ST. LAWRENCE
REMEDIAL ACTION PLAN
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ST. LAWRENCE RIVER REMEDIAL ACTION PLAN

TECHNICAL REPORT #7

St. Lawrence River Sediment Assessment, 1994
Cornwall, Ontario

Lisa A. Richman

February 1996

Remedial Action Plan
Plan d'Assainissement

Canada Ontario

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CORNWALL, ONTARIO

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February 1996

FOREWORD

This report has been prepared under the auspices of the Canada-Ontario Great Lakes Remedial Action Plan Program. Financial support for the sampling projects, data analysis and report writing was provided by Environment Canada and the Ontario Ministry of Environment and Energy. The report presents the findings, recommendations, and conclusions of the author and RAP Team, and does not necessarily represent the views or policies of the supporting agencies.

This report is part of a series of technical investigations conducted in support of the St. Lawrence River Remedial Action Plan (RAP). For additional technical reports or information on the RAP, contact the St. Lawrence River RAP Coordinator at:

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This project was proposed by the St. Lawrence River Remedial Action Plan Team to provide information for the development of the Cornwall contaminated sediment removal demonstration project at Courtaulds planned for 1996. This information will also be used for the development of the Remedial Action Plan.

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The author would like to acknowledge the contribution of funds from Courtaulds Fibre Canada for the analysis of sediment samples for polycyclic aromatic hydrocarbons.

This study was funded in part by Environment Canada and the Ontario Ministry of the Environment and Energy under the terms of the Canada-Ontario Agreement respecting Great Lakes Basin Ecosystems.

REPORT SUMMARY

Background

The St. Lawrence River near Cornwall, Ontario and Massena, New York has been designated as a binational Great Lakes Area of Concern (AOC) by the International Joint Commission. Environmental degradation and the integrity of the aquatic ecosystem has been impacted because of the discharge of contaminants from local point and non-point sources, in addition to the contaminant input from Lake Ontario and the upstream Great Lakes basin. The contamination of sediment in the AOC is of particular concern and is the focus of discussion in this report.

Cornwall, Ontario and Massena, New York are major industrial centres on the St. Lawrence River. Local point sources on the Canadian side of the river at the time of the survey (October, 1994), included ICI Forest Products, Stanchem, Cornwall Chemicals, Domtar Fine Paper Ltd. (pulp and paper mill) and the municipal sewage treatment plant (STP). Courtaulds Fibres Canada, a division of Courtaulds Fibres Inc. (a rayon manufacturer), closed its operation in Cornwall in November 1992. Non-point sources to the river include agricultural runoff, municipal storm sewers, combined sewer overflows and atmospheric deposition.

Previous sediment surveys in the St. Lawrence River near Cornwall have identified an area of contaminated sediment adjacent to, and downstream of, the Courtaulds property (Kauss *et al.* 1988; Anderson 1990; Beak 1993; Richman 1994). Sediment samples collected in this area in all the surveys exceeded the Ontario Sediment Quality Guidelines "severe effect level" (SEL) for lead, copper, zinc and mercury (Persaud *et al* 1993). Samples collected within two kilometres downstream of Courtaulds also exceeded the SEL for mercury, and sediment bioassays to estimate acute and chronic toxic effects associated with the sediment showed reduced growth in mayfly nymphs (*Hexagenia limbata*) and chironomid (*Chironomus*) larvae in sediment collected in 1991 from the area of Courtaulds' shore based outfalls (Bedard and Petro 1992). Accordingly, the sediment in the vicinity of the Courtaulds property and downstream until Pilon Island was targeted by the St. Lawrence RAP Team as an area to be investigated for sediment remediation.

The federal government "Cleanup Fund" contributes funding in RAP areas for sediment projects that demonstrate innovative removal technology. Since the St. Lawrence River provides an opportunity to demonstrate sediment removal technology in a fast flowing river, a site for the demonstration project was chosen using data from a sediment survey by TransCanada PipeLine in 1993. This study indicated that several sampling sites between the Courtaulds Acid Recovery Drain, (a shore based outfall) and Courtaulds' effluent diffuser were significantly contaminated with mercury, lead, zinc and copper. This sediment quality information (Beak 1993) was used by the St. Lawrence River RAP Team to designate this area for a sediment removal demonstration project under the management of the federal "Cleanup Fund" program. Characterization of the extent of contamination downstream of the zone designated for the demonstration project was requested by the RAP Team and the demonstration project committee to determine if the most effective location for sediment removal had been chosen. This request led to the initiation of the 1994 sediment survey.

Objectives

The objectives of the 1994 sediment survey were:

(1) to determine if the zone designated for the demonstration project represented the most contaminated locations in the study area, and

(2) to determine the areal extent and depth of sediment which exceeds the Provincial Sediment Quality Guidelines "severe effect level" (SEL) and "lowest effect level" (LEL).

Results

Sixty-three core samples were collected from an area extending up to about 400 metres from shore and about two kilometres downstream of the Courtaulds property. The cores were sectioned every 10 cm throughout the entire core length. Only the top 10 centimetres and bottom section were submitted for analysis. The remaining sections were frozen for future analysis if required. Sediment samples were analyzed for a variety of metals, nutrients and physical parameters. Surface sediment grab samples using a stainless steel Shipek grab were also collected from 16 stations. The upper three centimetres of one grab was used for each sample.

Sediment contaminant concentrations were compared with the Provincial Sediment Quality Guidelines and with upstream reference stations in Lake St. Lawrence. Based on the Provincial Sediment Quality Guidelines the metals of concern for the study area were mercury, zinc, copper and lead. These were the only metals that exceeded the SEL. The median concentrations for these metals in the study area were higher than concentrations at the upstream reference stations. Sediment with concentrations greater than the SEL for zinc, lead and copper were limited to the area near the shore in proximity to, and immediately downstream of the shore based outfalls which historically discharged these metals (Kauss *et al.* 1988; Anderson 1990; OMOE 1992a and OMOE 1992b). An area of contaminated sediment which included stations 4, 5, 6, 9, 14, 15 and 64 had consistently high concentrations of mercury, lead, zinc and copper in the sediment cores. Concentrations exceeded the SEL in the core top and/or the core bottom samples for most of these metals. Although there were exceptions at some stations, in general, contamination of sediment continued downstream with concentrations of lead, copper and zinc decreasing with increasing distance from the outfalls both in the downstream direction and perpendicular from shore.

A band of contaminated sediment was present along the shoreline almost as far as Pilon Island (the most westerly point in the study area).

Mercury contamination above the SEL was more extensive than zinc, copper and lead. Mercury concentrations exceeded the SEL in 49% of the core top samples and 91% of the core bottom samples. Courtaulds was a known discharger of mercury as were two other major upstream sources; Domtar and ICI. Domtar terminated its use of mercury as a slimicide in 1970 (Kauss *et al*. 1988) and ICI continued to discharge mercury until the closure of the chlor-alkali plant in 1995. High concentrations of mercury farther downstream of the shore based outfalls were likely the result of the other upstream sources in conjunction with the contribution from Courtaulds.

Several stations clustered in the immediate vicinity of the shore based outfalls show lower concentrations of lead, copper, zinc and mercury in core top samples relative to core bottom samples. This pattern of sediment quality improvement is different than patterns for parameters that are not known to have significant point sources in the AOC (for example arsenic, cadmium, nickel, total organic carbon and total kjeldahl nitrogen) and may be related to changes in the concentration and loading of these compounds from the shore based outfalls once the Courtaulds effluent diffusers came on line in 1977. This is particularly applicable to zinc and lead since there were no known significant point sources of these parameters upstream (Kauss *et al*. 1988; Anderson 1990; OMOE 1992a and OMOE 1992b).

The high concentrations of mercury in the sediment close to the shore based outfalls reflect the same distribution patterns seen for zinc, copper and lead suggesting that mercury contamination in this area was likely associated with the same source (i.e. the shore based outfalls). Although there was some contribution of mercury to the area from ICI upstream, the shore based outfalls were likely the most significant source of mercury to the local contamination in front of the Courtaulds property. Effluent plume modelling of the Domtar/ICI/Cornwall Chemical diffuser and the Courtaulds shore based outfalls suggest that the Courtaulds shore based effluent discharges contributed more mercury to the Courtaulds nearshore zone than upstream sources. This is because of the dilution effect of the St. Lawrence River from upstream and the fast current in the main channel. The shore based outfalls were estimated to have contributed between 90 to 95% of the total mercury (attributed to point sources) under both recent and historical loading scenarios. Although some settling of the upstream plume would have occurred in the area around the outfalls, the suspected contribution relative to the local source is small (Nettleton 1996).

The distribution patterns of contamination in the sediment for antimony were similar to zinc, copper and lead as were patterns for percent sulphur, oil and grease and PAHs. Although there is evidence of a local source, concentrations of PAHs in the sediment were similar to concentrations typically found in industrialized areas in the Great Lakes basin. Total PAH concentrations at most stations were below or slightly above the LEL. Sediment concentrations of arsenic, iron, manganese, cadmium, chromium, nickel, selenium, total organic carbon, total phosphorus and total kjeldahl nitrogen were similar to concentrations found in sediment collected from Lake St. Lawrence which suggests that there was no local enrichment of the compounds with the possible exception of chromium.

With the exception of lead, mercury, zinc and (possibly) copper, the concentration of most metals, oil and grease and nutrients in the grab samples (top 3 cm) were similar to the concentrations found in the core tops (top 10 cm) collected from the same stations. If it is assumed that the top three centimetres do represent the most recent sediment deposition, then for most parameters, recent sediment quality conditions have not changed. For copper, mercury, lead and zinc the surface grab concentrations were lower than the concentrations in core top samples for a few stations close to the shore based outfalls which discharged these metals. This suggests that local improvements may be due to the plant closure which was two years prior to the study.

<u>**Conclusions and Recommendations**</u>

An objective of the 1994 sediment survey was to compare the data from the original area designated for the demonstration project with the sediment data collected in the 1994 survey to assess if the designated zone was the most effective location for the sediment removal project. The sediment quality at stations 4, 5, 6, 9, 14, 15 and 64 in the 1994 survey was comparable to the most contaminated sites in the original area designated for the sediment removal project.

- *If the sediment from the most contaminated area is to be removed during the demonstration project, the stations listed above from the 1994 study should be considered for inclusion in the project.*

- *Based on significant contamination of mercury, lead, zinc and copper at the bottom of the cores, dredging during the demonstration project must be to hardpan to ensure the removal of the most contaminated sediment.*

Mercury concentrations exceed the SEL throughout the study area downstream of the zone targeted for remediation. Stations 16, 18, 19 and 22 are all high in mercury as are stations 26, 31, 34 and 35 as well as a band of contamination extending along station 41, 43, 46 and 48. Concentrations of the other parameters of concern are not high at these sites.

- *Since these areas of contamination are not in proximity to the area targeted for remediation it is recommended that further evaluation and management of these sites be separate from the area close to the outfalls.*

- *As well, since some of these stations are located farther downstream of the Courtaulds sources, other upstream point sources have likely contributed to the contamination and should be consulted concerning future remediation plans.*

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INTRODUCTION

The St. Lawrence River near Cornwall, Ontario has been designated as a Great Lakes Area of Concern (AOC) by the International Joint Commission. Environmental degradation and the integrity of the aquatic ecosystem has been impacted because of the discharge of contaminants from local point and non-point sources, in addition to the contaminant input from Lake Ontario and the upstream Great Lakes basin. The contamination of sediment in the AOC is of particular concern and is the focus of discussion in this report.

Cornwall, Ontario and Massena, New York are major industrial centres on the St. Lawrence River. Local point sources on the Canadian side of the river at the time of the survey (October, 1994), included ICI Forest Products (a mercury cell chlor-alkali plant), Stanchem (a packaging plant that produces small quantities of chemicals in bottles, carboys or cylinders), Cornwall Chemicals (producers of sodium hydrosulphide, hydrochloric acid, carbon tetrachloride and carbon disulphide), Domtar Fine Paper Ltd. (pulp and paper mill) and the municipal sewage treatment plant (STP). Courtaulds Fibres Canada, a division of Courtaulds Fibres Inc. (a rayon manufacturer), closed its operation in Cornwall in November 1992. Non-point sources to the river include agricultural runoff, municipal storm sewers, combined sewer overflows and atmospheric deposition.

The effluents from ICI, Cornwall Chemicals and Stanchem were combined and discharged through the Domtar diffuser. This diffuser was located about four kilometres upstream of Courtaulds. Prior to 1978, wastewater from Courtaulds Films (closed in 1989) and Courtaulds Fibres Canada was discharged to a bay of the St. Lawrence River through four outfalls that were either shore based or terminated between 10 and 17 metres from shore. In late 1977 the wastewater was discharged into the main current through a diffuser, although the shore based sewers were also still in use. The Cornwall sewage treatment plant discharges its treated wastewater to the St. Lawrence River downstream of Courtaulds. All these point sources have contributed contaminants to the AOC (St. Lawrence River RAP Team 1992).

Previous sediment surveys in the St. Lawrence River near Cornwall have identified an area of contaminated sediment adjacent to, and downstream of, the Courtaulds property (Kauss *et al.* 1988; Anderson 1990; Beak 1993; Richman 1994). Sediment samples collected in this area in all the surveys exceeded the Ontario Sediment Quality Guidelines "severe effect level" (SEL) for lead, copper, zinc and mercury (Persaud *et al* 1993). Oil and grease were also present at concentrations above the antecedent Ministry of Environment and Energy (MOEE) Open Water Disposal Guidelines for dredged materials. Samples collected within two kilometres downstream of

Courtaulds also exceeded the SEL for mercury and sediment bioassays to estimate acute and chronic toxic effects associated with the sediment showed reduced growth in mayfly nymphs (*Hexagenia limbata*) and chironomid (*Chironomus*) larvae in sediment collected in 1991 from the area of Courtaulds' shore based outfalls (Bedard and Petro 1992). Accordingly, the sediment in the vicinity of the Courtaulds property and downstream until Pilon Island was targeted by the St. Lawrence RAP Team as an area to be investigated for sediment remediation.

The federal government "Cleanup Fund" contributes funding in RAP areas for sediment projects that demonstrate innovative removal technology. Since the St. Lawrence River provides an opportunity to demonstrate sediment removal technology in a fast flowing river, a site for the demonstration project was chosen using data from a sediment survey by TransCanada PipeLine in 1993. This survey was initiated because of interest in installing pipes in the vicinity of the Courtaulds property. The sediment quality information was requested to assess spoil handling and disposal options since trenching in the nearshore and landfill areas on the Courtaulds property was anticipated for pipe installation. The survey included the area (about 150 metres in length) between the Courtaulds intake and outfalls (open water diffuser). This study, undertaken by Beak Consultants Limited, indicated that several sampling sites between Courtaulds' Acid Recovery Drain, (a shore based outfall) and Courtaulds' effluent diffuser were significantly contaminated with mercury, lead, zinc and copper. This sediment quality information (Beak 1993) was used by the St. Lawrence River RAP Team to designate this area for a sediment removal demonstration project under the management of the federal "Cleanup Fund" program.

Characterization of the extent of contamination downstream of the zone designated for the demonstration project was requested by the RAP Team and the demonstration project committee to determine if the most effective location for sediment removal had been chosen. This request led to the initiation of the 1994 sediment survey.

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The objectives of the 1994 sediment survey were:

(1) to determine if the zone designated for the demonstration project represented the most contaminated locations in the study area, and

(2) to determine the areal extent and depth of sediment which exceeds the Provincial Sediment Quality Guidelines "severe effect level" (SEL) and "lowest effect level" (LEL).

METHODOLOGY

Sampling Stations and Field Methods

An area extending up to about 400 metres from shore and about two kilometres downstream of the Courtaulds property was designated for intensive sediment collection. The selection of the stations was based on the results from previous sediment contaminant surveys, and from a 1993 Environment Canada study designed to classify sediment bottom type (eg. sand, silt, boulders) using an acoustic profiling system called Roxann (Rukavina 1994). The results from the Roxann survey provided information on the location of soft sediment indicative of a depositional environment with accumulations of fine grained materials. Preselecting stations with soft sediment facilitated the collection of core samples for chemical analysis. The same area was surveyed again by Environment Canada with Roxann during the contaminant survey so that particle size data from the sediment contaminant study could be used to calibrate the Roxann system.

Sampling stations were located using the Sercel GPS on loan to the MOEE by Environment Canada. Figures 1 to 3 provide maps of the sampling stations and study area. The scale on all maps in this report is 1 cm = 100 m. Appendix A5-1 provides the Northings and Eastings for all sampling locations.

Cores were collected from 63 stations to depth of refusal using a modified benthic corer fitted with polycarbonate core tubes. The cores were sectioned every 10 cm throughout the entire core length. Only the top 10 centimetres and bottom section (at least 7 cm in length) were submitted for analysis. The remaining sections were frozen for future analysis. There were a few bottom samples sectioned as long as 18 cm; however, most bottom samples were between 9 to 15 cm in length. Cores 15 cm or less were submitted whole. Core lengths are provided in Appendix A5-2 and A5-3. Sediment samples were analyzed for a variety of chemical and physical parameters (Table 1).

Although cores were not dated, the top ten centimetres were chosen for analysis since this section of the core was intended to represent recent contamination. This depth is expected to represent the area of bioturbation and greatest sediment mixing. As well, about 10 cm of sediment was required to provide sufficient biomass for contaminant analysis. Since the cores differed in total length throughout the study area, assumptions about the time span represented by the bottom section of the cores were not possible. Similarly, differences in total core lengths suggest different rates of sedimentation within the study area. However, the bottom ten centimetres of the core contained sediment that would provide information on historical contamination relative to the top of the core. The main purpose for analyzing the bottom of the cores was to determine the extent of contamination with respect to depth.

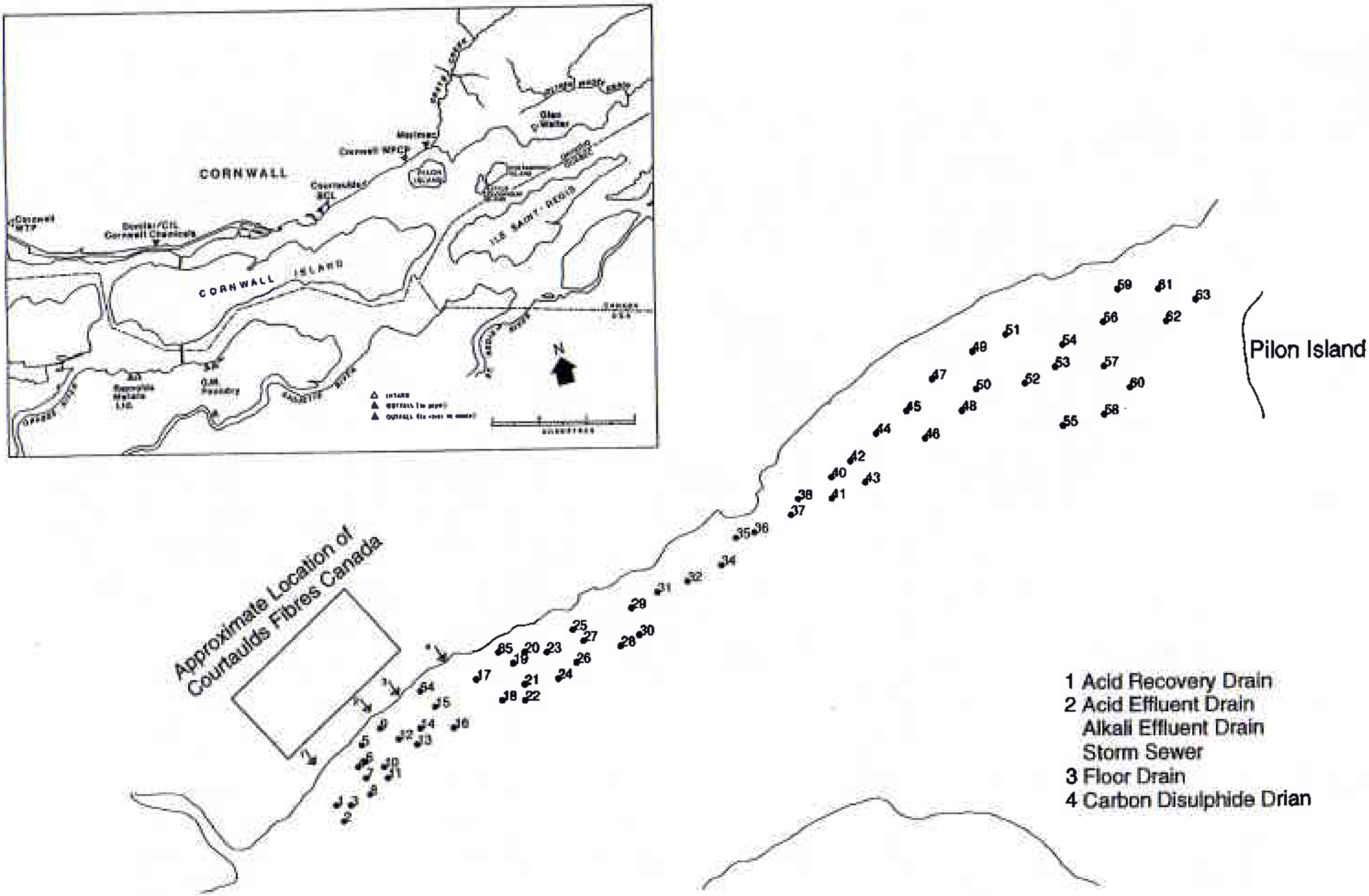


Figure 1:Core Top Sampling Stations

1cm=100m

Figure 2: Core Bottom Sampling Stations

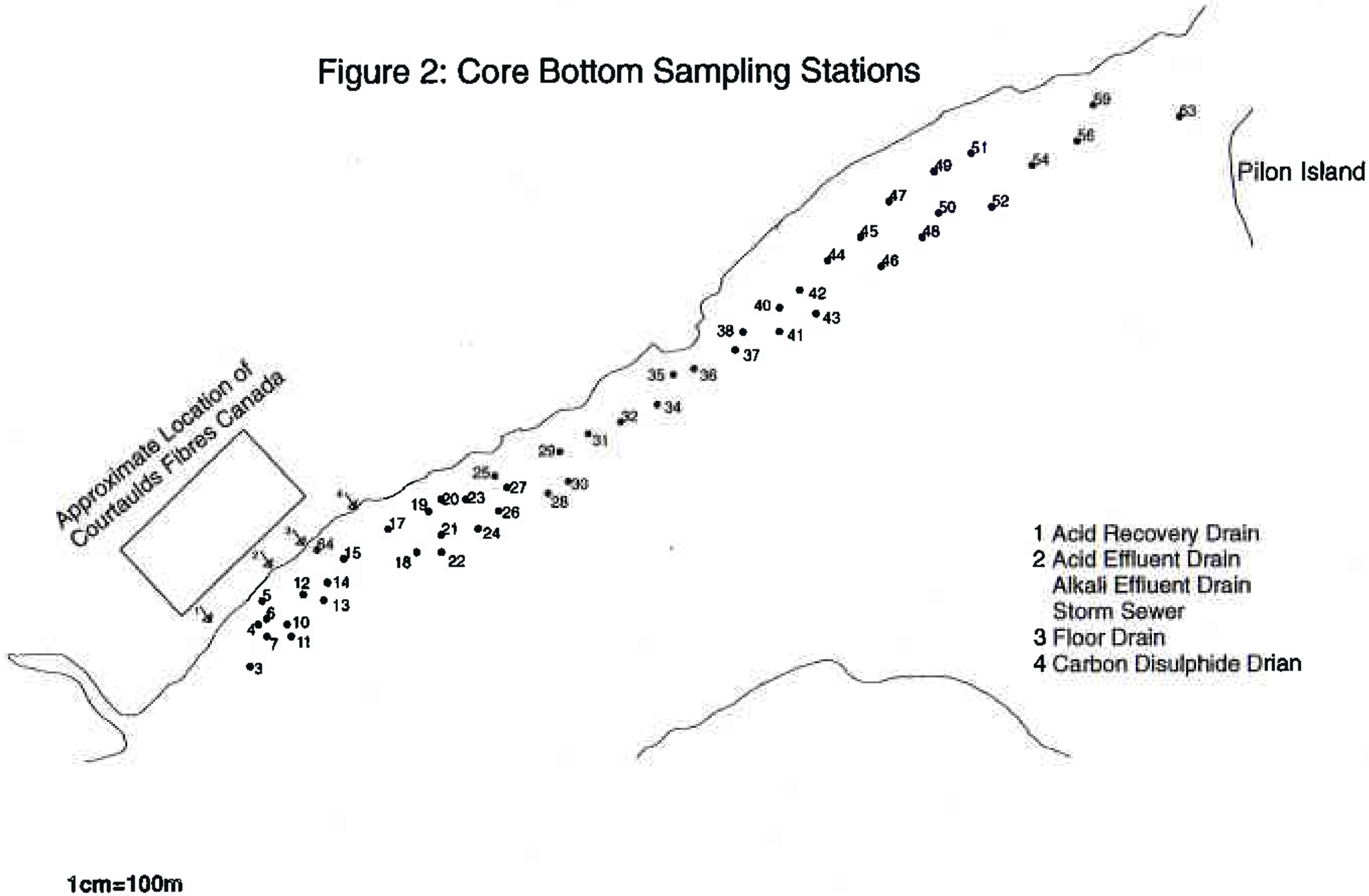
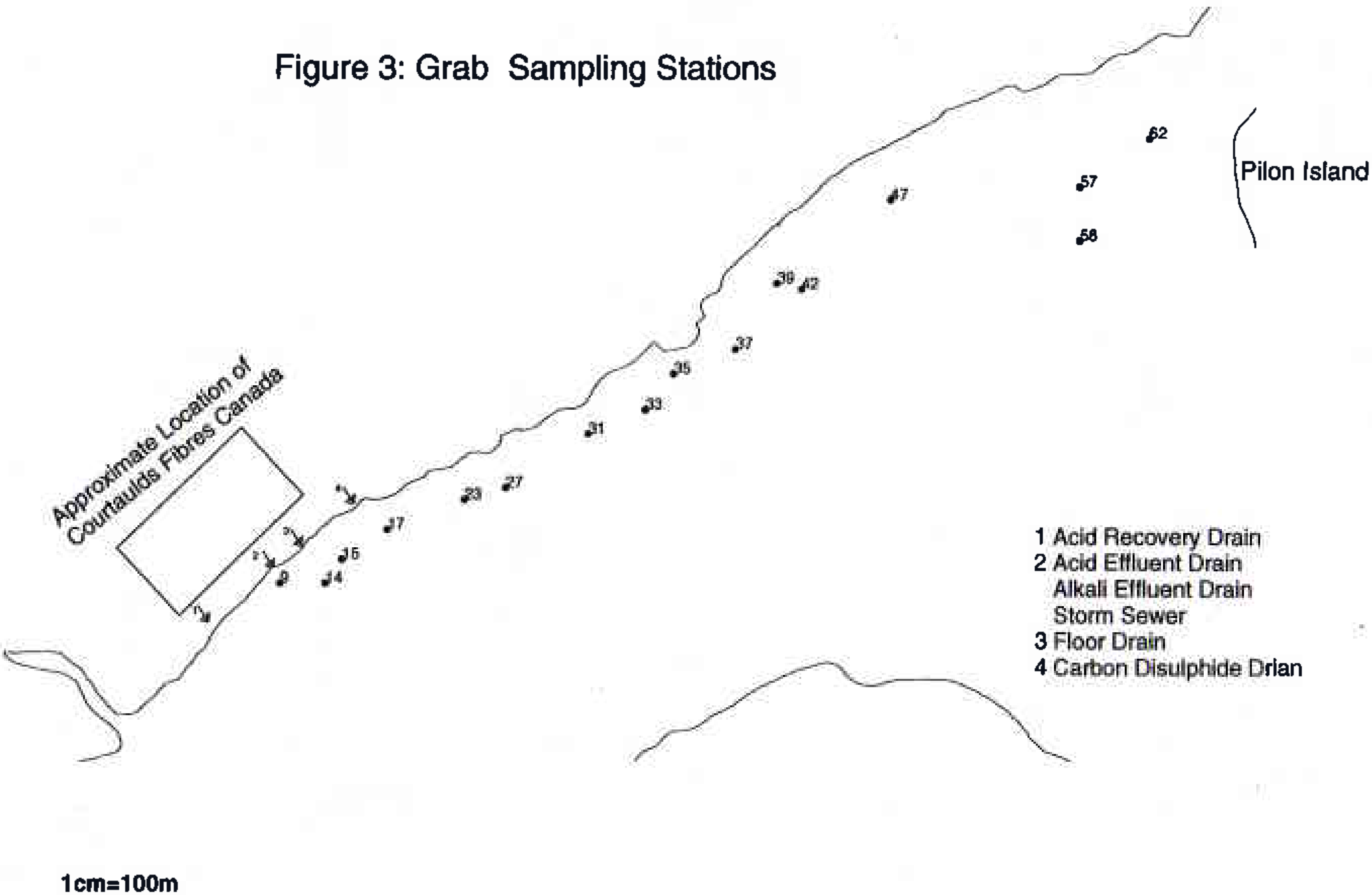


Figure 3: Grab Sampling Stations



These results would have implications concerning the depth of dredging and the volume of sediment to be removed should this form of remediation be required.

At six stations triplicate cores were collected to evaluate sample variability within a station.

Table 1: Sediment samples were analyzed for the following parameters:	
Total Organic Carbon (TOC) Total Phosphorus (TP) Total Kjeldahl Nitrogen (TKN)	
Selenium Chromium Mercury Arsenic Lead Aluminum %Sulphur Antimony	Cadmium Manganese Zinc Nickel Iron Copper Oil and Grease
Loss on Ignition (LOI) Particle Size % Moisture	Polycyclic aromatic hydrocarbons (PAH)

Surface sediment grab samples using a stainless steel Shipek grab were also collected from 16 stations. The upper three centimetres of one grab was used for each sample and submitted for analysis. These samples were intended to assess the most recent sediment contamination. Samples were homogenized in a pyrex tray with a porcelain or stainless steel spatula. Three replicate samples were collected at three of the 16 stations to assess within station variability. Sufficient sediment was collected (two separate grabs were pooled) to split each replicate into three subsamples to evaluate variability due to sample handling and collection methods.

All sediment samples were kept on ice in the field, and refrigerated at 4·C in the dark until analysis. The general sample composition (e.g. sand, silt etc.), sediment colour and any unusual features were recorded. Photographs were taken of each core sample.

Contaminant Analysis of Sediment

All laboratory analytical procedures for contaminants in sediment followed the methodology outlined in the Handbook of Analytical Methods for Environmental Samples (MOE 1983). Procedural updates for metals analysis are provided in MOE 1989a & b, and MOE 1990. Procedural updates for nutrient analysis, LOI, TOC, oil and grease and percent sulphur are provided in MOEE 1995a to d. Samples collected for PAH analysis were submitted to MDS Environmental Services Ltd. Analysis of PAHs was by GC/MS with a GC/MSD Hewlett-Packard 5890II GC, 5971A MSD, A/S UNIX 340DS. Samples were analyzed following the U.S. EPA Method No. 3510, Method No. 8270 and Method No. 3550. Determination of moisture content in sediment by weight was by the ASTM Method No. D2216-80.

Data Analysis

Mean inorganic contaminant concentrations in replicate sediment grab and core samples were compared among and within stations using a two-way nested ANOVA. This provided information on the proportion of total variability in the data set that was attributed to between station variability, within station variability and within sample variability for the grab samples by comparing the sum of the squares for each component. All sediment data were log transformed prior to statistical analysis to satisfy assumptions of normality. Within station variability and sample variability were also assessed using replicate grab and core samples by evaluating the coefficient of variation (CV) for all parameters. The CVs were based on non-transformed data. These results are provided in Appendix A7.

The Pearson product-moment correlation was performed on non-transformed data using the SAS statistical package (SAS Institute Inc. 1988) to examine the relationship and distribution patterns for major sediment contaminants and physical parameters. A principal components analysis using the Numerical Taxonomy and Multivariate Analysis System (PCA) (NTSYS-pc; Rohlf 1988) was also used to reduce the data onto three components representing the variables that best correlate with one another and explain the major sources of variation in sediment quality among the 63 stations. A correlation analysis and PCA were performed separately on the core top and core bottom samples since these represent two distinct data sets. The results from these analyses are presented in Appendix A8.

RESULTS AND DISCUSSION

Sediment contaminant concentrations were compared with the Provincial Sediment Quality Guidelines (Persaud *et al.* 1992). All data are summarized in Tables 2 to 6 and in Figures 4 to 11. All raw data for metals and nutrients are provided in Appendix Tables A1 and A2. These guidelines describe three "effect" levels for different contaminants in terms of potential effects on the benthic community: (1) the no observed effect level; (2) the lowest effect level (LEL) which is the level of sediment contamination that can be tolerated by 95% of benthic organisms (concentrations greater than this level indicate that the benthic communities in these areas may be impaired); and (3) the severe effect level (SEL) which is the sediment concentration of a compound that is expected to be detrimental to 95% of benthic species.

Sediment was collected from two stations upstream of Cornwall in Lake St. Lawrence in 1991 to serve as reference stations (relative to "pristine" conditions in the St. Lawrence River) for the 1991 sediment contaminant survey (Richman 1994). The data from these two stations and data from sediment collected in 1983 from Wolfe Island at the head of the St. Lawrence River (Persaud *et al.* 1989) are used as background data for comparisons with metal and nutrient concentrations in sediment samples collected in 1994. Table 3 compares the ranges and median values for metal and nutrient concentrations obtained in these studies. Sediment metal and nutrient concentrations at the upstream reference stations in Lake St. Lawrence were consistent with metal concentrations (and nutrients) found in sediment collected near Wolfe Island (Persaud *et al.* 1989) suggesting that the Lake St. Lawrence stations represent background concentrations. Only cadmium concentrations in sediment were lower at Wolfe Island than concentrations at the Lake St. Lawrence reference stations.

Metal Concentrations in Sediment.

Based on the Provincial Sediment Quality Guidelines and a comparison with the upstream reference stations in Lake St. Lawrence the metals of concern for the study area were mercury, zinc, copper and lead (Table 2). These were the only metals that exceeded the SEL. A comparison of the data from this sediment study with the upstream reference sites suggest local sources (point and/or non-point) of copper, mercury, lead and zinc since median values for these metals were higher than sediment concentrations at the reference stations (Table 3).

Zinc concentrations exceeded the LEL in 86% of the core top samples and in 46 out of 47 of the core bottom samples (98%). Eleven percent of the core tops and 23% of the core bottoms (11 samples) exceeded the SEL (Figures 4a&b). For lead and copper, 76% of core top samples exceeded the LEL as well as 91% and 100% of the core bottom samples, respectively (Figures 5a&b and 6a&b). The SEL for copper was exceeded or approached at three stations in the core top samples and four stations

TABLE 2: Metal Concentrations (µg/g dry weight) in Sediment Samples From the St. Lawrence River, 1994
(Means and [Standard Deviations] are provided if N>1)

ENV.CAN STN #	SMP TYPE	N	AL ug/g	AS ug/g	CD ug/g	CR ug/g	CU ug/g	FE ug/g	HG ug/g	MN ug/g	NI ug/g	PB ug/g	SB ug/g	SE ug/g	ZN ug/g
CS-01	C	1	7700	2.6	0.41	27.00	51.00	13000	1.64	230.00	19.00	99.00	1.8	0.8	730.00
CS-02	C	1	9528	2.9	0.82	31.20	36.72	16006	1.43	248.16	17.60	55.90	1.0	0.7	610.94
CS-03	C-T	1	9500	3.6	0.90	33.00	44.00	16000	2.12◆	240.00	20.00	73.00	1.5	1.0	700.00
CS-03	C-B	1	7200	4.2	0.46	30.00	84.00	12000	12.03◆	200.00	16.00	200.00	6.6	0.5	1500.00◆
CS-04	C-T	1	16230	5.4	1.56	64.48	75.31	23641	2.18◆	307.78	32.80	103.26	1.5	1.6	1181.10◆
CS-04	C-B	1	8388	4.3	0.68	36.23	99.96	11887	23.70◆	209.19	21.79	287.41◆	9.7	0.9	1671.00◆
CS-05	C-T	1	14047	6.3	2.13	70.46	124.60◆	20614	13.02◆	252.06	40.78	386.09◆	10.0	2.0	2568.60◆
CS-05	C-B	1	13635	7.1	1.81	83.74	176.92◆	21021	70.51◆	285.02	44.95	858.62◆	30.0	1.7	3646.50◆
CS-06	C-T	1	13154	4.0	1.46	48.82	60.58	18392	2.14◆	276.07	27.88	98.61	1.7	1.2	858.63◆
CS-06	C-B	1	8075	3.9	0.60	36.74	64.76	12778	17.84◆	241.06	18.34	344.17◆	12.0	0.5	1251.30◆
CS-07	C-T	1	8229	2.2	0.76	22.78	26.04	11755	0.66	231.14	14.48	36.36	0.5	0.5	384.44
CS-07	C-B	1	7174	1.9	0.62	21.90	26.04	10058	1.42	203.31	13.16	47.41	0.6	0.6	337.25
CS-08	C	1	5798	1.6	0.41	18.16	20.88	10940	0.86	197.99	11.71	51.26	1.0	0.3	379.26
CS-09	C	1	9642	3.4	0.94	41.27	108.85	15781	7.74◆	206.99	21.42	654.47◆	17.0	1.2	2044.60◆
CS-09	G	1	13978	5.7	1.82	61.10	82.35	20283	2.71◆	270.09	32.61	219.23	6.5	2.1	1469.20◆
CS-10	C-T	1	5717	1.4	0.66	15.59	19.22	7856	3.92◆	168.11	10.06	30.57	0.3	0.3	166.47
CS-10	C-B	1	6037	2.3	0.72	23.32	48.41	8906	1.21	163.63	15.84	123.27	3.2	0.6	978.98◆
CS-11	C-T	1	14200	4.3	1.53	43.34	52.85	20224	1.18	297.75	28.72	62.12	0.9	1.1	781.16
CS-11	C-B	1	12796	5.9	2.67	61.89	82.41	19609	6.98◆	276.22	32.34	229.89	5.8	2.1	2739.10◆
CS-12	C-T	3	8952[2932]	2.8[1.0]	1.00[0.40]	35.70[16.11]	47.25[19.72]	13673[4918]	1.35[0.79]	218.74[44.33]	18.89[7.30]	64.85[29.58]	1.0[0.3]	0.9[0.3]	571.10[246.19]
CS-12	C-B	3	7804[1903]	3.5[0.6]	1.49[0.46]	46.70[9.58]	130.36[4.8]◆	12591[2437]	9.82[2.01]◆	169.71[28.43]	44.91[10.91]	501.56[133.95]◆	17.0[6.0]	7.9[4.5]	2085.4[363.1]◆
CS-13	C-T	1	7341	2.0	0.73	20.34	23.43	11565	0.66	278.87	13.50	24.76	0.5	0.5	209.64
CS-13	C-B	1	7160	3.4	1.31	31.35	82.65	11234	47.50◆	169.94	24.18	467.83◆	14.0	1.9	2054.00◆
CS-14	G	1	7967	2.6	0.84	45.04	71.00	13533	1.34	199.64	20.36	106.79	1.6	1.0	971.64◆
CS-14	C-T	1	10911	3.7	1.10	60.87	96.94	17283	2.06◆	231.25	27.96	173.68	2.2	1.3	1450.80◆
CS-14	C-B	1	9648	4.5	1.52	51.21	161.32◆	14486	11.01◆	204.89	42.04	867.87◆	33.0	2.8	3729.20◆
CS-15	Split 1-G	3	10238[1000]	3.0[0.3]	1.03[0.16]	32.81[3.54]	61.16[12.16]	15777[1203]	1.20[0.12]	262.68[17.09]	16.69[1.67]	66.86[7.01]	0.8[0.1]	0.9[0.1]	430.80[66.18]
CS-15	Split 2-G	3	7965[718]	2.3[0.1]	0.65[0.16]	25.67[1.98]	41.02[2.90]	11729[963]	0.74[0.06]	227.75[11.64]	14.46[1.57]	67.39[8.14]	0.6[0]	0.6[0]	323.62[31.40]
CS-15	Split 3-G	3	11099[217]	3.5[0.2]	1.20[0.11]	36.01[1.52]	61.72[2.65]	16529[396]	1.13[0.06]	264.05[8.27]	21.70[1.01]	73.14[6.73]	0.9[0]	0.9[0.1]	466.96[19.64]
CS-15	C-T	3	12667[577]	4.1[0.1]	1.70[0.10]	46.67[2.52]	71.00[2.00]	19000[1000]	1.56[0.13]	300.00[10.00]	27.07[2.08]	113.33[5.77]	1.4[0.2]	1.1[0.2]	823.30[20.82]◆
CS-15	C-B	3	11100[4187]	4.4[2.3]	1.68[0.64]	41.09[16.52]	76.33[45.00]	15767[5600]	1.98[0.95]◆	256.67[49.33]	26.87[11.68]	147.88[88.75]	3.4[3.8]	0.9[0.4]	1166.0[757.2]◆
CS-16	C	1	7420	2.2	0.75	21.74	23.40	12368	10.81◆	245.95	13.46	55.11	1.3	0.4	276.40
CS-17	G	1	5595	1.8	0.50	22.8	40.00	9018	1.13	178.68	12.04	76.66	1.6	0.5	285.64
CS-17	C-T	1	7828	2.4	0.94	28.59	38.87	13128	1.77	196.90	18.70	90.99	1.1	0.8	405.41
CS-17	C-B	1	10445	4.1	1.16	33.92	51.41	16687	4.72◆	297.90	21.09	83.49	2.1	0.5	409.83
CS-18	C-T	1	9138	3.6	1.12	28.20	33.79	17235	7.67◆	312.81	18.00	46.82	0.9	0.5	216.52
Lowest Effect Level				6	0.6	26	16	2%	0.2	460	16	31			120
Severe Effect Level ◆				33	10	110	110	4%	2	1100	75	250			820

C-core, T-top, B-bottom, G-grab

TABLE 2: continued

ENV.CAN STN #	SMP TYPE	N	AL ug/g	AS ug/g	CD ug/g	CR ug/g	CU ug/g	FE ug/g	HG ug/g	MN ug/g	NI ug/g	PB ug/g	SB ug/g	SE ug/g	ZN ug/g
CS-18	C-B	1	8493	3.8	0.78	27.31	29.43	15124	4.28◆	318.25	16.53	60.08	1.4	0.2	386.68
CS-19	C-T	1	8000	3.2	0.60	29.00	51.00	14000	7.30◆	230.00	20.00	75.00	2.0	0.5	390.00
CS-19	C-B	1	8700	3.6	0.55	27.00	40.00	15000	1.31	310.00	18.00	51.00	1.2	0.3	260.00
CS-20	C	1	9200	3.1	0.61	30.00	37.00	15000	2.81◆	290.00	18.00	38.00	0.6	0.5	200.00
CS-21	C-T	1	11215	5.3	1.28	38.93	64.80	16559	3.77◆	263.97	23.92	97.18	2.7	0.7	666.40
CS-21	C-B	1	8258	3.1	0.24	24.43	26.37	14803	11.04◆	327.30	15.49	37.02	1.0	0.2	205.56
CS-22	C-T	1	8500	3.0	0.47	24.00	27.00	15000	7.95◆	330.00	16.00	33.00	0.7	0.4	220.00
CS-22	C-B	1	7700	3.2	0.48	25.00	26.00	14000	7.29◆	300.00	15.00	51.00	0.9	0.3	320.00
CS-23	G	1	9969	3.7	1.03	28.01	37.89	15830	0.01	322.69	18.89	32.66	0.5	0.5	169.42
CS-23	C-T	3	10200[721]	4.0[0.1]	0.78[0.11]	30.67[2.08]	44.67[4.73]	16330[577]	4.22[1.72]◆	308.67[5.77]	20.67[1.15]	45.33[6.67]	1.1[0.2]	0.5[0]	270.00[52.91]
CS-23	C-B	3	8967[737]	3.2[0.3]	0.68[0.19]	24.67[1.15]	29.67[0.58]	15333[577]	7.61[3.39]◆	320.00[51.96]	16.33[0.58]	45.67[25.48]	0.7[0.2]	0.3[0.1]	193.30[11.54]
CS-24	C-T	3	10600[1637]	4.1[1.0]	1.26[0.47]	35.33[5.51]	60.67[13.50]	16333[1528]	6.27[1.11]◆	250.00[20]	24.33[3.51]	60.00[4.36]	0.8[0.4]	0.7[0.1]	323.30[105.99]
CS-24	C-B	3	8733[379]	3.3[0.4]	0.56[0.11]	24.67[1.53]	30.00[4.58]	15000[0]	4.14[0.79]◆	326.67[15.27]	16.33[0.58]	32.33[8.96]	0.7[0.3]	0.3[0.1]	186.70[35.12]
CS-25	C-T	1	7400	2.5	0.67	23.00	26.00	13000	2.03◆	280.00	15.00	35.00	0.8	0.4	160.00
CS-25	C-B	1	7900	3.0	0.45	24.00	27.00	14000	6.44◆	320.00	14.00	41.00	0.9	0.3	270.00
CS-26	C-T	1	8631	3.1	1.36	29.14	47.18	15061	10.94◆	257.98	21.31	59.53	1.2	0.7	382.61
CS-26	C-B	1	9792	4.2	1.31	29.28	42.25	15646	10.07◆	321.03	21.34	41.23	1.0	0.5	213.12
CS-27	Split 1-G	3	4236[176]	0.9[0.1]	0.24[0.06]	10.35[0.21]	13.07[3.02]	7356[145]	0.61[0.12]	205.56[5.04]	6.52[0.36]	17.22[4.73]	0.2[0.1]	0.2[0]	67.92[10.18]
CS-27	Split 2-G	3	4185[249]	0.9[0.1]	0.28[0.09]	13.02[1.32]	33.12[18.12]	6379[307]	0.52[0.13]	177.23[7.06]	6.84[0.55]	50.32[7.09]	1.0[0.6]	0.2[0]	147.04[46.77]
CS-27	Split 3-G	3	4124[119]	0.8[0]	0.28[0.06]	11.29[1.03]	20.60[7.60]	6608[704]	0.46[0.32]	180.94[18.79]	6.52[0.66]	28.62[5.07]	0.3[0.1]	0.2[0]	105.93[20.70]
CS-27	C-T	1	4800	1.1	0.41	13.00	23.00	8600	0.88	220.00	9.30	29.00	0.3	0.2	110.00
CS-27	C-B	1	7500	2.6	0.74	20.00	26.00	14000	3.21◆	320.00	15.00	35.00	0.5	0.2	160.00
CS-28	C-T	1	11176	5.0	1.24	36.08	51.94	17116	3.86◆	321.47	25.47	67.36	1.5	0.6	286.38
CS-28	C-B	1	7392	2.6	0.73	21.18	23.88	13699	9.37◆	309.45	14.16	24.77	0.5	0.2	114.77
CS-29	C-T	1	7216	2.8	1.01	21.05	32.65	12131	6.80◆	227.02	15.05	38.32	1.2	0.5	217.80
CS-29	C-B	1	8380	3.5	1.05	24.18	29.55	15010	2.53◆	328.73	16.95	34.55	0.6	0.3	205.27
CS-30	C	1	4571	1.4	0.64	11.48	11.83	8166	0.67	202.92	7.62	7.16	0.2	0.2	50.78
CS-31	C-T	1	11000	4.3	1.3	36.00	72.00	16000	12.25◆	260.00	25.00	58.00	1.4	0.8	430.00
CS-31	C-B	1	8300	3.0	0.54	23.00	28.00	15000	7.82◆	330.00	16.00	29.00	0.4	0.2	150.00
CS-31	G	1	9254	2.8	0.77	31.69	34.26	14528	2.07◆	240.68	20.82	40.21	0.6	0.6	158.17
CS-32	C-T	1	10927	3.9	1.26	39.97	58.88	16269	0.01	250.84	26.52	59.18	0.8	0.7	281.52
CS-32	C-B	1	8508	3.3	0.57	24.68	28.19	15216	3.10◆	337.43	15.25	33.73	0.4	0.2	169.98
CS-33	G	1	6851	2.3	0.43	25.16	20.21	13090	1.96	275.39	13.66	30.19	0.7	0.3	139.51
CS-34	C-T	1	13000	5.4	1.50	40.00	74.00	18000	10.37◆	300.00	29.00	64.00	1.2	0.6	420.00
CS-34	C-B	1	8200	3.0	0.79	22.00	27.00	14000	7.79◆	330.00	15.00	27.00	0.5	0.2	130.00
CS-35	C-T	1	15000	6.3	2.00	51.00	82.00	20000	11.96◆	300.00	34.00	76.00	1.2	0.9	530.00
Lowest Effect Level				6	0.6	26	16	2%	0.2	460	16	31			120
Severe Effect Level ◆				33	10	110	110	4%	2	1100	75	250			820

C-core, T-top, B-bottom, G-grab

TABLE 2: continued

ENV.CAN STN #	SMP TYPE	N	AL ug/g	AS ug/g	CD ug/g	CR ug/g	CU ug/g	FE ug/g	HG ug/g	MN ug/g	NI ug/g	PB ug/g	SB ug/g	SE ug/g	ZN ug/g
CS-35	C-B	1	12000	5.0	1.00	36.00	54.00	17000	13.71◆	310.00	24.00	60.00	1.5	0.6	370.00
CS-35	Split 1-G	3	10170[287]	3.2[0.1]	1.09[0.07]	33.42[0.67]	43.92[1.83]	15756[421]	2.95[0.53]◆	256.81[9.77]	22.39[0.66]	54.05[5.20]	0.7[0.1]	0.7[0]	229.10[7.52]
CS-35	Split 2-G	3	12857[722]	5.0[0.1]	1.91[0.28]	43.48[1.36]	59.60[2.62]	18127[517]	4.93[0.36]◆	269.54[9.54]	30.06[1.58]	71.47[1.54]	0.6[0.1]	0.8[0]	325.32[13.68]
CS-35	Split 3-G	3	11113[565]	4.0[0.1]	1.57[0.13]	33.93[0.93]	43.52[0.78]	16608[317]	4.37[0.91]◆	289.94[9.64]	22.94[1.02]	47.16[5.77]	0.7[0.1]	0.7[0.06]	236.64[15.61]
CS-36	C-T	3	10033[839]	2.7[0.2]	1.30[0.05]	32.00[1.00]	38.67[0.58]	15667[1155]	1.66[0.73]	240.00[10.00]	22.70[1.15]	48.33[1.53]	0.5[0.1]	0.6[0.15]	216.70[37.86]
CS-36	C-B	3	10667[2517]	4.5[1.2]	1.13[0.26]	32.33[8.50]	46.67[16.01]	17000[2000]	5.87[2.76]◆	323.33[5.77]	22.00[5.57]	48.67[16.50]	1.1[0.7]	0.4[0.15]	313.30[145.72]
CS-37	C-T	1	11000	2.7	1.00	33.00	37.00	16000	1.63	240.00	22.00	53.00	0.7	0.8	230.00
CS-37	C-B	1	8800	3.6	0.56	26.00	36.00	15000	7.75◆	310.00	17.00	36.00	0.7	0.4	200.00
CS-37	G	1	12066	3.2	1.47	34.44	35.03	17676	1.09	240.58	26.13	42.83	0.8	1.0	250.94
CS-38	C-T	1	16257	4.4	1.83	48.00	64.05	22672	1.39	324.89	33.32	63.16	1.1	1.4	388.66
CS-38	C-B	1	10598	7.0	0.71	33.12	44.43	17137	9.75◆	325.58	20.39	53.06	1.4	0.4	357.64
CS-39	G	1	17362	5.6	2.06	48.80	63.29	22764	0.68	340.03	32.86	54.92	0.7	1.5	563.81
CS-40	C-T	1	17000	4.5	2.00	49.00	68.00	23000	0.78	320.00	36.00	61.00	0.7	1.3	410.00
CS-40	C-B	1	12000	5.0	1.40	37.00	51.00	18000	4.80◆	330.00	24.00	56.00	1.3	0.5	410.00
CS-41	C-T	1	11684	3.4	1.46	34.18	38.03	17666	2.62◆	253.72	24.67	48.21	1.0	0.9	270.78
CS-41	C-B	1	8167	3.2	1.17	23.45	27.77	14403	5.60◆	327.09	16.80	25.67	0.5	0.3	147.68
CS-42	C-T	1	17000	4.2	1.40	46.00	50.00	23000	0.91	340.00	32.00	50.00	0.9	1.4	380.00
CS-42	C-B	1	13000	5.5	1.20	42.00	74.00	17000	14.72◆	290.00	27.00	81.00	1.9	0.6	690.00
CS-42	G	1	17192	4.7	1.85	47.33	62.20	23221	0.68	330.63	33.00	63.82	0.8	1.4	398.27
CS-43	C-T	1	8274	3.2	0.66	23.97	27.81	14983	2.50◆	336.68	15.40	30.76	0.4	0.3	162.76
CS-43	C-B	1	9278	2.8	0.87	28.25	30.87	15004	1.90	253.01	20.48	42.17	0.6	0.6	175.76
CS-44	C-T	1	15000	4.0	1.70	42.00	52.00	22000	0.94	320.00	30.00	65.00	0.7	1.2	360.00
CS-44	C-B	1	10000	4.5	1.20	31.00	48.00	17000	6.01◆	330.00	20.00	62.00	1.4	0.5	330.00
CS-45	C-T	1	15000	4.0	1.40	40.00	47.00	21000	0.63	310.00	30.00	50.00	0.7	1.2	340.00
CS-45	C-B	1	12000	6.4	1.60	13.00	86.00	9900	15.87◆	280.00	29.00	85.00	2.5	0.6	760.00
CS-46	C-T	1	8087	3.3	0.86	25.67	30.09	14256	6.34◆	294.34	15.97	28.06	0.5	0.3	123.76
CS-46	C-B	1	9751	4.5	0.46	29.89	34.13	16745	3.39◆	346.42	19.11	38.45	0.7	0.4	237.03
CS-47	C-T	1	14000	3.6	0.94	39.00	43.00	20000	0.81	300.00	27.00	45.00	0.7	1.2	340.00
CS-47	C-B	1	13000	5.9	1.20	44.00	78.00	18000	15.92◆	290.00	28.00	88.00	2.1	0.6	640.00
CS-47	G	1	12858	3.7	1.76	36.19	40.05	18709	0.81	297.87	24.87	46.67	0.7	1.1	285.87
CS-48	C-T	1	8004	3.4	1.06	24.20	34.25	12627	8.44◆	229.65	20.81	41.51	1.0	0.4	205.76
CS-48	C-B	1	8763	4.0	0.88	25.38	28.28	15197	2.45◆	327.75	16.67	34.65	0.7	0.2	179.41
CS-49	C-T	1	14000	4.5	1.50	40.00	46.00	20000	0.82	280.00	28.00	49.00	0.7	1.4	330.00
CS-49	C-B	1	12000	6.8	1.70	42.00	96.00	15000	28.85◆	260.00	29.00	128.00	2.9	1.0	920.00
Lowest Effect Level				6	0.6	26	16	2%	0.2	460	16	31			120
Severe Effect Level ◆				33	10	110	110	4%	2	1100	75	250			820

C-core, T-top, B-bottom, G-grab