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Contribution of Sediment and Associated Elements to the Great Lakes from Erosion of the Canadian Shoreline: PLUARG Technical Report, Task D, Activity 1

International Reference Group on Great Lakes Pollution from Land Use Activities

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INTERNATIONAL REFERENCE GROUP ON GREAT LAKES POLLUTION FROM LAND USE ACTIVITIES

INTERNATIONAL JOINT COMMISSION

CONTRIBUTION OF SEDIMENT AND ASSOCIATED ELEMENTS TO THE GREAT LAKES FROM EROSION OF THE CANADIAN SHORELINE

DISCLAIMER

ACKNOWLEDGEMENT

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (Cont.)

LIST OF FIGURES

SUMMARY

From detailed surveys conducted under the Canada/Ontario Agreement on shoreline damage in the Great Lakes the following long-term sediment loadings to the Great Lakes from the Canadian shoreline were determined:-

Lake Ontario	1,430,400 m.t./yr.
Lake Erie	8,701,750 m.t./yr.
Lake Huron	290,006 m.t./yr.

During the profiling surveys undertaken in this study a total of 493 samples of shoreline materials were taken and analysed for particle size, major and trace element composition.

On the basis of the interpretation of the shoreline loadings data together with the results of the analyses the following conclusions could be made:-

1) Shoreline erosion is a significant source of sediment to the Great Lakes, particularly Lake Erie.

2) Shoreline erosion has been a continuing process of consistent magnitude through at least the past 150 years.

3) Concentrations of elements are at background level and equate to the concentrations observed in deep pre-historic open lake sediments.

4) The contribution of total phosphorus to the lakes is low in Lakes Huron and Ontario but high in Lake Erie, with maximum percentages of 9.3, 6.2 and 35.2 percent respectively.

5) The contribution of available phosphorus is low for all three lakes with maximum percentages of 4.0, 5.0 and 1.1 for lakes Huron, Erie and Ontario expressed against the 1976 total phosphorus loadings.

6) The contributions of Hg, Pb, Zn, Cd, Cu, Org.C and N from shoreline erosion expressed as percentages of the annual loadings to the sediment are low except for Cd, Cu and Org. C in Lake Erie. The loadings in this lake however still represent a background condition and are lower than the total estimated natural loading to the open lake as indicated by pre-colonial loading estimates.

7) On the basis of 1 to 6 above, elements derived from shoreline erosion <u>do</u> <u>not</u> constitute a water quality problem though shoreline erosion as such remains a problem insofar as it affects property loss and value.

INTRODUCTION

The primary base for this study of erosion of the Great Lakes shoreline is the detailed investigation conducted under the Canada/Ontario agreement on Great Lakes Shoreline Damage. This study incorporated an assessment of long-term shoreline recession/accretion rates by photogrammetry between 1952 and 1973 and the short-term erosion rates during the high water levels of 1972 and 1973. For this latter part of the study shore erosion transects were established in the region from southern Georgian Bay to Pres'quille on Lake Ontario. Samples for analysis for PLUARG were collected from a number of these transects for analysis of texture, major and trace elements.

The objectives of the present study were to attempt to establish whether or not shoreline erosion has a deleterious effect on the water quality of the Great Lakes and to understand the role of sediment derived from this source on the sedimentation processes of the Great Lakes.

Shoreline erosion in general is the result of the attrition of unconsolidated bluff materials by the action of waves and by surface runoff. These effects are modified by such factors as bluff composition, ground water flow, stratigraphy and removal of sloughed materials by entrainment in the littoral zone. Materials so removed to the lake are subject to selective sorting by physical processes.

The breakdown of bluff materials (disaggregation by wave perturbation) results in the release of particles, which span the textural characteristics of the parent material, to the aqueous system.

A crude but significant classification is used whereby these materials are grouped into three size populations defined on the Wentworth Classification as follows:

	Size of Particles	
	ϕ^{1}	mm
Sand and gravel	<4	>.625
Silt	4-8	.039-.625
Clay	>8	<.039

Thomas et al. (1972) noted that sediment in Lake Ontario was deficient in silt size particles, a fact which was subsequently confirmed in studies on Lakes Huron, Erie and Superior (Thomas et al., 1973; 1975 and Thomas and Jaquet 1975). These authors explained the distribution of the textural characteristics of the sediments of the Great Lakes on the basis of selective sorting of a sand and a clay size population. The sand occurs in the shallow water nearshore zone whereas the clays and silty clays occur offshore in the deeper water depositional basins. This implies a net transport of clay and silt size materials offshore into quiescent physical conditions which permit the accumulation of these materials. Sands tend to occur outwards to water depths where wave generated energy declines to a level where movement of these sizes ceases (Sly 1977). Bluff material eroded into this situation thus fractionalizes into two major components. Sands and gravel remain in the high energy zone and move in the littoral zone as bed transport; and

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ϕ phi = diameter in mm to the negative log base 2 the fines are selectively winnowed into the suspended load and rapidly transported to a situation where accumulation may proceed. Fine particles may settle in shallow waters under quiet conditions but during variable wind events will be resuspended and subject to onward transportation in response to the physical circulation of the lake.

The coarse material with a tendency for "longshore" transport will ultimately accumulate as lacustrine sand and gravel deposits, beaches and dunes. For a discussion of these processes in the lower Great Lakes see Rukavina (1975). Needless to say the processes pertaining to the coarser fraction of shoreline material is intimately involved in the fine balances established between supply and demand for material in maintaining beaches and dunes as a human amenity. Shoreline protection, unless well planned, may delete sediment supply with rapid wide-scale impact in other parts of the system.

A detailed discussion of nearshore processes is beyond the scope of this study in that the impact of shoreline erosion on water quality is evaluated in chemical terms, and merely supplements information already available from the Canada/Ontario agreement and other scientific studies on physical processes. From a conceptual point of view, however, it should be noted that shoreline erosion is a natural process of coastal readjustment to lake levels that have been steadily rising since the formation of the modern Great Lakes system some 10,000 years before present. Variable erosion rates are related to the cyclical fluctuation of water levels but the long-term geological trend remains one of deepening water due to tilting of the crustal surface as a rebound phenomenon adjusting to the loss of ice mass during the last glaciation.

METHODS

CALCULATION OF SEDIMENT LOADINGS

a) Short-term loadings (1972-1973)

Short-term loadings to each lake were calculated for the Canadian shore of the lake basin plus reaches within the lake basin (see Table 1). Each reach within the lake was subdivided into sub-reaches, which were determined by the bluff type, shoreline configuration and soil composition, and the rate at which they were eroding or accreting. Volumes of material eroded or accreted per sub-reach were calculated using equation 1.

Equation 1 $\quad Vol. = ER \times SRL$

where: Vol. = volume of material eroded or accreted per sub-reach (m^3)

ER = erosion rate of the sub-reach (m^2)

SRL = sub-reach length (m)

Erosion rates for each sub-reach were obtained from the ground survey stations indicated in Canada/Ontario Great Lakes Shore Damage Survey Technical Report, and supplemented by data from subsequent monitoring up to and including year 1977.

Table 1. Description of Shoreline Reaches in Lakes Ontario, Erie and Huron

Lake	Reach No.	Reach Description
Lake Ontario	1	Niagara to Burlington Canal
	2	Burlington Canal to Toronto Is.
	3	Toronto Is. to Frenchman's Bay
	4	Frenchman's Bay to Presquille Pt.
Lake Erie	1	Detroit River to Point Pelee
	2	Point Pelee to Rondeau
	3	Rondeau to Long Point
	4	Long Point to Niagara
*Lake Huron	1	Sauble River to Point Clark
	2	Point Clark to Drysdale
	3	Drysdale to Kettle Point
	4	Kettle Point to Sarnia

*Georgian Bay not included as marginal erosion with shoreline predominantly consisting of bedrock (Canadian Shield - 30,000 islands, Bruce Peninsula) or sandy beaches (Midland and Nottawasaga Bays) contributed insignificantly to sediment loadings.

Using the volumes/sub-reach calculated in equation 1, tonnages (metric tons) pro-rated for soil composition of the bluff were calculated from Equation 2:

Equation 2 Tonnage: (per sub-reach) = Vol. x % comp. x (Wt x K)

where: Vol. = volume/m^3 per sub-reach

Wt. = dry bulk unit weight of soil type

Gravel = 19-21 kN/m^3

Sand = 17-18 kN/m^3

Silt = 16-17 kN/m^3

Clay = 15-18 kN/m^3

(dry bulk unit weight calculated from natural density values as given in Handbook of Soil Mechanics, Vol. 1: Kezdi 1974)

K = 9.80665 m/s^2 (conversion factor)

% comp = percentage of soil type at a given erosion station.

Added tonnage values for each soil type per sub-reach gives total tonnage per sub-reach. Total tonnage per reach is obtained by adding all sub-reach tonnages within that reach. Similarly, total tonnage per lake basin is obtained.

Lake Ontario data showed no survey stations along the Scarboro Bluffs. An average tonnage for the Scarboro Bluffs was obtained using data from Pleistocene Geology of the Scarboro Area (Karrow, P. F., Ont. Dept. of Mines, G.R. #46, p. 21, Appendix B, Fig. 5, 1967). This value is conservative since an average recession rate of .3657 m was used which is not indicative of the high water rate.

b) Long-Term Loadings (1953-1973)

Long-term loadings were calculated using the same procedures as those for short term loadings, with the exception that 20 yr. recession rates (m) were used instead of erosion rates ($m^3/m/m$) in equation 1.

In most cases, more stations and sub-reaches were included in the long-term loadings due to the availability of photogrammetric data for this time period. (Canada-Ontario Great Lakes Shore Damage Survey, Haras, 1974).

Lake St. Clair

Both long-term and short-term calculations were omitted for Lake St. Clair due to the presence of only two survey stations on the south shore and large beach and dune complexes covering all of this area.

c) Parameter Loadings

Short-term and long-term loadings for sediments, major elements, trace elements, chlorine and fluorine were calculated using equation 3.

Erosion tonnages only were used. Tonnages were calculated for both whole basin and reaches of each lake.

Equation 3

$$\text{Tonnage/parameter} = \text{TT/lake or reach} \times \begin{cases} \text{a) } \% \text{ by wt}/100 \\ \text{b) ppb} \times 1.0 \times 10^{-12} \\ \text{c) ppm} \times 1.0 \times 10^{-9} \end{cases}$$

where: TT = total tonnage due to erosion per lake or reach (metric tons)

a) $\frac{\%\ \text{by wt}}{100}$ = used to calculate loadings for major elements and sediments

b) ppb $\times 1.0 \times 10^{-12}$ - calculate loadings of mercury

c) ppm $\times 1.0 \times 10^{-9}$ - calculate trace metals, chlorine and fluorine

SAMPLING AND SAMPLE PREPARATION

A total of 493 samples were taken on transects established for the shoreline damage survey. At each sampling location a short vertical section was cleaned and a sample of about one kilogram taken from the section. An aliquot of the sample was used for textural analysis and the residue ground to pass 100 mesh, to ensure complete homogenization for geochemical analyses. A further aliquot of the ground sample was ground to 250 mesh, mixed 6:1 with resin and pelletized for X-ray determination of the major elements.

Textural Analysis

Sieve and long pippette analysis at one phi size increments were employed. Grain size statistics were computed by moment measures as described by Coakley and Beal (1972).

Major Elements

Total SiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, Na_2O, K_2O, TiO_2, P_2O_5, MnO and S were analysed by X-ray fluorescence spectrometry using a Phillips PW-1220C automatic X-ray spectrometer. Sediment standards were prepared from lake sediment and analysed by wet chemical methods and checked by comparison with analyses of the U.S. Geological Survey standard rocks G-2, PCC1, and DTS1.

Trace Elements

Trace elements Hg, Pb, Cu, Zn, Ni, Co, Cr, Cd, Be, V, Sr, U, Ag, Mo, Se, As, Se, Cl and F were determined on contract by Bondar Clegg Ltd., Ottawa, a laboratory that has been involved in the PLUARG round robin series of sediment analyses.

Organic and Inorganic Carbon and Nitrogen

Organic and inorganic carbon were measured on 34 samples. Organic-C was determined by dry combustion in a LECO furnace after removal of the carbonate with sulphurous acid. Total carbon was determined on a separate aliquot and carbonate carbon calculated as the difference between the two determinations (Kemp 1971).

Total N was also analysed on the same 34 samples. Total N was determined by the Dumas method in a LECO Model UO-14SP nitrogen determinator as described by Wong and Kemp (1977).

Phosphorus Fractionation

For the purpose of this study 37 samples were analysed by the techniques of Williams et al. (1976) for Total P and Apatite P.

SEDIMENT LOADING TO THE GREAT LAKES

Both long-term (1953-1973) and short-term (1972-1973) loadings were calculated for Lakes Ontario, Erie and Huron. Reaches used in the calculation of the loadings are given in Figs. 1, 2 and 3. Loadings for sub-reaches are not tabulated in this report; sub-reach loadings have been accumulated to provide a tabulation by reach (see methods).

Particle Size

The results of particle size analysis for sand and gravel, silt, clay and mean grain size averaged by reach and by lake are given in tables 2, 3 and 4.

In general the composition of the bluff materials in Lakes Erie and Ontario is similar though Lake Huron shows a generally coarser nature with increased percentages of sand and gravel relative to silt and clay.

In Lake Ontario, reach #5 is high in sand and gravel compared to the other reaches whereas reach #1 is proportionally enriched in clay size material (Table 2). Reach #5 occurs in a region of net accretion (Prince Edward County) (Fig. 1) Rukavina (1976) and is not further discussed in this report nor included in the loadings calculation.

Evaluation of the mean composition of the reaches for Lake Erie (Table 3), shows that reach #1 is of a coarser nature than the other three reaches which are compositionally very similar.

For Lake Huron, (table 4) reach #1 is deficient in clay; a higher value for silt with proportionally lower sand and gravel can be seen in reach #2.

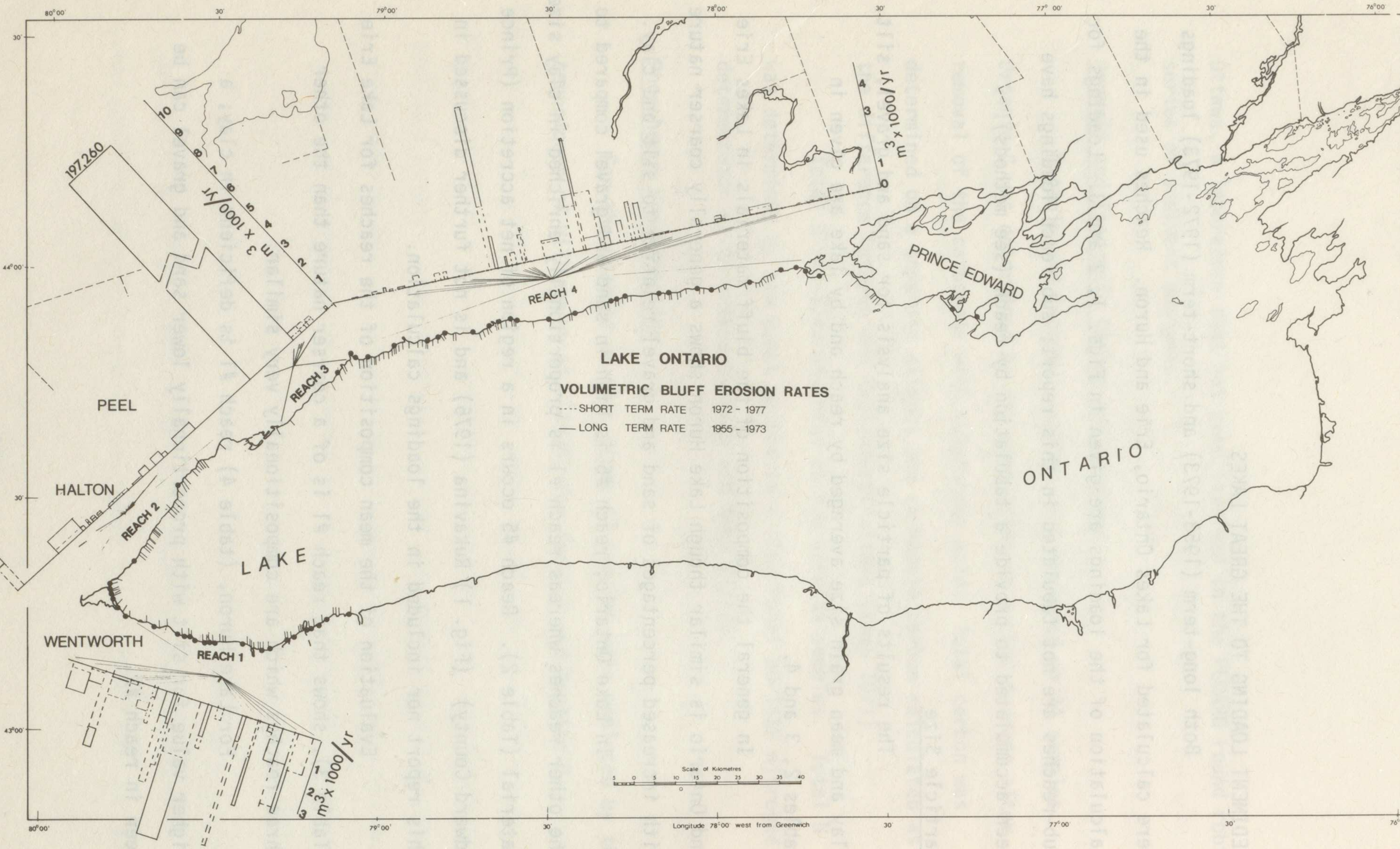

Figure 1 VOLUMETRIC BLUFF EROSION RATES AND SHORELINE REACHES IN LAKE ONTARIO

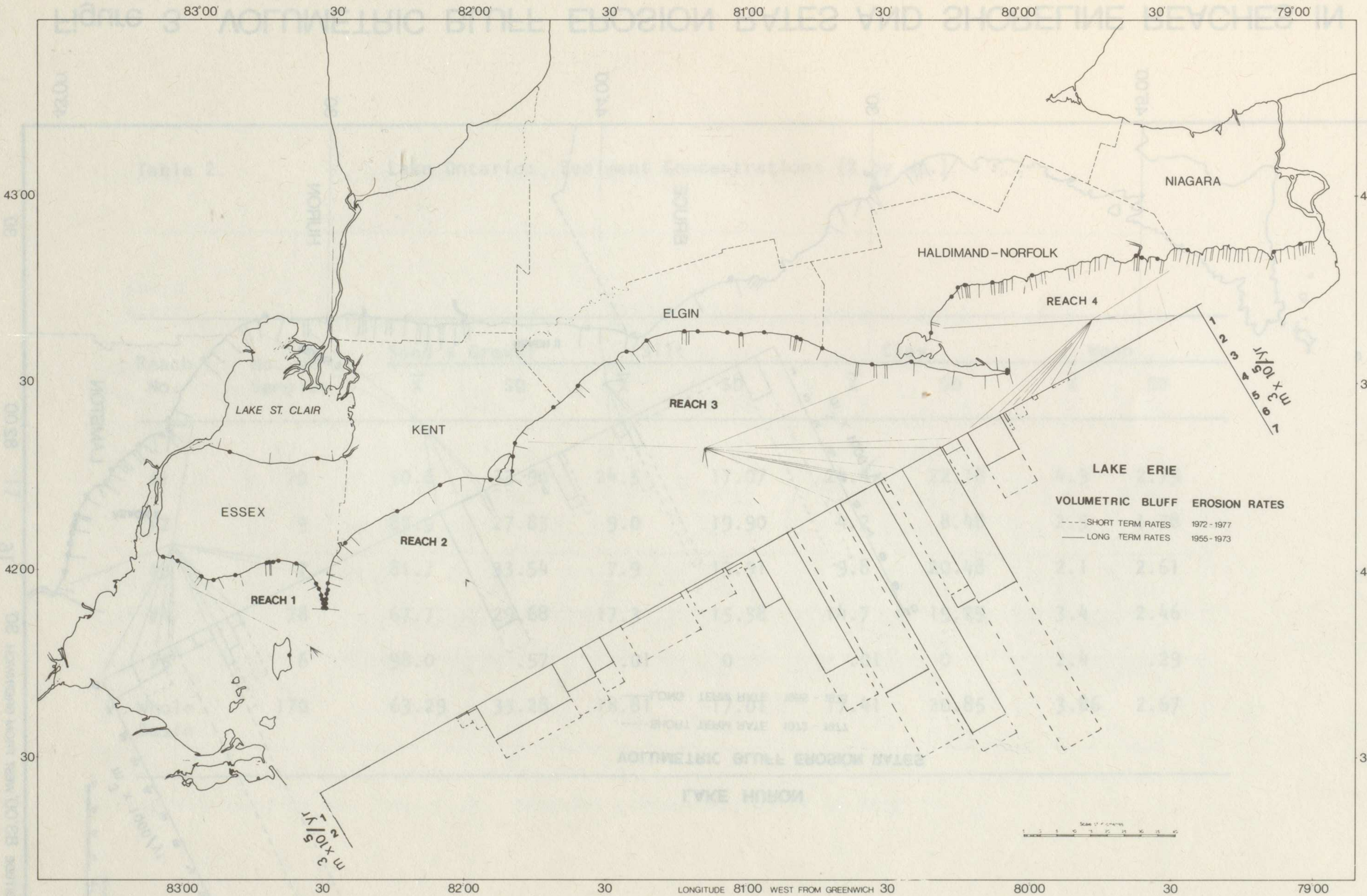

Figure 2 VOLUMETRIC BLUFF EROSION RATES AND SHORELINE REACHES IN LAKE ERIE

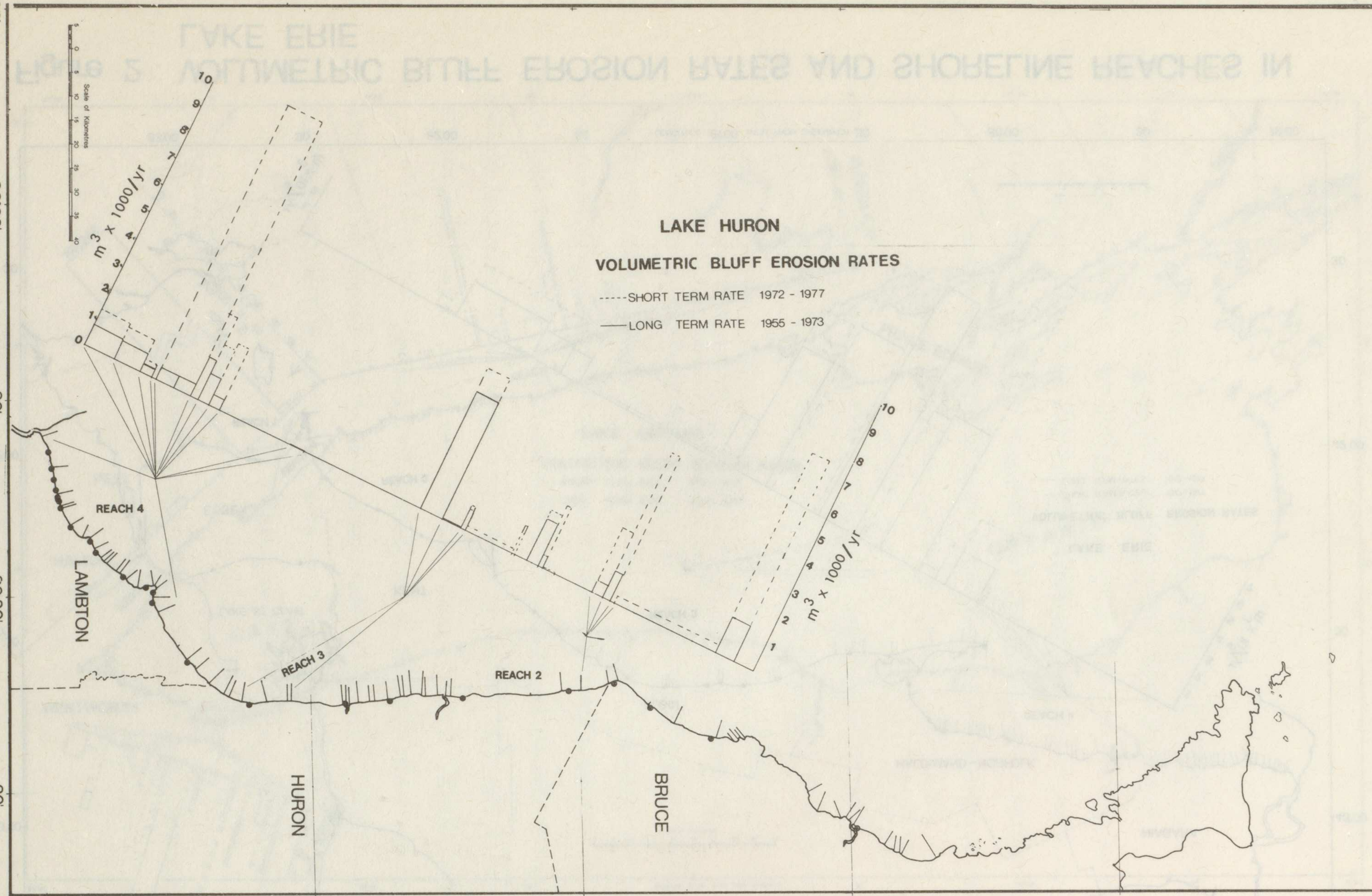

Figure 3 VOLUMETRIC BLUFF EROSION RATES AND SHORELINE REACHES IN LAKE HURON

Table 2. Lake Ontario: Sediment Concentrations (% by wt.)

Reach No.	No. of Samples	Sand & Gravel		Silt		Clay		Mean	
		$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
#1	70	50.6	33.90	24.5	17.07	24.4	22.18	4.9	2.75
#2	9	85.9	27.83	9.0	19.90	4.2	8.48	2.5	1.78
#3	7	81.7	33.54	7.9	13.91	9.8	20.48	2.1	2.61
#4	78	67.7	29.68	17.3	15.38	14.7	19.29	3.4	2.46
#5	6	98.0	.57	.01	0	.01	0	2.4	.29
Whole Basin	170	63.29	33.28	18.81	17.01	17.41	20.85	3.86	2.67

Table 3. Lake Erie: Sediment Concentrations (% by wt.)

Reach No.	No. of Samples	Sand & Gravel		Silt		Clay		Mean	
		$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
#1	59	71.0	33.85	15.4	20.73	12.7	19.61	3.3	2.62
#2	22	61.6	38.19	13.7	14.29	24.1	24.99	4.1	3.28
#3	73	54.4	43.13	20.6	20.99	24.3	28.18	4.8	3.25
#4	40	64.5	43.55	9.7	15.65	25.1	34.17	4.2	3.69
Whole Basin	194	62.4	40.35	15.9	19.54	20.9	27.30	4.2	3.22

Table 4. Lake Huron: Sediment Concentrations (% by wt.)

Reach No.	No. of Samples	Sand & Gravel		Silt		Clay		Mean	
		$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
#1	19	98.5	.78	.01	0	.01	0	1.4	.64
#2	19	58.9	39.27	22.2	22.60	18.2	20.60	4.0	3.14
#3	16	79.7	29.72	8.3	12.75	10.9	17.75	2.9	2.31
#4	63	75.9	33.71	9.9	15.23	13.1	20.29	2.9	2.75
Whole* Basin	117	78.5	32.46	9.5	15.93	10.8	18.57	2.8	2.57

* includes Georgian Bay

Sediment Loadings

Loadings for total sediment and the size fractions by reach and whole lake are given for both long and short-term in tables 5 to 10. In Lake Ontario long-term loadings are in the order of 1.4 million tonnes which show little difference to the 1.3 million tonnes in the short-term calculation of 1972-1973 (tables 5 and 6). Greatest erosion both long and short-term occurs in reach #1 on the north shore of the Niagara Peninsula. Similarly the lowest erosion for both periods occurs in reach #2 with both reaches 3 and 4 showing significant loadings similar in magnitude to reach #1.

In Lake Erie (tables 7 and 8) shoreline erosion along the north shore is extremely high with a long-term annual erosion rate of 8.7 million tonnes increasing to a short-term high lake level loading of 14 million tonnes. In both short and long-term periods the major contribution is derived from reach #3 which accounts for approximately 80% of the total sediment loading to the lake from Canadian shoreline erosion.

The contribution of sediment to Lake Huron from the Canadian shoreline on the west side of the Bruce Peninsula is relatively small, 0.3 million tonnes for long-term erosion increasing to a short-term loading of 1.1 million tonnes (tables 9 and 10).

In all lakes (tables 5 to 10) it can be observed that sand and gravel constitute the predominant material supplied to the lake from shoreline erosion. This material, as stated previously, remains in the littoral zone and as such will not impact on lake water quality. The finer materials in the silt and clay sizes will tend ultimately to disperse offshore to settle in the deeper, open water lake basins.

Table 6. Lake Ontario: Short-Term Sediment Loadings (in metric tons/year)

Reach No.	Total Sediment	Sand & Gravel	Silt	Clay
#1	599,125	282,917	136,986	136,427
#2	32,050	27,530	2,884	1,346
#3	354,900	289,953	28,037	34,780
#4	308,275	208,702	53,331	45,316
Total for Basin	1,254,350	794,003	235,817	218,256

Table 7. Lake Erie: Long-Term Sediment Loadings (in metric tons/year)

Reach No.	Total Sediments	Sand & Gravel	Silt	Clay
#1	172,550	122,510	26,572	21,913
#2	876,300	539,800	120,053	211,188
#3	6,583,200	3,581,260	1,356,139	1,599,717
#4	1,069,700	689,956	103,760	268,494
Total for Basin	8,701,750	5,429,892	1,392,280	1,818,665

Table 8. Lake Erie: Short-Term Sediment Loadings (in metric tons/year)

Reach No.	Total Sediment	Sand & Gravel	Silt	Clay
#1	200,685	142,486	30,905	25,486
#2	1,669,125	102,818	228,670	402,259
#3	11,131,700	6,055,644	2,293,130	2,705,003
#4	959,350	618,780	93,056	240,796
Total for Basin	13,960,860	8,711,576	2,233,737	2,917,819

Table 9. Lake Huron: Long-Term Sediment Loadings (in metric tons/year)

Reach No.	Total Sediments	Sand & Gravel	Silt	Clay
#1	nil	nil	nil	nil
#2	101,407	59,173	22.512	18,456
#3	93,495	74,515	7,760	10,190
#4	95,104	72,183	9,415	12,458
Total for Basin	290,006	227,944	27,550	31,320

Table 10. Lake Huron: Short-Term Sediment Loadings (in metric tons/year)

Reach No.	Total Sediment	Sand & Gravel	Silt	Clay
#1	nil	nil	nil	nil
#2	364,675	214,793	80,957	66,370
#3	108,975	86,853	9,044	11,878
#4	581,025	440,997	57,521	76,114
Total for Basin	1,054,675	828,974	100,194	113,904

Tonnages of these materials are summarized as follows:-

	Silt & Clay Long-term (m.t./year)	Silt & Clay Short-term (m.t./year)
Lake Ontario	517,800	454,070 (36%)
Lake Erie	3,210,950	5,151,560 (37%)
Lake Huron	58,870	214,100 (20%)

(   ) denotes percentage of total loading which applies to both short and long-term loading.

Major Element Loadings

The mean concentrations of the major elements in shoreline material by reach and lake are given in tables 11 , 12 and 13 . The loadings calculated from these data and the sediment loss data for both long-term and short-term are summarized in tables 14 to 19 . Other than phosphorus these elements are not considered to be a problem insofar as water quality considerations are concerned and merely represent the mineralogical composition of the parent material. This being the case the major elements will not be discussed any further than the presentation of the concentration and loadings data given in tables 11 to 19.

Phosphorus

The mean concentrations of total P as P_2O_5 together with loadings have been summarized in the tables of major elements noted above. These loadings expressed as total P are independently summarized in table 20 .

Table 11. Lake Ontario: Major Element Concentrations (% by wt.)

Reach No.	No. of Samples	SiO_2		Al_2O_3		Fe_2O_3		MgO		CaO		Na_2O		K_2O		TiO_2		P_2O_5		MnO		S		CO_2		Org.C	
		$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
#1	70	61.99 (67)	9.75	8.40 (67)	1.47	3.82 (67)	1.16	2.55 (67)	.833	8.17 (67)	4.45	1.08 (67)	.14	2.34 (67)	.52	.59 (67)	.14	.16 (67)	.03	.12 (67)	.04	.03 (68)	.04	6.42 (4)	5.16	.24 (4)	.20
#2	9	71.66 (8)	8.57	6.64 (8)	.80	1.67 (8)	.83	1.63 (8)	.648	10.76 (8)	2.52	1.33 (8)	.10	1.94 (8)	.23	.29 (8)	.17	.13 (8)	.04	.08 (8)	.02	.01 (8)	0				
#3	8	53.07	9.05	6.14	2.42	2.27	1.75	2.36	.338	18.36	7.72	.78	.37	1.72	.75	.38	.24	.13	.05	.15	.18	.08	.08	5.17 (2)	6.50	.67 (2)	.66
#4	78	39.76 (76)	13.41	5.41 (76)	1.40	1.59 (76)	1.03	2.55 (76)	.489	25.69 (76)	7.30	.43 (76)	.45	1.50 (76)	.50	.35 (76)	.16	.11 (76)	.14	.07 (76)	.02	.04 (76)	.07	11.91 (6)	3.03	1.02 (6)	.46
#5	6	73.37	6.07	7.17	.85	.44	.17	1.08	.193	11.07	2.19	1.71	.22	2.13	.23	.06	.02	.09	.01	.02	.01	.01	0				
Whole Basin	171	52.20 (165)	16.55	6.78 (165)	2.01	2.49 (165)	1.57	2.44 (165)	.723	16.97 (165)	10.27	.80 (165)	.50	1.90 (165)	.64	.43 (165)	.21	.13 (165)	.10	.10 (165)	.06	.04 (166)	.07	8.96 (12)	5.05	.70 (12)	.53

Table 12. Lake Erie: Major Element Concentrations (% by wt.)

Reach No.	No. of Samples	SiO_2 $\bar{X}$	SiO_2 SD	Al_2O_3 $\bar{X}$	Al_2O_3 SD	Fe_2O_3 $\bar{X}$	Fe_2O_3 SD	MgO $\bar{X}$	MgO SD	CaO $\bar{X}$	CaO SD	Na_2O $\bar{X}$	Na_2O SD	K_2O $\bar{X}$	K_2O SD	TiO_2 $\bar{X}$	TiO_2 SD	P_2O_5 $\bar{X}$	P_2O_5 SD	MnO $\bar{X}$	MnO SD	S $\bar{X}$	S SD	CO_2 $\bar{X}$	CO_2 SD	Org.C $\bar{X}$	Org.C SD
#1	59	58.55 (57)	11.52	7.20 (57)	1.97	2.90 (57)	1.59	2.86 (57)	.889	11.98 (57)	5.94	.98 (57)	.21	2.14 (57)	.67	.44 (57)	.32	.14 (57)	.09	.07 (57)	.04	.09 (57)	.12	9.02 (3)	1.46	1.30 (3)	.42
#2	22	49.88	7.52	7.72	2.00	3.39	.99	3.39	.642	14.73	5.12	.87	.15	2.32	.83	.49	.16	.15	.02	.08	.03	.21	.24	9.82 (2)	.63	1.13 (2)	.15
#3	73	52.31	12.90	7.09	1.78	3.50	3.61	3.41	1.33	14.21	5.08	1.05	.32	2.06	.80	.61	.75	.16	.07	.10	.11	.07	.07	9.66 (12)	1.78	.88 (12)	.34
#4	40	57.21	14.87	7.24	1.73	2.81	2.23	3.39	1.34	11.61	5.25	1.24	.39	2.12	.70	.42	.37	.15	0	.08	.06	.02	.03	8.52 (5)	4.92	.53 (5)	.27
Whole Basin	194	54.90 (192)	12.79	7.23 (192)	1.85	3.16 (192)	2.62	3.24 (192)	1.17	13.07 (192)	5.50	1.05 (192)	.31	2.13 (192)	.74	.51 (192)	.53	.15 (192)	.08	.09 (192)	.08	.08 (192)	.12	9.33 (22)	2.60	.88 (22)	.39

Table 13. Lake Huron: Major Element Concentrations (% by wt.)

Reach No.	No. of Samples	SiO_2 $\overline{X}$	SiO_2 SD	Al_2O_3 $\overline{X}$	Al_2O_3 SD	Fe_2O_3 $\overline{X}$	Fe_2O_3 SD	MgO $\overline{X}$	MgO SD	CaO $\overline{X}$	CaO SD	Na_2O $\overline{X}$	Na_2O SD	K_2O $\overline{X}$	K_2O SD	TiO_2 $\overline{X}$	TiO_2 SD	P_2O_5 $\overline{X}$	P_2O_5 SD	MnO $\overline{X}$	MnO SD	S $\overline{X}$	S SD
#1	19	52.77	14.31	4.99	.44	1.90	1.18	5.43	1.87	12.97	3.63	1.21	.21	1.02	.18	.27	.23	.11	.03	.07	.04	.01	0
#2	19	50.70	20.26	5.34	1.33	1.67	.78	4.59	1.89	14.65	6.45	.88	.25	1.60	.67	.27	.17	.11	.03	.05	.01	.02	.02
#3	15	61.62 (15)	19.01	5.89 (15)	1.60	1.50 (15)	.93	3.47 (15)	1.72	10.94 (15)	5.73	.99 (15)	.26	1.72 (15)	.66	.20 (15)	.15	.09 (15)	.03	.04 (15)	.02	.04 (15)	.07
#4	59	61.04 (59)	15.73	5.45 (59)	2.11	1.90 (59)	1.17	3.23 (59)	1.27	13.34 (59)	5.93	.79 (59)	.17	1.55 (59)	.80	.23 (59)	.17	.11 (59)	.03	.06 (59)	.02	.03 (60)	.05
Whole Basin	117	58.77 (119)	16.99	5.60 (119)	1.85	1.79 (119)	1.07	3.72 (119)	1.807	12.96 (119)	5.60	.96 (119)	.34	1.52 (119)	.71	.24 (119)	.17	.10 (119)	.03	.06 (119)	.03	.02 (120)	.04

Table 14. Lake Ontario: Long Term Major Element Loadings (in metric tons/year)

Reach No.	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	S	CO_2	Org.C.
#1	306,912	41,588	18,912	12,625	40,449	5,347	11,585	2,921	792	594	148	31,785	1,188
#2	55,966	5,185	1,304	1,273	8,403	1,038	1,515	226	101	62	7	6,997[1]	546[1]
#3	193,652	22,404	8,283	8,611	66,995	2,846	6,276	1,386	474	547	291	18,865	2,444
#4	195,738	26,633	7,827	12,553	126,471	2,116	7,384	695	541	344	196	58,632	5,021
Whole[2] Basin	746,668	96,981	35,616	34,901	242,738	11,443	27,177	6,150	1,859	1,430	572	128,163	10,012

[1] No analyses of samples available in Sector 2, loading computed using whole basin mean.

[2] Whole Basin loadings determined using total sediment loading and mean concentration

Table 15. Lake Ontario: Short Term Major Element Loadings (in metric tons/year)

Reach No.	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	S	CO_2	Org.C.
#1	346,601	46,966	21,358	14,257	45,680	6,038	13,083	3,298	894	670	167	35,895	1,341
#2	22,967	2,128	535	522	3,448	426	621	92	41	25	3	2,871[1]	224[1]
#3	188,345	21,790	8,056	8,375	65,159	2,768	6,104	1,348	461	532	283	18,348	2,377
#4	122,570	16,677	4,901	7,861	79,195	1,325	4,624	1,078	339	215	123	36,715	3,144
Whole[2] Basin	654,770	85,044	31,233	30,606	212,863	10,034	23,832	5,393	1,630	1,254	501	112,389	8,780

[1] No analyses of samples available in Sector 2, loading using whole basin mean.

[2] Whole basin loadings determined using total sediment loading and mean concentration for all samples.

Table 16. Lake Erie: Long Term Major Element Loadings (in metric tons/year)

Reach No.	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	S	CO_2	Org.C.
#1	101,028	12,423	5,003	4,934	20,671	1,690	3,692	759	241	120	155	15,564	2,243
#2	437,098	67,650	29,706	29,706	129,078	7,623	20,330	4,293	1,314	701	1,840	86,052	9,902
#3	3,443,671	466,748	230,412	224,487	935,472	69,123	135,613	40,157	10,533	6,583	4,608	635,937	57,932
#4	611,975	77,446	30,058	36,262	124,192	13,264	22,677	4,492	1,604	855	213	91,138	5,669
Whole Basin[1]	4,777,260	629,136	274,975	281,936	1,137,318	91,368	185,347	44,378	13,052	7,831	6,961	811,873	76,575

[1] Whole basin loadings determined using total sediment loading and mean concentration for all samples.

Table 17. Lake Erie: Short Term Major Element Loadings (in metric tons/year)

Reach No.	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	S	CO_2	Org.C.
#1	117,501	14,449	5,819	5,739	24,042	1,966	4,294	883	280	140	180	18,101	2,608
#2	832,559	128,856	56,583	56,583	245,862	14,521	38,723	8,178	2,503	1,335	3,505	163,908	18,861
#3	5,822,992	789,237	389,609	379,590	1,581,814	116,882	229,313	67,903	17,810	11,131	7,792	1,075,322	97,958
#4	548,844	69,456	26,957	32,521	111,380	11,895	20,338	4,029	1,439	767	191	81,736	5,084
Whole Basin[1]	7,664,512	1,009,370	441,163	452,331	1,824,684	146,589	297,366	71,200	20,941	12,564	11,168	1,302,548	122,855

[1] Whole basin loadings determined using total sediment loading and mean concentration for all samples.

Table 18. Lake Huron: Long Term Major Element Loadings (in metric tons/year)

Reach No.	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	S
#1[1]											
#2	51,413	5,415	1,693	4,654	14,856	892	1,622	273	111	50	20
#3	57,611	5,506	1,402	3,244	10,228	925	1,608	186	84	37	37
#4	58,051	5,183	1,806	3,071	12,686	751	1,474	218	104	57	28
Whole[2] Basin	170,436	16,240	5,191	10,788	37,584	2,784	4,408	696	290	174	58

1 Reach #1 insufficient data.

2 Whole basin loadings determined using total sediment loading and mean concentration for all samples.

Table 19. Lake Huron: Short Term Major Element Loadings (in metric tons/year)

Reach No.	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	S
#1[1]											
#2	184,890	19,473	6,090	16,738	53,424	3,209	5,834	984	401	182	72
#3	67,150	6,418	1,634	3,781	11,921	1,078	1,874	217	98	43	43
#4	354,657	31,665	11,039	18,767	77,508	4,590	9,005	1,336	639	348	174
Whole[2] Basin	619,832	59,061	18,878	39,233	136,685	10,124	16,031	2,531	1,054	632	210

[1] Insufficient data Reach #1

[2] Whole basin loadings determined using total sediment loading and mean concentration for all samples.

Chemical fractionation of bluff materials was carried out to determine the forms of phosphorus using the technique of Wilkins et al. (1976) in which organic P, apatite P and non-apatite inorganic P were determined. Organic P proved to be insignificant and two fractions apatite P and non-apatite inorganic P (NAIP) were determined. NAIP is presumed to be predominantly bound by the iron oxide component of the sediment (Williams, 1976). Further, as discussed by the same author, apatite P is only sparingly soluble under the pH conditions of the Great Lakes and is considered to represent the non-available fraction.

Table 20 summarizes the concentrations of apatite P and total P on the samples used for the fractionation by lake and by lake reach. Also, the apatite or non-available P fraction is expressed as a percentage of total P. These data have been used to compute the total long and short-term loading of available P summarized in Table 21.

These data are placed in perspective with the total phosphorus loads to the lakes in Table 22. Total phosphorus loads for 1976 as computed in PLUARG studies are used. These loads do not include the total phosphorus loading to the lakes from shoreline erosion. The percentage contributions of total P and available P for long and short-term erosion rates are presented in Table 22 for both 1976 total P loading plus the shoreline contribution of total and available phosphorus. Other than total erosion phosphorus in Lake Erie, the differences in percentages between the 1976 annual loading and 1976 plus shoreline total phosphorus are small.

Table 20. Apatite phosphorus concentrations in Canadian shoreline bluffs.

	APAP			Tot. P			% APAP/ Tot. P
LAKE ONTARIO							
	X̄	S.D.	n	X̄	S.D.	n	
Whole basin	482.13	196.6	16	601.47	223.63	17	80.16%
#1	579.4	50.61	5	688.6	73.65	5	84.14%
#2	387.5	233.2	4	481.5	212.93	4	80.48%
#3	649.6	301.93	2	799.0	381.84	2	81.30%
#4	393.6	185.2	5	543.0	245.99	6	72.5%
LAKE ERIE							
	X̄	S.D.	n	X̄	S.D.	n	% APAP/ Tot. P
Whole basin	395.31	143.59	13	457.62	158.63	13	86.38
#1	295.67	8.96	3	367.0	21.63	3	80.56
#2	-	-	-	-	-	-	-
#3	485.29	125.96	7	564.14	147.41	7	86.022
#4	285.0	120.24	3	343.0	19.3	3	83.09
LAKE HURON							
	X̄	S.D.	n	X̄	S.D.	n	% APAP/ Tot. P
Whole basin	184.0	110.74	8	288.11	183.09	9	63.86
#1	90.0		1	283.0	371.94	2	31.80
#2	193.0	168.29	2	242.5	184.55	2	79.59
#3	71.0		1	176.0	-	1	40.34
#4	231.25	94.56	4	291.5	142.62	4	79.33

Table 21. Phosphorus loadings to Lakes Ontario, Erie and Huron from shoreline erosion in metric tons per year. LT = Long term; ST = Short term.

Lake Reach #	Lake Ontario Total P LT	Lake Ontario Total P ST	Lake Ontario Available P LT	Lake Ontario Available P ST	Lake Erie Total P LT	Lake Erie Total P ST	Lake Erie Available P LT	Lake Erie Available P ST	Lake Huron Total P LT	Lake Huron Total P ST	Lake Huron Available P LT	Lake Huron Available P ST
1	342	413	54	66	105	122	20	24	nil	nil	nil	nil
2	44	18	9	4	570	1085	77[1]	148[1]	49	175	10	36
3	204	194	38	36	4542	7681	635	1074	36	45	7	9
4	187	117	51	32	695	624	117	106	46	279	27	167
Whole basin	777	742	152	138	5912	9512	849	1352	131	499	44	212

[1] Whole basin mean % Apatite P used for this reach.

Table 22. Phosphorus from shoreline erosion as percentage of total lake phosphorus loadings for 1976 -- Canadian shoreline

	Shore Erosion			
	Total Phosphorus m.t.		Available Phosphorus m.t.	
	Long Term	Short Term	Long Term	Short Term
Lake Huron				
1976 Total Phosphorus loading 4957[1] m.t.				
Annual Loading	131	499	44	212
P from erosion as percent 1976 loading	2.7	10.3	0.9	4.4
P from erosion as percent 1976 loading + Total P from erosion	2.6	9.3	0.9	4.0
Lake Erie				
1976 Total Phosphorus loading 17474[1] m.t.				
	Long Term	Short Term	Long Term	Short Term
Annual Loading	5912	9512	849	1352
P from Erosion as percent 1976 loading	33.8	54.4	4.9	7.7
P from Erosion as percent 1976 loading + Total P from erosion	25.3	35.2	3.6	5.0
Lake Ontario				
1976 Total Phosphorus loading 11755[1] m.t.				
	Long Term	Short Term	Long Term	Short Term
Annual Loading	777	742	152	138
P from erosion as percent 1976 loading	6.6	6.3	1.3	1.2
P from Erosion as percent 1976 loading + Total P from erosion	6.2	5.9	1.2	1.1

[1] Excludes total Phosphorus from shore erosion

Total phosphorus loading from shoreline erosion in Lakes Huron and Ontario are small with a maximum contribution of approximately 10% of the total phosphorus loadings to Lake Huron. In Lake Erie total phosphorus from shoreline erosion represents a large component of the total phosphorus load with a contribution of up to 54%. Available phosphorus for all lakes represents only a small fraction of the total phosphorus loads. Maximum percentages occur in Lake Erie where the contribution of available phosphorus from the Canadian shoreline accounts for about 8% of the total lake phosphorus load excluding the shoreline total P contribution.

These data as summarized in Table 22 indicate that the contribution of total phosphorus to Lake Erie is significant but is low for the lakes Huron and Ontario in terms of total lake phosphorus loading. The data further indicate that available P represents a small fraction of the total phosphorus mass balance and thus cannot be construed as a major source of nutrients to the lakes.

Trace Elements

Mean trace element concentrations by lake reach and by lake are summarized in Tables 23, 24 and 25. Concentrations throughout are low and may be indicative of the natural background levels of these elements in parent lake sediment material. A comparison of bluff concentration to open lake sediment values for five metals is given in Table 26. The values given in Table 26 for the open lake are designated recent and pre-colonial. The former indicates mean concentration for the upper 1 or 2 centimeters of sediment whereas the latter occurs at a depth below the increase in Ambrosia[1] pollen

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[1] Ambrosia - common ragweed which flourished after forest clearance and creation of pasture.

Table 23. Lake Ontario: Trace Metal Concentrations (ppm)

Reach No.	No. of Samples	Hg* X̄	Hg* SD	Pb X̄	Pb SD	Cu X̄	Cu SD	Zn X̄	Zn SD	Ni X̄	Ni SD	Co X̄	Co SD	Cr X̄	Cr SD	Cd X̄	Cd SD	Be X̄	Be SD
#1	70	28.6 (68)	21.3	18.5 (69)	9.65	30.4 (69)	13.46	53.4 (69)	16.99	23.4 (69)	8.58	14.2 (69)	4.37	28.7 (69)	16.52	1.1 (69)	.24	1.6 (69)	.57
#2	9	9.2 (6)	8.01	13.9	2.37	15.6	11.39	25.6	10.56	11.0	5.63	7.7	3.20	7.5	9.74	1.0	0	1.2	.44
#3	7	19.3 (7)	22.81	19.0	2.33	12.0	8.26	28.6	19.43	15.1	8.46	10.8	5.34	20.2	23.77	1.3	.46	1.1	.35
#4	78	8.6 (47)	8.70	12.3	17.12	10.6	12.0	37.8	43.94	13.2	6.38	10.9	3.30	11.6	12.49	1.9	.33	1.3	.53
#5	6	5.0 (3)	0	9.7	.816	2.8	.41	11.3	4.41	5.7	1.21	5.2	.98	.1	0	1.0	0	1.3	.52
Whole Basin	170	19.5 (131)	19.53	18.3 (170)	13.26	18.7 (170)	15.65	42.1 (170)	65.4	17.1 (170)	9.08	11.9 (170)	4.43	18.3 (170)	17.11	1.5 (170)	.51	1.4 (170)	.56

Reach No.	V X̄	V SD	Sr X̄	Sr SD	U X̄	U SD	Ag X̄	Ag SD	Mo X̄	Mo SD	Se X̄	Se SD	As X̄	As SD	Tot.N X̄	Tot.N SD	Cl X̄	Cl SD	F X̄	F SD
#1	62.1 (63)	21.77	255.4 (69)	69.26	1.0 (62)	.48	.5 (63)	.28	1.9 (68)	.67			3.3	1.92	.03 (4)	.01	61.6 (68)	14.57	447.9 (69)	191.08
#2	33.1	14.86	321.0	38.37	1.1 (8)	.42	.3 (8)	.20	2.3	.50	5.0 (1)	1.41	2.0 (2)	1.41			74.8	13.49	210.6	101.75
#3	48.1	21.05	334.6	34.55	.8 (7)	.39	.5	.29	3.0	.93					.04 (2)	0	118.3	22.63	290.6	209.7
#4	33.7	25.8	395.7	42.55	.9 (69)	.49	.7	.27	2.9	.89	1.0 (1)	1.41	2.1 (60)	1.26	.01 (5)	0	100.5	17.57	310.3	156.9
#5	20.8	15.34	457.0	45.64	.6 (4)	.37	.3	.15	1.8	.41			1.5 (2)	.71			95.8	16.35	115.0	45.17
Whole Basin	45.5 (170)	27.14	334.1 (170)	88.10	.9 (50)	.48	.6 (163)	.40	2.4 (169)	.92	3.0 (2)	2.83	2.6 (118)	1.69	.02 (11)	.02	84.2 (169)	25.69	353.1 (170)	189.9

*Hg: measured in ppb

Table 24. Lake Erie: Trace Metal Concentrations (ppm)

Reach No.	No. of Samples	Hg* X̄	Hg* SD	Pb X̄	Pb SD	Cu X̄	Cu SD	Zn X̄	Zn SD	Ni X̄	Ni SD	Co X̄	Co SD	Cr X̄	Cr SD	Cd X̄	Cd SD	Be X̄	Be SD
#1	59	20.5	12.84	16.4	4.09	17.7	10.27	43.0	19.01	19.2	10.02	9.0	3.28	43.0	53.67	1.4	.53	1.3	.65
#2	22	25.0	12.49	19.8	6.64	20.2	9.04	66.7	39.0	26.3	10.10	12.1	3.37	48.0	28.75	1.8	.53	1.3	.93
#3	73	17.6	15.63	20.0	5.39	14.4	8.08	44.4	32.89	17.3	9.93	10.0	4.62	36.0	45.85	1.2	.43	1.6	1.00
#4	40	15.5	13.73	17.8	6.58	10.5	7.75	40.3	25.10	14.8	11.67	8.2	5.35	27.6	24.02	1.1	.48	1.8	.70
Whole Basin	194	19.0 (148)	14.18	17.2	5.52	15.3	9.31	45.7	29.40	18.4	10.79	9.6	4.42	37.8	43.58	1.3	.53	1.5	.86

Reach No.	V X̄	V SD	Sr X̄	Sr SD	U X̄	U SD	Ag X̄	Ag SD	Mo X̄	Mo SD	Se X̄	Se SD	As X̄	As SD	Tot.N X̄	Tot.N SD	Cl X̄	Cl SD	F X̄	F SD
#1	58.8	33.3	264.1	61.70	1.2 (58)	.81	.7	.27	4.5	3.07	1.0 (2)	0	6.1 (45)	4.04	.02 (3)	.02	69.0	11.56	274.9	138.1
#2	73.2	25.49	260.7	36.49	1.7	1.01	.9	.17	9.1	5.66	1.0 (2)	0	11.4	4.01	.06 (3)	(0)	70.7	11.47	396.6	148.3
#3	54.8	32.72	328.4	68.10	.7 (67)	.52	.8	.27	2.8 (72)	1.14	1.7 (3)	1.15	5.2 (57)	3.10	.02 (10)	.01	68.3	12.11	394.3	196.3
#4	51.0	30.57	364.2	77.47	1.2 (35)	.53	.5	.20	2.3	.91			2.0 (17)	.94	.02 (5)	.01	65.5	16.44	377.1	283.2
Whole Basin	57.3	32.13	308.6	76.73	1.1 (182)	.76	.7	.28	3.9 (193)	3.34	1.3 (7)	.57	6.1 (141)	4.27	.02 (20)	.02	68.2	12.89	354.7	203.9

*Hg: measured in ppb

Table 25. Lake Huron: Trace Metal Concentrations (ppm)

Reach No.	No. of Samples	Hg* $\overline{X}$	Hg* SD	Pb $\overline{X}$	Pb SD	Cu $\overline{X}$	Cu SD	Zn $\overline{X}$	Zn SD	Ni $\overline{X}$	Ni SD	Co $\overline{X}$	Co SD	Cr $\overline{X}$	Cr SD	Cd $\overline{X}$	Cd SD	Be $\overline{X}$	Be SD
#1	19	4.0 (3)	0	16.3	4.95	5.3	2.65	16.9	13.10	10.3	2.42	5.5	1.61	18.5	19.59	1.1	.23	.4	.45
#2	19	17.3 (13)	19.78	17.6	4.79	10.6	6.08	22.5	9.83	14.2	6.36	8.0	2.89	27.2	43.61	1.3	.45	.6	.46
#3	16	25.0 (14)	21.93	13.3	7.74	15.7	21.69	22.0	16.74	13.1	8.90	11.8	4.86	31.1	23.34	1.3	.45	1.2	.40
#4	63	25.7 (61)	19.60	18.5 (62)	15.69	26.0 (62)	59.0	38.9 (62)	30.13	17.5 (62)	10.35	13.7 (62)	5.36	18.0 (62)	13.18	1.3 (62)	.48	1.0 (62)	.66
Whole Basin	117	23.1 (94)	19.92	18.3 (123)	19.02	17.9 (123)	43.37	29.1 (123)	25.75	14.6 (123)	9.11	10.7 (123)	5.72	20.8 (123)	23.0	1.2 (123)	.45	.9 (123)	.64

Reach No.	V $\overline{X}$	V SD	Sr $\overline{X}$	Sr SD	U $\overline{X}$	U SD	Ag $\overline{X}$	Ag SD	Mo $\overline{X}$	Mo SD	Se $\overline{X}$	Se SD	As $\overline{X}$	As SD	Cl $\overline{X}$	Cl SD	F $\overline{X}$	F SD
#1	45.3	31.61	257.4	32.88	1.2	.64	1.1	.41	2.0	.52			6.1 (10)	11.23	89.4	16.34	160.0	93.3
#2	39.3	28.0	214.2	38.02	.9 (18)	.49	1.2 (18)	.47	2.6 (18)	.92	4.0 (1)	1.41	2.3 (9)	1.73	74.7	10.53	282.4	175.5
#3	34.5	13.69	170.0	40.12	.8 (13)	.74	.4	.28	3.5	4.0	1.0 (1)	1.41	2.3 (4)	1.26	72.3	12.54	183.8	176.9
#4	35.5 (62)	21.68	153.7 (62)	34.93	1.0 (54)	.64	.6 (61)	.28	3.5 (61)	2.92			4.3 (54)	2.78	70.7 (62)	14.59	218.9 (62)	184.i
Whole Basin	37.8 (123)	24.0	195.5 (123)	73.06	1.0 (105)	.62	.7 (121)	.44	3.0 (121)	2.63	2.5 (2)	2.12	4.2 (77)	4.67	74.0 (123)	15.33	208.4 (123)	169.4

*Hg: measured in ppb

Table 26. Comparison of mean metal concentrations in bluffs to open lake, present and pre-Colonial sediments (after Kemp & Thomas 1976a).

	Lake Huron Sediments			Lake Erie Sediments			Lake Ontario Sediments		
Element	Recent	Pre-Colonial	Bluff	Recent	Pre-Colonial	Bluff	Recent	Pre-Colonial	Bluff
Hg ppb	210	150	23	855	78	19	2350	78	20
Pb ppm	129	39	18	106	28	17	220	29	18
Zn ppm	197	94	29	279	98	46	475	104	42
Cd ppm	2	1	1.2	4	1	1.3	5	1	1.5
Cu ppm	58	38	18	57	29	15	98	44	19

Table 27. Lake Ontario: Long Term Trace Element Loadings (in metric tons/year)

Reach No.	Hg	Pb	Cu	Zn	Ni	Co	Cr	Cd	Be	V	Sr	U	Ag	Mo	Se	As	Tot.N	Cl	F
#1	.014	9.1	15.0	26.4	11.6	7.0	14.2	0.5	0.8	30.7	126.4	0.5	0.2	0.9	1.5[1]	1.6	149	30.5	221.7
#2	.001	1.1	1.2	2.0	0.8	0.6	0.6	0.1	0.1	2.6	25.1	0.1	0.02	0.2	0.4	0.2	16	5.8	16.4
#3	.007	6.9	4.4	10.4	5.5	3.9	7.4	0.5	0.4	17.5	122.0	0.3	0.2	1.1	1.1[1]	0.9[1]	146	43.2	106.0
#4	.004	6.1	5.2	18.6	6.5	5.4	5.7	0.9	0.6	16.6	194.8	0.4	0.3	1.4	0.5	1.0	49	49.5	152.7
Whole Basin[2]	.028	26.2	26.7	60.2	24.4	17.0	26.2	2.1	2.0	65.0	477.8	1.3	0.8	3.4	4.3	3.7	286	120.4	505.1

[1] Whole basin concentration used to calculate loading

[2] Whole basin loadings determined using total sediment loading and mean concentration for all samples.

Table 28. Lake Ontario: Short Term Trace Element Loadings (in metric tons/year)

Reach No.	Hg	Pb	Cu	Zn	Ni	Co	Cr	Cd	Be	V	Sr	U	Ag	Mo	Se	As	Tot.N	Cl	F
#1	.02	10.3	17.0	29.8	13.1	7.9	16.0	0.6	0.9	34.7	142.8	0.6	0.3	1.1	1.7[1]	1.8	0.02	34.4	250.4
#2	*	0.4	0.5	0.8	0.3	0.2	0.2	0.03	0.04	1.1	10.3	0.03	0.01	0.07	0.2	0.06	*	2.4	6.7
#3	.006	6.7	4.3	10.1	5.4	3.8	7.2	0.5	0.4	17.1	118.7	0.3	0.2	1.1	1.1[1]	0.9[1]	0.01	42.0	103.1
#4	.003	3.8	3.3	11.6	4.1	3.4	3.6	0.6	0.4	10.4	121.9	0.3	0.2	0.9	0.3	0.6	0.003	31.0	95.6
Whole[2] Basin	.024	23.0	23.4	52.8	21.4	14.9	22.9	1.9	1.8	57.1	419.1	1.1	0.8	3.0	3.7	3.3	0.03	105.6	442.9

* Less than 1.0 Kg

1 Loading calculated using whole basin mean concentration.

2 Whole basin loadings determined using total sediment loading and mean concentration for all samples.

Table 29. Lake Erie: Long Term Trace Element Loadings (in metric tons/year)

Reach No.	Hg	Pb	Cu	Zn	Ni	Co	Cr	Cd	Be	V	Sr	U	Ag	Mo	Se	As	Tot.N	Cl	F
#1	.003	2.8	3.0	7.4	3.3	1.5	7.4	0.2	0.2	10.1	45.6	0.2	0.12	0.77	0.2	1.0	34	11.9	47.4
#2	.022	17.3	17.7	58.4	23.0	10.6	42.1	1.6	1.1	64.1	228.4	1.5	0.78	7.9	0.9	9.9	526	61.9	347.5
#3	.116	131.6	94.8	292.3	113.9	65.8	236.9	7.9	10.5	360.7	2161.9	4.6	5.3	18.4	11.2	34.2	1317	449.6	2595.7
#4	.016	19.0	11.2	43.1	15.8	8.7	29.5	1.1	1.9	54.5	389.6	1.3	0.53	2.5	1.4[1]	2.1	214	70.1	403.4
Whole[2] Basin	.165	149.7	133.1	397.6	160.1	83.5	328.9	11.3	13.1	498.6	2685.4	9.6	6.09	33.9	11.3	53.1	1740	593.4	3086.5

[1] Whole basin mean concentration used to calculate loading.

[2] Whole basin loadings determined using total sediment loading and mean concentration for all samples.

Table 30. Lake Erie: Short Term Trace Element Loadings (in metric tons/year)

Reach No.	Hg	Pb	Cu	Zn	Ni	Co	Cr	Cd	Be	V	Sr	U	Ag	Mo	Se	As	Tot.N	Cl	F
#1	.004	3.3	3.6	8.6	3.8	1.8	8.6	0.3	0.3	11.8	53.0	0.2	0.1	0.9	0.2	1.2	0.004	13.8	55.2
#2	.042	33.0	33.7	111.3	43.9	20.2	80.1	3.0	2.1	122.2	435.1	2.8	1.5	15.2	1.7	19.0	0.10	118.0	661.9
#3	.196	222.6	160.3	494.2	192.6	111.3	400.7	13.3	17.8	610.0	3655.6	7.8	8.9	31.1	18.9	57.9	0.22	760.3	4389.2
#4	.015	17.0	10.1	38.6	14.2	7.8	26.5	1.1	1.7	48.9	349.4	1.1	0.5	2.2	1.2[1]	1.9	0.02	62.8	361.7
Whole[2] Basin	.265	240.1	213.6	638.0	256.9	134.0	527.7	18.1	20.9	799.9	4308.3	15.3	9.7	54.4	18.1	85.1	0.27	952.1	4951.9

[1] Loading calculated using whole basin mean concentration

[2] Whole basin loadings determined using total sediment loading and mean concentration for all samples.

Table 31. Lake Huron: Long Term Trace Element Loadings (in metric tons/year)

Reach No.	Hg	Pb	Cu	Zn	Ni	Co	Cr	Cd	Be	V	Sr	U	Ag	Mo	Se	As	Cl	F
#1*																		
#2	.0017	1.8	1.1	2.3	1.4	0.8	2.8	0.13	0.06	4.0	21.7	0.09	0.12	0.3	0.40	0.23	7.6	28.6
#3	.0023	1.2	1.5	2.1	1.2	1.1	2.9	0.12	0.11	3.2	15.9	0.07	0.04	0.3	0.09	0.21	6.8	17.2
#4	.0024	1.8	2.5	3.7	1.6	1.3	1.7	0.12	0.09	3.4	14.6	0.09	0.06	0.3	0.24[1]	0.41	6.7	20.8
Whole[2] Basin	.0067	5.3	5.2	8.4	4.2	3.1	6.0	0.35	0.26	10.9	56.7	0.29	0.20	0.9	0.7	1.22	21.5	60.4

* Insufficient data for Reach #1

1 Loading computed using whole basin mean concentration.

2 Whole basin loadings determined using total sediment loading and mean concentration for all samples.

Table 32. Lake Huron: Short Term Trace Element Loadings (in metric tons/year)

Reach No.	Hg	Pb	Cu	Zn	Ni	Co	Cr	Cd	Be	V	Sr	U	Ag	Mo	Se	As	Cl	F
#1*																		
#2	.006	6.4	3.9	8.2	5.1	2.9	9.9	0.5	0.2	14.3	78.1	0.3	0.4	0.9	1.4	0.8	27.2	103.0
#3	.003	1.4	1.7	2.4	1.4	1.3	3.4	0.1	0.1	3.7	18.5	0.1	0.04	0.4	0.1	0.2	7.9	20.0
#4	.015	10.7	15.1	22.6	10.2	8.0	10.4	0.7	0.6	20.6	89.3	0.6	0.3	2.0	1.4[1]	2.5	41.1	127.2
Whole[2] Basin	.024	19.3	18.9	30.7	15.4	11.2	21.9	1.2	0.9	39.8	206.1	1.1	0.7	3.2	2.6	4.4	78.0	219.8

* Reach #1 insufficient data

1 Loading calculated using whole basin mean concentration

2 Whole basin loadings determined using total sediment loading and mean concentration for all samples.

which marks the influx of western man into the region. Hg, Pb, Zn and Cu concentrations in the bluff materials show lower values to those observed in pre-colonial sediment which in turn are lower than those in the recent sediment. The increased values in the pre-colonial sediment represent a lacustrine background level and are elevated due to a finer texture (higher percent clay content) resulting from lake sediment sorting processes. The increase in recent sediment concentrations from pre-colonial levels including Cd (Table 26) is due to increased loadings from anthropogenic sources. The higher value for Cd in the bluffs over the observed value in pre-colonial sediment (Table 26) has not been explained but probably indicates Cd associated with a coarser sediment fraction. However, Cd concentrations are low even though the increases from pre-colonial to recent concentrations in Lakes Erie and Ontario are significant.

Loadings for all the trace elements analysed for the three lakes, both long term and short term for the Canadian erodable shoreline are given in Tables 27 to 32 inclusive.

Loadings Summary

In order to place in perspective, the contribution of elements derived from the Canadian shoreline to Lakes Huron, Erie and Ontario, a summary of loadings for selected metals Organic C, nitrogen and phosphorus is provided in Table 33. Bluff loadings are given in comparison to estimates of the elements accumulating in the open lake sediments and not in relation to total lake input loadings. Anthropogenic and natural loading estimates for the open lake sediments were determined, as previously described, by use of pre-colonial and recent sediment concentrations and a mean annual sedimentation

Table 33. Loadings derived from shoreline erosion compared to open lake accumulation. All values in metric tons/year with long-term erosion values quoted for bluffs.

	Lake Huron					Lake Erie					Lake Ontario				
Element	Anthro-pogenic	Natural	Total	Bluff	Bluff as percent of Total	Anthro-pogenic	Natural	Total	Bluff	Bluff as percent of Total	Anthro-pogenic	Natural	Total	Bluff	Bluff as percent of Total
Hg	0.34	0.42	0.76	.007	0.9	5.7	0.6	6.3	0.165	2.6	11.8	0.8	12.6	0.028	0.2
Pb	400	120	520	5.3	1.0	889	263	1152	150	13.0	895	95	990	26	2.6
Zn	520	275	795	8.4	1.1	2140	1041	3181	398	12.5	2,090	380	2,470	60	2.4
Cd	3	5	8	0.35	4.4	28	15	43	11	25.6	20	4	24	.2	8.3
Cu	125	110	235	5.2	2.2	287	314	601	133	22.1	290	150	440	27	6.1
Org.C	33,900	126,700	160,600	-	-	216,916	135,753	352,669	76,575	21.7	158,000	69,500	227,500	10,012	4.4
N	4,140	16,200	20,340	-	-	31,740	15,121	46,861	1,740	3.7	21,300	7,870	29,170	286	1.0
P	1,460	3,290	4,750	131*/44	2.8*/0.9	5,290	8,793	14,083[1]	5912*/849	42.0*/6.0	4,160	3,680	7,840	777*/152	9.9*/1.9

* Total P/Available P

[1] Open lake accumulation values quoted after Kemp and Thomas (1976b) modified for Lake Erie after Kemp et al. (1978), J. Great Lakes Res. (in press) to compensate for revised open lake sedimentation rate.

rate from the Ambrosia pollen horizon to present. Since the estimates of annual accumulation are based on the period 1835 to present, only the long term erosional loadings from the bluffs are used in Table 33. In all cases the total Canadian bluff loading is less than the natural annual loading. This not only relates to texture as discussed earlier but reflects the fact that the natural loading is a composite of all sources to the entire lake at background levels. Such sources include watershed loadings and shoreline erosion.

The shoreline loading of each element expressed as a percentage of the total annual accumulation in the open lake sediments for each lake is given in Table 33. For Lakes Huron and Ontario these percentages are extremely small, ranging from 0.2% for mercury to Lake Ontario to 8.3% for Cu, also to Lake Ontario. The percentage contribution of elements from shoreline erosion to Lake Erie is significantly higher than the other two lakes and reflects the large volumes of bluff sediment being eroded from the Canadian shoreline of this lake. The percentage contributions are highest for Cd and Cu with 25.6 and 22.1 percent respectively. The marked increase in the natural pre-colonial loading for Lake Erie over Lakes Huron and Ontario (Table 33) reflects the larger volumes of materials derived from shoreline erosion indicating that this process has been operating in a consistent fashion at least over historical times.

Conclusions

The major conclusions that can be derived from this study are as follows:-

1) Shoreline erosion is a significant source of sediment to the Great Lakes, particularly Lake Erie.

2) Shoreline erosion has been a continuing process of consistent magnitude through at least the past 150 years.

3) Concentrations of elements are at background level and equate to the concentrations observed in deep pre-historic open lake sediments.

4) The contribution of total phosphorus to the lakes is low in Lakes Huron and Ontario but high in Lake Erie, with maximum percentages of 9.3, 6.2 and 35.2 percent respectively.

5) The contribution of available phosphorus is low for all three lakes with maximum percentages of 4.0, 5.0 and 1.1 for Lakes Huron, Erie and Ontario expressed against the 1976 total phosphorus loadings.

6) The contributions of Hg, Pb, Zn, Cd, Cu, Org C and N from shoreline erosion expressed as percentages of the annual loadings to the sediment are low except for Cd, Cu and Org. C in Lake Erie. The loadings in this lake however still represent a background condition and are lower than the total estimated natural loading to the open lake as indicated by pre-colonial loading estimates.

7) On the basis of 1 to 6 above, elements derived from shoreline erosion <u>do not</u> constitute a water quality problem though shoreline erosion as such remains a problem insofar as it affects property loss and value.

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