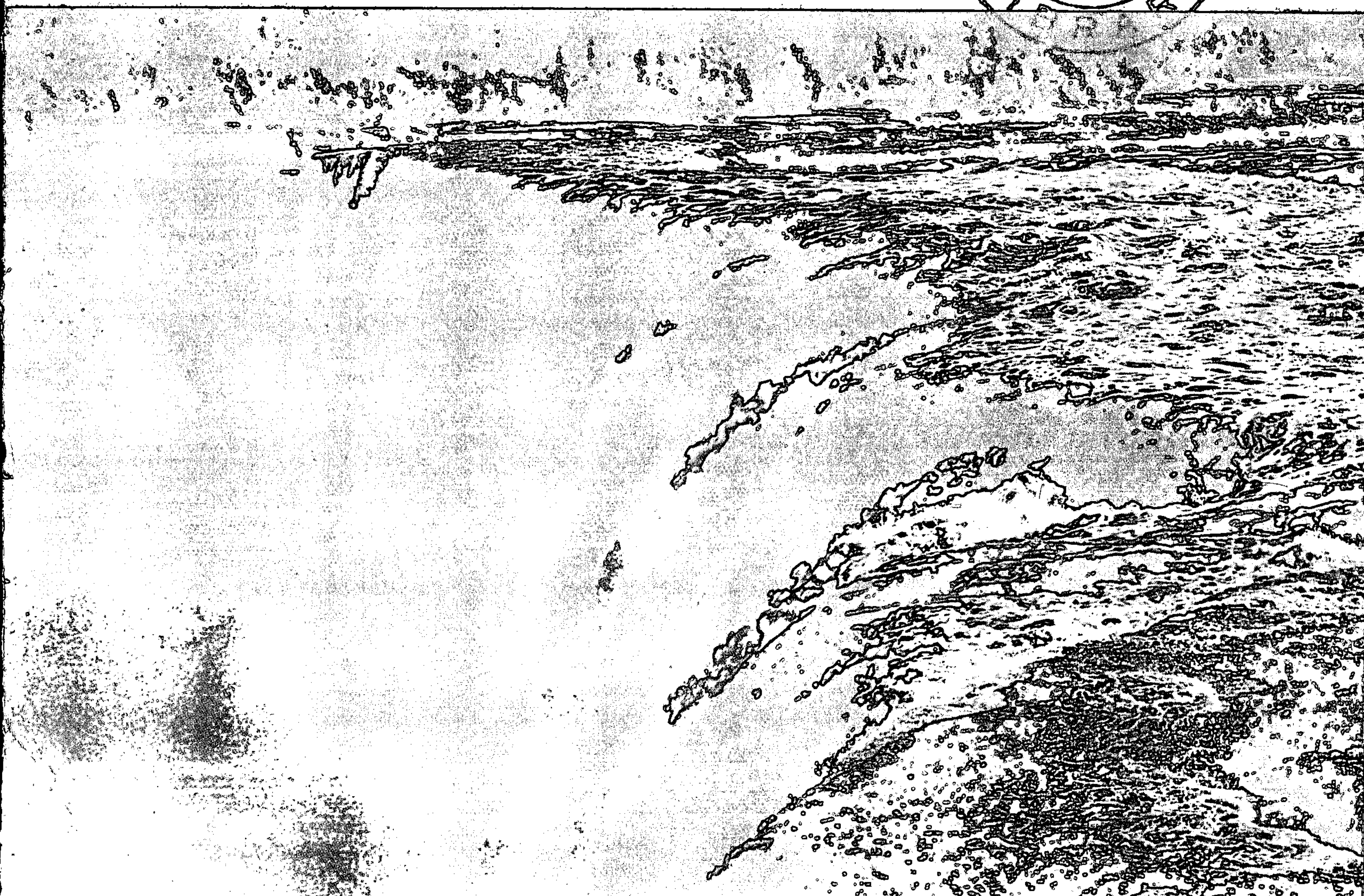
153

Environment Canada Environnement Canada

Bottom Sediment Quality of the Ottawa River

J.C. Merriman



TECHNICAL BULLETIN NO. 153

INLAND WATERS/LANDS DIRECTORATE
WATER QUALITY BRANCH
ONTARIO REGION
BURLINGTON, ONTARIO, 1987

(Disponible en français sur demande)

Environment Canada Environnement Canada

Bottom Sediment Quality of the Ottawa River

J.C. Merriman

TECHNICAL BULLETIN NO. 153

INLAND WATERS/LANDS DIRECTORATE
WATER QUALITY BRANCH
ONTARIO REGION
BURLINGTON, ONTARIO, 1987

(Disponible en français sur demande)

Published by authority of
the Minister of the Environment

Cat. No. En 36-503/153E

ISBN 0-662-15754-0

Contents

Tables

Illustrations

Abstract

In 1982 the Water Quality Branch, Ontario Region, completed a bottom sediment survey of the Ottawa River extending from the headwaters of Lake Timiskaming to Carillon at the Ontario-Quebec border. Thirty-five sediment samples were collected from 11 transects and analyzed for a variety of trace elements and trace organic contaminants. Results of metal analyses indicated that concentrations were significantly higher at stations located upstream from Petawawa, compared to sites downstream. The highest concentrations of all elements except cadmium were at the Petawawa transect. Arsenic, cadmium, lead, and zinc were found to be above background or ambient levels at some locations and exceeded MOE guidelines for open water disposal of dredged material.

Organic contaminants analyzed included organochlorine pesticides, PCBs, chlorobenzenes, and PAHs. The detection frequency for these trace organic contaminants was 1.8%. 1,3-Dichlorobenzene had the highest frequency of detection at 29% and was found to be widely distributed throughout the river.

Résumé

En 1982, la Direction de la qualité des eaux, région de l'Ontario, a réalisé une étude sédimentologique de la rivière des Outaouais, des sources du lac Témiskamingue jusqu'à Carillon, à la limite de l'Ontario et du Québec. Dans 35 échantillons de sédiments prélevés sur 11 transects, on a dosé divers éléments et contaminants organiques à l'état de traces. L'analyse des métaux montre que les concentrations de ces derniers sont notablement plus élevées aux stations situées en amont de Petawawa qu'aux stations d'aval. Sauf pour le cadmium, les concentrations maximales de tous les éléments ont été observées à Petawawa. Les concentrations d'arsenic, de cadmium, de plomb et de zinc se sont révélées supérieures aux concentrations naturelles ou ambiantes en certains endroits et ont excédé les recommandations du ministère de l'Environnement de l'Ontario qui portent sur l'élimination des déblais de dragage en eau libre.

Les contaminants organiques dosés comprenaient les pesticides organochlorés, les BPC, les chlorobenzènes et les hydrocarbures aromatiques polycycliques. Leur fréquence de détection était de 1.8 %. C'est le dichloro-1,3 benzène qui a été décelé le plus souvent, au taux de 29 %, et il s'est révélé largement distribué dans l'ensemble de la rivière.

Bottom Sediment Quality of the Ottawa River

J.C. Merriman

INTRODUCTION

The interprovincial section of the Ottawa River extending from the headwaters of Lake Timiskaming to the Ontario-Quebec provincial border at Carillon has been the subject of several water quality studies dating back to the 1950s (Thomas, 1952; Piché, 1954; Ontario Department of Health, 1956; Bonk, 1958; Lesauteur, 1965; Ontario Water Resources Commission, 1967; Ontario Water Resources Commission and Quebec Water Board, 1971). These studies focused primarily on the physical, chemical, and bacteriological quality of the river. The joint Ontario/Quebec study (1971) provided the most detailed information from a basinwide perspective. Fisheries and Environment Canada (1977) reported on the basin a number of years later. This report was similar to the Ontario/Quebec study and contained more up-to-date information on the environmental quality, hydrology, and the socio-economics of the basin.

In the early 1970s, Oliver and Kinrade (1972) and Oliver and Agemian (1974) examined heavy metal concentrations in the bottom sediments of the Ottawa River from Ottawa downstream to Carillon. An intensive study by the University of Ottawa and the National Research Council (1977) determined the distribution and transport of mercury in the Ottawa River near Ottawa. Goulet and Laliberté (1982a) reported on metal concentrations in sediments of the Ottawa River and some of its tributaries sampled in 1978. A follow-up survey in 1980 on metals in bottom sediments was reported on by Croteau *et al.* (1984b).

A good summary of work carried out for trace organic contaminant analysis in water and fish is contained in the Contaminants Task Force report to the Federal/Provincial Technical Working Group on Water Quality in the Ottawa River (1980). It describes findings from both federal surveys and provincial fish monitoring programs that first confirmed the presence of PCBs in the Ottawa River ecosystem.

In 1982, the Water Quality Branch, Ontario Region, completed a bottom sediment survey of the Ottawa River extending from the headwaters of Lake Timiskaming to the outflow of the river into Quebec at Carillon. Samples were analyzed for a wide range of metals and trace organic contaminants. This report summarizes those findings, discusses the spatial distribution of contaminants throughout the river, and compares results with previous findings.

METHODOLOGY

Bottom sediment samples were collected from 35 stations (Table 1) at 11 transects in the river (Fig. 1) using a mini-Shipek sampler. The top 3 cm were removed, placed in glass jars, and stored on ice until reaching the laboratory, where they were placed in a freezer. Jars for trace metal and particle size samples were prewashed in 10% nitric acid. Jars for trace organic samples were rinsed in acetone followed by hexane, then put in an oven overnight at 130°C. On removal from the oven, the jars were covered with caps rinsed with hexane and lined with aluminum foil.

In preparation for submission to the laboratory, samples for trace metal and particle size analyses were thawed, freeze-dried, and then gently homogenized using a mortar and pestle. Samples for trace organic analysis were thawed and submitted wet.

A brief description of the analytical methodologies is provided below. More detailed descriptions may be found in the *Analytical Methods Manual* (Environment Canada, 1979).

Trace Metals

Analyses were done for nonresidual cadmium, copper, chromium, lead, nickel, and zinc, while arsenic, mercury, and selenium were analyzed for their total form.

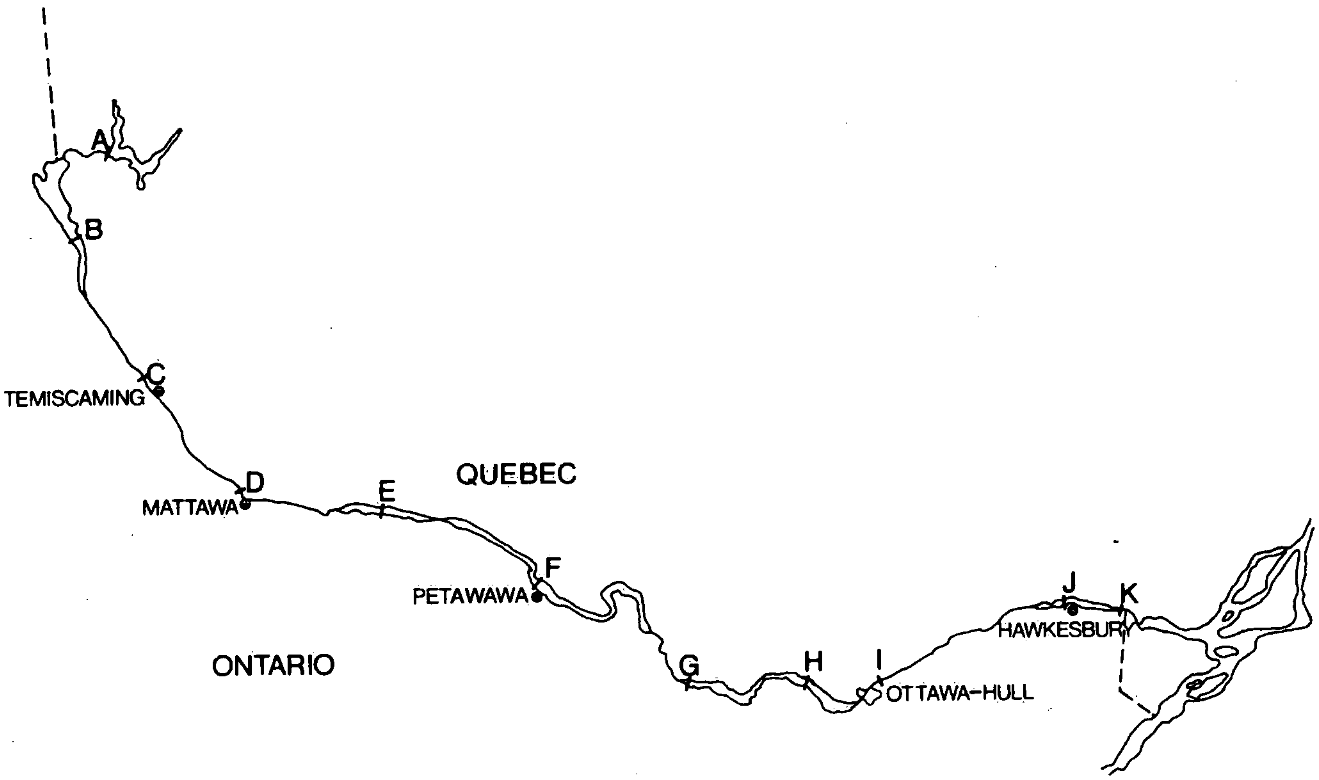


Figure 1. Ottawa River sampling transects.

Table 1. Station Locations

Station	Latitude	Longitude
A-1	47°35′06″	79°30′00″
A-2	47°35′18″	79°30′00″
B-1	47°16′48″	79°26′36″
B-2	47°16′36″	79°27′06″
B-3	47°16′30″	79°27′30″
C-1	46°44′54″	79°07′24″
C-2	46°44′54″	79°07′36″
C-3	46°44′54″	79°07′48″
D-1	46°23′30″	78°45′30″
D-2	46°23′18″	78°45′48″
D-3	46°23′06″	78°46′06″
E-1	46°15′54″	78°19′06″
E-2	46°15′48″	78°19′12″
E-3	46°15′42″	78°19′24″
E-4	46°15′36″	78°19′30″
F-1	45°56′54″	77°16′30″
F-2	45°56′30″	77°16′48″
F-3	45°56′12″	77°17′06″
F-4	45°55′54″	77°17′30″
F-5	45°55′42″	77°17′48″
G-1	45°31′54″	76°33′42″
G-2	45°31′36″	76°33′48″
G-3	45°31′12″	76°33′54″
H-1	45°28′54″	75°58′54″
H-2	45°28′42″	75°59′06″
H-3	45°28′30″	75°59′12″
I-1	45°29′12″	75°32′54″
I-2	45°29′06″	75°33′00″
I-3	45°29′00″	75°33′06″
J-1	45°38′36″	74°38′42″
J-2	45°38′30″	74°38′06″
K-1	45°34′48″	74°26′12″
K-2	45°34′36″	74°26′36″
K-3	45°34′30″	74°26′54″
K-4	45°34′24″	74°27′06″

For the nonresidual metals analysis, 100 mL of 0.5 N hydrochloric acid were added to 10 g of dried sediment and shaken at room temperature overnight. The solution was filtered using a 0.45-μm cellulose acetate filter, and the filtrate was analyzed directly by flame atomic absorption spectrometry.

For arsenic and selenium analyses, a 1-g portion of dried sediment was digested with nitric acid, perchloric acid, potassium persulphate, and hydrofluoric acid. After oxidation and solubilization of the silicates, an automated system was used to determine As and Se by reduction and quartz tube atomic absorption spectrometry.

Total mercury was analyzed by digesting 1 g of dried sediment with sulphuric acid, nitric acid, hydrochloric acid, potassium permanganate, and potassium persulphate. A solution of hydroxylamine sulphate-sodium chloride was added to dissolve the precipitate and clear the solution. An aliquot was then run through an automated system in which Hg^{2+} was reduced to elemental mercury. The mercury was sparged from solution with a stream of air and passed through a cell in an atomic absorption spectrophotometer where the absorption was measured.

Organic Contaminants

Trace organic contaminants were analyzed by extracting a 10-g portion of homogenized sediment with 1:1 hexane-acetone. The extract was filtered, then partitioned with distilled water, and subsequently extracted with benzene. The combined extracts were dried, reduced in volume, and cleaned on a gel-permeated chromatographic column. Further clean-up was done on a silica gel column from which two fractions were obtained. Each fraction was analyzed by gas liquid chromatography using two columns, one packed and one capillary.

Organic carbon content in sediment samples was determined by thermal combustion at 850°C of the sample to form CO_2, H_2O, and N_2 gases, which were then separated chromatographically. Quantitation was made with a thermal conductivity detector, which was coupled with a recorder and electronic integrator.

Particle Size

Particle size analysis of bottom sediments was determined using the sieve and sedigraph method (Duncan and La Haie, 1979). Results were reported as percentages for gravel, sand, silt, and clay (Table 2). All particles large enough to block the sedigraph suction tube (0.80 mm) were removed. The sample was then dispersed in a Calgon suspension, and automated analysis was completed with the sedigraph. Results were processed with SIZDIST, a FORTRAN IV computer program (Sandilands and Duncan, 1980). A more detailed description of the methodology may be found in Duncan and La Haie (1979).

Table 2. Particle Size Distribution and Organic Carbon Content (%)

Station	Gravel	Sand	Silt	Clay	Carbon
A-1	0	1.2	49.8	49.0	9.2
A-2	0	7.8	52.5	39.8	7.4
B-1	0	0.4	25.4	74.2	1.1
B-2	0	1.4	27.1	71.5	1.3
B-3	0	3.5	25.9	70.6	1.1
C-1	0	7.5	31.1	61.3	4.8
C-2	0	2.2	22.7	75.2	3.8
C-3	0	12.5	28.6	58.9	2.0
D-1	0	7.4	34.6	58.1	6.7
D-2	0	6.5	30.4	63.1	4.9
D-3	0	2.6	36.8	60.6	4.2
E-1	0	1.2	19.9	78.9	4.6
E-2	0	0.8	18.8	80.5	5.2
E-3	0	0.6	70.4	29.0	4.4
E-4	0	0.3	19.9	79.8	4.9
F-1	0	5.0	30.2	64.8	4.0
F-2	0	3.9	24.3	71.8	4.0
F-3	0	1.4	21.4	77.2	3.9
F-4	0	0.8	21.8	77.4	3.4
F-5	0	10.4	37.0	52.6	1.5
G-1	0	14.7	69.0	16.3	2.0
G-2	0	38.0	45.5	16.5	1.3
G-3	0	5.2	84.4	10.5	2.1
H-1	5.4	16.2	35.5	42.9	1.8
H-2	0	1.0	46.3	52.7	2.8
H-3	0	3.5	48.7	47.8	2.7
I-1	NA	NA	NA	NA	2.5
I-2	0	100.0	0	0	0.8
I-3	0	11.8	28.1	60.2	1.4
J-1	0	16.9	66.1	17.0	2.0
J-2	0	7.6	32.4	60.1	2.7
K-1	0	5.2	64.0	30.8	3.2
K-2	0	3.5	39.8	56.7	2.2
K-3	0	3.7	58.7	37.6	3.1
K-4	0	4.9	48.5	46.6	3.9

NA = no analysis.

RESULTS AND DISCUSSION

Trace Metals

Studies carried out in the 1970s on bottom sediments provide good background information on metal concentrations for certain reaches of the Ottawa River. With the exception of Oliver and Agemian (1974), who reported extractable concentrations, these studies reported total concentrations of metals in sediment. Relative comparisons can be made between concentrations found by Goulet and Laliberté (1982a) and Oliver and Kinrade (1972). Direct comparisons between Oliver and Agemian (1974) and this Water Quality Branch study, however, are not valid because of the different analytical methodologies used. When comparisons are made between concentrations found in this study and concentrations of elements found in common types of rocks and the earth's crust as cited in Hem (1970) and Hawley (1979), elements including arsenic, cadmium, lead, and zinc appear to be present in Ottawa River bottom sediments above these background levels at some locations.

Trace metal concentrations are presented in Table 3. Table 4 summarizes the data and indicates the range of values found for each metal with its respective mean and standard deviation.

Trace metals in Ottawa River bottom sediments showed somewhat similar patterns in their distributions. In most cases, the upstream transects A to F had higher concentrations of elements than the downstream transects G to K. The highest concentration of all the elements except cadmium was found at transect F. There was no other particular trend or pattern evident at the upstream transects.

Table 3. Concentrations of Trace Metals ($mg \cdot kg^{-1}$)

Station	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn
A-1	6.3	1.8	4.6	28.0	21.0	<0.10	8.7	110
A-2	6.7	2.7	3.5	32.0	28.0	<0.10	6.4	99
B-1	25.8	1.8	9.8	19.0	18.0	<0.10	11.0	100
B-2	33.0	2.2	9.5	19.0	21.0	<0.10	11.0	100
B-3	33.6	1.2	9.8	23.0	21.0	<0.10	13.0	110
C-1	46.3	2.1	8.1	34.0	35.0	0.17	12.0	110
C-2	45.7	1.6	8.8	33.0	36.0	0.16	12.0	140
C-3	57.2	1.0	5.4	21.0	21.0	0.11	9.4	77
D-1	13.7	1.4	5.0	31.0	24.0	0.12	7.7	100
D-2	23.3	2.2	7.1	44.0	31.0	0.14	12.0	140
D-3	17.8	2.0	8.4	42.0	37.0	0.14	12.0	140
E-1	27.7	1.6	10.0	38.0	48.0	0.17	14.0	190
E-2	24.3	2.2	11.0	42.0	46.0	0.16	13.0	190
E-3	30.0	2.0	11.0	42.0	51.0	0.15	16.0	200
E-4	26.3	1.7	9.1	37.0	49.0	0.15	12.0	190
F-1	35.8	2.0	8.5	35.0	55.0	0.18	13.0	190
F-2	48.4	1.9	9.5	40.0	65.0	0.19	14.0	190
F-3	96.4	2.2	13.0	47.0	78.0	0.18	20.0	300
F-4	68.6	2.3	11.0	44.0	71.0	0.19	16.0	220
F-5	21.6	0.9	5.0	16.0	26.0	<0.10	7.0	79
G-1	10.8	1.1	4.4	12.0	26.0	<0.10	6.1	100
G-2	7.4	1.1	3.8	9.6	21.0	<0.10	5.4	90
G-3	10.7	1.2	4.4	15.0	50.0	<0.10	6.3	130
H-1	10.5	0.7	5.7	14.0	32.0	<0.10	7.8	95
H-2	13.4	1.2	6.1	19.0	48.0	<0.10	9.1	150
H-3	12.3	1.3	5.7	19.0	56.0	0.11	9.1	150
I-1	2.7	0.3	2.5	7.3	11.0	0.13	2.2	39
I-2	1.7	0.1	0.7	0.9	1.6	<0.10	1.1	12
I-3	3.4	0.4	7.8	19.0	32.0	0.11	7.8	78
J-1	2.1	0.3	2.8	9.2	7.3	<0.10	2.3	46
J-2	4.6	0.6	6.7	17.0	30.0	0.18	5.7	80
K-1	3.9	0.7	6.8	20.0	24.0	0.14	5.4	90
K-2	3.0	0.6	6.5	16.0	21.0	0.12	5.5	81
K-3	4.0	0.8	6.5	20.0	24.0	0.15	5.5	90
K-4	4.2	0.6	6.1	17.0	25.0	0.16	5.7	77

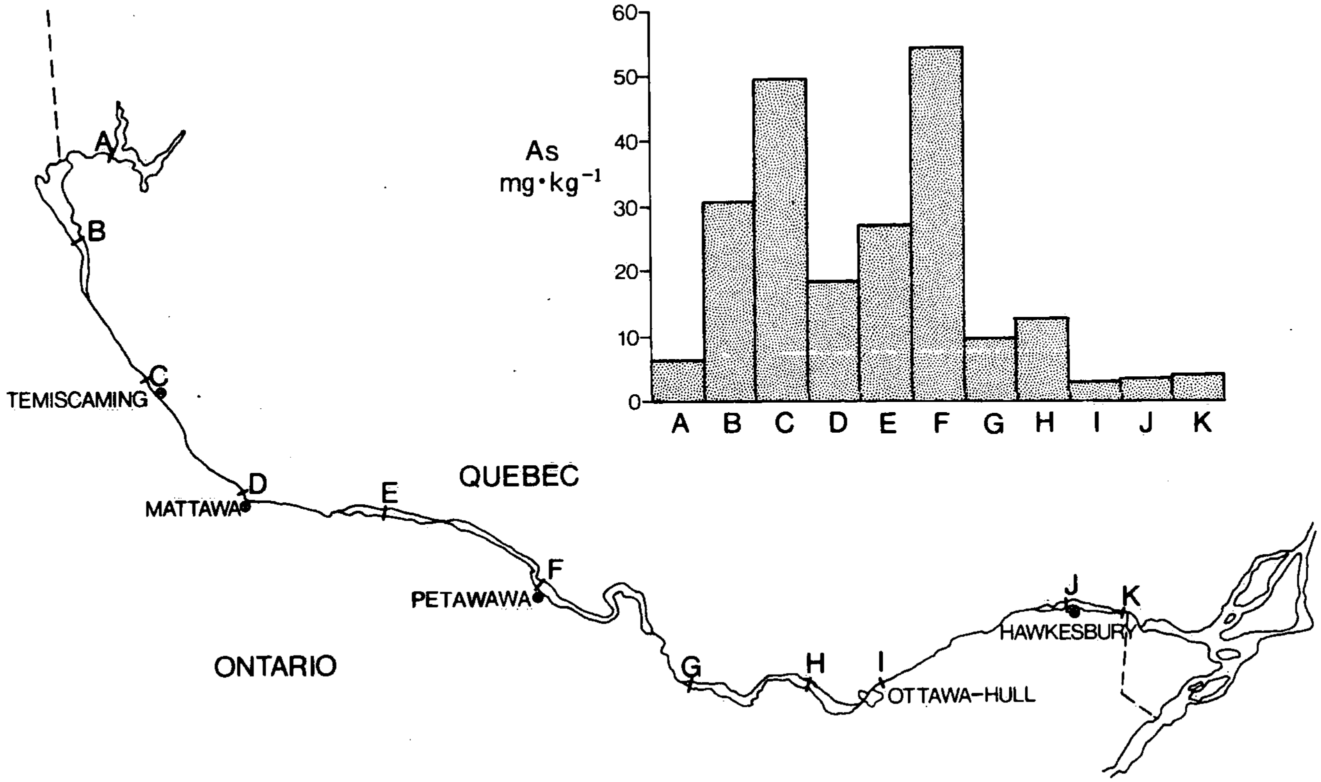


Figure 2. Total arsenic by transect mean.

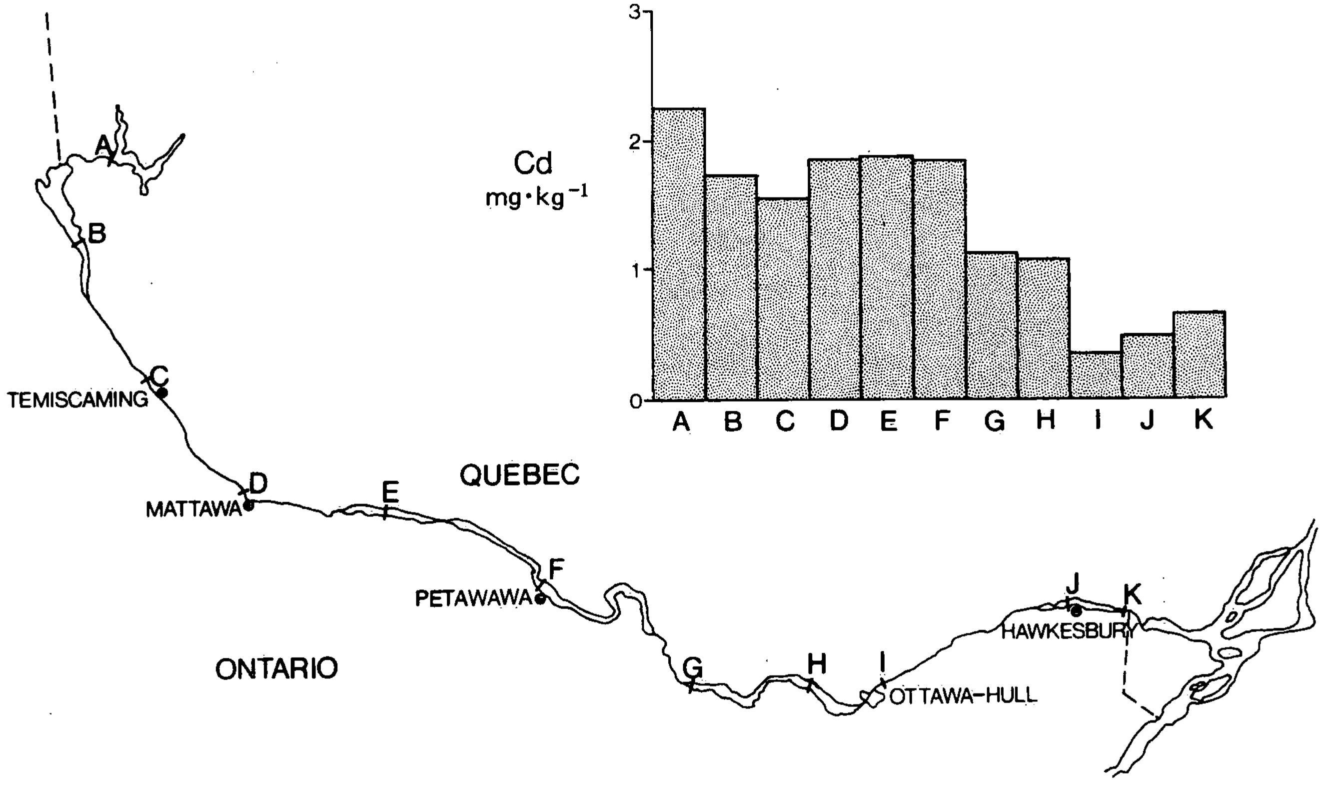


Figure 3. Nonresidual cadmium (0.5 N HCl) by transect mean.

Downstream transects were characterized by lower concentrations. There was a distinct pattern evident at these transects: for all the metals except cadmium, transect mean concentrations increased between G and H, decreased at I, and then increased in concentration between I and K.

Arsenic in Ottawa River bottom sediments showed two distinct increasing trends in a downstream direction between transects A and F (Fig. 2). Concentrations ranged between 6.3 and 96.4 $mg \cdot kg^{-1}$ and averaged 34.4 $mg \cdot kg^{-1}$ at these upstream transects. A sharp decline in concentration was evident at downstream transects G to K, where values ranged from 1.7 to 13.4 $mg \cdot kg^{-1}$, with a mean concentration of 6.3 $mg \cdot kg^{-1}$.

Arsenic concentrations in commonly occurring igneous and sedimentary rocks are usually less than 13 $mg \cdot kg^{-1}$ (Hawley, 1979). High concentrations at the upstream transects can be attributed to tributary inputs into the Ottawa River from the mining industry in the Cobalt and Larder Lake areas. Average concentrations of arsenic in tailings, as reported by Hawley (1979), were 1245 ppm for the former and 4275 ppm for the latter. With the exception of Croteau *et al*. (1984b), no other work has been carried out documenting arsenic in Ottawa River bottom sediments. Croteau's data showed concentrations ranging from below the detection limit to 7.3 $mg \cdot kg^{-1}$. This compared well with the Water Quality Branch data, which ranged from 1.7 to 13.4 $mg \cdot kg^{-1}$ for the comparable section of the river that was sampled.

Cadmium concentrations in bottom sediments ranged from 0.9 to 2.7 $mg \cdot kg^{-1}$ between transects A and F (Table 3), with a mean concentration of 1.8 $mg \cdot kg^{-1}$ (Table 4). At the downstream transects, concentrations ranged from 0.1 to 1.3 $mg \cdot kg^{-1}$ (Table 3), and had a mean concentration of 0.7 $mg \cdot kg^{-1}$. The distribution of cadmium throughout the river by transect means (Fig. 3) indicates that the elevated levels are found at transects A through F and decreased concentrations are found downstream from Petawawa to the Ontario-Quebec border.

Unlike the other elements examined, which showed the highest concentrations at transect F, cadmium showed

Table 4. Summary Statistics for Metals, Clay, and Organic Carbon

	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn	Clay (%)	Organic carbon (%)
				(mg kg^{-1})						
Detection limit	0.025	0.1	0.5	0.1	0.5	0.1	0.1	0.1	0	0.005
				All transects						
Minimum	1.7	0.1	0.7	0.9	1.6	<0.1	1.1	12.0	0	0.8
Maximum	96.4	2.7	13.0	47.0	78.0	0.19	20.0	300.0	80.5	9.2
Mean*	22.4	1.4	7.0	25.2	34.0	0.09	9.3	122.4	52.6	3.3
Std. dev.	21.6	0.7	2.8	12.4	17.7	0.08	4.3	58.4	22.1	1.9
No. of samples	35	35	35	35	35	35	35	35	34	35
				Upstream transects A–F						
Minimum	6.3	0.9	3.5	16.0	18.0	<0.1	6.4	77.0	29.0	1.1
Maximum	96.4	2.7	13.0	47.0	78.0	0.19	20.0	300.0	80.5	9.2
Mean*	34.4	1.8	8.4	33.4	39.1	0.11	12.0	149.0	64.7	4.1
Std. dev.	21.6	0.5	2.5	9.5	18.1	0.08	3.3	58.0	14.0	2.1
No. of samples	20	20	20	20	20	20	20	20	20	20
				Downstream transects G–K						
Minimum	1.7	0.1	0.7	0.9	1.6	<0.1	1.1	12.0	0	0.8
Maximum	13.4	1.3	7.8	20.0	56.0	0.18	9.1	150.0	60.2	3.9
Mean*	6.3	0.7	5.1	14.3	27.3	0.07	5.7	87.0	35.4	2.3
Std. dev.	4.1	0.4	2.0	5.5	15.2	0.07	2.4	38.0	20.1	0.8
No. of samples	15	15	15	15	15	15	15	15	14	15

*Means are based on less than detection limits equaling 0.

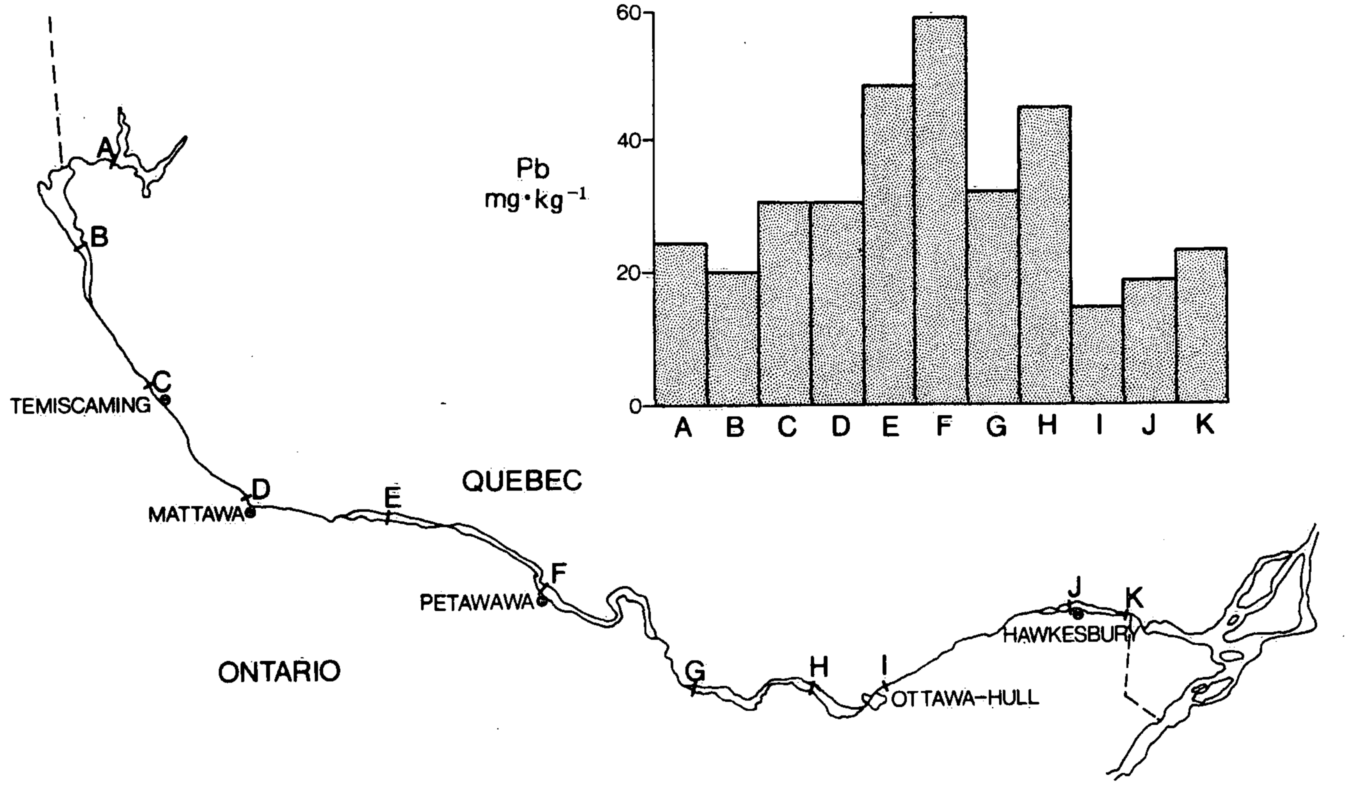


Figure 4. Nonresidual lead (0.5 N HCl) by transect mean.

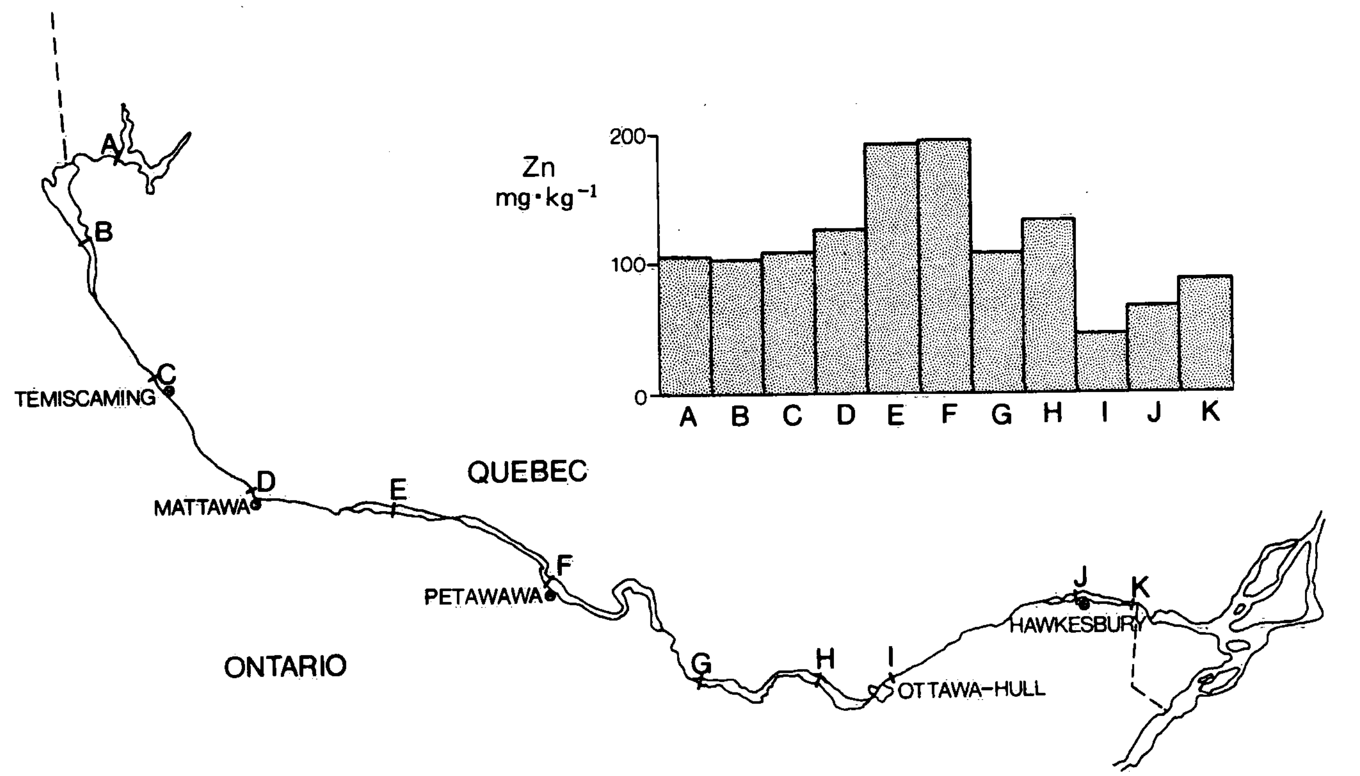


Figure 5. Nonresidual zinc (0.5 N HCl) by transect mean.

the highest concentration (2.7 mg·kg^{-1}) at transect A. Cadmium data for fish indicate a similar trend in that highest concentrations were found at the upstream end of the basin (Goulet and Laliberté, 1982).

Lead in Ottawa River bottom sediments increased in concentration between transects A and F (Fig. 4). Values ranged from a low of 18 mg·kg^{-1} at transect B to a high of 78 mg·kg^{-1} at F, while at the downstream transects, concentrations ranged from 1.6 to 56 mg·kg^{-1} (Table 3). Upstream transects A to F had a mean concentration of 39.1 mg·kg^{-1}, while the downstream transects averaged 27.3 mg·kg^{-1}. Lead concentrations appeared to be within the ranges of what would be expected in natural background levels for the basin, below 50 mg·kg^{-1} (Hawley, 1979). There were some instances, however, where samples showed concentrations above 50 mg·kg^{-1}.

Transect means for zinc increased in a downstream direction between transects A and F (Fig. 5). Concentrations in this stretch of the river ranged from a low of 77 mg·kg^{-1} to a high of 300 mg·kg^{-1} and averaged 149 mg·kg^{-1}. The downstream transects G through K showed lower concentrations, ranging from 12 to 150 mg·kg^{-1} and averaging 87 mg·kg^{-1}. Average concentrations of zinc found in commonly occurring igneous and sedimentary rocks are below 150 mg·kg^{-1} (Hawley, 1979). The higher concentrations found at transects E and F indicate that sediments are above background levels and that there are sources of zinc either at or above these transects.

Concentrations of arsenic, chromium, copper, lead, mercury, nickel, and zinc were highest at the Petawawa transect (F). Because there is no evidence of point source inputs in the vicinity of this site, it is difficult to explain the occurrence of these elevated levels. Very little work has been done on the hydrology of the Ottawa River. From Lake Timiskaming downstream to Petawawa, there are three dams with impounded areas. Downstream from Petawawa, the first dam is a hydroelectric facility at Chénaux. The high degree of flow regulation for power generation and flood control has made the hydrological characteristics of the basin quite complex and may result in the Petawawa transect being a high depositional area having high metal concentrations in the bottom sediments.

In order to evaluate the data further, transects were divided into two groups: the upstream transects as far as Petawawa and the remaining downstream transects. This grouping was chosen because of the drop in concentration downstream from Petawawa. A Student's t test was run on the data and results showed that the upstream transects were significantly higher ($P < .01$) than the downstream transects for all metals except lead ($P < .05$). Mining activities within the basin, particularly at the upstream end, are a source of metals to the river. This is one of the determining factors in finding higher concentrations at the upstream transects.

Significantly higher ($P < .01$) clay content was found in the upstream bottom sediments. This, in fact, would be expected at sites on Lake Timiskaming and downstream a certain distance because of the clay belt that extends through northeastern Ontario and northwestern Quebec. There is considerable agriculture in this area, which would result in erosion of clay into tributaries and the Ottawa River.

Organic carbon was significantly higher ($P < .01$) in the bottom sediments at the upstream transects. The Ottawa River basin upstream from Arnprior is located in the Canadian Shield. This physiographic region is characterized by boreal forests and wetland areas, which have higher background levels of organic carbon. This, in addition to the pulp and paper mill inputs into the river, results in the higher organic carbon concentrations at the upstream sites.

Table 4 gives summary statistics for metals, clay content, and organic carbon for both the upstream and downstream stations. Concentration differences range from 43% higher at the upstream stations for lead, to almost 450% higher at the upstream stations for arsenic. Variation in concentrations within transects differed along the length of the river. In particular, the transect at Petawawa, which usually exhibited the highest metal concentrations, also had the largest variability within the transect. Concentrations at this transect tended to increase from the Quebec side, peak in the middle of the river, and then drop off sharply on the Ontario side of the river.

Multiple regression analysis was used to assess the effects of the clay-sized fraction, organic carbon, and distance downstream on metal concentrations. A forward step-wise regression was used in which independent variables were included in an order determined by their respective contribution to the explained variance (Nie, 1975). The purpose in using multiple regression was to evaluate correlations between the three independent variables and the dependent variables, to estimate how much of the variation could be explained, and to see which of the independent variables were significant in accounting for the explained variation. Table 5 lists each metal, the percentage of variation explained, and which independent variables were significant in explaining the variation. The independent variables are listed in order of selection based on explained variance. Mercury is not included because almost 40% of the samples were below the detection limit.

Table 5. Explained Variation in Step-wise Multiple Regression

	Explained variation (%)	Variable
Arsenic	34.2	Clay
Cadmium	65.5	Distance, carbon
Chromium	60.4	Clay
Copper	66.4	Clay, carbon
Lead	62.9	Clay, distance, carbon
Nickel	59.3	Clay, distance
Zinc	58.6	Clay, distance

The percentage of clay was the first independent variable entered into the step-wise regression, thus contributing most to the explained variance. It also showed the highest correlation with all the metals except cadmium, for which distance was the most important. Distance downstream was the second most important variable for lead, nickel, and zinc, while for cadmium, the percentage of organic carbon ranked second.

Metal concentrations in bottom sediments were compared to Ontario Ministry of the Environment (MOE) dredged material guidelines as summarized by Thomas and Mudroch (1979). Table 6 lists the percentage of exceedences for all the metals analyzed. There was a relatively high frequency of guideline exceedence for both arsenic and cadmium, which exceeded the MOE guideline 66% of the time.

Copper and zinc exceeded the guideline 43% of the time, while lead showed an exceedence frequency of 17%. Chromium, mercury, and nickel were below the MOE guideline.

Guideline exceedences were further broken down into upstream and downstream station groupings. The high frequency of upstream exceedences (Table 6) reflects the higher concentrations of elements found in the bottom sediments at these sites (Table 3).

Organic Contaminants

A wide range of organic contaminants were analyzed including organochlorine pesticides, total PCBs, chlorobenzenes, and PAHs. Table 7 lists all the contaminants analyzed, their detection limits, and the frequency of detection. The overall detection frequency for parameters at all stations was only 1.8%, suggesting that bottom sediments of the Ottawa River are relatively uncontaminated with the trace organic contaminants analyzed.

PAHs were found to be virtually absent from the bottom sediments, with only one sample found above the detection limit (Table 8). Very few detectable levels of organochlorine pesticides were found. There were four detections of p,p′-DDE, the degradation product of p,p′-DDT. Other than DDE, there was only one detection of p,p′-TDE. This compares well to data collected by Paul *et al.* (1984), who found no detectable DDT or its metabolites in Ottawa River bottom sediments.

PCBs were found below the detection limit of 90 $\mu g \cdot kg^{-1}$ for all samples collected. Work carried out by Croteau *et al.* (1984a) during their 1980 surveys of the river showed PCB concentrations in bottom sediments ranging from 28 $\mu g \cdot kg^{-1}$ at Templeton to a maximum of 80 $\mu g \cdot kg^{-1}$ at Thurso. Studies by Merriman and McCrea (1985) have shown PCBs to be present in Ottawa River water. Findings by Goulet and Laliberté (1982b), Croteau *et al.* (1984a), and the Contaminants Task Force (1980) have shown PCBs to be present in Ottawa River fish.

The most frequently detected group of contaminants was the chlorobenzene group. Concentrations of 1,3-dichlorobenzene ranged from less than the detection limit of 50 $\mu g \cdot kg^{-1}$ to a maximum of 110 $\mu g \cdot kg^{-1}$. As indi-

Table 6. MOE Dredged Material Guideline Exceedences

Parameter	MOE guidelines* ($mg \cdot kg^{-1}$)	Guideline exceedences (%)		
		All transects	Upstream A–F	Downstream G–K
Arsenic	8	66	90	33
Cadmium	1	66	90	33
Chromium	25	0	0	0
Copper	25	43	75	0
Lead	50	17	25	7
Mercury	0.3	0	0	0
Nickel	25	0	0	0
Zinc	100	43	70	20

*Guidelines based on total metal concentrations.

cated in Table 7, 1,3-dichlorobenzene was detected in almost 30% of the samples and appeared to be evenly distributed throughout the river. Both 1,4- and 1,2-dichlorobenzene were detected, but in only five samples downstream from Ottawa. There were three detections of trichlorobenzenes (all at transect E), one detection of tetrachlorobenzene, and one detection of pentachlorobenzene; no hexachlorobenzene was found.

SUMMARY AND RECOMMENDATIONS

Bottom sediments of the Ottawa River were found to be moderately contaminated from metals and relatively uncontaminated from trace organics. Concentrations of trace metals showed distinctive spatial patterns with the highest concentrations usually found at the Petawawa transect. The complex hydrological characteristics of the

Table 7. Summary of Organic Contaminants Measured, Detection Limits, and Frequency of Detection

	Detection limit ($mg \cdot kg^{-1}$)	No. of samples	No. of detections	Frequency of detections (%)
Organochlorine pesticides and PCBs				
p,p'-DDT	0.004	35	0	0
o,p'-DDT	0.004	35	0	0
p,p'-TDE	0.004	35	1	3
p,p'-DDE	0.004	35	4	11
p,p'-Methoxychlor	0.004	35	0	0
Heptachlor	0.004	35	0	0
Heptachlor epoxide	0.004	35	0	0
α-Endosulfan	0.004	35	0	0
β-Endosulfan	0.004	35	0	0
α-Chlordane	0.004	35	0	0
γ-Chlordane	0.004	35	0	0
γ-BHC (Lindane)	0.004	35	0	0
α-BHC	0.004	35	0	0
Mirex	0.004	35	0	0
Aldrin	0.004	35	0	0
Endrin	0.004	35	0	0
HEOD (Dieldrin)	0.004	35	0	0
PCBs (Total)	0.09	35	0	0
Chlorobenzenes				
1,3-Dichlorobenzene	0.050	35	10	29
1,4-Dichlorobenzene	0.050	35	2	6
1,2-Dichlorobenzene	0.050	35	3	9
1,3,5-Trichlorobenzene	0.005	35	0	0
1,2,4-Trichlorobenzene	0.005	35	2	6
1,2,3-Trichlorobenzene	0.005	35	1	3
1,2,4,5-Tetrachlorobenzene	0.005	35	0	0
1,2,3,5-Tetrachlorobenzene	0.005	35	0	0
1,2,3,4-Tetrachlorobenzene	0.005	35	1	3
Pentachlorobenzene	0.005	35	1	3
Hexachlorobenzene	0.004	35	0	0
PAHs				
Indene	0.050	35	0	0
1,2,3,4-Tetrahydronaphthalene	0.050	35	0	0
2-Methylnaphthalene	0.050	35	0	0
Quinoline	0.050	35	0	0
1-Methylnaphthalene	0.050	35	0	0
β-Chloronaphthalene	0.050	35	0	0
Acenaphthalene	0.050	35	0	0
Fluorene	0.050	35	0	0
Phenanthrene	0.050	35	0	0
Fluoranthene	0.050	35	1	3
Pyrene	0.050	35	0	0

Table 8. Concentrations of Detectable Trace Organic Contaminants ($mg \cdot kg^{-1}$)

Parameter	Station	Concentration
p,p'-DDE	F-2	0.004
	F-4	0.009
	F-5	0.010
	I-3	0.005
p,p'-TDE	F-5	0.011
1,3-Dichlorobenzene	A-1	0.055
	B-2	0.062
	D-2	0.058
	F-3	0.073
	F-4	0.058
	F-5	0.110
	I-3	0.066
	J-2	0.054
	K-1	0.059
	K-2	0.054
1,4-Dichlorobenzene	I-1	0.050
	I-2	0.086
1,2-Dichlorobenzene	I-1	0.054
	K-1	0.064
	K-2	0.050
1,2,4-Trichlorobenzene	E-2	0.007
	E-3	0.014
1,2,3-Trichlorobenzene	E-3	0.010
1,2,3,4-Tetrachlorobenzene	E-1	0.007
Pentachlorobenzene	A-2	0.011
Fluoranthene	I-3	0.120

river, with its many dams and reservoirs, may be a contributing factor to high concentrations at this transect as there do not appear to be any point sources in the vicinity that could account for the concentrations found. Multiple regression analysis showed that metal concentrations were significantly correlated to the clay-sized fraction, and the relative percentage of clay-sized fraction was high in this area.

Four metals, namely, arsenic, cadmium, copper, and zinc, most frequently exceeded the MOE guidelines for dredged material disposal into open water. Of these, arsenic and cadmium warrant further investigation as to their fates and effects on the aquatic ecosystem.

Trace organic contaminants do not appear to be a problem in the bottom sediments. The frequency of detection (29%) of 1,3-dichlorobenzene, which has widespread industrial and agricultural applications, requires source identification.

It is recommended that a thorough municipal and industrial point source study be carried out to determine levels and sources of metals and organics to the Ottawa River.

ACKNOWLEDGMENTS

The author would like to thank Aline Sylvestre and Eric Tozer for their sampling support, the National Water Quality Laboratory for the chemical analyses of the sediments, and George Duncan for the particle size analysis of the samples.

REFERENCES

Bonk, S. 1958. Report on pollution of the Ottawa River between Deschenes Rapids and Cumberland Ferry. City of Ottawa Water Works Department, Ottawa, Ont.

Contaminants Task Force. 1980. Report of the Contaminants Task Force of the Federal/Provincial Technical Working Group on Water Quality in the Ottawa River. Ottawa, Ont.

Croteau, G., M. Goulet, and D. Laliberté. 1984a. Biphényles polychlorés: contamination du milieu aquatique au Québec méridional en 1980. Ministère de l'Environnement, Service de la qualité des eaux. Doc. de travail 84-17. Québec.

Croteau, G., M. Goulet, and D. Laliberté. 1984b. Contamination du milieu aquatique au Québec méridional en 1980: arsenic, cadmium, chrome, cuivre, mercure, nickel, plomb, zinc. Ministère de l'Environnement, Service de la qualité des eaux. Doc. de travail 84-18. Québec.

Duncan, G.A., and G.G. La Haie. 1979. Size analysis procedures used in the sedimentology laboratory. National Water Research Institute, Hydraulics Division, Burlington, Ont.

Environment Canada. 1979. *Analytical Methods Manual*. Inland Waters Directorate, Water Quality Branch, Ottawa, Ont.

Fisheries and Environment Canada. 1977. Monograph on the Ottawa River Basin. Environmental Management Service, Québec, Que.

Goulet, M., and D. Laliberté. 1982a. Métaux: contamination du milieu aquatique au Québec méridional. Ministère de l'Environnement, Service de la qualité des eaux. Doc. de travail Q.E.-51. Québec.

Goulet, M., and D. Laliberté. 1982b. BPC: contamination du milieu aquatique au Québec méridional. Ministère de l'Environnement, Service de la qualité des eaux. Doc. de travail Q.E.-53. Québec.

Hawley, J.R. 1979. The chemical characteristics of mineral tailings in the Province of Ontario. Ontario Ministry of the Environment, Waste Management Branch, Toronto, Ont.

Hem, J.D. 1970. Study and interpretation of the chemical characteristics of natural water. U.S. Department of Interior, Geological Survey Water Supply Paper 1473, Washington, D.C.

Lesauteur, T. 1965. Rapport sur l'état des eaux de la rivière des Outaouais. Cahiers n^os 1 et 2. Régie des eaux du Québec, Québec.

Merriman, J.C., and R.C. McCrea. 1985. Trace organic contaminants in the Ottawa River, National Capital Region, 1980. Tech. Bull. No. 136, Water Quality Branch, Ontario Region, Inland Waters Directorate, Environment Canada, Burlington, Ont.

Nie, N.H. 1975. SPSS: Statistical Package for the Social Sciences. New York: McGraw-Hill Book Company.

Oliver, B.G., and J. Kinrade. 1972. Heavy metal concentrations in Ottawa River and Rideau River sediments. Sci. Ser. No. 14, Inland Waters Branch, Department of the Environment, Ottawa, Ont.

Oliver, B.G., and H. Agemian. 1974. Further studies on the heavy metal levels in Ottawa and Rideau River sediments. Sci. Ser. No. 37, Water Quality Branch, Inland Waters Directorate, Environment Canada, Ottawa, Ont.

Ontario Department of Health. 1956. Report on Ottawa River and tributaries. Toronto, Ont.

Ontario Water Resources Commission. 1967. Water quality survey of the Ottawa River. Toronto, Ont.

Ontario Water Resources Commission and Quebec Water Board. 1971. Ottawa River Basin—Water quality and its control in the Ottawa River. Vol. 1.

Paul, M., D. Laliberté, and M. Goulet. 1984. Réseau de surveillance des substances toxiques en 1980: pesticides organochlorés dans le milieu aquatique au Québec méridional. Ministère de l'Environnement, Direction des relevés aquatiques. Doc. de travail 84-20. Québec.

Piché, L. 1954. Report on the pollution of the Ottawa River and its tributaries between Ottawa-Hull and Montréal. Anti-pollution League of Quebec, Montréal, Que.

Sandilands, R.G., and G.A. Duncan. 1980. SIZDIST-A computer program for size analysis. National Water Research Institute. Hydraulics Division Technical Note, Rep. No. 80-08, Burlington, Ont.

Thomas, J.F.J. 1952. Industrial water resources of Canada. Water survey report No. 2. Ottawa River drainage basin. Canada Department of Mines and Technical Surveys, Ottawa, Ont.

Thomas, R.L., and A. Mudroch. 1979. Small craft harbours—Sediment survey, Lakes Ontario, Erie and Lake St. Clair, 1978, Dredging summary and protocol. Report to the Great Lakes Biolimnology Laboratory, Burlington, Ont.

University of Ottawa and National Research Council. 1977. Distribution and transport of pollutants in flowing ecosystems, Vol. I & II. Ottawa, Ont.