Canada Centre for Inland Waters

Atmospheric Loading of the Upper Great Lakes

Volume 1
Summary Report

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FOREWORD

The three volumes of this report constitute a study of the atmospheric loadings of the Upper Great Lakes which is a portion of the International Joint Commission Study of Pollution Problems of Lake Huron and Lake Superior.

This summary volume presents the principal findings of the report. Volume 2, Main Text, contains descriptions of methodologies, assumptions, results, accuracies and interpretations. Volume 3, Appendixes, contains the relevant data used.

In addition, two interim reports were submitted at the completion of the first two phases of this study dated September 1974 and March 1975, respectively.

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1 INTRODUCTION

This summary volume presents the principal findings of a 2-year project having as objectives:

Objective to estimate atmospheric loadings of sixteen pollutants

- the estimation of the annual input or loading of sixteen atmospheric pollutants to the international waters of the Upper Great Lakes (Superior and Huron)

- the identification of the relative contributions from thirty large-area major sources of the pollutants considered.

The results provide a basis for comparing the extent of contamination of the Upper Great Lakes from air- versus land-based sources. The approach taken to meet the stated objectives can be divided into two parts, although extensive interaction between them took place as the work efforts proceeded in parallel.

Two independent procedures used

One part involved development and application of a mathematical model describing long distance/time transport, dispersion, chemical change and deposition of pollutants from source regions for which emissions to the atmosphere were known. Calculations were then made of pollutant inputs or loadings to the lakes during both dry weather and precipitation.

Mathematical model estimates loadings

The other part involved the collection and chemical analysis of precipitation from a network of seventy stations around the lakes, on islands and on buoys, operated by a number of co-operating agencies in Canada and the United States. These data, together with analyses of a number of specific precipitation events measured on shipboard and at shoreline stations, were used to independently estimate pollutant loadings from the atmosphere to the lakes.

Loadings independently estimated from international precipitation chemistry network

The two independent estimates were compared for consistency, possible sources of error were examined and, finally, recommendations were made, wherever possible, of preferred loading rates for Lakes Superior and Huron and their subdivisions.

Basis for recommending loading values indicated

Descriptions of methodologies, assumptions, results, accuracies and interpretations are contained in Volume 2, Main Text, and the relevant data in Volume 3, Appendixes of this three-volume report. Additional details may be found in the Phase II interim report dated March 1975.

2 METHODOLOGY

2.1 Model Estimates

Model driven by emissions and meteorology

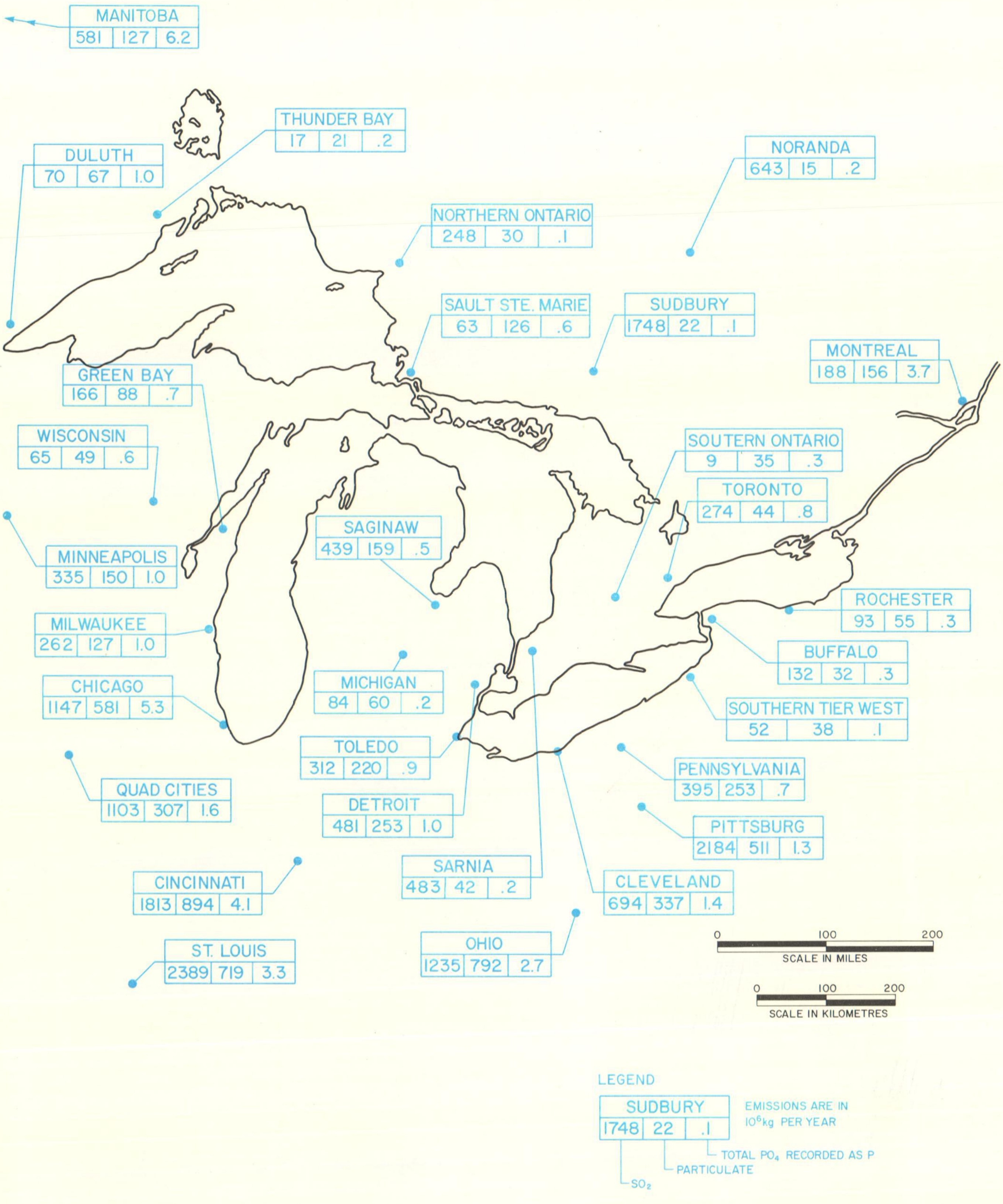
The basic elements that drive a modified version of Slade's box model developed for this project are the mean annual air-pollutant emissions at known major sources and the daily mean atmospheric conditions between sources and receptors on and around the Upper Great Lakes.

Major emission areas within 1,000 km of the lakes included

Figure 1 shows the major emission areas used in the calculations. Many of these areas represent groupings of two or more of the clustered and smaller individual source regions for which the basic data were available. The model calculations are relatively insensitive to this scale of detail, particularly for the more distant source areas which include up to seven of the smaller source regions. Detailed on this figure are the 1974 emissions of sulphur dioxide and total particulates as obtained from air-pollution agencies and the derived total phosphorous component. These pollutants were selected partly for illustrative purposes, but mainly because they are among the pollutants of primary concern in this report.

Model incorporates wide range of dispersion parameters

The meteorological parameters required as daily input to model calculations are the mixing height defining the layer through which the pollutants are assumed to be uniformly mixed after a significantly long travel time, mean wind speed through the mixing depth, angle of pollutant dispersion by both atmospheric diffusion processes and wind direction variability, precipitation intensity and duration, and rates of gaseous and particulate pollutant deposition in both dry weather and precipitation. For the major non-conservative pollutant, sulphur dioxide, a rate of oxidation from the gaseous state at the emission sources to the particulate state en route to the lakes was applied.



SOURCE EMISSIONS

FIGURE 1

ATMOSPHERIC LOADING OF THE UPPER GREAT LAKES

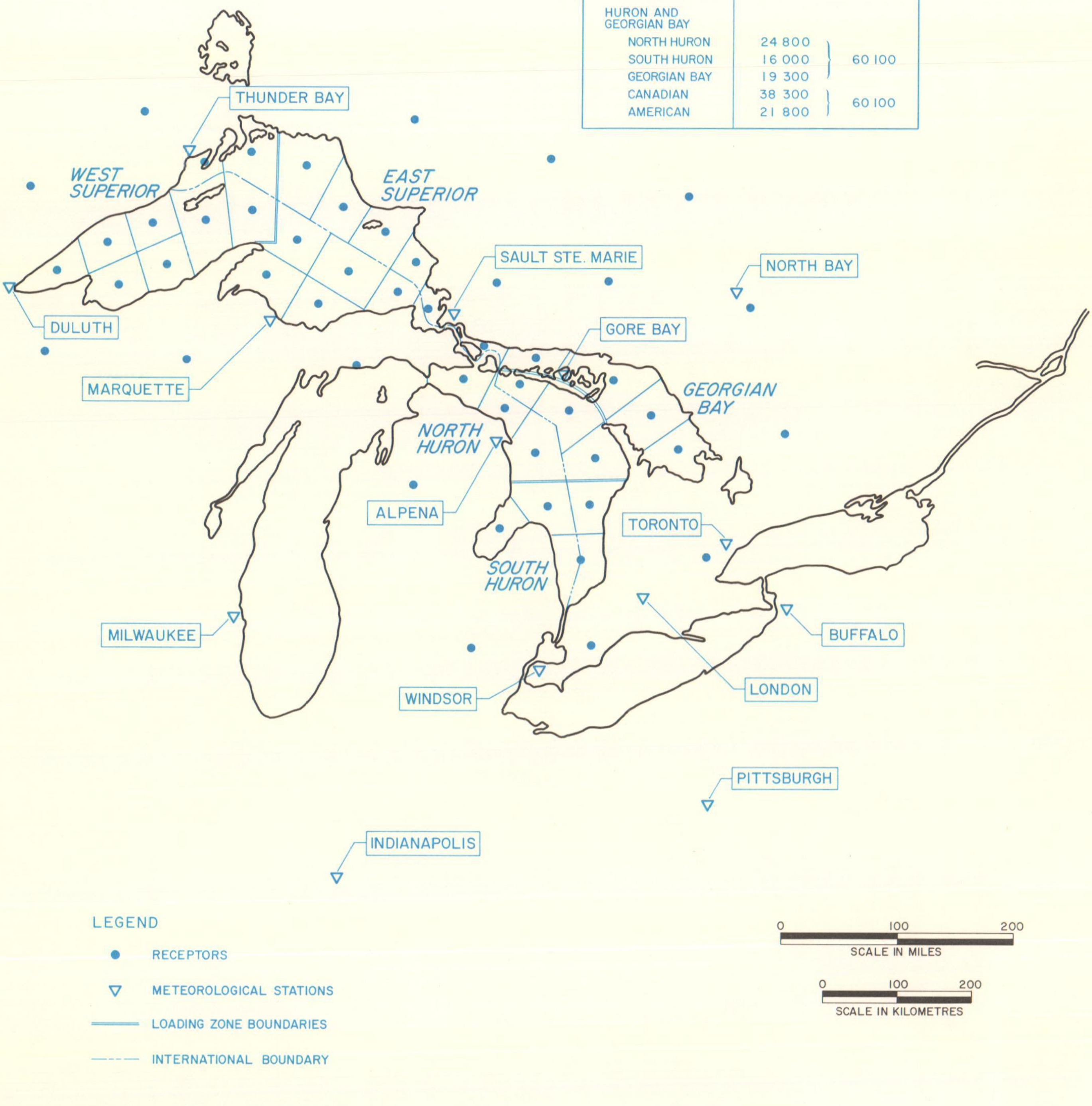
Meteorological network of fourteen stations used

Figure 2 shows in map form the fourteen stations for which the required daily mean meteorological data were used, and the fifty receptor grid points on and around the Upper Great Lakes at which daily pollutant loadings were calculated. Calculations were made using meteorological and emission data for 1974. Meteorological data were obtained from the Atmospheric Environment Service, Canada and the National Oceanographic and Atmospheric Administration, United States. Calculations were also made using meteorological data for 1972 and 1973, but retaining emission data for 1974, to show the effect of year-to-year climatic differences. Variations in loading rates of up to 20 per cent were found in the 3 test years. Also shown are the Upper Great Lakes International Boundaries and pollutant loading zones — West and East Superior, North and South Huron, and Georgian Bay — selected to show areal distribution of atmospheric loadings.

Particulate breakdown into constituents based on literature review

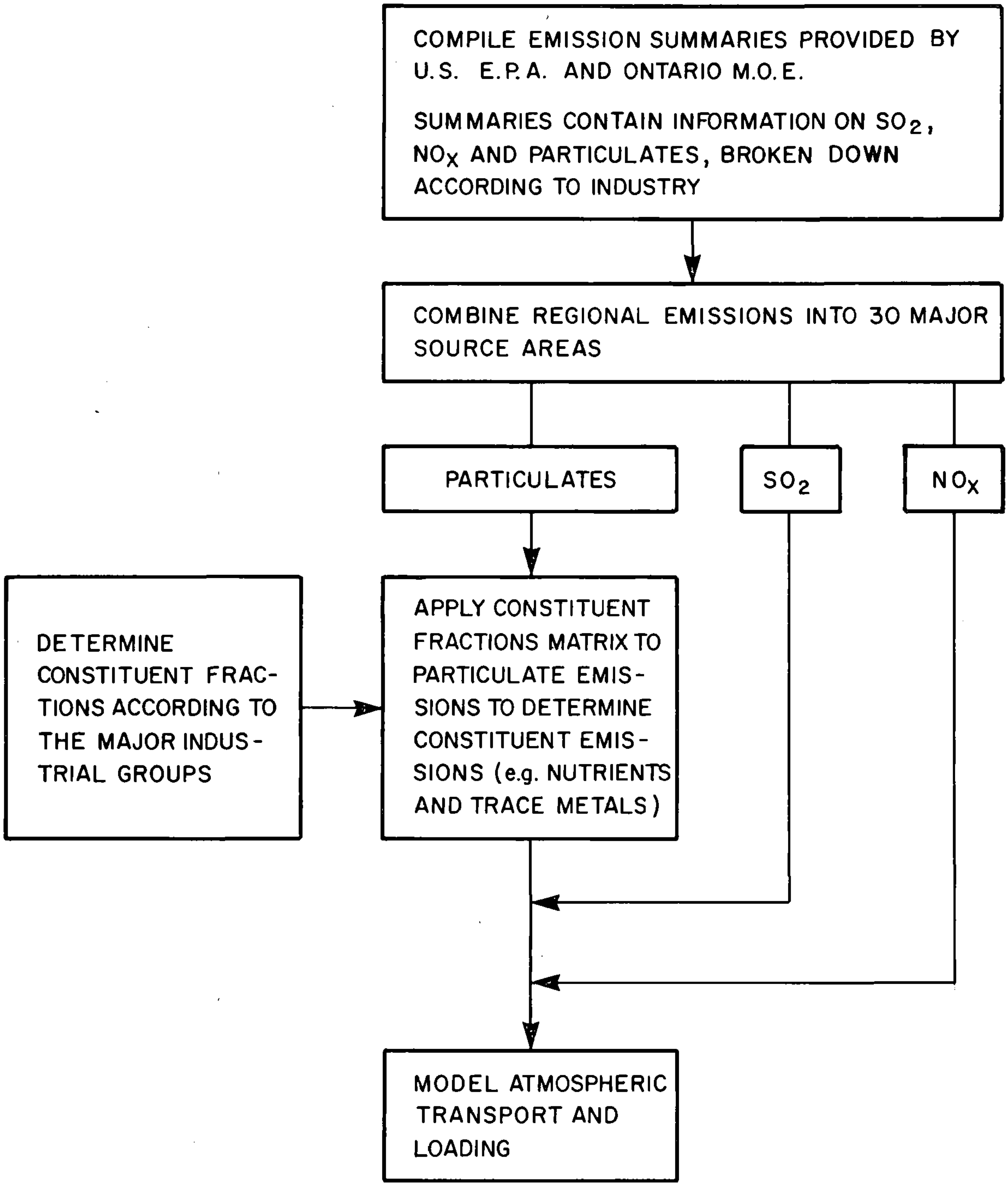
Figure 3 shows schematically the major steps followed to obtain emissions of pollutants for which loading estimates were required. Total annual emissions of the five major pollutants (sulphur dioxide, oxides of nitrogen, particulates, carbon monoxide and hydrocarbons) in 1974 were provided for Air Quality Control Regions by the United States Environmental Protection Agency and for Pollution Monitoring Regions by the Ontario Ministry of Environment. The first three of these pollutants were of direct concern in this study. However, the total particulate emissions had to be broken down to obtain twelve trace components of concern. The basic emission data were provided by major industrial categories. The required breakdown was made by determining constituent fractions for these industrial categories according to literature survey, and applying them to the industrial make-up of thirty major emission areas.

LAKE SUBDIVISIONS	AREA (km2)	TOTAL (km2)
SUPERIOR		
WEST	37 600	82 600
EAST	45 000	
CANADIAN	28 600	82 600
AMERICAN	54 000	
HURON AND GEORGIAN BAY		
NORTH HURON	24 800	60 100
SOUTH HURON	16 000	
GEORGIAN BAY	19 300	
CANADIAN	38 300	60 100
AMERICAN	21 800	



MATHEMATICAL MODEL GRIDS FIGURE 2

ATMOSPHERIC LOADING OF THE UPPER GREAT LAKES



EMISSION METHODOLOGY FIGURE 3

ATMOSPHERIC LOADING OF THE UPPER GREAT LAKES

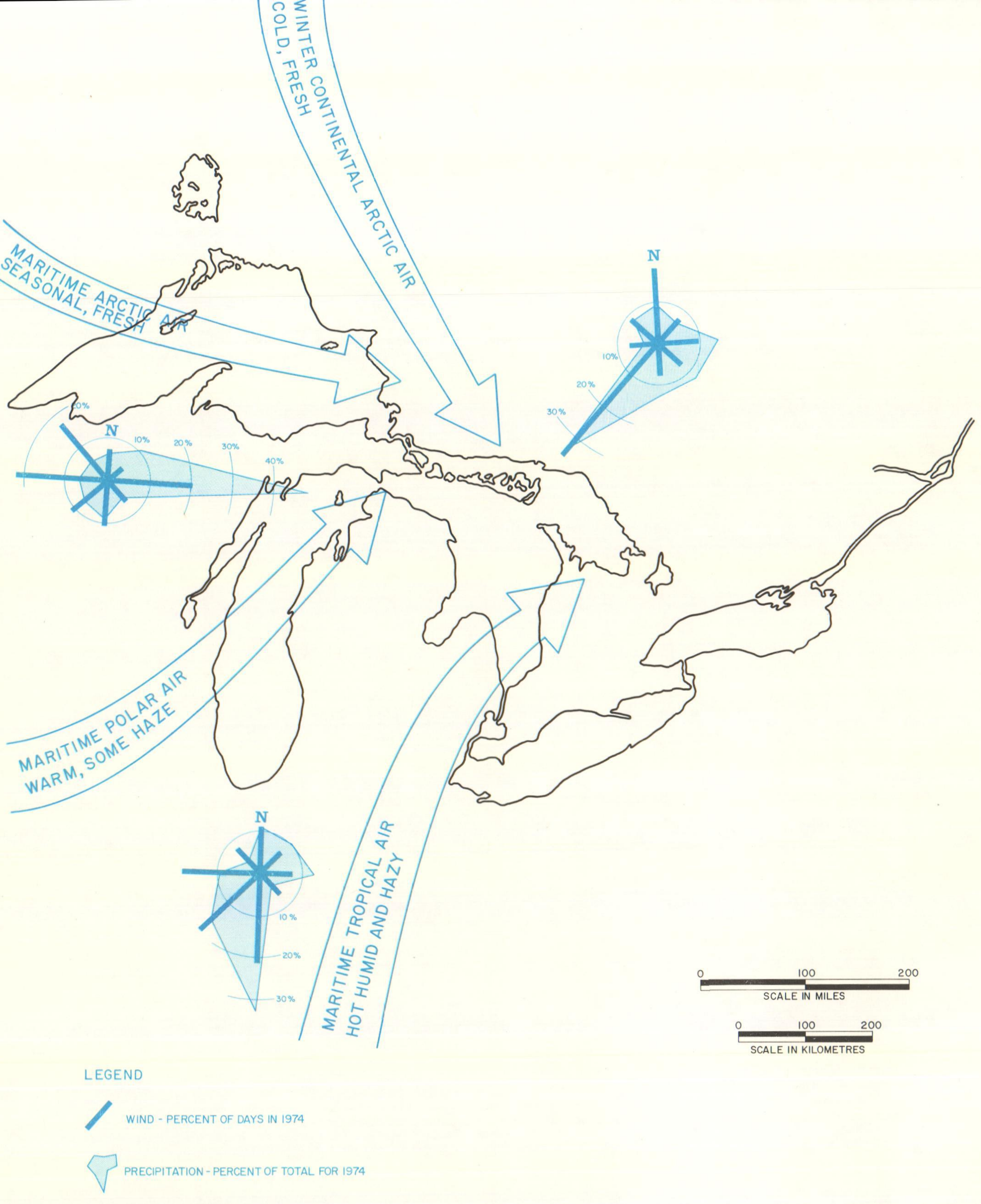
It is evident from the foregoing discussion that, once pollutants are emitted to the atmosphere, their subsequent behavior and ultimate fate will be governed by the physical and chemical atmospheric conditions they encounter. Although this is recognized for the near field where individual sources produce highest concentrations locally in the ambient air, it is perhaps more significant in the far field. In the latter case, the residual pollutants from many sources intermingle and interact to produce significant concentrations over long distances and broad areas.

Air masses govern mixing heights

In the model calculations of atmospheric loadings on the Upper Great Lakes, the predominant air masses and/or synoptic weather types have been used to estimate mean daily depth of the mixed layer throughout 1974.

Four air masses dominate dispersion in the Great Lakes

The four principal air masses that affect the Great Lakes Basin are schematically depicted in Figure 4. Three of these occur with varying frequencies year-round, viz Maritime Tropical, Maritime Polar and Maritime Arctic, while the fourth, Continental Arctic, strictly speaking is confined to the colder months (Environment Canada, Atmospheric Environment Service nomenclature). There are interplays among these air masses in the form of fronts where the warmer air overrides (warm front) or is undercut (cold front) by the cooler air, and where incipient low-pressure areas on some frontal configurations may develop into major storms. The warmest of these air masses, Maritime Tropical, has its usual origin in the Gulf of Mexico-southeastern United States and is typically humid and hazy as it moves into the Great Lakes region. Maritime Polar air moves from the Pacific Ocean inland across North America and undergoes several modifications in passage over the Rockies and the Great Central Plains; this air mass is mild and



AIR MASSES DOMINATING DISPERSION

FIGURE 4

ATMOSPHERIC LOADING OF THE UPPER GREAT LAKES

frequently somewhat hazy. Seasonable temperatures usually prevail in Maritime Arctic air as it moves eastward and southeastward through south central Canada; this air is relatively clean and fresh. The coldest air experienced in North America is Continental Arctic that forms during the long winter over northwestern Canada and from time to time breaks out over the central and eastern continent; in its unmodified form this air is clear and fresh, although it is characteristically stable with poor diffusive capacity.

Atmospheric loadings governed by winds and precipitation

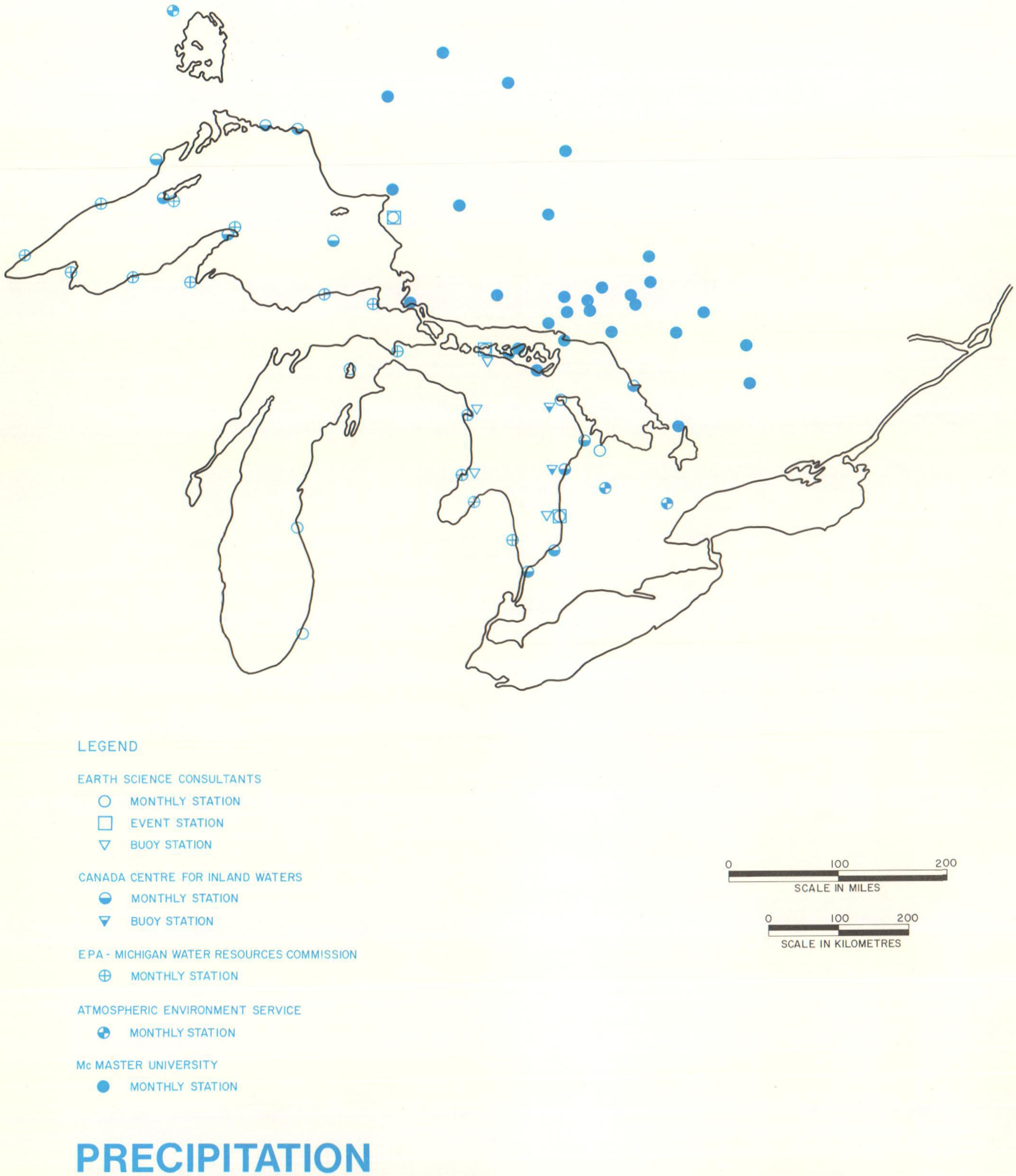
Presented in Figure 4 are the 1974 combined wind and precipitation roses for Indianapolis, North Bay and Duluth. In that year, the bulk of precipitation fell at Indianapolis during south and southwest winds, at North Bay with southwest winds, and at Duluth with easterly winds. A generalized synopsis indicates frequent intrusions of the warmer, moist air masses into and across Lake Huron, and the frequent passage of low-pressure areas to the south and east of Lake Superior. This pattern of air mass movements and precipitation dominates in the atmospheric loading estimates for 1974.

2.2 Precipitation Chemistry Estimates

Field measurements involved an International Monthly Sampling program

Field measurement were made to obtain estimates of loadings, and to determine if land stations represent conditions overwater.

Atmospheric loading measurements were obtained from an international network of stations from which precipitation samples were collected and analyzed for loadings on a monthly basis. The five agencies carrying out this work are shown in Figure 5. To obtain an estimate of overall analytical and



PRECIPITATION CHEMISTRY STATIONS

FIGURE 5

ATMOSPHERIC LOADING OF THE UPPER GREAT LAKES

sampling quality, duplicate sampling sites operated by different groups were maintained at four locations. Priority of analysis of parameters was agreed upon in committee to ensure uniform coverage. Details are presented in the Phase II interim report dated March 1975.

All data were computer processed

Analyzed data were submitted from the four laboratories and processed into one computer data file. Processing involved an elaborate checking procedure so that processing would be accurate. The file was manipulated so that statistical information, graphical plots and contour maps could be generated automatically. Actual loading estimates are obtained from averaging computer-generated loadings for equal areas within the depositional region. Results were obtained by eliminating certain questionable sampling stations and/or using various seasonal portions of the data. These tests showed a few anomalous stations and indicated a seasonal pattern for particulate and nutrient loading.

Final loading estimates result from individual station sensitivity tests and seasonal variations

Buoy loading estimates compare favorably to land-based estimates

Results from five collectors on buoys in Lake Huron were compared to extrapolations between land-based stations. Results for most parameters compared favorably (less than 60 per cent reproducibility), except that sulphate and iron estimates were consistently higher on buoys, and land-based estimates indicated higher cadmium and nickel loadings.

Event studies verify model parameters and model estimates

Three event stations were operated to obtain information to validate portions of the model as well as to validate the monthly sampling technique employed at the network stations. Data from individual precipitation events and air particulate concentrations were used to calculate actual deposition coefficients and amounts. These data were compared to coefficients used in the model and model loading estimates obtained by trajectory analyses. Comparison of model and measured values was acceptable.

Re-entrainment affects P, Fe, Ca, Mg, Na and K values

Results of elevated sampling using towers were compared with ground level and buoy samples at the event stations. Statistical tests showed that tower loadings were greater than buoy loadings which in turn were greater than the land loadings.

Land stations can be extrapolated to predict lake loading estimates

Parameters showing major differences were generally P, Fe, Ca, Mg, Na and K, which are probably influenced by re-entrainment from local sources. Results of analysis supported the use of land-based stations for extrapolation overwater. In summary, land-based loading estimates appear to reflect loading estimates over Great Lakes waters. However, physical re-entrainment and biological activity during summer overestimates concentration and loading values for nutrients and particulates. Therefore, winter samples were used to estimate annual loadings of these parameters.

3 RESULTS

3.1 Lake Loadings

As discussed in Section 2, two independent estimates of atmospheric loadings of the Upper Great Lakes have been made. The one, based on calculations by a mathematical modelling method, produces loadings directly at grid points on the lakes and nearby land areas from which lake surface loadings can be estimated. The other is based on chemical analysis of precipitation samples collected from a network of stations in Canada and the United States at nearshore, island and buoy sites; lake loadings are then estimated from contours drawn across the lakes.

Preferred loading values shown

The results of both methods are shown in Table 1. Where evaluation of the merits and limitations of the two methods have indicated a preference for one estimate over the other, that value is shown in color. Where each value was considered equally valid, both values are shown in color; the user may wish to accept the larger value of the two for conservative application. Where evidence favoring one value over the other is too slight to warrant a preference, neither value is colored. Emission data were not available to make a reasonable estimate of deposition for total dissolved solids or for silica from the mathematical model; and data on total particulates from the precipitation chemistry network were considered inadequate to justify an estimate for Lake Superior. To indicate spatial variation across the lakes, loadings have been calculated separately for west and east Superior, and for north and south Huron and Georgian Bay; totals are entered for each lake. The boundaries of these areas are shown in Figure 2.

10^6 kg PER YEAR

PARAMETERS		LAKE SUPERIOR EASTERN	LAKE SUPERIOR WESTERN	LAKE SUPERIOR TOTAL	LAKE HURON NORTHERN	LAKE HURON SOUTHERN	LAKE HURON GEORG. BAY	LAKE HURON TOTAL
SO_4	PC	110	110	220	90	70	70	230
	MM	140	70	210	130	110	140	380
N	PC	38	18	56	22	12	18	52
	MM	10	7	17	11	12	8	31
PARTIC.	PC	NA	NA	NA	90	140	120	350
	MM	25	16	41	21	17	15	53
TDS_{65}	PC	68	52	120	42	30	38	110
	MM	NA	NA	NA	NA	NA	NA	NA

10^3 kg PER YEAR

PARAMETERS		LAKE SUPERIOR EASTERN	LAKE SUPERIOR WESTERN	LAKE SUPERIOR TOTAL	LAKE HURON NORTHERN	LAKE HURON SOUTHERN	LAKE HURON GEORG. BAY	LAKE HURON TOTAL
TP	PC	200	260	460	210	160	140	510
	MM	150	110	260	110	90	80	280
Cl	PC	36 000	19 000	55 000	20 000	13 000	16 000	49 000
	MM	110	80	190	80	60	60	200
SiO_2	PC	15 000	11 000	26 000	4 900	2 600	1 700	9 200
	MM	NA	NA	NA	NA	NA	NA	NA
Ca	PC	15 000	18 000	33 000	30 000	240 000	10 000	280 000
	MM	800	500	1 300	630	510	460	1 600
Mg	PC	3 800	1 800	5 600	4 100	2 600	1 500	8 200
	MM	360	240	600	290	230	210	730
Na	PC	5 000	10 000	15 000	19 000	23 000	3 000	45 000
	MM	230	140	370	180	150	140	470
K	PC	5 000	8 000	13 000	21 000	9 000	2 000	32 000
	MM	700	400	1 100	550	450	400	1 400
Cd	PC	43	12	55	42	17	20	79
	MM	20	14	34	15	13	11	39
Pb	PC	360	290	650	290	170	320	780
	MM	470	310	780	370	320	270	960
Ni	PC	67	53	120	36	44	130	210
	MM	29	18	47	24	19	21	64
Cu	PC	230	140	370	220	120	420	760
	MM	27	17	44	22	17	20	59
Fe	PC	7600	2 100	9700	1 300	900	2 400	4 600
	MM	2500	1 600	4 100	2 100	1 700	1 500	5 300

NOTE

PC - PRECIPITATION CHEMISTRY
MM - MATHEMATICAL MODEL
NA - NOT AVAILABLE

PREFERRED VALUE - eg 220
WHEN BOTH VALUES OF A PAIR ARE MARKED PREFERRED, USE THE LARGER ONE TO BE CONSERVATIVE

LOADING ESTIMATES

TABLE I

In general, the mathematical model and precipitation chemistry results for sulphate, nitrogen, phosphorus, cadmium, lead and iron are in reasonable agreement and within the limits of accuracy expected for either method. Fair agreement shows for nickel and, to a lesser extent, for total particulates. In the latter case, scarcity of reliable measured data for Superior makes overall comparison and the recommendation of a preferred value difficult. The degree of agreement on sulphate, phosphorus, lead and iron is particularly gratifying since emissions data for these pollutants are considered to be reasonably well defined compared to other parameters.

Model and chemistry results compare favorably

3.2 Transboundary Loadings

Tables 2, 3 and 4 show, for sulphate, phosphorus and trace metals respectively, the percentage contributions of American and Canadian sources to each nation's waters. These three pollutants were chosen because of the reasonably good agreement between the total loadings data as shown in Table 1. Place names have been used to designate these source areas although, as discussed in Subsection 2.1, many major source areas include two or more smaller adjacent source regions. For example, the source designation Chicago in this report covers five such smaller regions, Toronto covers three, and Cincinnati seven. The grouping of individual source regions into larger emission areas is described in Volume 2.

Total lakes loadings for sulphate show about a 58 per cent American and 42 per cent Canadian contribution to both Superior and Huron. Whereas the American contribution to both lakes is spread somewhat uniformly over many sources, the majority of the Canadian contribution to Superior is from the northern Ontario and Sudbury regions, and to Huron from the Sudbury region.

Sulphate loadings about equal, but American sources predominate for phosphorus and heavy metals

Major source regions are identified

SOURCE	LAKE SUPERIOR			LAKE HURON		
	AMERICAN	CANADIAN	TOTAL	AMERICAN	CANADIAN	TOTAL
CHICAGO	7.0	5.2	6.2	5.4	3.5	4.1
SAGINAW	4.7	3.5	4.1	14.3	7.1	9.4
DETROIT	4.4	4.5	4.4	13.0	9.2	10.4
GREEN BAY	3.1	2.0	2.6	1.6	.9	1.1
DULUTH	3.1	.8	2.2	.3	.2	.2
MINNEAPOLIS	2.6	1.4	2.1	.8	.6	.6
WISCONSIN	1.7	.9	1.4	.4	.3	.3
MILWAUKEE	2.6	1.8	2.3	1.6	1.0	1.2
QUAD CITIES	6.1	3.9	5.1	2.8	2.0	2.2
ST. LOUIS	8.2	6.0	7.2	4.9	3.5	3.9
CINCINNATI	7.3	5.7	6.5	6.7	4.7	5.3
MICHIGAN	4.1	2.0	3.2	2.2	1.5	1.7
TOLEDO	2.0	1.8	2.0	3.8	2.7	3.0
CLEVELAND	1.9	1.7	1.8	4.2	3.9	4.0
OHIO	2.3	1.9	2.1	2.9	2.7	2.8
PITTSBURG	4.1	3.1	3.6	5.1	5.5	5.4
PENNSYLVANIA	1.0	.7	.9	1.4	1.6	1.5
SOUTHERN TIER WEST	.1	.1	.1	.1	.2	.2
ROCHESTER	.1	.1	.1	.2	.2	.2
BUFFALO	<.1	<.1	<.1	.1	.2	.2
AMERICAN TOTAL	66.4	47.1	57.9	71.8	51.5	57.7
TORONTO	1.2	1.1	1.2	2.0	2.3	2.0
SUDBURY	11.8	15.4	13.0	17.9	38.6	32.4
THUNDER BAY	1.0	1.6	2.6	.1	.1	.1
SAULT ST. MARIE	.8	.3	.6	.3	.2	.2
MONTREAL	.4	.4	.4	.2	.2	.2
SARNIA	1.0	1.2	1.1	3.8	2.9	3.2
NORTHERN ONTARIO	13.1	28.9	19.0	1.2	.8	.9
SOUTHERN ONTARIO	.2	.2	.2	.5	.4	.5
NORANDA	2.5	2.5	2.5	1.6	2.5	2.3
MANITOBA	1.6	1.3	1.5	.6	.5	.5
CANADIAN TOTAL	33.6	52.9	42.1	28.2	48.5	42.3
NOTE LOADINGS ARE PRESENTED AS PERCENTAGE OF THE FOLLOWING TOTAL LOADINGS (10^6 kg PER YEAR)	127	83	210	116	264	380

TRANSBOUNDARY LOADING OF SO_4

TABLE 2

SOURCE	LAKE SUPERIOR AMERICAN	LAKE SUPERIOR CANADIAN	LAKE SUPERIOR TOTAL	LAKE HURON AMERICAN	LAKE HURON CANADIAN	LAKE HURON TOTAL
CHICAGO	13.3	14.2	13.5	14.0	12.4	13.2
SAGINAW	2.1	2.2	2.1	6.1	4.4	5.0
DETROIT	3.5	4.8	4.0	10.5	9.8	10.1
GREEN BAY	4.5	4.4	4.5	3.5	2.9	3.1
DULUTH	9.0	5.7	7.7	2.5	2.1	2.2
MINNEAPOLIS	2.5	2.2	2.4	1.6	1.4	1.5
WISCONSIN	5.6	4.4	5.2	2.5	2.1	2.2
MILWAUKEE	4.0	4.0	4.0	3.5	3.1	3.2
QUAD CITIES	3.8	3.5	3.7	2.6	2.5	2.5
ST. LOUIS	5.2	5.1	5.2	4.7	4.3	4.5
CINCINNATI	7.4	8.0	7.6	9.8	8.9	9.2
MICHIGAN	8.2	4.4	6.9	3.6	4.1	3.9
TOLEDO	2.6	3.1	2.8	5.7	5.5	5.5
CLEVELAND	1.9	2.2	2.0	5.2	6.2	5.8
OHIO	2.3	2.7	2.5	4.5	5.2	5.0
PITTSBURG	1.1	1.2	1.1	2.0	2.7	2.4
PENNSYLVANIA	.9	.9	.9	1.6	2.3	2.1
SOUTHERN TIER WEST	.1	.1	.1	.2	.3	.3
ROCHESTER	.2	.2	.2	.3	.4	.4
BUFFALO	.2	.3	.2	.4	.6	.5
AMERICAN TOTAL	78.4	73.6	76.6	84.8	81.2	82.6
TORONTO	1.5	1.9	1.7	3.1	4.0	3.7
SUDBURY	.2	.3	.2	.3	.7	.5
THUNDER BAY	3.6	5.7	4.3	.6	.8	.7
SAULT ST. MARIE	3.7	1.7	3.1	1.0	1.6	1.4
MONTREAL	3.3	4.5	3.7	2.5	3.7	3.2
SARNIA	.1	.1	.1	.3	.3	.3
NORTHERN ONTARIO	1.0	2.7	1.6	.2	.1	.1
SOUTHERN ONTARIO	.3	.7	.5	2.1	2.3	2.3
NORANDA	.4	.6	.5	.4	.6	.5
MANITOBA	7.5	8.2	7.7	4.7	4.7	4.7
CANADIAN TOTAL	21.6	26.4	23.4	15.2	18.8	17.4

NOTE

LOADINGS ARE PRESENTED AS PERCENTAGE OF THE FOLLOWING TOTAL LOADINGS (10^3 kg PER YEAR)

	LAKE SUPERIOR AMERICAN	LAKE SUPERIOR CANADIAN	LAKE SUPERIOR TOTAL	LAKE HURON AMERICAN	LAKE HURON CANADIAN	LAKE HURON TOTAL
TOTAL LOADINGS (10^3 kg PER YEAR)	174	86	260	100	180	280

TRANSBOUNDARY LOADING OF PHOSPHATE

TABLE 3

SOURCE	LAKE SUPERIOR AMERICAN	LAKE SUPERIOR CANADIAN	LAKE SUPERIOR TOTAL	LAKE HURON AMERICAN	LAKE HURON CANADIAN	LAKE HURON TOTAL
CHICAGO	9.7	9.9	9.8	8.4	7.5	7.8
SAGINAW	4.8	4.9	4.8	11.4	8.3	9.4
DETROIT	5.4	7.2	6.0	13.5	12.6	13.0
GREEN BAY	3.5	3.3	3.5	2.3	1.9	2.0
DULUTH	3.8	2.3	3.3	.8	.7	.8
MINNEAPOLIS	2.6	2.3	2.5	1.4	1.2	1.3
WISCONSIN	2.6	2.0	2.4	1.0	.8	.9
MILWAUKEE	3.2	3.1	3.2	2.3	2.0	2.1
QUAD CITIES	4.6	4.2	4.4	2.6	2.5	2.6
ST. LOUIS	7.3	7.1	7.2	5.5	5.0	5.2
CINCINNATI	10.1	10.8	10.4	11.1	10.1	10.5
MICHIGAN	12.4	6.8	10.5	5.2	5.6	5.4
TOLEDO	4.1	5.0	4.4	7.6	7.3	7.4
CLEVELAND	2.8	3.2	2.9	6.4	7.7	7.2
OHIO	4.4	4.8	4.5	6.8	8.0	7.6
PITTSBURG	2.9	3.0	3.0	4.2	5.8	5.2
PENNSYLVANIA	1.9	1.9	1.9	2.9	4.3	3.8
SOUTHERN TIER WEST	.2	.3	.2	.3	.6	.5
ROCHESTER	.3	.3	.3	.3	.4	.4
BUFFALO	.2	.3	.2	.3	.5	.4
AMERICAN TOTAL	86.8	82.7	85.4	94.3	92.8	93.5
TORONTO	.5	.6	.5	.8	1.1	1.0
SUDBURY	.1	.2	.1	.2	.3	.2
THUNDER BAY	1.9	3.0	2.3	.3	.3	.3
SAULT ST. MARIE	5.4	2.5	4.4	1.2	1.9	1.6
MONTREAL	.8	1.0	.9	.5	.7	.6
SARNIA	.1	.2	.1	.3	.3	.3
NORTHERN ONTARIO	3.2	8.2	4.9	.4	.3	.4
SOUTHERN ONTARIO	.3	.6	.4	1.5	1.	1.
NORANDA	.2	.3	.3	.2	.3	.2
MANITOBA	.7	.7	.7	.3	.3	.3
CANADIAN TOTAL	13.2	17.3	14.6	5.7	7.2	6.5

NOTE: LOADINGS ARE PRESENTED AS PERCENTAGE OF THE FOLLOWING TOTAL LOADINGS

(10^3 kg PER YEAR)	3300	1700	5000	2300	4200	6500

CONSTITUENT	Fe	Pb	Ni	Cu	Cd
% OF TOTAL	82.3	15.2	1.0	.9	.6

TRANSBOUNDARY LOADING OF TRACE METALS

TABLE 4

Total lake loadings for phosphates are about 77 per cent American and 23 per cent Canadian origin on Superior and 83 per cent American and 17 per cent Canadian on Huron. Trace metal loadings on Superior are about 85 per cent American and 15 per cent Canadian, and on Huron the contributions are 93.5 per cent American and 6.5 per cent Canadian. Large loadings of phosphorus on Superior come from the Chicago area and on Huron from Chicago, Detroit and Cincinnati. For the trace metals, major contributing sources to Superior are Chicago, Cincinnati and Michigan, and to Huron are Detroit, Saginaw and Cincinnati.