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HAMILTON HARBOUR
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THE CHEMICAL FORM AND POTENTIAL AVAILABILITY OF TRACE METALS

IN THE SOUTHEASTERN PART OF HAMILTON HARBOUR

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EXECUTIVE SUMMARY

The chemical forms of ten elements have been determined for thirty-four samples of suspended sediments from the Southeastern portion of Hamilton Harbour. This area is adjacent to Windermere Basin (which receives inputs from Redhill Creek and the Hamilton Sewage Treatment Plant) and the steel-making industrial complex.

The average concentrations of dissolved Cd, Cr, Cu and Pb are elevated by ca 4X, 1.7X, 1.6X and 8X relative to the concentrations in nearshore areas of the Western Basin of Lake Ontario.

Readily exchangeable forms comprised a significant proportion of the total metal content for Cd (13%), Co (15%), Cu (15%), Mn (15%) and Ni (20%). The amount of metal ions in this fraction can be considered to arise from inputs of salt-laden (CaCl_2) water during the spring runoff period. The metal ions in this fraction (extracted by MgCl_2 in 10 minutes) are then available to the biotic community at a very sensitive stage in the life cycle of many organisms.

Carbonate and surface oxide bound forms were found to be significant for Cd (24%), Co (11%), Mn (20%), Ni (8%), Pb (6%) and Zn (16%). This fraction (extracted at pH 5.0 with acetate buffer) can be regarded as potentially arising from inadvertent inputs of acidic effluent which may persist because of density differences in the receiving waters.

March 3, 1982

ACKNOWLEDGEMENTS

For their cheerful and expert assistance in the collection of a portion of the samples, we thank Pat Healey, Steve Smith, Eric Tozer, Bob Hess and Mike Sieloff of Technical Operations Division, N.W.R.I., and the officers and crew of C.S.S. Limnos. Thanks are due to Susan Binns, Gunter Haase and Kelly Perrins for their help in the laboratory

The study was aided by grants from the Province of Ontario, Experience 1981 program, and the West-Central Region of Environment Ontario, and this support is gratefully acknowledged.

We thank Dr. Keith Rodgers, Director, NWRI, for his permission to carry out the laboratory work at CCIW.

A B S T R A C T

The chemical forms of Al, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn have been determined for thirty-four samples of suspended sediments from the southeastern portion of Hamilton Harbour. Exchangeable forms comprised a significant proportion of the total metal content for Cd (13%), Co (15%), Cu (15%), Mn (15%) and Ni (20%). Carbonate and surface-oxide bound forms were found to be significant for Cd (24%), Co (11%), Mn (20%), Ni (8%), Pb (6%) and Zn (16%).

The most important phases regulating the chemical forms of the trace metals studied were the Fe - Mn oxides. The average concentrations of dissolved Cd, Cr, Cu and Pb in southeastern Hamilton Harbour are elevated by Ca 4X, 1.7X, 1.6X and 8X relative to the concentrations in the nearshore areas of Lake Ontario.

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INTRODUCTION

The contamination of aquatic systems by metal inputs arising from urban and industrial activities has been well documented in numerous studies (Forstner and Wittmann, 1979). In general, the assessment of the nature and extent of metal pollution has been made using bottom sediment analyses. As a result, a great deal of valuable information has been amassed on the sources and sinks of metals in the environment. In contrast, less work has been done on trace metals in and on suspended particles in natural waters. The formation and removal of particles through sedimentation would be expected to be an important pathway of trace metals in waters. Recently, Turekian (1977) re-emphasized the role of particles in determining the fate of metals in the oceans. In addition, because of the relatively long residence time of particles in lakes and the oceans, they would be expected to play a significant part in regulating the chemical forms and hence the potential availability of metal ions in water.

The purpose of the study described here is to determine (1) the partitioning of Al, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn in suspended particulates from the southeastern portion of Hamilton Harbour and (2) whether any of the metals are transported to Lake Ontario within two days following a storm event.

TABLE 1
Sampling Locations In Hamilton Harbour

<u>Station</u>	<u>Latitude</u>	<u>Longitude</u>
1	43° 16' 12"	79° 47' 18"
2	43° 16' 54"	79° 47' 18"
3	43° 17' 48"	79° 47' 54"
4	43° 17' 54"	79° 48' 24"
5	43° 17' 24"	79° 48' 12"
6	43° 17' 12"	79° 48' 12"
7	43° 17' 45"	79° 48' 12"

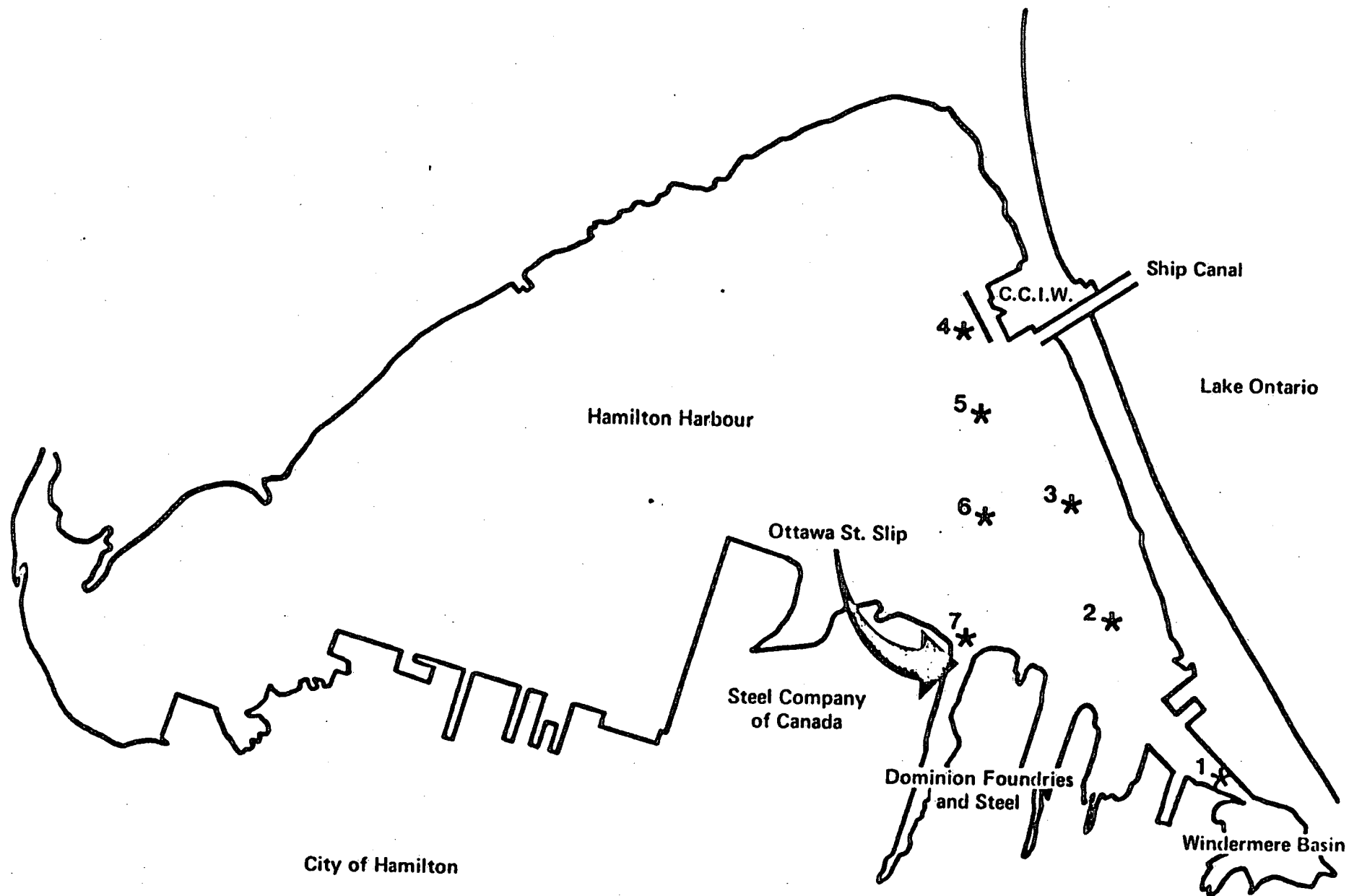


Fig. 1 Location of Sampling Stations in Hamilton Harbour, Ontario

STUDY AREA

Hamilton Harbour is a natural embayment separated from the western end of Lake Ontario by a sandbar, which is traversed by a ship canal (Fig. 1). The harbour waters are highly eutrophic, with a summer Secchi depth of about 1 m. Harbour muds are heavily contaminated with iron, phosphorus, manganese and lead and by chemical oxygen demand. (Ontario Ministry of the Environment, 1977.) The sampling locations (Fig. 1 and Table 1) were in the southeastern part of the harbour which receives inputs from the Hamilton Sewage Treatment Plant and Redhill Creek via Windermere Basin and the iron and steel-making facilities of the Steel Company of Canada and the Dominion Foundries and Steel Company.

SAMPLING METHODOLOGY

Two-hundred litres of harbour water were collected from two metres and three metres off the bottom, and continuous-flow centrifuged at 6 l min^{-1} using a Westphalia Separator operated at 8800 rpm. The recovery of particulates has been assessed by pre and post filtration through pre-weighed $0.4 \text{ }\mu\text{m}$ Nuclepore membranes to be ca 90-95% (Allan, 1979). After at least ten minutes, two litres of centrifugate were collected for the determination of dissolved metal ions. On completion of centrifuging, the particulate concentrate (ca 2 l) was immediately frozen and subsequently freeze-dried. The freeze-dried material was gently homogenized in an agate-mortar and stored in a plastic bottle.

Following a period of heavy rain, surface samples (one litre) were obtained within forty-eight hours at transects shown in Figure 2. These samples were returned to the laboratory and immediately filtered through $0.4 \text{ }\mu\text{m}$ Unipore (Bio-Rad) membranes. The filtrate was preserved by the addition of nitric acid to achieve a final concentration of 0.1 M and stored in polyethylene bottles which had been soaked for at least twenty-four hours in 2M nitric acid and thoroughly washed using doubly-distilled water. These samples were analyzed by D. C. Argon Plasma Atomic Emission Spectrometry.

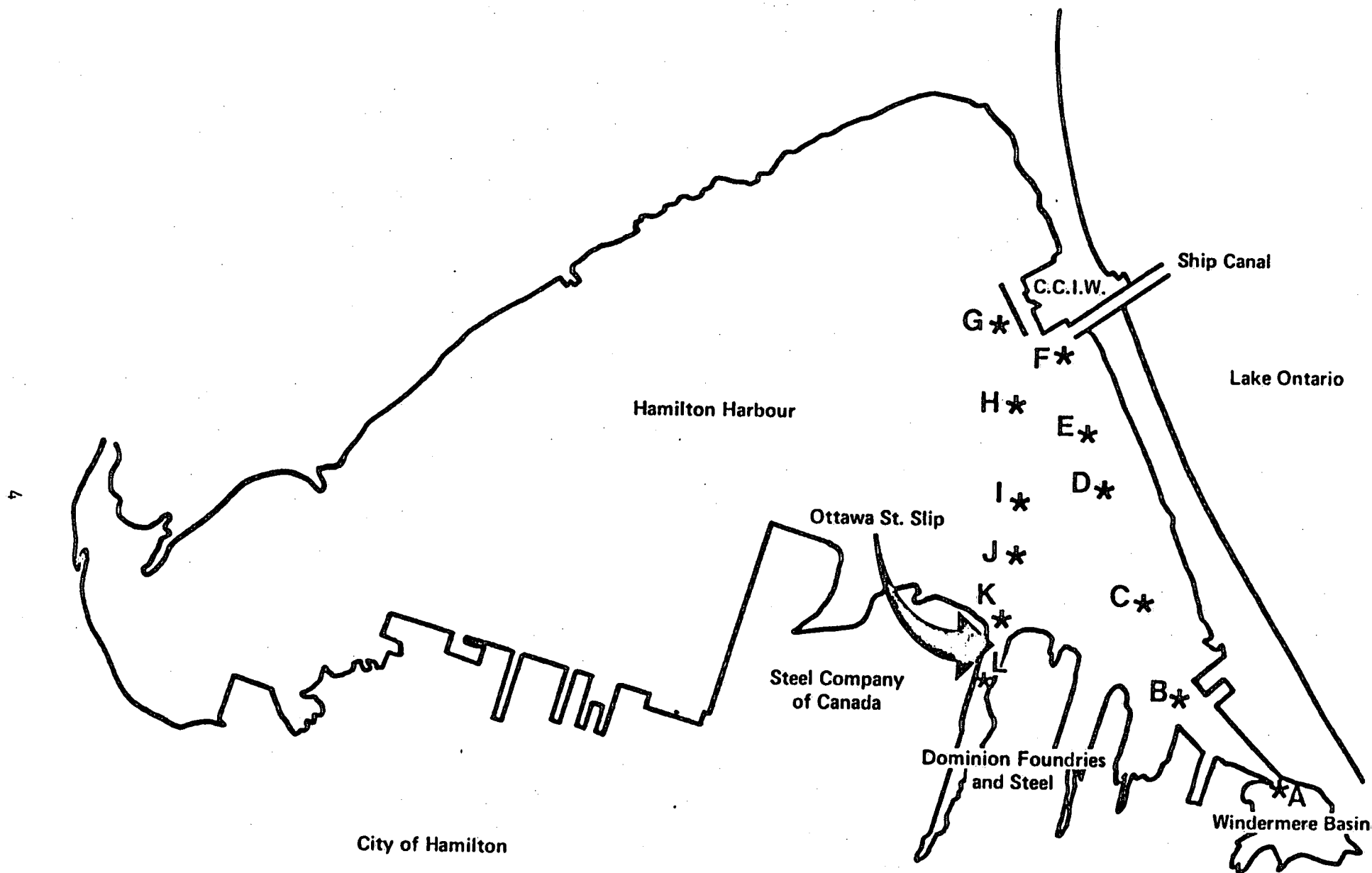


Fig. 2 Sampling Stations for the Plume Study

ANALYTICAL METHODS

DETERMINATION OF DISSOLVED Cd, Cr, Cu and Pb

Two litres of centrifugate were passed through a Chelex-100 chelating ion-exchange resin, Na⁺ form) column (4 cm x 1.0 cm²) at a flow rate of $5 \pm 0.5 \text{ ml min}^{-1}$. (Riley and Taylor, 1968, 1972.) The columns were then washed with twenty-five ml of distilled water and eluted with 2M nitric acid. After allowing fifteen ml of 2M nitric acid to stand in the column for fifteen minutes, a further twenty-five ml of acid were added and the eluate collected at a rate of $2-3 \text{ ml min}^{-1}$ in a teflon beaker. The eluate was carefully reduced to near dryness on a hot plate, taken up in 0.1 M nitric acid and made up to ten ml in a volumetric flask using the 0.1 M acid. The sample was then stored in an acid-washed polyethylene bottle.

SEQUENTIAL CHEMICAL EXTRACTION OF METAL FORMS IN PARTICULATE MATERIAL

Approximately 0.100 g (dry weight) of particulate material was subjected to the procedure developed by Tessier et al (1979). This procedure fractionates metal ions in and on particles as follows:

A: Exchangeable metal ions

The particulate samples were extracted for ten minutes with 8 ml of 1 M MgCl₂ at pH 7.0, with continuous agitation using a Burrell wrist-arm shaker.

B: Surface oxide and carbonate-bound metal ions

The residue from (A) was extracted for five hours with 8 ml of 1 M sodium acetate adjusted to pH 5.0 with acetic acid. Continuous agitation was maintained during the extraction.

C: Metal ions bound to Fe - Mn oxides

The residue from (B) was extracted for six hours at $90 \pm 5^\circ\text{C}$ with 20 ml of 0.04 M hydroxylamine hydrochloride in 25% (v/v) acetic acid, with occasional agitation.

D: Organically-bound metal ions

The residue from (C) was extracted with three ml of 0.02 M nitric acid and five ml of 30% hydrogen peroxide (adjusted to pH 2) by slowly heating the mixture in a water bath to $90 \pm 5^{\circ}\text{C}$. The sample was periodically agitated and after two hours a second three ml aliquot of 30% hydrogen peroxide was added and the mixture heated to 90°C as before. After three hours, five ml of 1.2 M ammonium acetate in 10% (v/v) nitric acid were added and the samples were diluted to ca 15 ml and agitated for thirty minutes.

E: Residual metals ions

The residue from (D) was dislodged and transferred to a teflon beaker with a fine spray of 0.02 M nitric acid, and digested to near dryness with two ml of concentrated hydrochloric acid, six ml of concentrated nitric acid and three ml of 30% hydrogen peroxide. Next, three ml of concentrated nitric acid, ten ml of concentrated hydrofluoric acid and three ml of 30% hydrogen peroxide were added and the mixture was heated to near dryness. Finally, three ml of concentrated hydrochloric acid, one ml of concentrated nitric acid, and one ml of 30% hydrogen peroxide and twenty ml of distilled water were added, and the volume reduced to ca 15 ml. The final extract was diluted to twenty-five ml with distilled water and stored in a polyethylene bottle. The extractions (A) - (D) were carried out in polysulfone (DuPont) centrifuge tubes; after each extraction, separation was effected by centrifuging (Sorvall-SS3) at 13,000 rpm (20,000 g) for forty minutes. The supernatant was decanted into a twenty-five ml volumetric flask and made up to the mark with doubly-distilled water, and stored in polyethylene bottles.

The Chelex eluates were analyzed for Cd, Cr, Cu and Pb by graphite furnace electrothermal atomization using a Hitachi Model 170-70 Zeeman Effect A.A.S. system. The operating conditions are summarized in Table 2. Calibration of the analysis was done by the method of standard addition because the slopes of the calibration curves in the sample matrix were in all cases smaller than those for standards made up in 0.1 M nitric acid.

The particulate extracts were analyzed by D.C. Argon Plasma Atomic Emission Spectrometry (DCPAES) using a Spectraspan III (Spectrametrics Inc.) equipped with a three-electrode jet assembly and a DBC-33, background compensator module. The analytical conditions are summarized in Table 3.

A multi-element standard containing 150 mg l^{-1} of Fe and Al, 10 mg l^{-1} of Mn and 6 mg l^{-1} of the remaining elements, was found to be generally the best compromise for the variety of matrices and the concentration ranges of the samples. All determinations were made using position Hi 12 on the DBC-33 background compensator. Prior to running samples, the DBC-33 was used to obtain emission spectra of pure single-element standard solutions (2 mg l^{-1} concentration) and the various sample matrices. On the basis of these spectra, which span $Ca \ 1 \text{ \AA}$ on each side of the emission peak wavelength, the Hi 12, absolute correction option, was selected as a compromise for the ten elements. In the case of Cu and Ni, correction generally had little effect on the analytical results. The need for correction was found to be necessary in most cases for Cd, Co, Cr, Pb and Zn. Because of the increased time and sample volume required to do a background scan and at the same time carry out three five-second integrations of each sample's emission intensity for ten elements, a two-point correction was not considered. Calibration stability was checked periodically (every sixth sample for fractions A and B, and every tenth sample for fractions C, D and E). Re-calibration was done when the standard run as a sample showed a 10% drift for the elements present at the 6 mg l^{-1} level.

The Unipore filtrates were analyzed by DCPAES using a multi-element standard containing 5 mg l^{-1} of each of the ten elements.

TABLE 2

Analytical Conditions For Graphite Furnace Atomic Absorption Determination of Cd, Cr, Cu and Pb					
Element	Wavelength nm	Temperature Program			Limit of Determination $\mu\text{g l}^{-1}$
		DRY RAMP MODE	ASH STEP MODE	ATOMIZE RAMP MODE	
Cd	228.8	0.6A sec ⁻¹	20 sec	28A sec ⁻¹	0.004
		325°C	60A	200A	
			600°C	2200°C	
Cr	359.3	"	"	50A sec ⁻¹	0.03
				310A	
				2800°C	
Cu	324.7	"	"	50A sec ⁻¹	0.08
				310A	
				2800°C	
Pb	283.3	"	"	32A sec ⁻¹	0.02
				220A	
				2400°C	

Limit of determination = 2 x S.D. of at least 20 determinations of a suitable standard addition spike to Chelex eluates.

TABLE 3

Analytical Conditions for D.C. Argon Plasma Atomic Emission Spectrometry			
Element	Wavelength nm	Output Slit	Limit of Determination mg l ⁻¹
Al	308.22	A	0.050
Cd	214.44	A	0.008
Co	238.89	B	0.012
Cr	425.44	A	0.004
Cu	324.75	A	0.004
Fe	259.95	A	0.050
Mn	257.61	A	0.008
Ni	341.48	A	0.004
Pb	405.75	A	0.024
Zn	213.86	B	0.012

Output Slit Dimensions: A: 25 μm x 100 μm

B: 50 μm x 200 μm

Input Slit Dimensions: 50 μm x 200 μm

RESULTS AND DISCUSSION

DISSOLVED METALS

The distribution of Cd, Cr, Cu and Pb at the seven stations during July and August, 1981 is summarized in Table 4. It is difficult to obtain from these data a dominant trend; indeed, the data suggest that at times bottom resuspension may be responsible for the higher concentrations observed at station 1, whereas for station 3 intrusion of a lens of cleaner lake water may lead to the lower levels found for the four metals. In spite of the well established dynamic nature of the water column (Ministry of the Environment, 1977) the dissolved Cd, Cr, Cu and Pb contents in the open part of the southeastern portion of the Harbour, appear to be regulated within quite small limits (see Table 5). The overall means do not include those values which are at least four times the mean standard deviation. The high concentration spikes are all observed either at stations 1 and 7 which are close to the principal sources of metals to this part of the Harbour.

Comparison of the average concentrations of the four metals in Table 5 with those obtained for the nearshore area of the western and central basin of Lake Ontario (K. R. Lum, in preparation) shows that Cd in the Harbour is elevated by ca 4X, Cr, 1.7X, Cu, 1.6X and Pb, 8X.

TABLE 4

Distribution of dissolved Cd, Cr, Cu and Pb in the southeastern part of Hamilton Harbour during July and August, 1981							
Units in $\mu\text{g l}^{-1}$							
Station	Depth	Cd ¹		Cr ¹		Cu ¹	Pb ¹
1	2 m	(3)	0.12±0.6	(3)	1.08±0.38	(3) 1.73±0.48	(1) 3.4
	B-3	(3)	0.19±0.15	(3)	2.45±2.88	(3) 2.23±1.20	(1) 7.4
2	2 m	(3)	0.18±0.13	(3)	0.69±0.22	(2) 2.10±0.33	(1) 2.40
	B-3	(3)	0.13±0.8	(3)	0.60±0.15	(3) 3.06±2.57	
3	2 m	(2)	0.20±0.10	(2)	0.18±0.26	(2) 3.14±3.14	(1) 4.02
	B-3	(3)	0.70±0.03	(3)	0.59±0.26	(3) 1.61±1.04	(1) 1.10
4	2 m	(2)	0.14±0.03	(2)	0.80±0.35	(3) 1.36±0.39	
	B-3	(2)	0.21±0.17	(2)	0.53±0.06	(3) 1.90±0.33	
5	2 m	(2)	0.18±0.25	(2)	0.88±0.18	(2) 1.30±0.03	
	B-3	(2)	0.07±0.01	(2)	0.52±0.12	(1) 1.24	
6	2 m	(2)	0.09±0.06	(2)	0.54±0.01	(2) 1.52±0.32	
	B-3	(1)	0.12	(1)	0.42	(1) 1.65	
7	2 m	(2)	0.31±0.11	(2)	0.03±0.11	(2) 1.64±0.61	(1) 3.32
	B-3	(2)	0.19±0.10	(2)	1.74±1.52	(2) 1.70±1.72	(1) 4.21

*For each row, the number of samples is indicated in brackets, (),
for which the mean value and standard deviation has been calculated.*

TABLE 5

Overall summary of dissolved Cd, Cr, Cu and Pb in the southeastern portion of Hamilton Harbour during July and August, 1981				
Units in $\mu\text{g l}^{-1}$				
	Cd	Cr	Cu	Pb
Mean	0.137	0.66	1.96	3.09
S.D.	0.025	0.08	0.43	0.61
Relative Standard Deviation	18%	12%	22%	20%

TABLE 6

Total Metal Concentrations in Suspended Particulate Matter from Hamilton Harbour During July and August, 1981			
Units in $\mu\text{g g}^{-1}$ except where noted			
Element	Mean ¹ \pm S.D.	Sediment ² 0 - 1 cm	Windermere ³ Basin 0 - 5 cm Average Content
Al	1.80 \pm 0.49%		
Cd	16 \pm 3	20	12
Co	18 \pm 3	36	
Cr	265 \pm 55	516	1070
Cu	140 \pm 4	220	500
Fe	2.95 \pm 0.43%	10%	4.2%
Mn	8070 \pm 4355	3290	
Ni	110 \pm 60	105	
Pb	365 \pm 70	720	700
Zn	1970 \pm 530		

1. No. of samples = 34

2. Data from Nriagu et al (1981)

3. Data from Ontario Ministry of the Environment

DISTRIBUTION OF THE CHEMICAL FORMS OF Al, Cd, Co, Cr, Cu,
Fe, Mn, Ni, Pb and Zn IN SUSPENDED PARTICULATE MATERIAL
IN HAMILTON HARBOUR

In discussing the results obtained during the sequential extraction procedure, it should be borne in mind that the partitioning pattern does not necessarily reflect the scavenging action of discrete, conceptually distinct solid phases. The speciation data should be regarded as experimentally defined by the procedure adopted. However, the approach used in this study does yield information which is valuable for understanding the geochemical behaviour of trace metals. (Tessier et al 1980; Rendell et al, 1980.)

Cd and Ni are found in concentrations comparable to those reported for the bottom sediments. In contrast, Co, Cr, Cu, Pb and Ni concentrations are significantly lower in the suspended particulates. Interestingly, Mn is the only element which is enriched in the particulates.

In Table 6, the total metal content of thirty-four samples of particulate materials analyzed in this study are compared with data on the metal levels in the surficial sediment of the Harbour (Nriagu et al, 1981) and in the top five centimetres of sediment from Windermere Basin (Ontario Ministry of the Environment, unpublished data). The exchange of water between the harbour and Lake Ontario has been established to be $5.3 \times 10^6 \text{ m}^3$ (Ontario Ministry of the Environment, 1978) which represents about 1.8% of the harbour volume. As a result, a portion of the metal budget of the harbour will be transported to the lake. The results on the distribution of the selected elements in the five fractions can be viewed as a measure of the probable impact of the harbour particulate metals on the nearshore waters of Lake Ontario. A summary of the thirty-four samples analyzed by the sequential extraction procedure is presented in Table 7.

TABLE 7

The Speciation of Al, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn
In Suspended Particulate Material From Hamilton Harbour.

Percentages of the Various Metals in the Five Fractions

	Al	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
% A	<0.05	13±6	15±7	1.2±0.3	15±2	<0.05	15±7	20±3	5±3	3±0.3
% B	<0.05	24±8	11±2	0.8±0.2	4±0.2	<0.05	20±9	8±2	6±1	16±8
% C	10±3	30±4	26±9	46±9	21±9	27±10	52±14	29±4	63±3	59±9
% D	13±8	11±3	18±7	23±11	38±5	16±5	4±2	14±8	17±8	12±2
% E	76±12	30±5	52±9	29±1	22±5	59±10	7±2	28±4	14±8	12±2

Aluminum:

Not surprisingly, aluminum is present as residual chemical forms although significant amounts of this element are found associated with Fe - Mn oxides and bound to organic materials.

Cadmium:

High proportions of cadmium are present in exchangeable and carbonate/surface oxide - bound forms. These results are in agreement with those of other workers. (e.g. Gardiner, 1974; Van der Weijden et al, 1977; Tessier et al, 1980.) The Fe - Mn oxide fraction represents ca 30% of the total cadmium and this is consistent with the experimental findings of Rao Gadde and Laitinen, 1974 and Van der Weijden, 1976. The results for fraction D indicate that cadmium is not strongly bound to organic material in Hamilton Harbour and this phase is not a particularly important one for this element. Because a large proportion of cadmium is associated with carbonates and surface oxide coatings (released at pH 5.0), it is possible that an appreciable percentage of cadmium could be made available following a decrease in pH.

Cobalt:

The behaviour of cobalt resembles that of cadmium except for the relatively larger amounts of cobalt found in the residual fraction (52%). This element is distributed fairly evenly between exchangeable, carbonate/surface oxide-bound and organically bound forms, with the Fe - Mn oxides being second in importance after the residual forms. Both Gibbs (1977) and Tessier et al (1980) found that levels of cobalt in the Amazon and Yukon Rivers and in the Yamaska and St. Francois Rivers to be near to or below the detection limit for fractions A and B. The disagreement between our results and theirs is probably a result of the better detection limits that can be achieved by DCPAES compared with flame AAS.

Chromium:

The most important phase for Cr speciation are the Fe - Mn oxides (46%). Unlike Cd and Co, the exchangeable and carbonate/surface oxide bound fractions are not important. The organically bound fraction is significant (23%). It is perhaps not surprising to find that in the southeastern part of Hamilton Harbour, Fe and Mn oxides are the forms controlling the potential availability of chromium. In areas not affected by iron and steel making activities, most of the chromium would be expected to be in the residual fraction (eg. Gibbs, 1977).

Copper:

The dominant phase for this element is organic material (38%). Similar results have been reported by Tessier et al (1980). Such a trend can be supported by the fact that for most ligands copper exhibits the largest formation constants of the series of elements $Cu > Pb > Ni > Zn > Fe$ (Irving and Williams, 1948). Gibbs (1977) has reported that copper bound to organic matter represented 8 - 15% of the total metal, with the residual fraction accounting for 74 - 84%. This difference between Gibbs and Tessier et al (and also the results of this study) is probably caused by the dominance of terrigenous material in the particulate composition of the Yukon and Amazon Rivers compared with the highly productive waters of Hamilton Harbour and the Yamaska and St. François Rivers which are closer to industrial and agricultural activities.

Iron:

High proportions of particulate iron are found as residual metal (59%), as oxides (27%) and bound to organic matter (16%). These results are in reasonable agreement with those of Tessier et al (1980).

Manganese:

The speciation of particulate manganese differs from that of the preceding metals in that the organically bound and residual fractions are relatively unimportant. As for Cr, the Fe - Mn oxide fraction is dominant, although high percentages of Mn are found in the exchangeable and carbonate/surface oxide bound fractions.

Nickel:

The behaviour of this metal is quite similar to that of Cd. Of all the metals studied, Ni exhibits the highest percentage in the exchangeable fraction. Other workers (Gibbs, 1977 and Tessier et al, 1980) found that levels in the exchangeable fraction were low, <5%. The reason for this apparent discrepancy is not known but is probably a result of the unique environmental conditions prevailing in Hamilton Harbour. Like the previous metals discussed, the magnitude of the Ni - Fe oxide fraction is significant. The percentage observed (29%) is in agreement with the known association of Ni with Fe - Mn oxides (Jenne, 1968).

Lead:

The most important chemical forms of Pb are the Fe - Mn oxide-bound forms which represent 63% of the total Pb. The levels of exchangeable and carbonate/surface oxide bound Pb are low but detectable and the organically bound and residual bound forms are of roughly equivalent importance (17 and 14%).

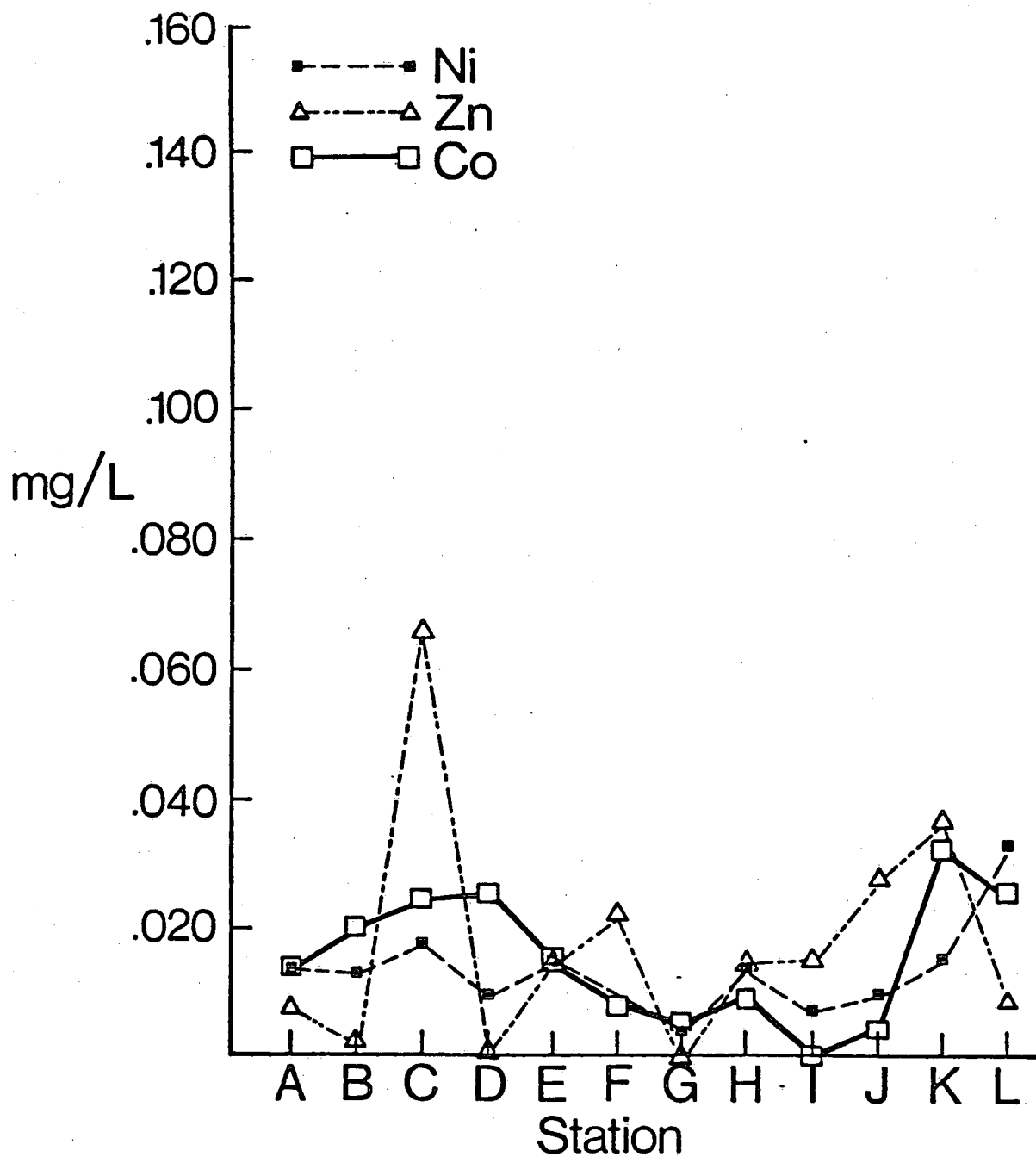
Zinc:

Like Pb, this element's speciation is dominated by the Fe - Mn oxide phase. In contrast, the carbonate/surface-oxide bound fraction is significant (16%). Exchangeable Zn forms are low but detectable.

TRANSPORT OF METALS IN THE SOUTHEASTERN PART
OF HAMILTON HARBOUR

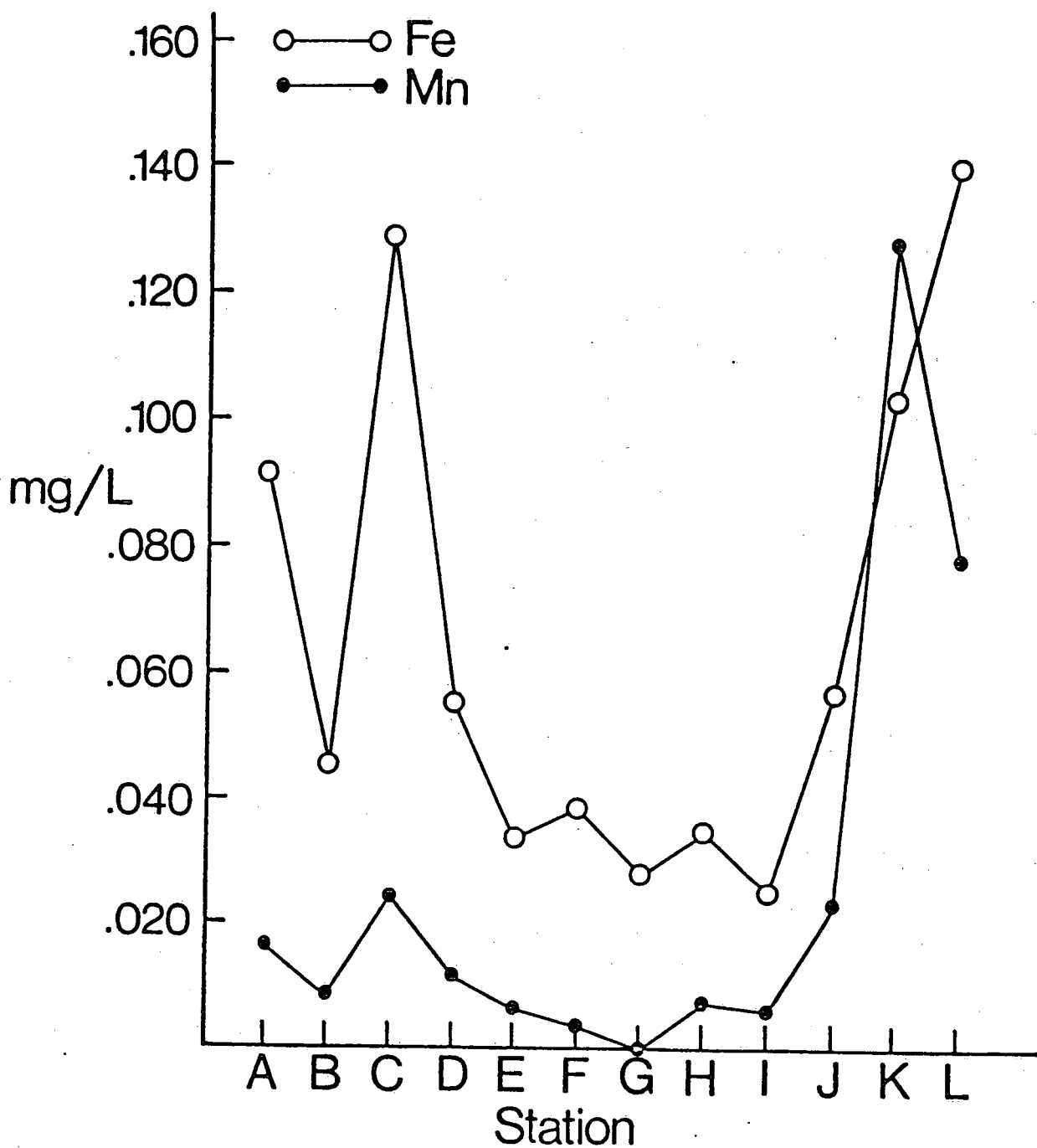
The concentrations of Fe, Mn, Cr, Ni, Cu, Zn and Co in surface water from the twelve stations shown in Figure 2 (page 2) are shown in Figures 3 - 6 (pages 19-22). The samples collected on July 29, 1981 followed a storm event which occurred about forty-eight hours previously. On August 10, 1981, the sampling took place during a steady rainfall which had been in progress for about twenty-four hours.

The frequency of sample collection does not permit a definite statement regarding metal transport from the Southeastern part of the Harbour towards the lake. However, Figures 3 - 6 indicate that stations close to the outlet of Windermere Basin and adjacent to industry are enriched with metals relative to the "control" station, G, close to the ship canal. On the basis of two sampling periods, the data does lend support to the combined action of dilution and removal mechanisms (e.g. particle formation, sorption reactions) being responsible for the decreased metal contents in that part of the Harbour which would be expected to be affected by inputs of Lake Ontario water.



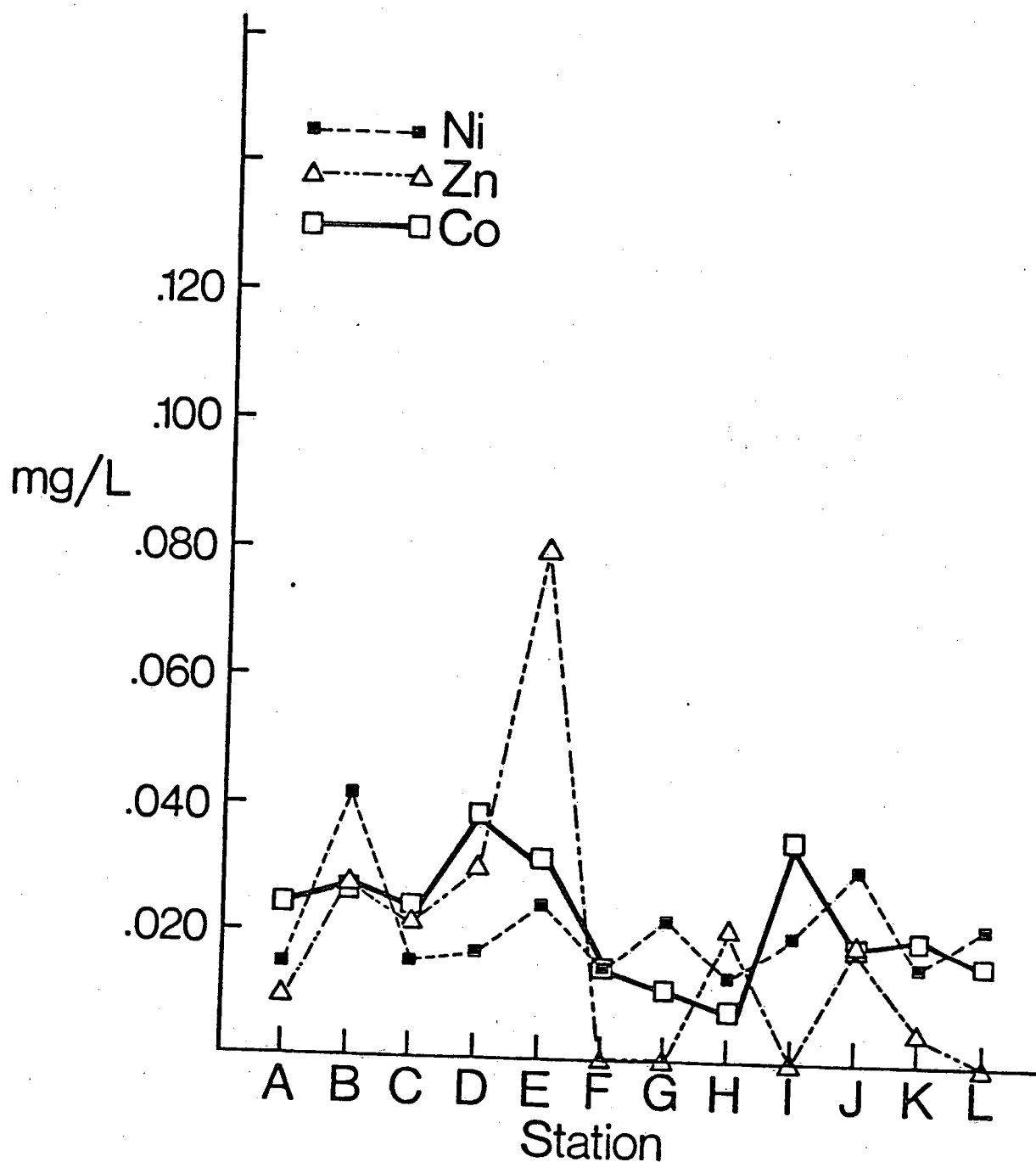
Hamilton Harbour Plume Study - July 29/81

FIG. 3



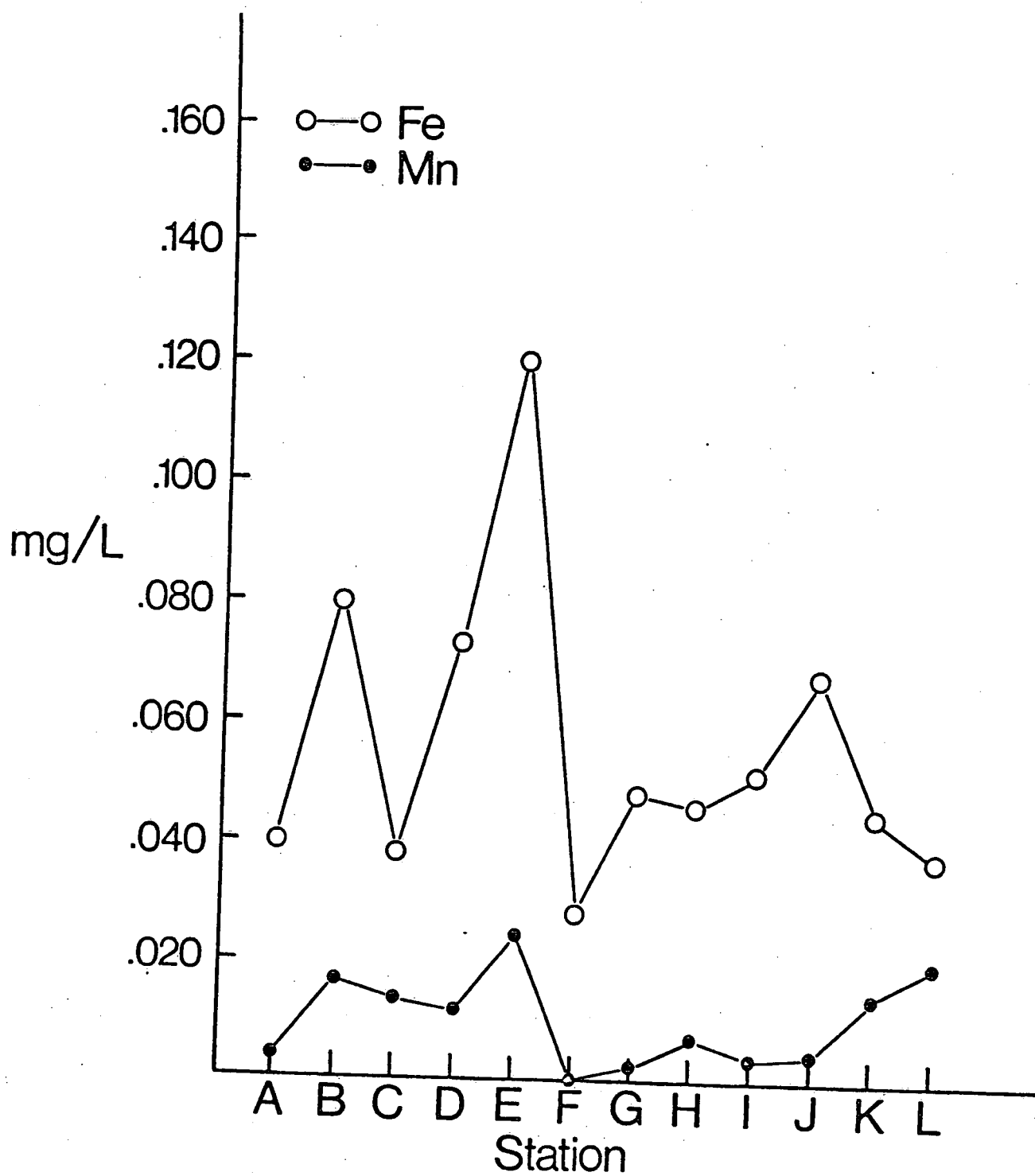
Hamilton Harbour Plume Study - July 29/81

FIG. 4



Hamilton Harbour Plume Study - Aug. 10/81

FIG. 5



Hamilton Harbour Plume Study - Aug. 10/81

FIG. 6

S U M M A R Y

In general, the results of this study have demonstrated the over-riding importance of sorption and occlusion of trace metals by Fe - Mn oxides in determining the potential availability of the metals. Of greater environmental relevance are the large proportions of Cd, Co, Cu, Mn, Ni and Zn found in exchangeable and/or carbonate/surface oxide bound forms. The former may be appreciably released as a result of an increase in ionic strength as may occur during the spring thaw when salt laden ice and snow melts. Metal ions bound to carbonates could be made available during accidental discharge of acidic effluent from industry located in the southeastern portion of the Hamilton Harbour.

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