2	2.4	0.2
4	0.2	0.2	3	0.28
5	0.2	0.2	3.48	0.32
6	0.2	0.2	3.68	0.24
7	0.2	0.4	3.72	0.28
8	0.2	0.6	3.32	0.32
9	0.2	1.12	4.52	0.36
10	0.24	1.28	5.2	0.48
11	0.28	1.56	5.88	0.4
12	0.28	1.64	4.8	0.52
13	0.32	1.84	7.92	0.52
14	0.28	1.96	9.12	0.6
15	0.24	2.04	9	0.6
16	0.28	2.28	7.64	0.64
17	0.32	2.28	13.08	0.6
18	0.4	2.28	19.36	0.68
19	0.4	2.44	16.72	0.68
20	1.4	2.52	18.64	0.72
21	0.6	2.88	20.92	0.72
22	0.6	3.16	22.68	0.72
23	0.64	3.16	24.24	0.689
24	0.64	3.36	26.36	0.32
25	0.64	3.56	28.6	0.32
26	.72	3.72	30.88	0.32
27	0.76	4.04	32.84	0.32
28	0.84	4	34.68	0.72
29	0.84	4.2	36.52	0.68
30	0.92	4.4	38.76	0.64
31	1	4.68	40.08	0.68
32	0.88	4.72	38.95	0.72
33	1	5.08	37.91	0.72
34	1	4.84	45.3	0.72
35	1.04	4.56	47.4	0.72
36	1.12	1.32	58.6	0.72
37	1.16	4	48.6	0.72
38	1.08	3.64	40.6	0.72
39	1.2	3.4	49.6	0.68
40	1.28	3	65.5	0.68
41	1.28	2.68	60.8	0.72
42	1.12	2.4	62.7	0.68
43	1.24	2	55.3	0.68
44	1.16	1.64	55.6	0.68
45	1.36	1.64	64.1	0.68
46	1.36	0.00	64.8	0.52
47	1.36	0.00	65	0.00
48	1.4	0.00	65	0.00
49	1.44	0.00	64	0.00
50	1.56	0.00	64	0.00

Table A7 Porewater NO_3+NO_2 ($mg.L^{-1}$)

Depth	Station 1	Station 2	Station 8	Station 14
-6	0.00	0.00	0.00	0.24
-5	0.23	0.00	0.00	0.00
-4	0.24	0.00	0.00	0.00
-3	0.24	0.00	0.00	0.00
-2	0.23	0.275	0.00	0.00
-1	0.21	0.31	0.00	0.00
0	0.04	0.265	0.00	0.00
1	0.00	0.265	0.00	0.00
2	0.00	0.169	0.00	0.00

FIGURES

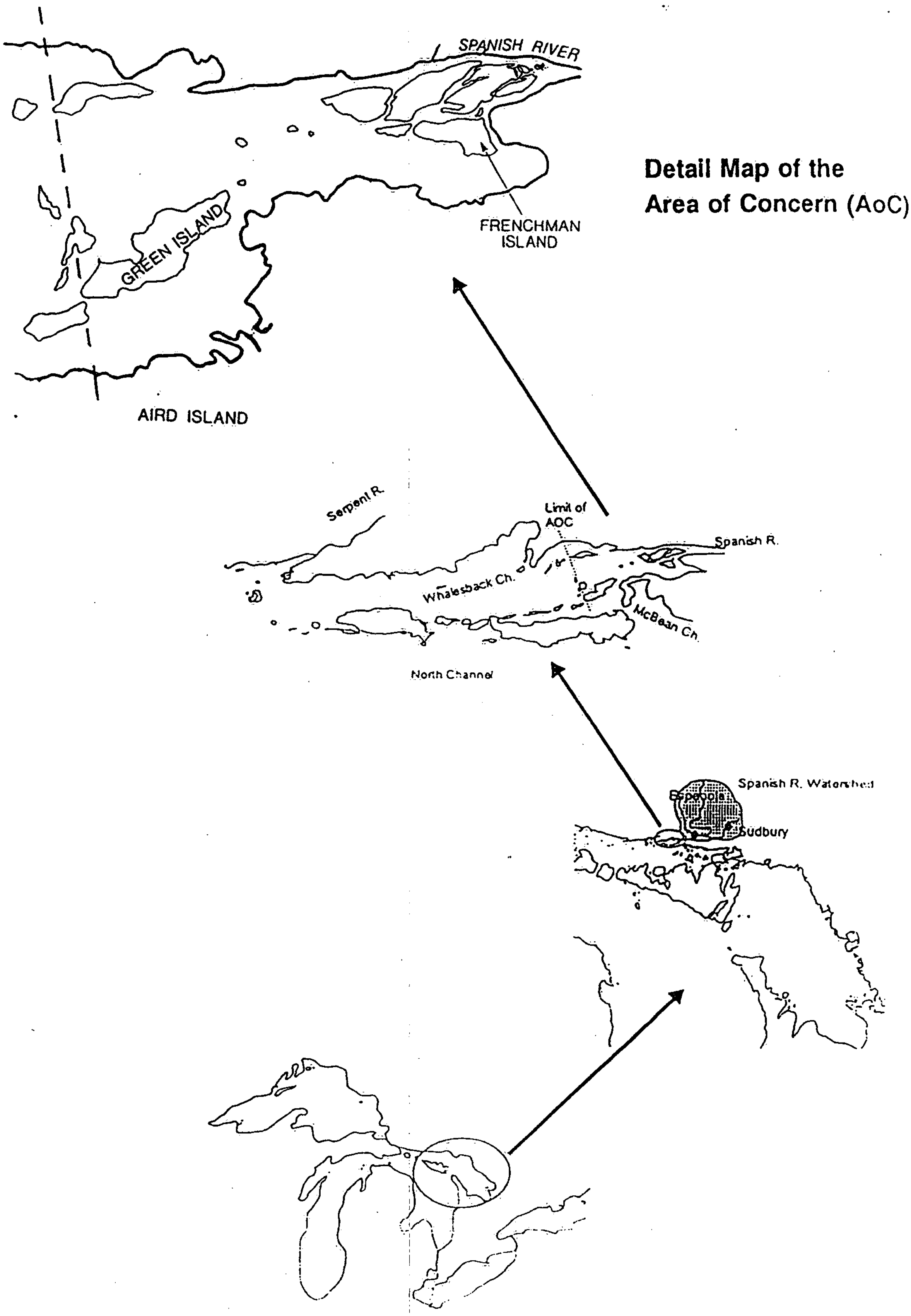


Figure 1a. SPANISH HARBOUR - NORTH CHANNEL STUDY AREA
(Modified after Reynoldson *et al* 1995)

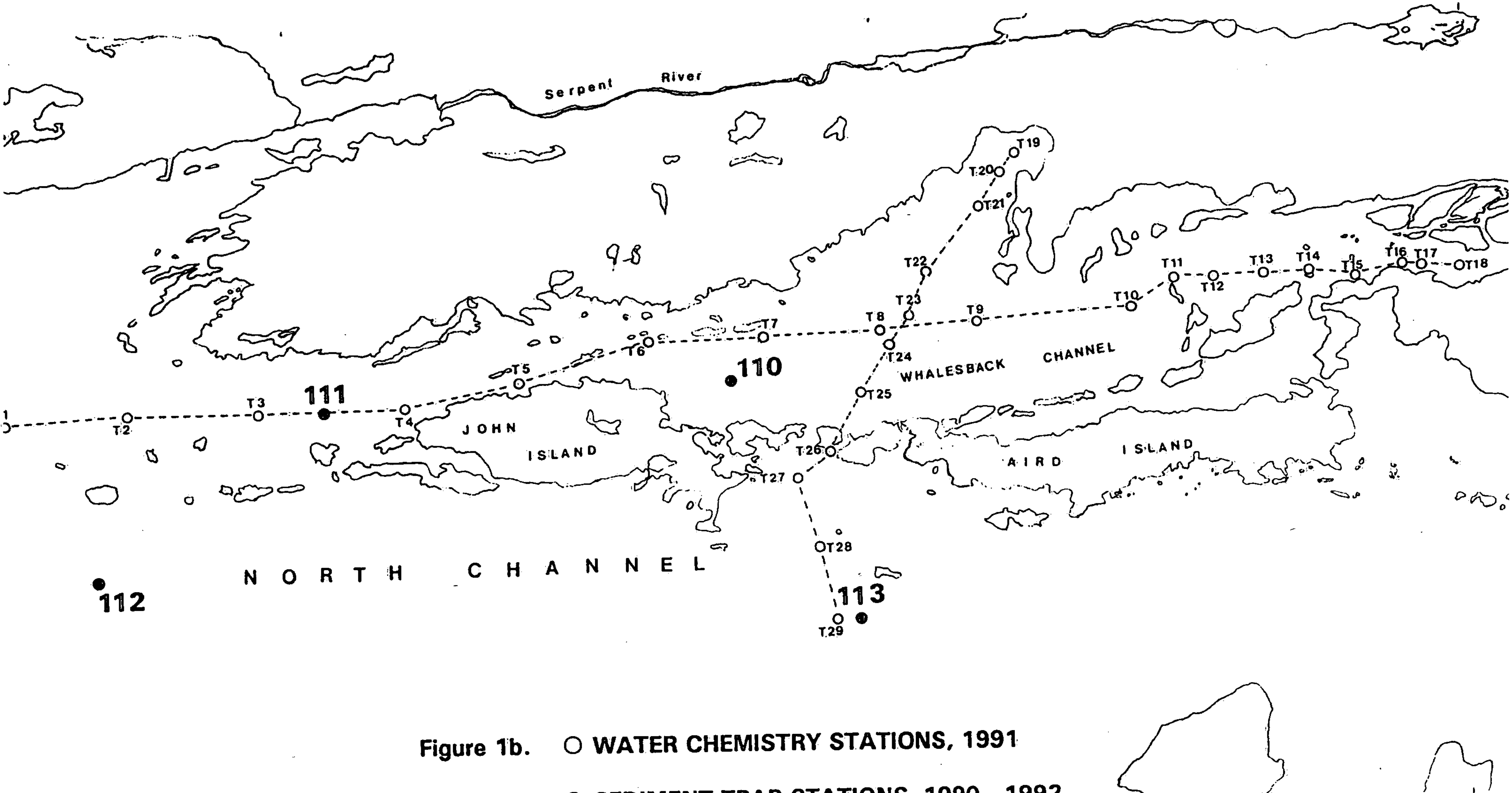


Figure 1b. ○ WATER CHEMISTRY STATIONS, 1991

● SEDIMENT TRAP STATIONS, 1990 - 1992

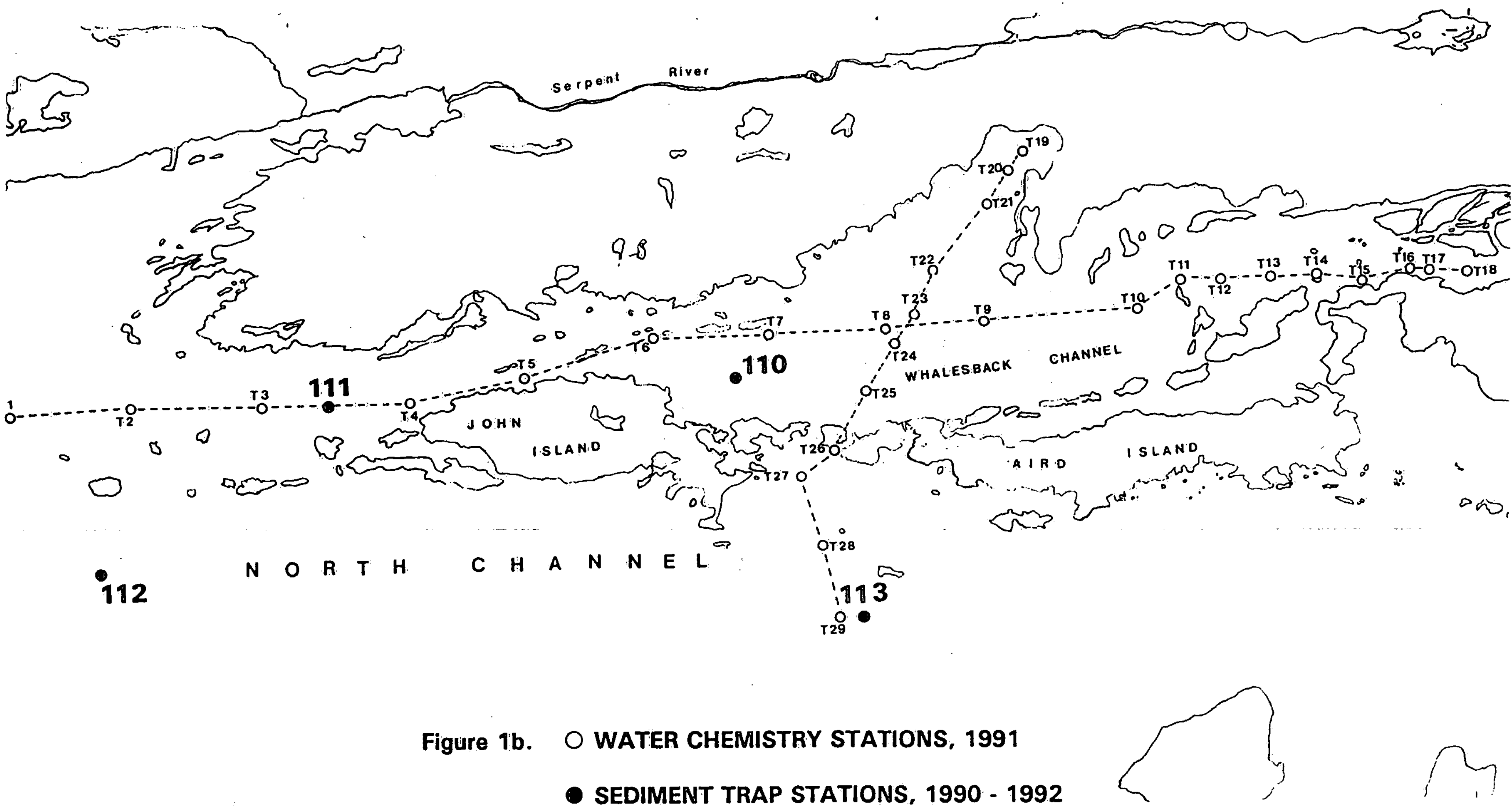
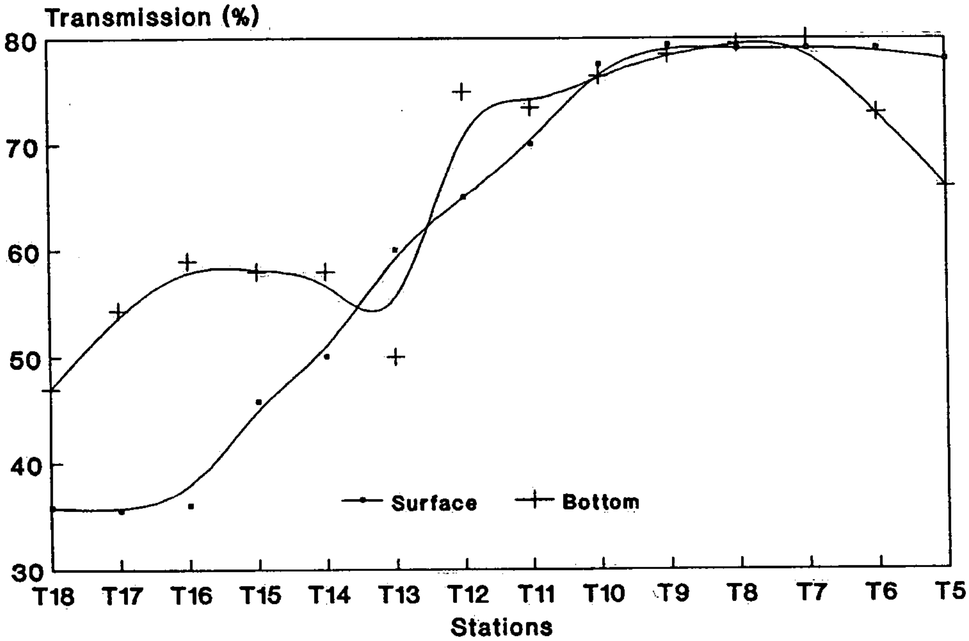


Figure 1b. ○ WATER CHEMISTRY STATIONS, 1991

● SEDIMENT TRAP STATIONS, 1990 - 1992

Figure 2. North Channel Surface and Bottom Transmission (%)

East to West Transect



North to South Transect

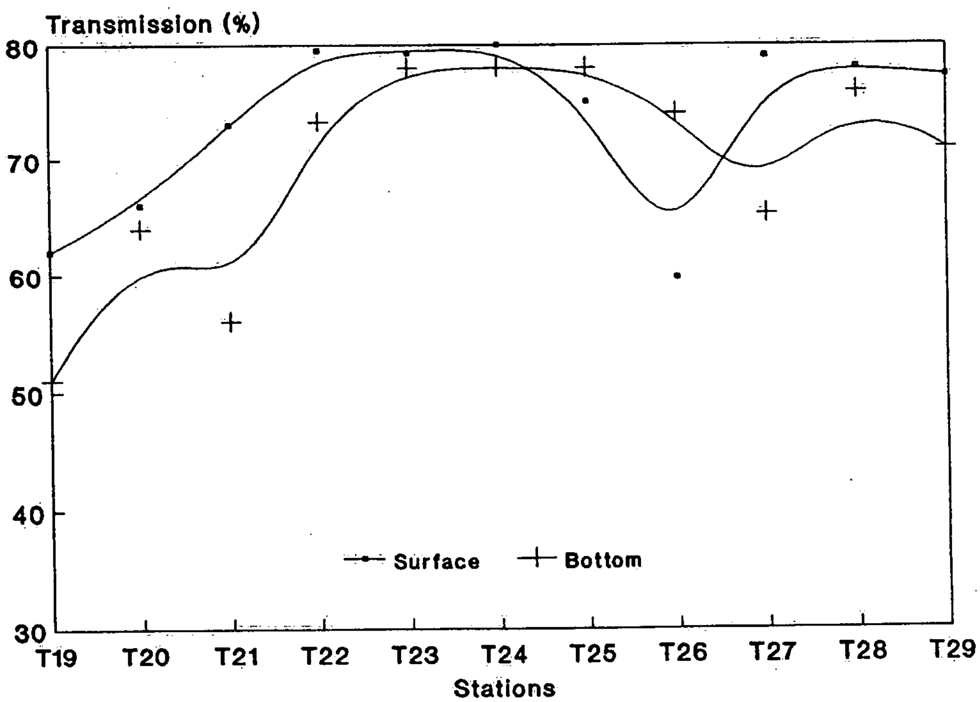
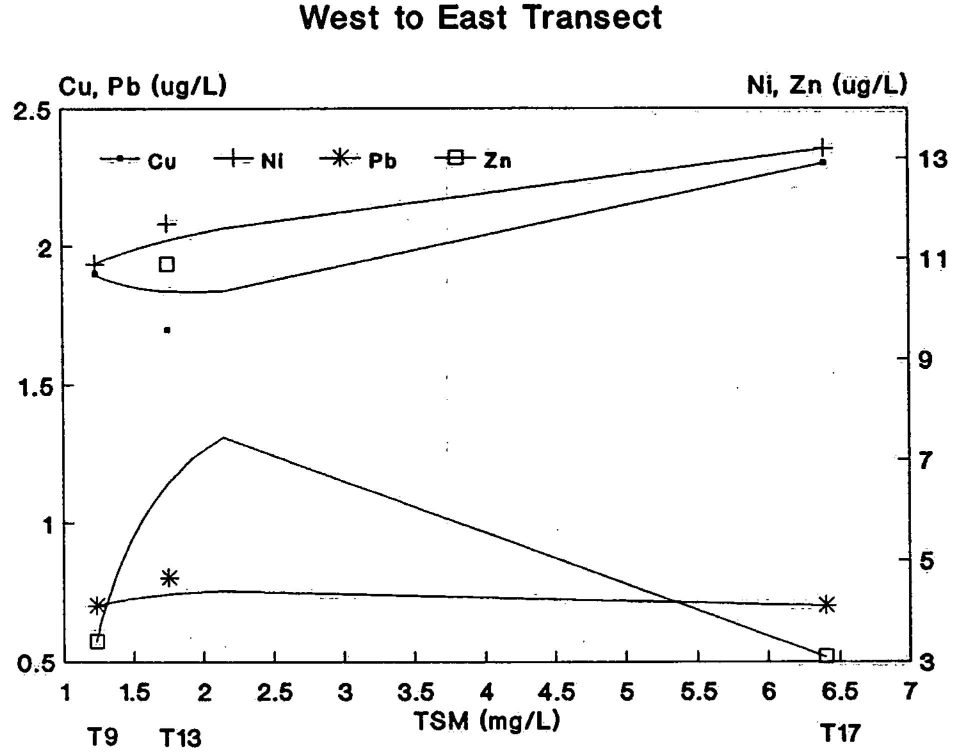


Figure 3. Metal Concentration Relationship with TSM and % Transmission



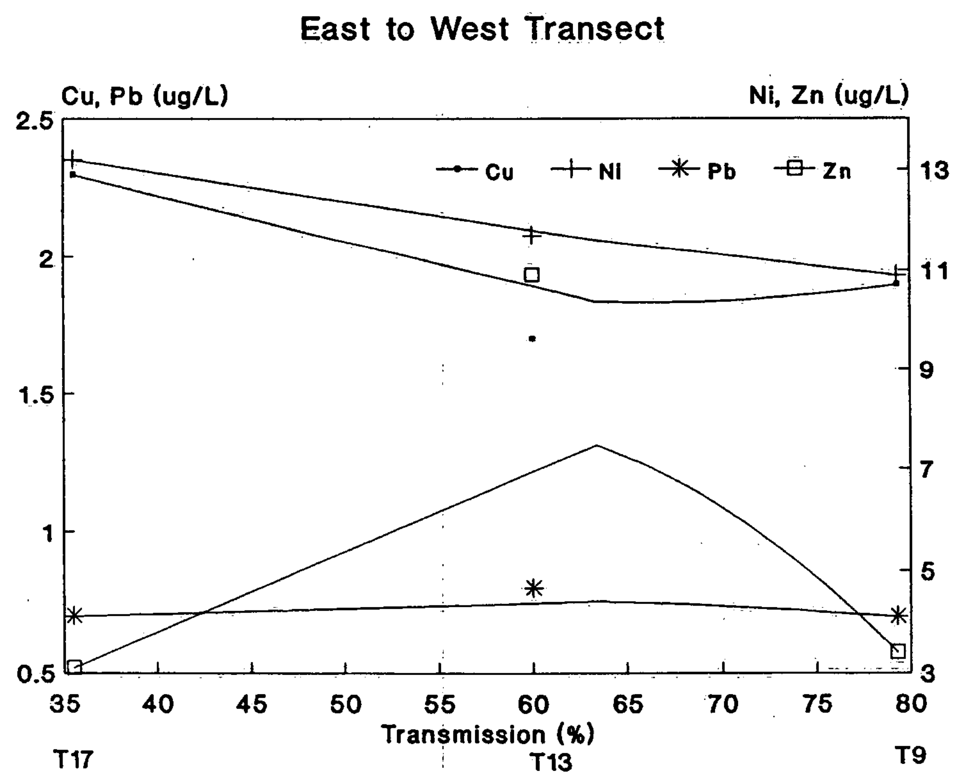
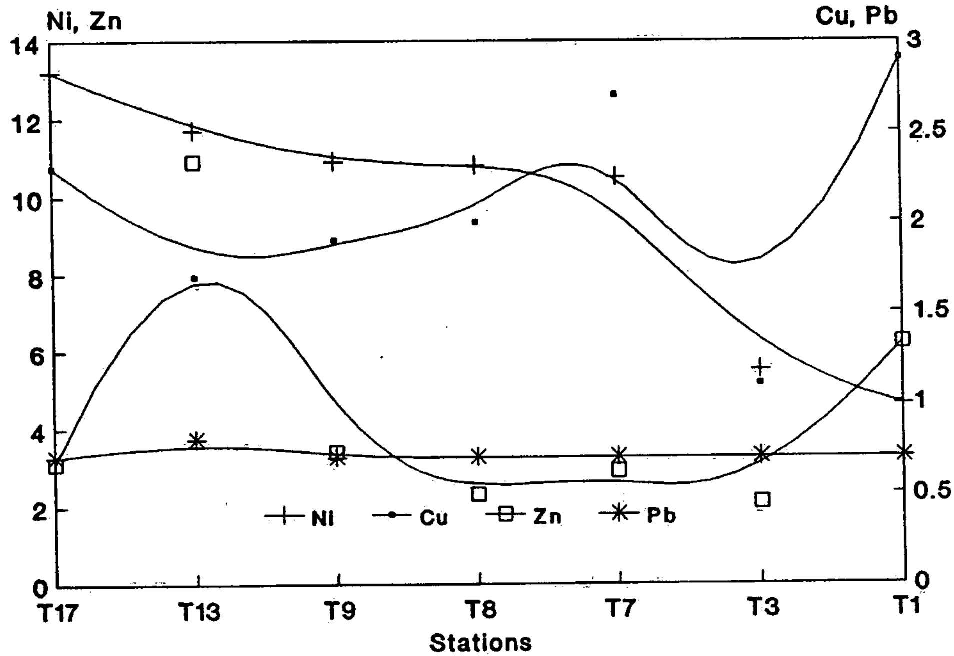


Figure 4. Total Metal Concentrations (ug/L) in the Water Column

East to West Transect



North to South Transect

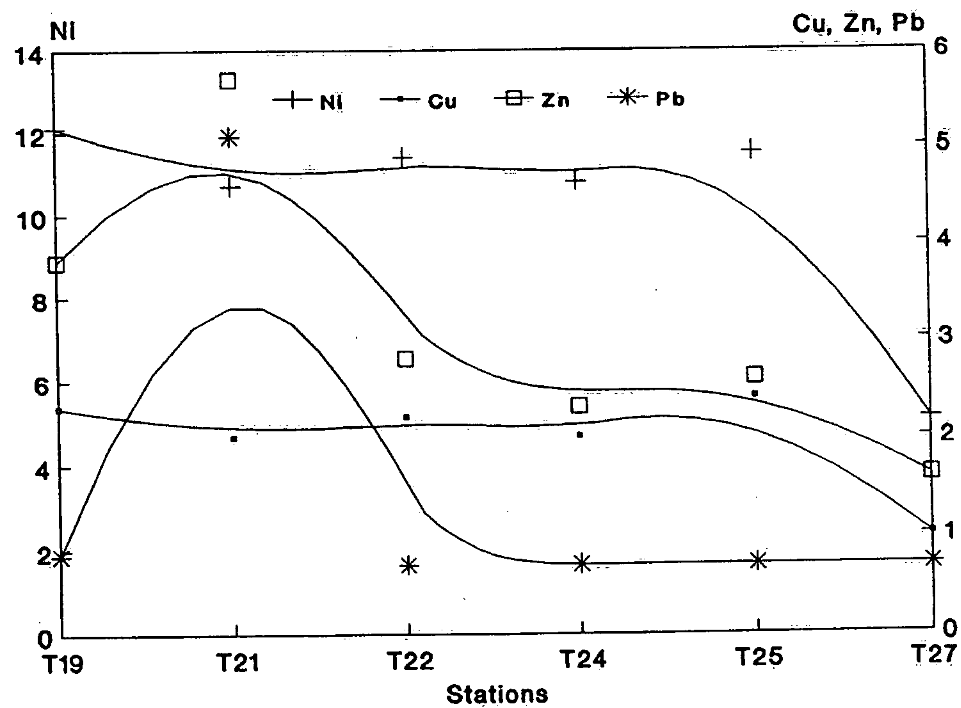
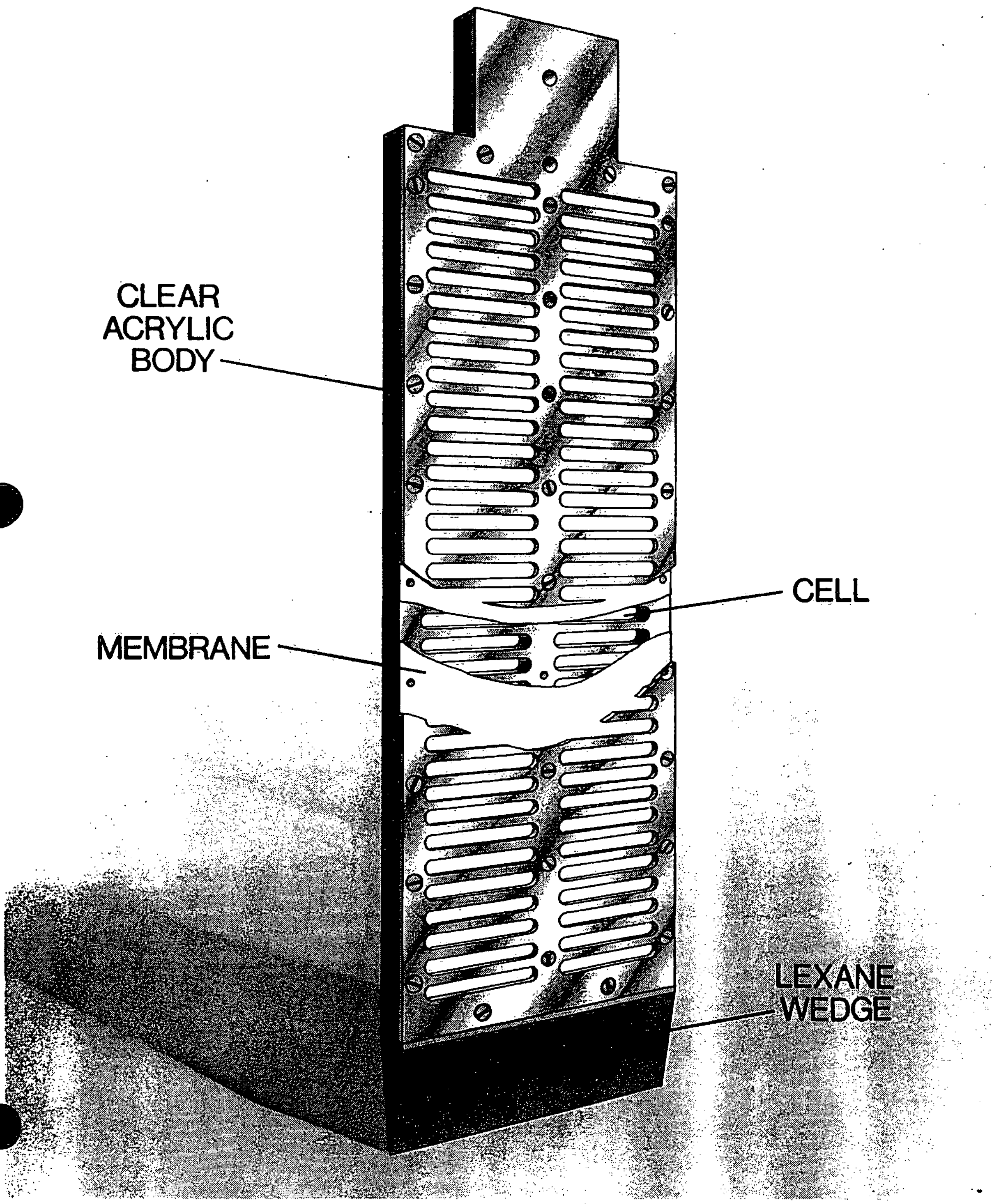


Figure 5. POREWATER SAMPLER



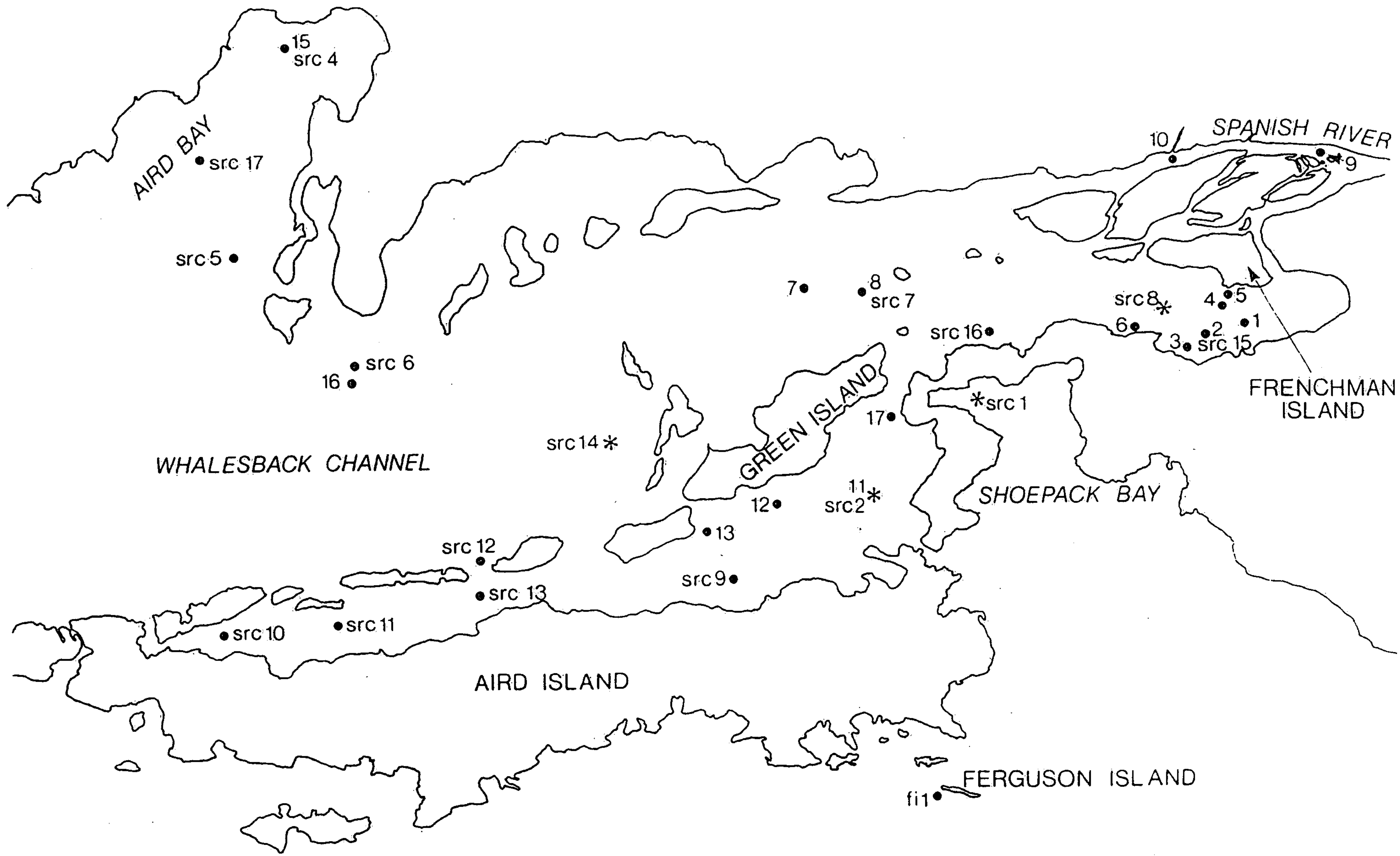


Figure 6. SPANISH RIVER HARBOUR STUDY AREA, 1988

*** Porewater Stations**

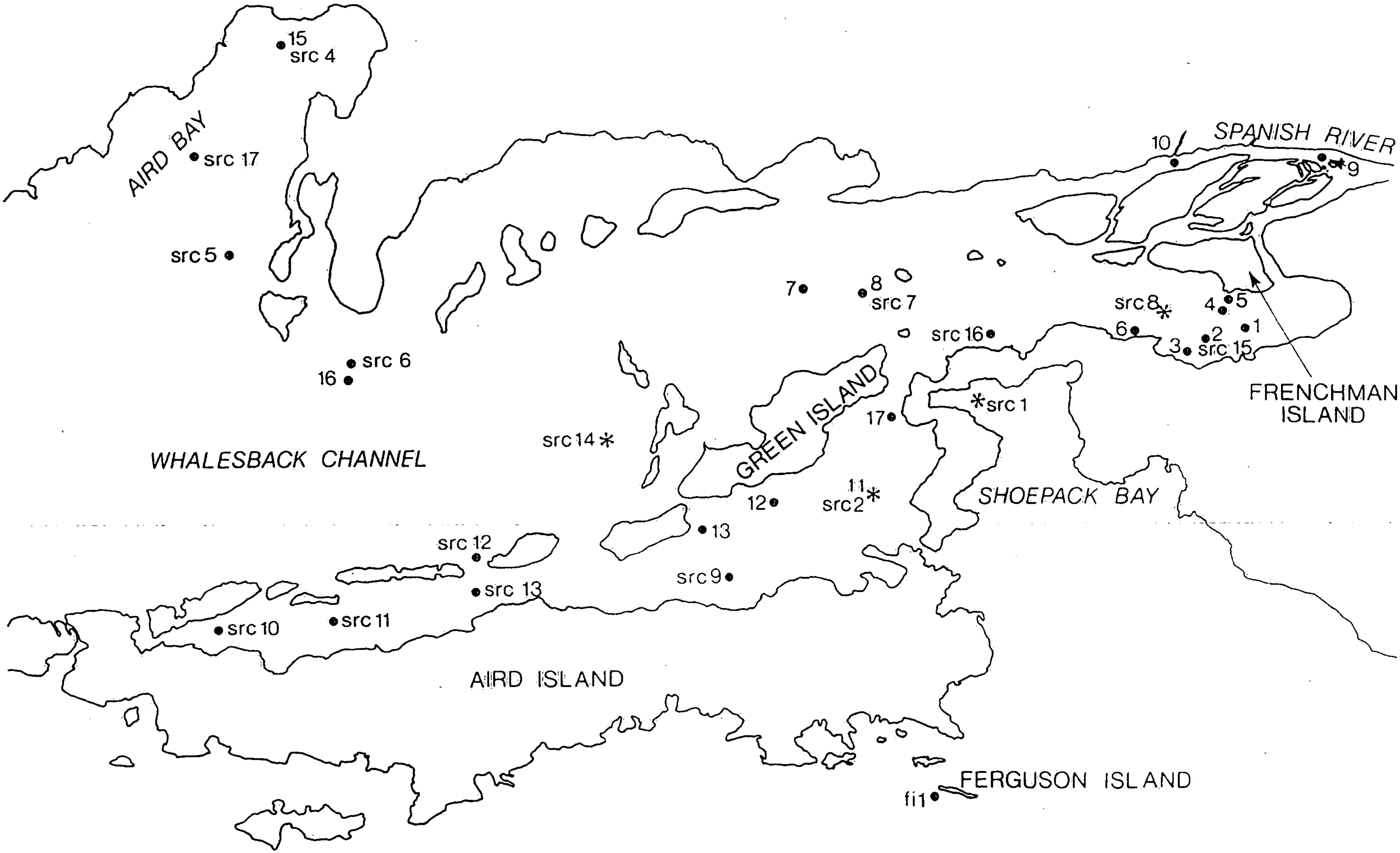


Figure 6. **SPANISH RIVER HARBOUR STUDY AREA, 1988**

*** [illegible]ewater Stations**

Figure 7. Sediment Porewater Profiles; SRP & NH3

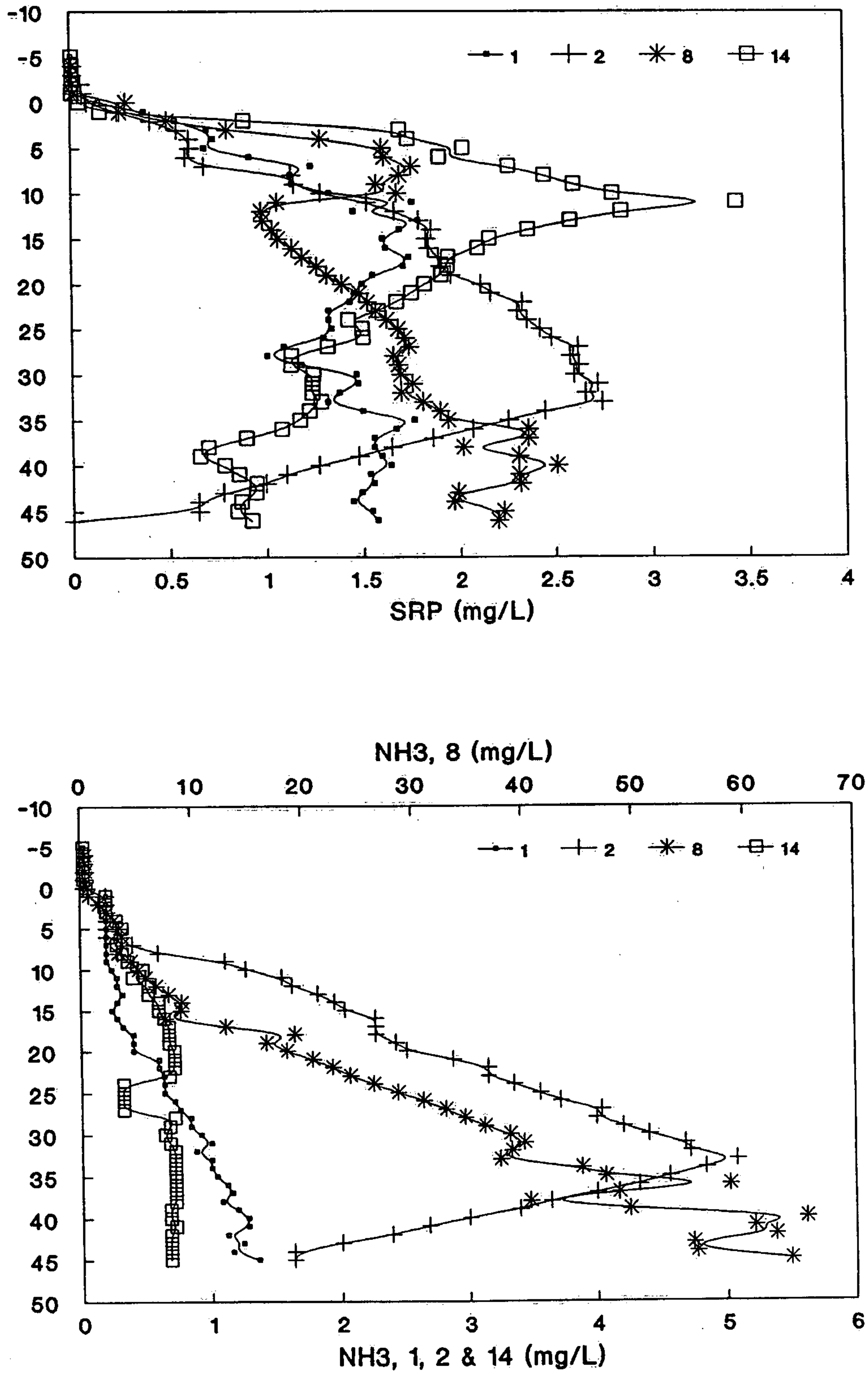
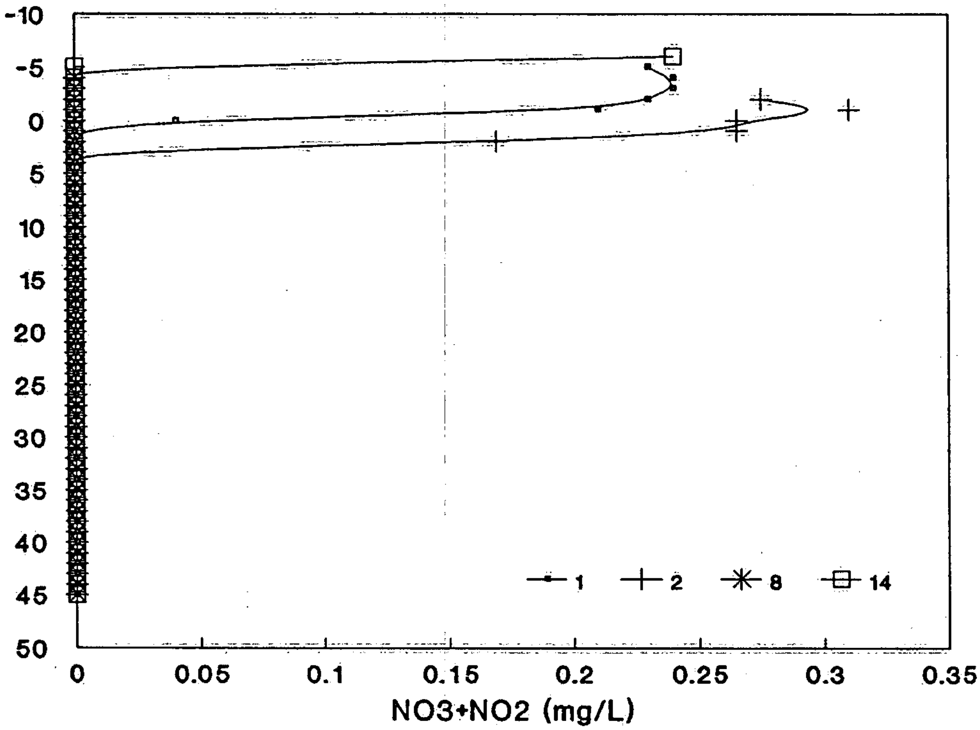


Figure 8. Sediment Porewater Profiles; NO3+NO2 & Ca



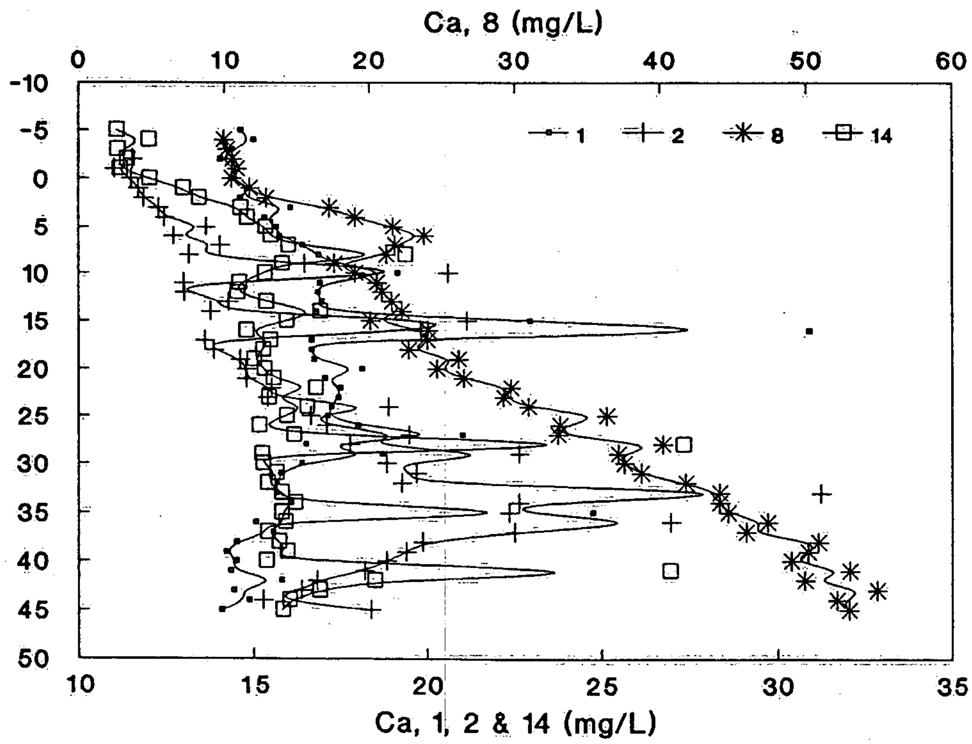
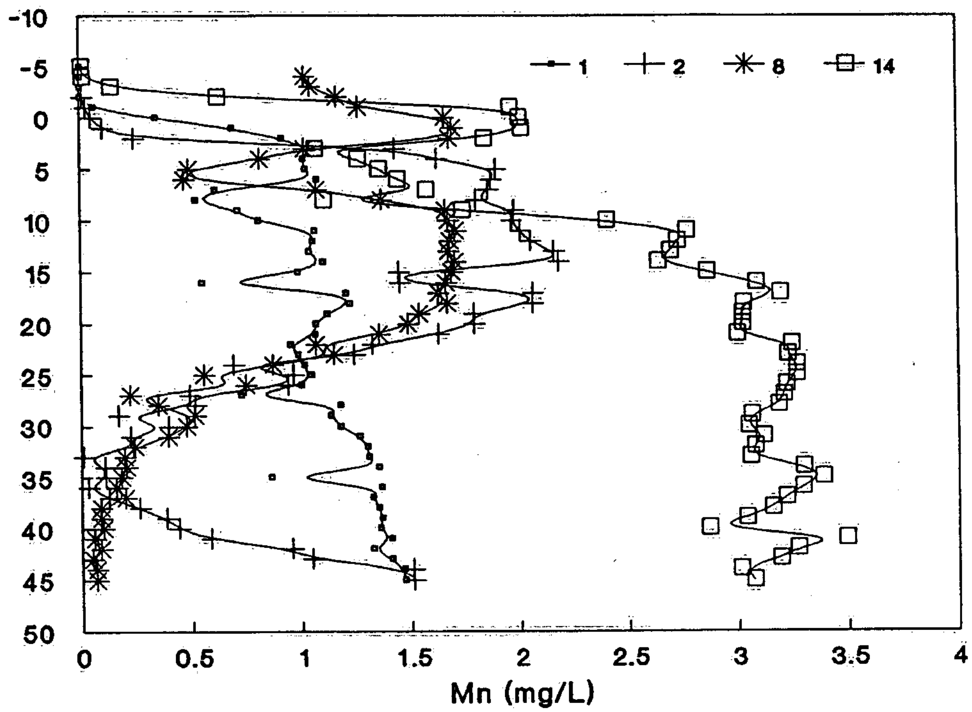


Figure 9. Sediment Porewater Profiles; Mn & Fe



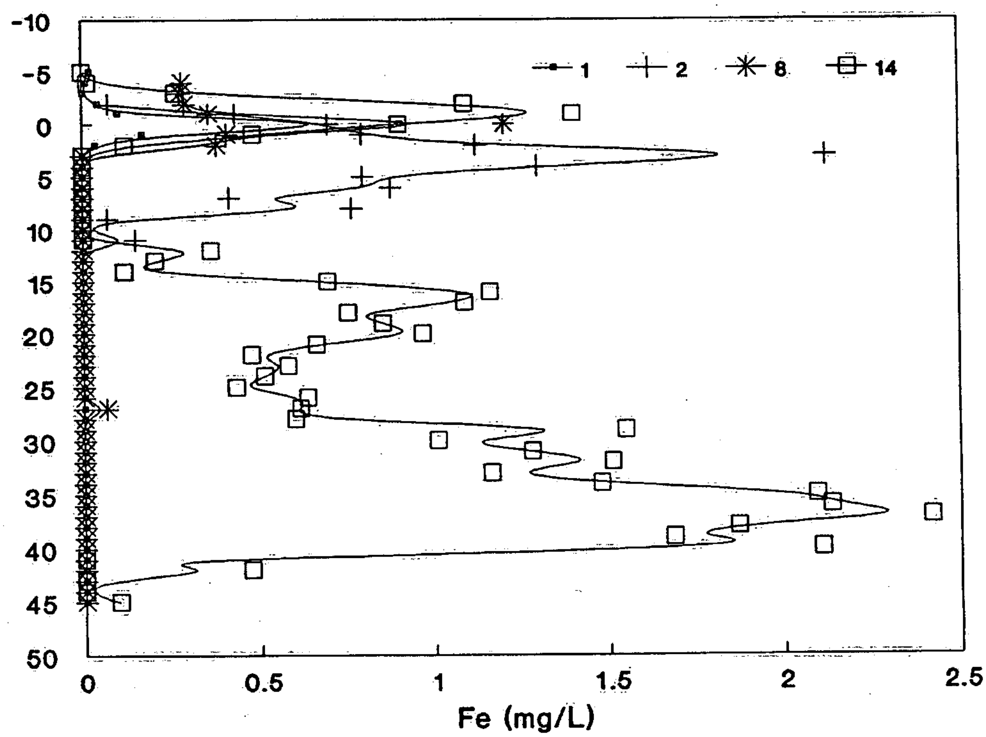
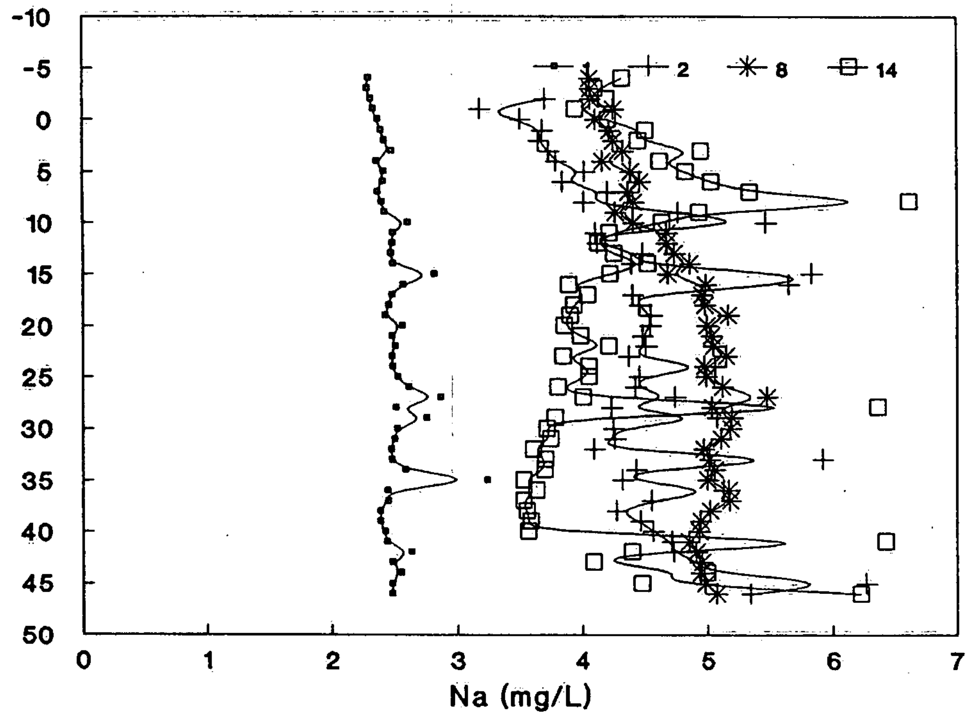


Figure 10. Sediment Porewater Profiles; Na & Sr



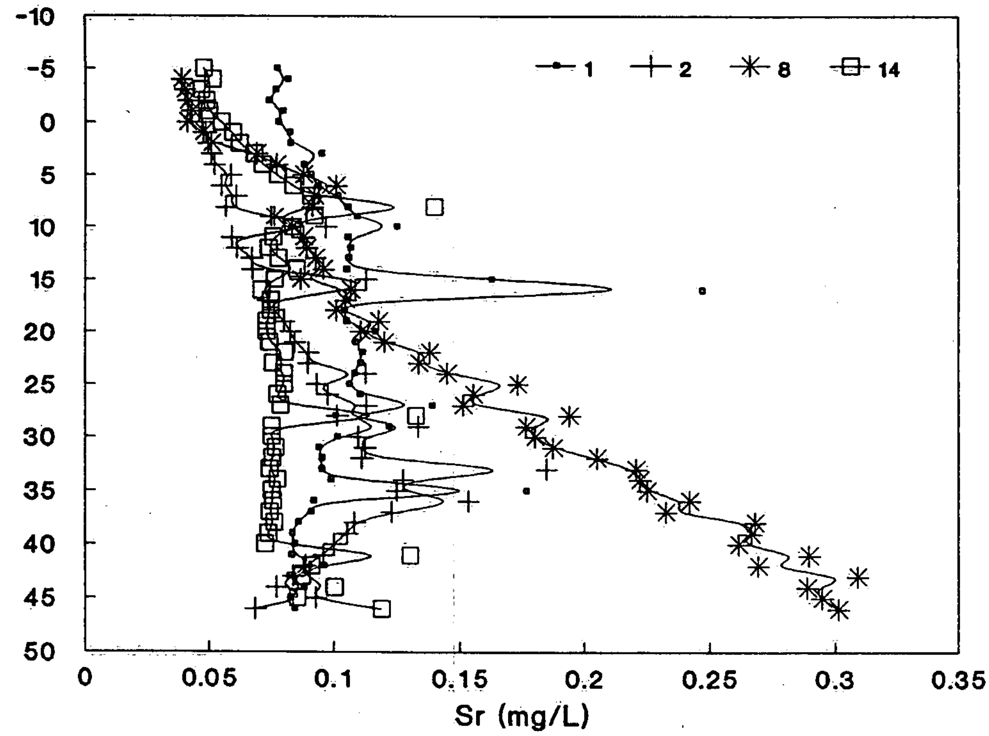
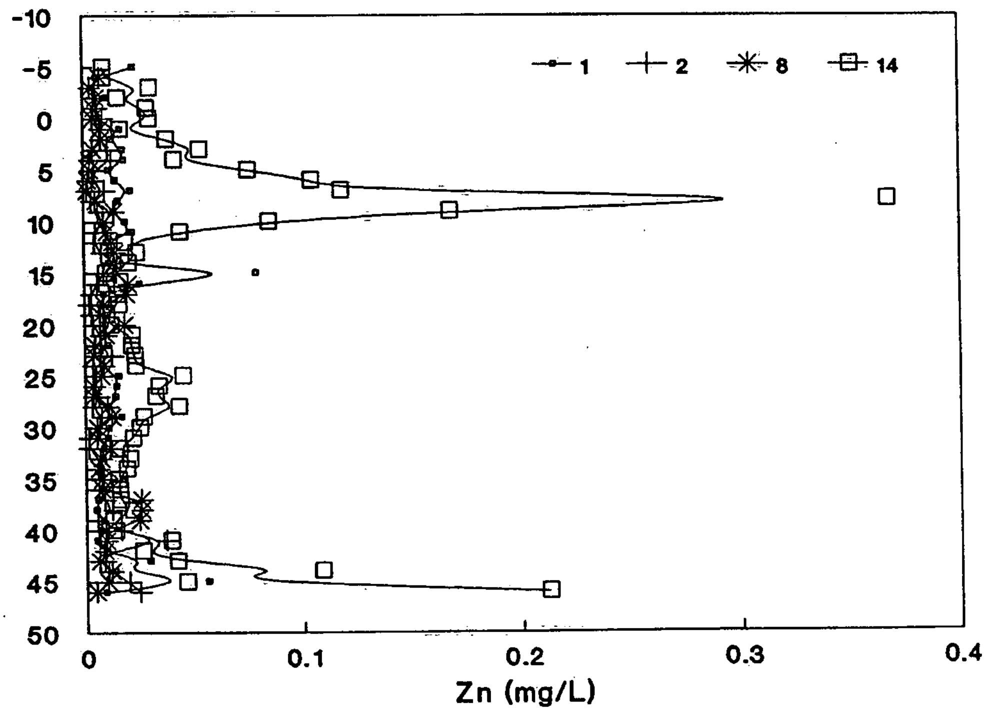


Figure 11. Sediment Porewater Profiles; Zn & Cu



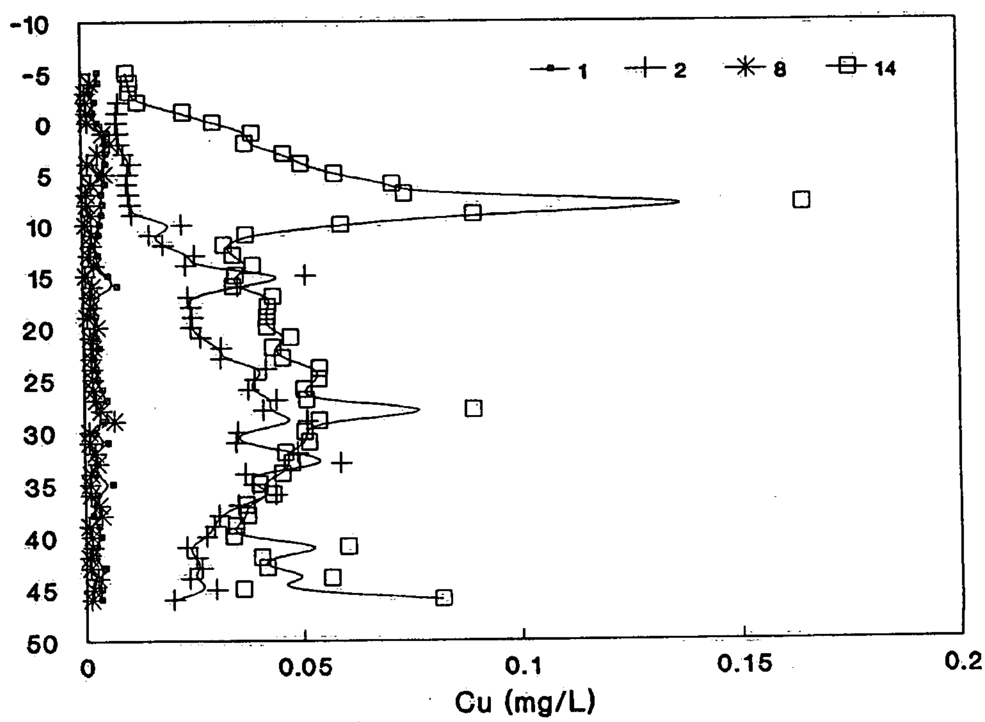
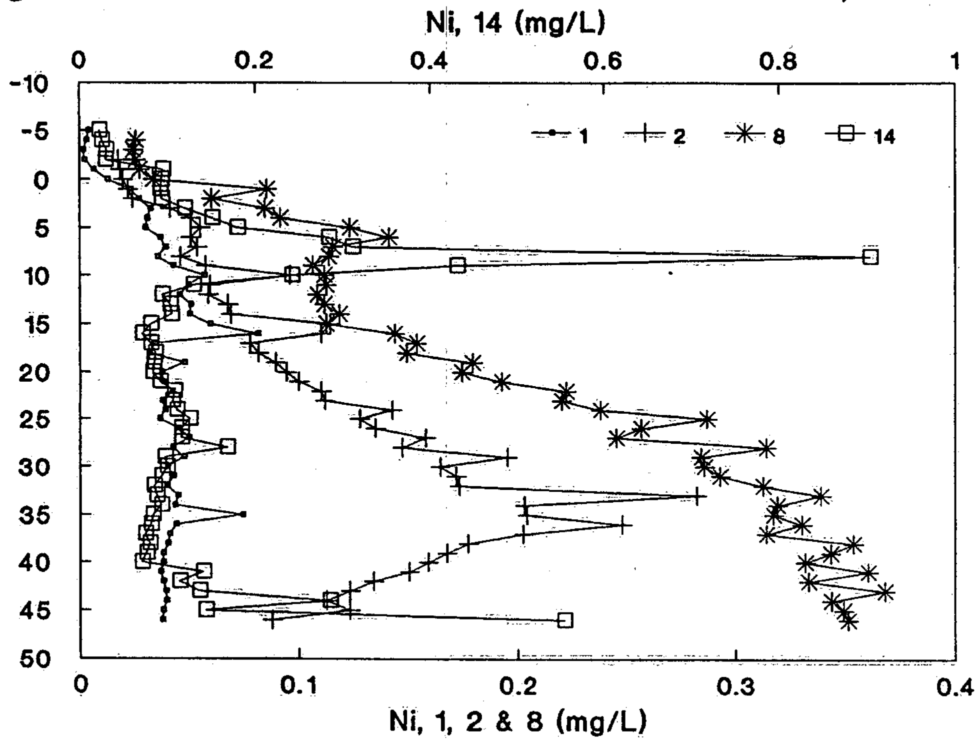
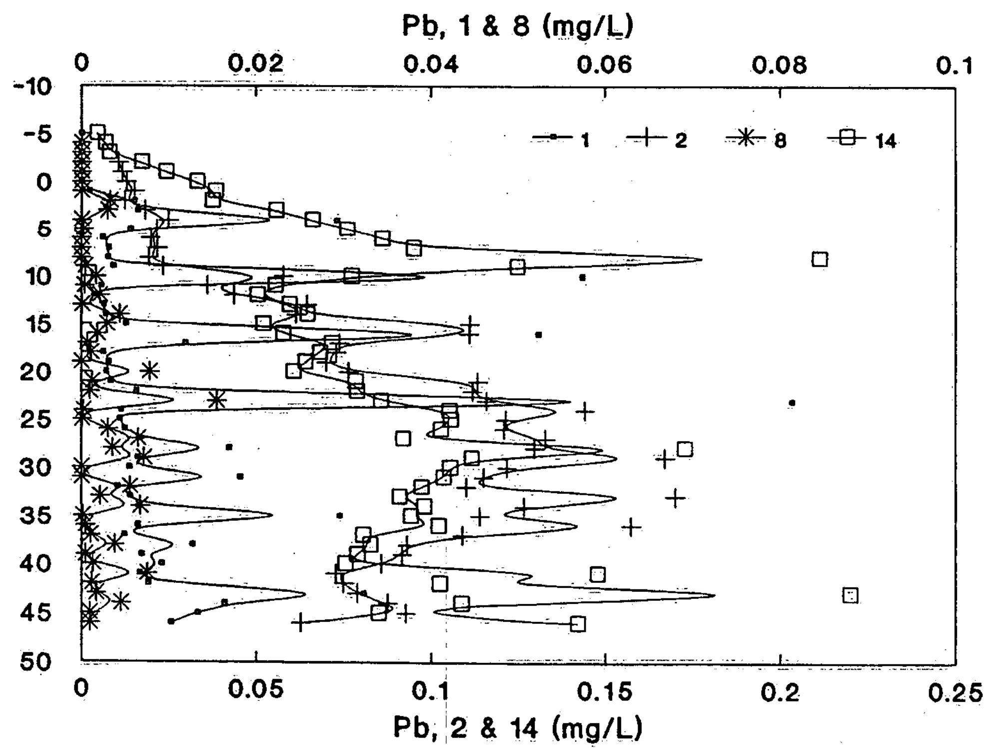


Figure 12. Sediment Porewater Profiles; Ni & Pb





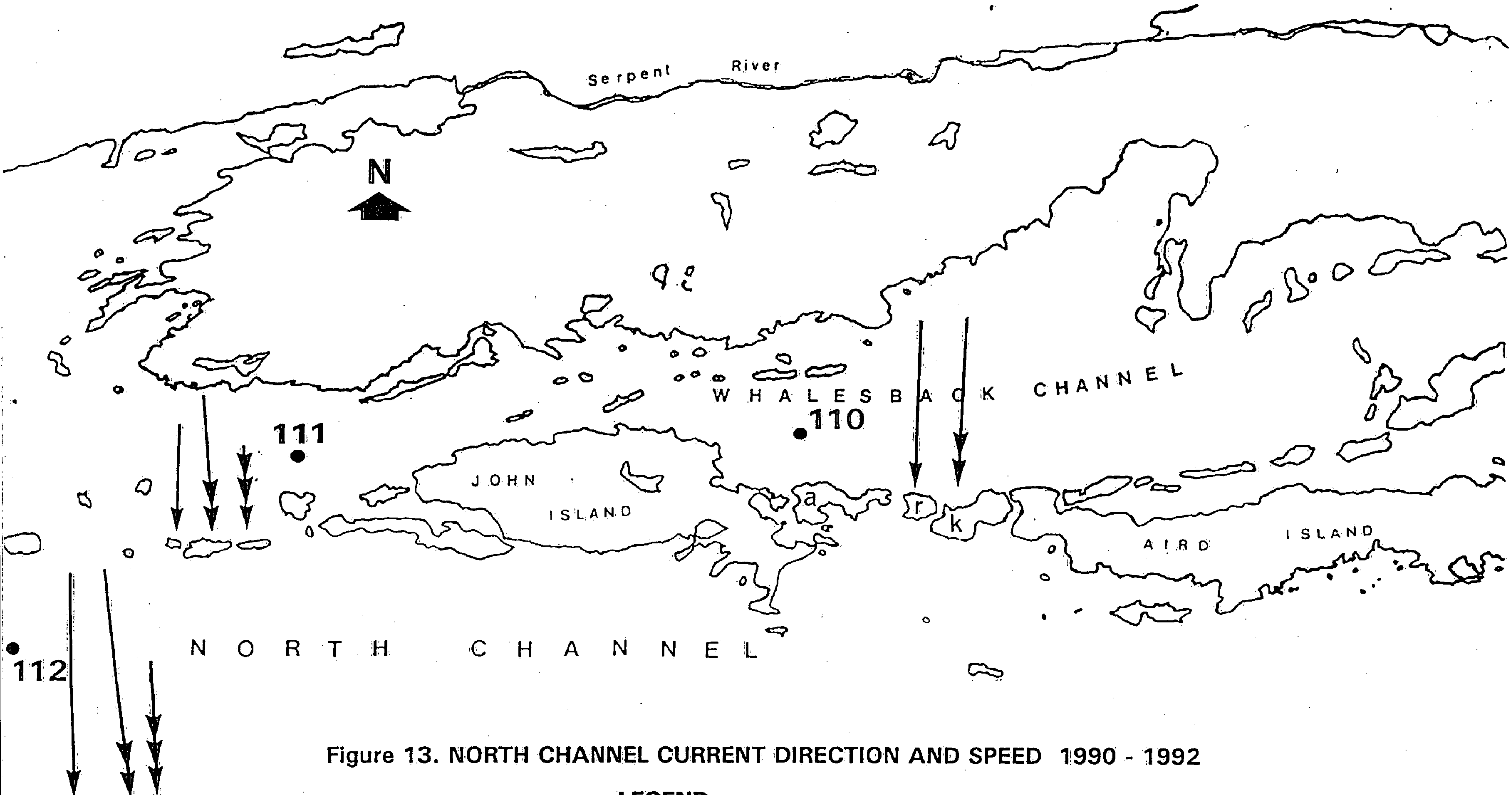
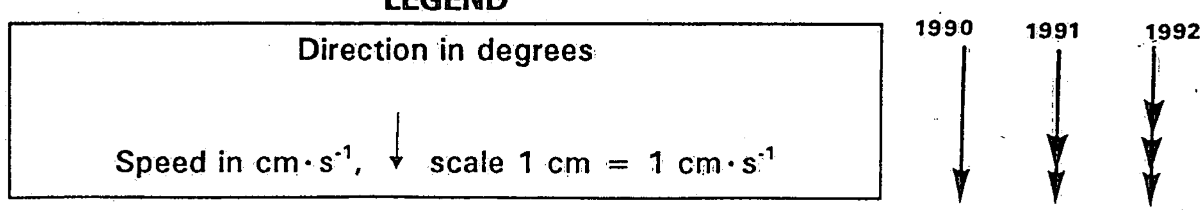


Figure 13. NORTH CHANNEL CURRENT DIRECTION AND SPEED 1990 - 1992

LEGEND



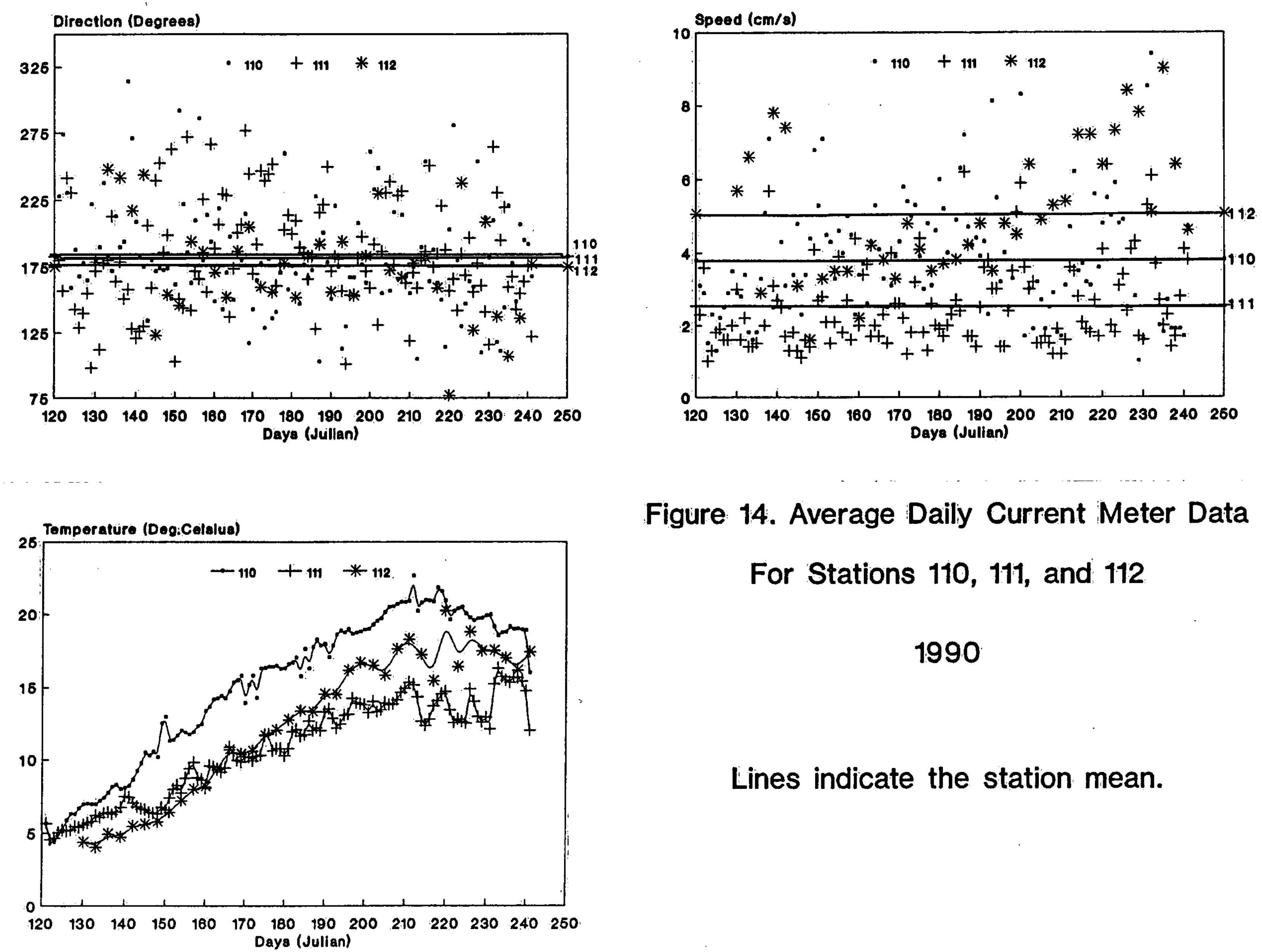


Figure 14. Average Daily Current Meter Data

For Stations 110, 111, and 112

1990

Lines indicate the station mean.

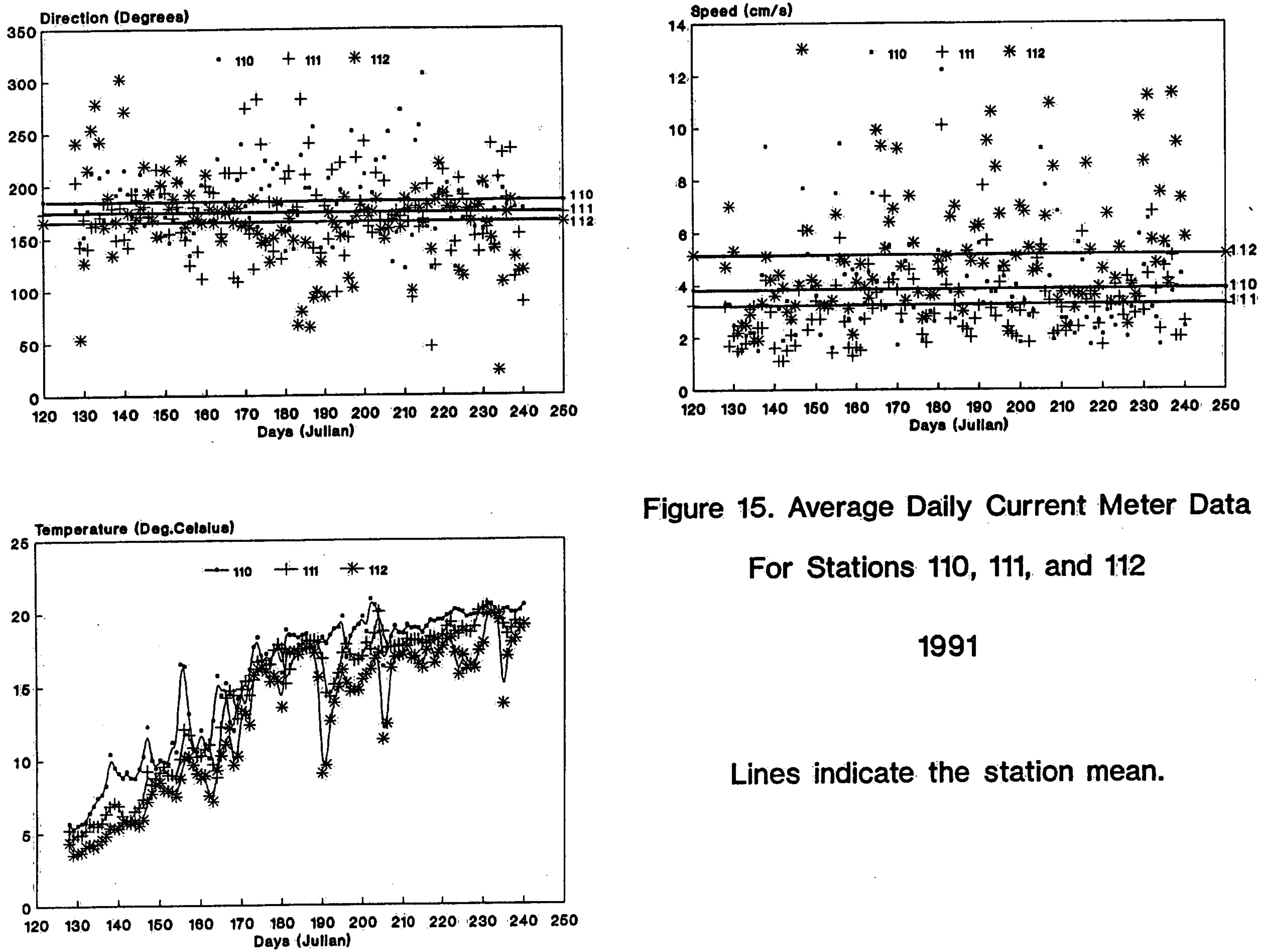


Figure 15. Average Daily Current Meter Data

For Stations 110, 111, and 112

1991

Lines indicate the station mean.

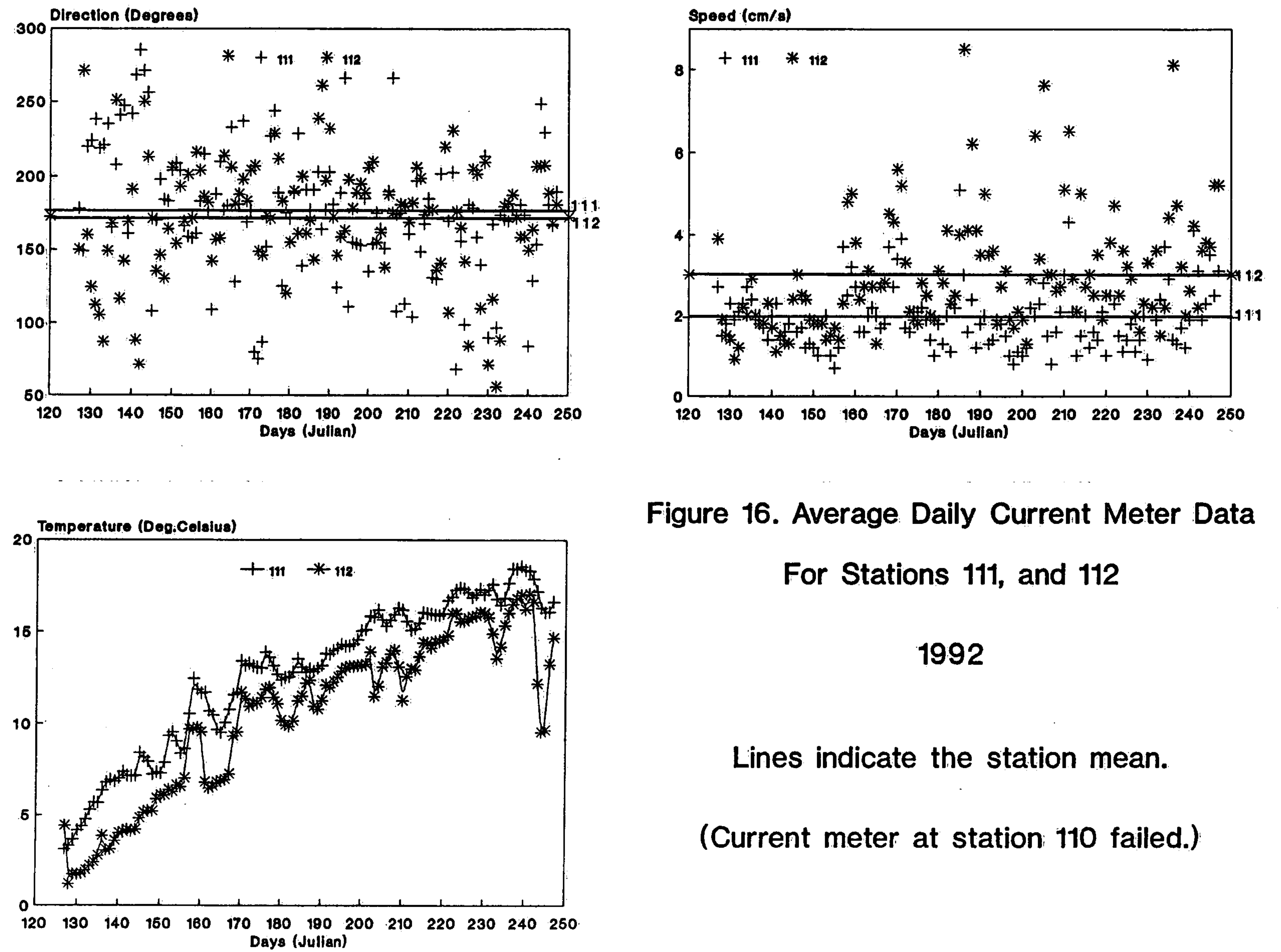


Figure 16. Average Daily Current Meter Data

For Stations 111, and 112

1992

Lines indicate the station mean.

(Current meter at station 110 failed.)