Canada Centre for Inland Waters

Atmospheric Loading of the Lower Great Lakes and the Great Lakes Drainage Basin

Acres Consulting Services Limited

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ACRES

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Dear Mr Elder:

We are pleased to forward one hundred copies of the final report "Atmospheric Loading of the Lower Great Lakes and the Great Lakes Drainage Basin", as per contract DSS 01SS KL347-6-0146.

We appreciate the helpful comments which you and other reviewers provided on an earlier draft, and have incorporated them in this report where appropriate.

Yours very truly,

Paul Denison

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1 INTRODUCTION

1 INTRODUCTION

By contract DSS 01SS KL347-6-0146, dated July 27, 1976, Acres Consulting Services Limited was authorized to carry out scientific investigations of deposition of airborne material on the Lower Great Lakes and the entire Great Lakes drainage basin. The project is essentially an extension to the report "Atmospheric Loading of the Upper Great Lakes", Acres Consulting Services Limited and Applied Earth Science Consultants, December 1975 (Acres–ESC 1975).

In that report, a mathematical model was developed that simulated, on a daily average basis, the meteorological transport, diffusion and deposition (loading) of atmospheric pollutant emissions from large sources in and around the Great Lakes basin. Using the model, calculations were made of the loadings in 1974 of 16 pollutants originating from 30 major emission regions in Canada and the United States. Emissions data were available only on an annual basis and it was necessary to assume that these were distributed uniformly throughout the year. Daily average meteorological data were used from a network of 14 stations in the study area. The calculated loadings were then compared with loadings estimated from a network of shoreline, island and buoy precipitation chemistry stations.

Results from the two methods were in reasonable agreement for those pollutants for which relatively reliable atmospheric emissions data were available.

In this contract, model estimates were required for Lakes Michigan, Erie and Ontario, as well as for the entire land drainage area in the Great Lakes basin, subdivided into 37 individual areas. Additional meteorological stations and emission regions to the east and southeast of Lake Ontario were added to the data file for estimating loadings on Lakes Erie and Ontario and their drainage areas. Emission regions distant from these lakes to the northwest were grouped or eliminated. The results were compared with loading estimates made by ESC from existing precipitation chemistry data for Lakes Erie and Ontario and 4 of the 37 individual land drainage areas. The model results were grouped according to Canadian and American emission source regions to give estimates of the transboundary movement of the air pollutants studied.

Projections were made of growth rates to the year 2000 for those industrial sectors that contribute the bulk of emissions (about 90 percent of the total). Assumptions were made on the future control of sulphur dioxide (SO_2) emissions. These future data sets were input to the model to estimate loadings of total particulates and sulphates on each of the Great Lakes in year 2000.

Seasonal variations in loading rates based on precipitation chemistry data are discussed in the main text and Appendix 1, and those based on model estimates are discussed in Appendix 2.

A test of the validity of the model assumptions for wind transport of air pollutants was made by comparing model air motions with air trajectories analyzed from surface and upper-level weather maps on 25 randomly selected days in 1974.

A substantial effort was made to obtain data in both Canada and the United States on atmospheric emissions of polychlorinated biphenyls (PCB's) for input to the model. The information collected was judged to be insufficient to permit calculations of loadings. Consequently, populations of each emissions region were extracted from published data, and dimensionless distribution patterns were calculated on the assumption that PCB air emissions are related to population density.

This summary of material contained in subsequent sections of the report is intended to provide an overview of the work undertaken; the results presented are not always in the chronological order of the preceding discussions.

2 MATHEMATICAL MODEL

2 MATHEMATICAL MODEL

The computer model used in this study was developed on the "box" concept and incorporates both wet and dry deposition components. A detailed description of its development and testing is contained in the report "Atmospheric Loading of the Upper Great Lakes", Acres–ESC 1975. The following is a brief summary of the salient features of this model, indicating modifications that were made to input data.

2.1 Model Description

The model is based on the "box" concept, able to handle 25 receptor locations and up to 30 regional emission sources. Calculations are carried out on a daily time step with output in the form of monthly and yearly summaries of air pollutant concentrations and wet and dry loadings of the pollutants.

The model is driven by the meteorological data file containing the following daily averaged data:

- mean wind speed and direction through the mixing height
- precipitation amounts and durations
- air mass type which governs the mixing height and dispersion angle of the "box".

This data file has been expanded from the original 14 stations (Acres–ESC 1975) to include Kingston, Montreal, Albany and La Guardia Airport, thus accommodating the addition of emission sources along the eastern seaboard of the United States (see Subsection 2.2 – Emission Data), some of which contribute significantly to loadings on the Lower Great Lakes.

Meteorological data for 1974 were used throughout this study. Previous computer runs using 1972 and 1973 data indicated variations in yearly loading rates of up to 20 percent because of annual climatic differences (Acres–ESC 1975).

Wet and dry deposition rates vary for gaseous and particulate pollutants. Following the Upper Great Lakes report, the washout coefficient (λ) governing wet deposition has been chosen as

gases $\lambda = 6 \times 10^{-5} I$ (sec^{-1}) or
particulates $\lambda = 3 \times 10^{-5} I$ (sec^{-1})

Where I is the precipitation intensity in mm hour^{-1}.

The deposition velocity (v_d) governing dry deposition has been chosen as

gases $v_d = .01 \text{ m sec}^{-1}$
particulates $v_d = .001 \text{ m sec}^{-1}$

Atmospheric oxidation rates have been incorporated in the model to determine the proportion of gaseous SO_2 to particulate sulphate (SO_4) in the air reaching a receptor calculation point in the Great Lakes basin. The appropriate λ and v_d are then applied to these proportions. These oxidation rates were based on a survey of the literature as discussed in the Upper Great Lakes report and are summarized as follows.

Zone	Description	SO_2 Half Life (hours)
1	Within 16 km of power plants and heavy industry	0.2 – 4
2	More than 16 km from main power plants and industrial areas	10 – 15
3	Average nonurban areas	40 – 50
4	Countryside, unpolluted	100+

2.2 Emission Data

Regional emissions are input directly to the model and are transported, diffused and deposited according to the meteorology, oxidation rates and wet and dry deposition rates described in Subsection 2.1. The procedure for determining these emissions, as detailed in the Upper Great Lakes report (Acres—ESC 1975), includes the following steps.

(a) Obtaining from Ontario Ministry of Environment (MOE) and United States Environmental Protection Agency (U.S. EPA) air quality data on annual emissions of SO_2, oxides of nitrogen (NO_x), and total particulates for all control regions in and around (up to 600 km) the Great Lakes drainage basin.

(b) Grouping the major pollutants (SO_2, NO_x and particulates) into regional sources for model input.

(c) Determining constituent breakdown of the particulate emissions into nutrient and trace metal components.

Emissions data used for the Lake Michigan and Upper Great Lakes basin loading calculations are the same as for the Upper Great Lakes, except for a few modifications to the Canadian sources based on updated information from the Ontario MOE. The final tabulation of model source emissions is presented in Figure 2.1.

The following modifications to the emission data were made for calculating the Lake Erie and Lake Ontario loadings.

(a) The more distant sources to the northwest were combined where practical.

(b) The Manitoba source was eliminated.

(c) Four new sources were included at Albany, Boston, New York and Philadelphia.

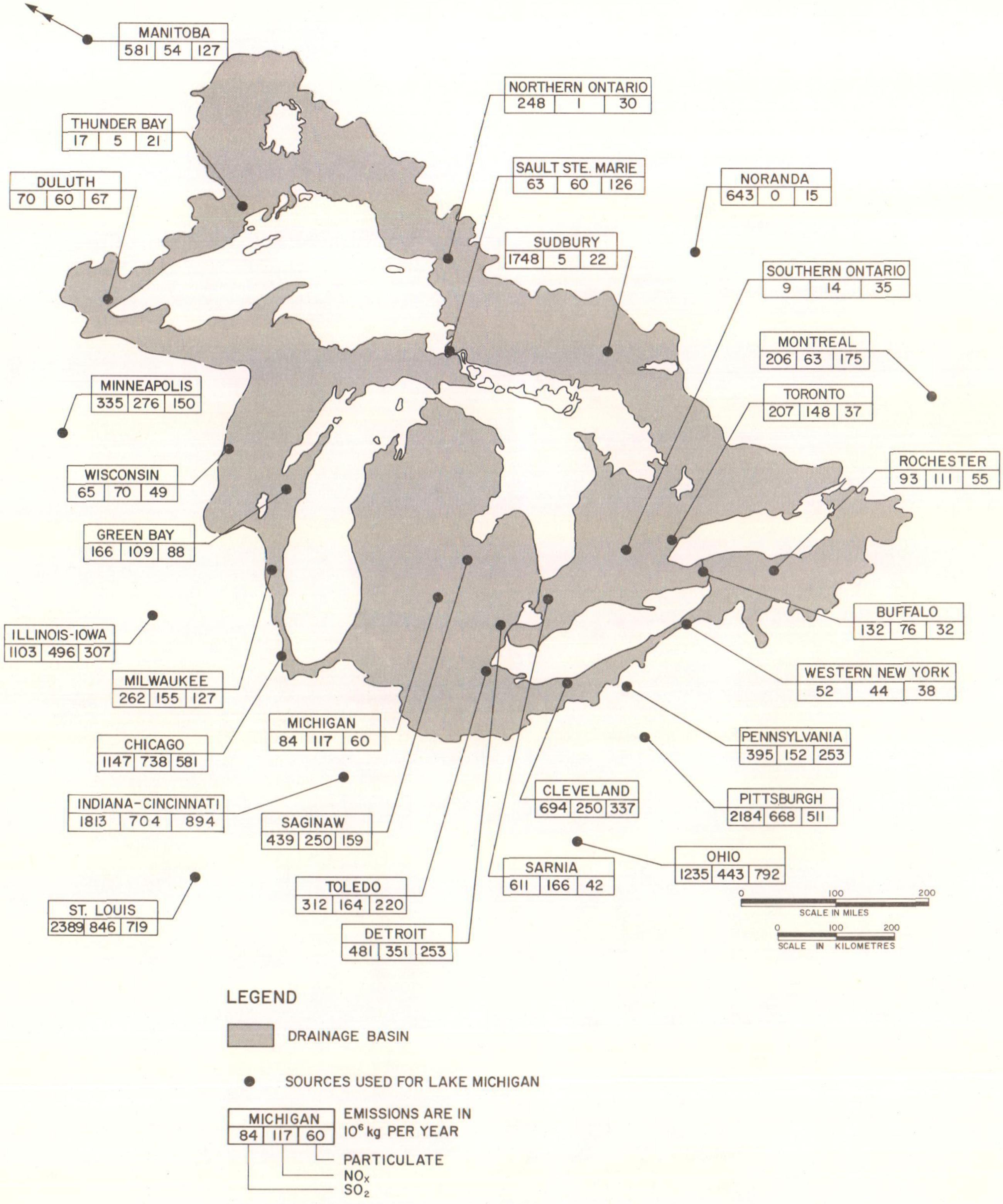
The final tabulation of emission data used for the Lower Great Lakes (Erie and Ontario) is presented in Figure 2.2.

2.3 Trajectory Analysis

The following procedure was developed to test the accuracy of the mathematical model in reproducing the movement of pollutants as predicted by analysis of wind trajectories on specific days:

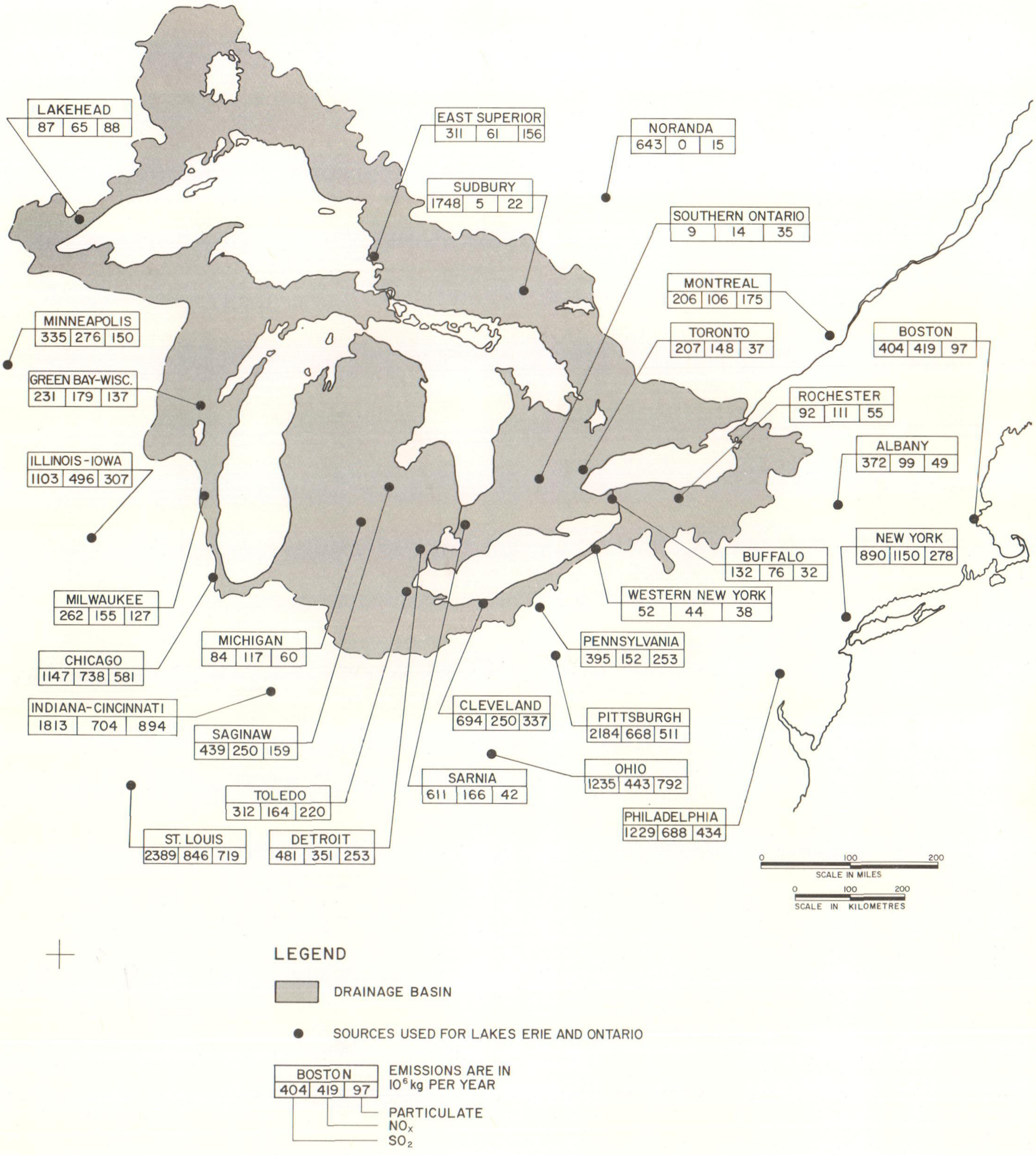
- there were 25 days randomly selected from 1974

- wind trajectories were drawn from each source region for a 24-hour period, using 6-hourly surface maps and 12-hourly 850-mb maps



UPPER LAKES EMISSION SOURCES

FIGURE 2.1



LOWER LAKES EMISSION SOURCES

FIGURE 2.2

ATMOSPHERIC LOADING OF THE LOWER GREAT LAKES

- using the appropriate dispersion angle for the trajectory based on the air mass type as discussed in Acres–ESC 1975, each occurrence of a source plume reaching one of the study lakes was recorded

- the same procedure was repeated using the wind data employed in the model, with the modification that the box angle was 60 degrees plus the dispersion angle used in the above step; in the model, only the wind at the source region is used for pollutant transport, with no curvature in the trajectories to the receptor.

The results of this test are presented in Table 2.1. Two cases are considered for each lake. The first considered only the dominant sources which accounted for 75 percent of the total loadings, and the second considered all sources.

Using only the dominant sources, 80 percent of the trajectory loading occurrences were duplicated by the model. However, when the additional sources representing the remaining 25 percent of the total loading were included, this agreement dropped to as low as 60 percent in the case of Lake Superior.

Because of the larger dispersion angle used in the model, the number of loading occurrences predicted by the model consistently exceeded the number of trajectory occurrences. This value has been presented in Table 2.1 as a percentage of the trajectory occurrences. It is interesting to note that for the lakes that are central to the emission sources (i.e. Lakes Erie, Huron and Michigan), the number of sources dominating the loading is 8 compared with 11 and 12 for Lakes Superior and Ontario, respectively. In addition, there is a better agreement in terms of overall loading occurrences between the model and the trajectory analysis, varying from 113 percent in the case of Lake Michigan to 124 percent for Lake Erie. Lakes Superior and Ontario show significantly higher percentages at 168 and 174, respectively.

It is apparent that as the sources become more distant the model tends to spread the pollutants over a larger area, thereby becoming less representative of the actual trajectories. However, for the dominant sources which account for 75 percent of the total loading the agreement is quite acceptable. The fact that the more distant sources load the lakes more frequently than would be predicted by the trajectories may be compensated by the reduced concentrations in the plume that result from the significantly larger dispersion angle.

TABLE 2.1

TRAJECTORY AND MODEL COMPARISON
(Mean wind through the mixing path)

	No. of Sources	Percentage* Agreement	Percentage** Occurrence Model/Trajectory
Lake Ontario			
75 percent of loading	12	81	174
Total loading	30	79	173
Lake Erie			
75 percent of loading	8	80	124
Total loading	30	75	143
Lake Huron			
75 percent of loading	8	78	122
Total loading	30	69	121
Lake Michigan			
75 percent of loading	8	80	113
Total loading	30	76	142
Lake Superior			
75 percent of loading	11	80	168
Total Loading	30	60	138

*Number of occurrences for which the model indicates loading on the same day as the trajectories, expressed as a percentage of the trajectory loading occurrences.

**Total number of model loading occurrences, expressed as a percentage of the trajectory loading occurrences.

3 ANALYSIS OF FIELD DATA

3 ANALYSIS OF FIELD DATA

Measurements of precipitation chemistry were collected for the period 1973 – 1974 in order to estimate atmospheric deposition of selected parameters on Lakes Ontario and Erie and drainage basins 16, 17, 21 and 22 (Figure 4.1). In addition, maps showing average atmospheric loadings as well as seasonal variations in deposition were obtained from the measurements of precipitation chemistry.

Data were compiled into a common file from measurements taken by McMaster University (MU), Canada Centre for Inland Waters (CCIW), U.S. Environmental Protection Agency, Grosse Isle, Michigan and Michigan Water Resources Commission (EPA–MICH), Atmospheric Environment Service (AES), U.S. Environmental Protection Agency, Rochester, New York (EPA–NY), the University of Windsor (UW), U.S. Geological Survey, Albany, New York (USGS), and Cornell University (CO).

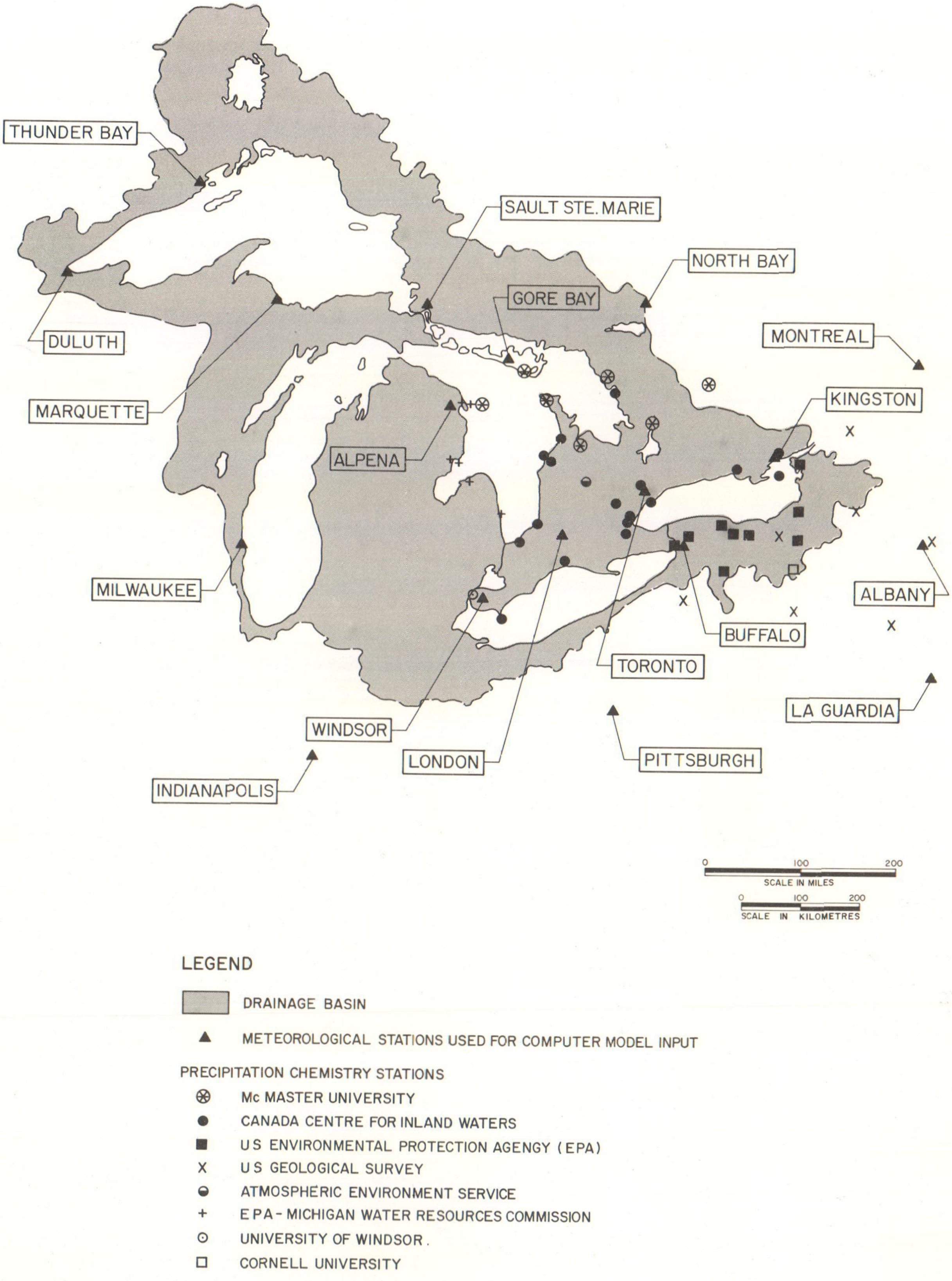
3.1 Sampling and Analysis

Figure 3.1 shows the distribution of precipitation chemistry stations from which data were obtained for this study. Monthly bulk samples were obtained for stations operated by MU, CCIW, EPA–MICH, UW and the USGS. MU, EPA–MICH and UW used an unheated cylindrical collector with an Alter Shield (see Figure 3.2, Acres–ESC 1975). The USGS sampler consisted of a heated collector with a pyrex glass funnel. CCIW employed both cylindrical and heated glass funnel collectors at most of their stations on a monthly basis. Data from EPA–NY and AES are for wet only deposition on a monthly basis. Data for CO exist for monthly bulk, wet only, and individual precipitation events.

Table 3.1 is a list of parameters that are considered in this study. The table lists the code numbers, acronyms, and units of concentration and loading used throughout the study.

Table 3.2 lists stations, their latitudes and longitudes, and the code numbers of variables that were measured at each group of stations.

Not all of the stations were operative during the entire period 1973 – 1974. Table 3.3 lists the percentage of the sampling period for which data were available to obtain an average loading estimate for each station. Geometric averages were obtained for each station for the time period considered, and these data were used to obtain contour maps of areal deposition rates and estimates of loading.



METEOROLOGICAL AND PRECIPITATION CHEMISTRY STATIONS FIGURE 3.1

ATMOSPHERIC LOADING OF THE LOWER GREAT LAKES

The geometric average value for a parameter at a station was not modified to take into consideration the percentage of the study period within which the parameter was measured.

The data file was formulated as follows: all data used in this study derived from data previously accumulated by other agencies. All data submitted by these agencies were processed into the data file. The instances in which data were deleted from the file occurred only at the suggestion of the agency. Careful attention was paid to compatibility of data from different agencies. In particular, units and the exact nature of parameter (total, filtered) were checked very carefully. Volume of sample was not measured for wet or bulk samplers operated by EPA—NY, USGS and CO. Precipitation data from standard meteorological gauges were employed in these cases to estimate loadings from concentration data. Information regarding emplacement and removal of samples was incomplete for EPA—NY data; in these cases estimates were made in consultation with personnel from EPA—NY.

AES and EPA—NY data represent the precipitation fraction of loading only. Various calculations were made to estimate a fraction of dry fall in order to adjust the data from EPA—NY and AES to total loadings. CCIW at Burlington, Ontario and Cornell University at Ithaca, New York carried out a series of studies where bulk samplers and precipitation samplers were operated adjacent to each other at the same time. Assessment of these data gave inconclusive results. Although the average ratio of precipitation loading to bulk loading was about 0.7, the data scattered widely, and in almost one half of the cases the bulk loading was less than the precipitation only loading. Furthermore, analysis of multiple samplers of the same kind at CCIW showed that the volume for the cylindrical bulk samplers was much less variable under multiple sampling conditions than was the volume for the precipitation only samplers. Obviously a new careful assessment of all samplers is required.

No adjustments to the precipitation only estimates were made due to the poor quality of results from the above study. This places a significant limitation on the confidence that can be placed on these loading estimates. More study is required to better assess the validity of bulk sampler data versus precipitation only data.

TABLE 3.1

CODES, ACRONYMS AND UNITS FOR PARAMETERS CONSIDERED IN THIS STUDY

Name	Code No.	Definition	Units Concentration	Loading
Cd T	101	Total cadmium	µg/l	ng/cm^2/day
Cu T	107	Total copper	µg/l	ng/cm^2/day
Fe T	110	Total iron	µg/l	ng/cm^2/day
Pb T	113	Total lead	µg/l	ng/cm^2/day
Ni T	116	Total nickel	µg/l	ng/cm^2/day
Zn T	119	Total zinc	µg/l	ng/cm^2/day
SO_4	127	Sulphate	mg/l	µg/cm^2/day
Na F	222	Filtered sodium	mg/l	µg/cm^2/day
K F	224	Potassium filtered	mg/l	µg/cm^2/day
Mg F	226	Magnesium filtered	mg/l	µg/cm^2/day
Ca F	228	Calcium filtered	mg/l	µg/cm^2/day
P T	240	Total phosphorus	µg/l	ng/cm^2/day
NO_3 F	237	Filtered nitrate–N	mg/l	µg/cm^2/day
NH_3 R	244	Total reactive ammonia–N	mg/l	µg/cm^2/day
NH_3 F	252	Filtered reactive ammonia–N	mg/l	µg/cm^2/day
NO_3 R	243	Total reactive nitrate–N	mg/l	µg/cm^2/day
KJ T	234	Total kjeldahl nitrogen	mg/l	µg/cm^2/day
N T*	242	Total nitrogen	mg/l	µg/cm^2/day

Note: Insufficient data were available to include chloride.

*N T was calculated as a combination of NO_3 (243 or 237) and NH_3 (244 or 252) for EPA, ESC, MU, USGS data.

TABLE 3.2

LATITUDE, LONGITUDE, AND PARAMETERS MEASURED AT EACH STATION

McMaster University

Codes measured: 101, 107, 110, 113, 116, 127, 222, 224, 226, 228, 240, 242.

Station	Name	Latitude	Longitude
18	Sparrow Lake	44.798	79.383
23	Lake St. Peter	45.300	78.033
25	Shawanaga	45.533	80.200
35	South Baymouth	45.585	82.012
36	Tobermory	45.207	81.523
37	Owen Sound	44.491	80.871
43	Manitoulin Buoy	45.118	82.939

Canada Centre for Inland Waters

Codes measured: 101, 107, 110, 113, 116, 127, 222, 224, 226, 228, 240, 242.

Station	Name	Latitude	Longitude
113	Wiarton Airport	44.650	81.233
120	Sarnia Airport	42.983	82.283
134	Pinery Park	43.233	81.800
135	Inverhuron Park	44.300	81.567
137	Kilbear Park	45.350	80.200
138	Southampton Buoy	44.325	81.650
142	Wiarton Airport	44.650	81.233
143	Sarnia Airport	42.983	82.283
148	Pinery Park	43.233	81.800
149	Inverhuron Park	44.300	81.567
150	Kilbear Park	45.350	80.200
151	Guelph Funnel	43.634	80.114
152	Guelph Snow	43.634	80.114
153	Port Stanley Funnel	42.671	81.224
154	Port Stanley Snow	42.671	81.224
155	Pelee Funnel	41.751	82.687
157	CCIW Funnel 1	43.299	79.799
158	CCIW Funnel 2	43.299	79.799

TABLE 3.2 (Cont'd)

Station	Name	Latitude	Longitude
159	CCIW Funnel 3	43.302	79.794
160	Ancaster Funnel	43.175	79.950
161	CCIW Snow 1	43.299	79.799
162	CCIW Snow 2	43.299	79.799
163	Toronto Island Funnel	43.632	79.397
164	Woodbridge Funnel	43.793	79.569
165	Toronto Island Snow	43.632	79.397
166	Woodbridge Snow	43.793	79.569
167	Duck Island Funnel	43.931	76.637
168	Trenton Funnel	44.111	77.544
169	Trenton Snow	44.111	77.544
170	Kingston Funnel	44.221	76.596
171	Kingston Snow	44.221	76.596

U.S. Environmental Protection Agency, Michigan

Codes measured: 101, 107, 110, 113, 116, 127, 222, 224, 226, 228, 240, 242.

Station	Name	Latitude	Longitude
208	U.S. Coast Guard Station Alpena	45.034	83.239
209	U.S. Coast Guard Station Tawas	44.254	83.447
210	Albert Sleeper Park	43.977	83.211
211	Port Sanilac	43.429	82.552
213	Tawas Buoy	44.225	83.422
219	Alpena Buoy	45.167	83.217

Canada, Atmospheric Environment Service

Codes measured: 127, 222, 224, 226, 228, 240, 242.

Station	Name	Latitude	Longitude
301	Mount Forest Wet	43.973	80.736

TABLE 3.2 (Cont'd)

U.S. Environmental Protection Agency, New York

Codes measured: 101, 107, 110, 113, 127, 222, 224, 226, 228, 240, 242.

Station	Name	Latitude	Longitude
410	Macedon Wet	43.088	77.312
411	Skaneateles Wet	42.946	76.419
412	Oswego Wet	43.461	76.374
413	Brockport Wet	43.280	77.931
414	Rochester Wet	43.180	77.624
415	Cape Vincent Wet	44.122	76.239
416	Buffalo Wet	42.915	78.872
417	Clarence Wet	43.020	78.631
418	Nunda Wet	42.539	77.945

University of Windsor

Codes measured: 127, 240.

Station	Name	Latitude	Longitude
450	Windsor	42.255	83.036

U.S. Geological Survey

Codes measured: 127, 222, 224, 226, 228, 242.

Station	Name	Latitude	Longitude
703	Rock Hill	41.624	74.521
704	Athens	41.925	76.526
705	Salamanca	42.100	78.750
706	Mays Point	42.999	76.763
707	Canton	44.578	75.111
708	Hinckley	43.310	75.110
709	Albany	42.743	73.808

TABLE 3.2 (Cont'd)

Cornell University

Codes measured: 127, 222, 226, 228, 242.

Station	Name	Latitude	Longitude
710	Ithaca	42.457	76.521

TABLE 3.3

NUMBER OF MONTHLY SAMPLES ANALYZED FROM EACH STATION EXPRESSED AS A PERCENTAGE OF THE 24-MONTH PERIOD 1973 – 1974

Station	Name	Percent
18	Sparrow Lake	100
23	Lake St. Peter	100
25	Shawanaga	33
35	South Baymouth	100
36	Tobermory	90
37	Owen Sound	90
43	Manitoulin Buoy	30
113	Wiarton Airport	100
120	Sarnia Airport	100
134	Pinery Park	58
135	Inverhuron Park	75
137	Kilbear Park	71
138	Southampton Buoy	21
142	Wiarton Airport	88
143	Sarnia Airport	88
148	Pinery Park	71
149	Inverhuron Park	83
150	Kilbear Park	83
151	Guelph Funnel	79
152	Guelph Snow	4
153	Port Stanley Funnel	79
154	Port Stanley Snow	42
155	Pelee Funnel	88
157	CCIW Funnel 1	83
158	CCIW Funnel 2	41
159	CCIW Funnel 3	13
160	Ancaster Funnel	83
161	CCIW Snow 1	17
162	CCIW Snow 2	13
163	Toronto Island Funnel	83
164	Woodbridge Funnel	79
165	Toronto Island Snow	13

TABLE 3.3 (Cont'd)

Station	Name	Percent
166	Woodbridge Snow	42
167	Duck Island Funnel	33
168	Trenton Funnel	88
169	Trenton Snow	21
170	Kingston Funnel	83
171	Kingston Snow	25
208	USCGS Alpena	46
209	USCGS Tawas	54
210	Albert Sleeper Park	29
211	Port Sanilac	25
213	Tawas Buoy	8
219	Alpena Buoy	8
301	Mount Forest Wet	100
410	Macedon Wet	21
411	Skaneateles Wet	29
412	Oswego Wet	4
413	Brockport Wet	25
414	Rochester Wet	21
415	Cape Vincent Wet	21
416	Buffalo Wet	17
417	Clarence Wet	13
418	Nunda Wet	8
450	Windsor	92
703	Rock Hill	92
704	Athens	38
705	Salamanca	71
706	Mays Point	100
707	Canton	88
708	Hinckley	96
709	Albany	83
710	Ithaca	8

3.2 Contour Maps and Loading Estimates

Geometric means of the data from up to 63 stations were compiled on a data file and, from this array, estimates for an equal area grid intersect were calculated. The number of grid intersects was about four or more times the number of data points. Contouring could be carried out routinely on a computer using these grid intersect values. Furthermore, loading estimates were calculated for the various areas using the same values. Figure 3.2 shows the grid overlaid on a map of the study area.

A moving second order polynomial least squares routine was used to estimate values at grid points. In order to avoid possible extreme results from the least squares function values were deleted if they were 30 percent greater or less than the maximum and minimum values used in the least squares determination. Moreover, data were weighted with respect to distance from grid intersects by $1/d^2$, where d is the distance of a data point from a grid intersect.

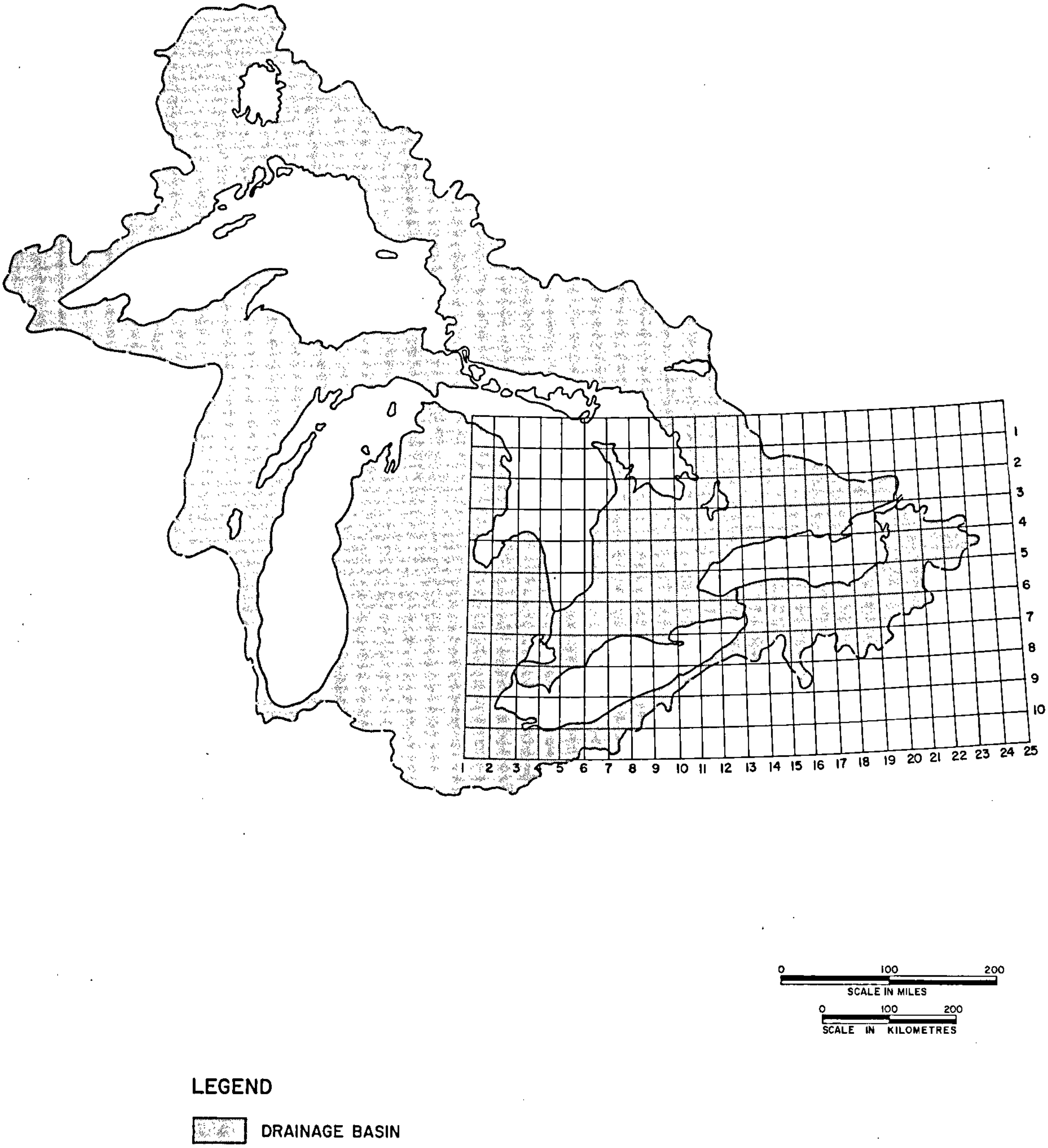
Various combinations of data were used to obtain different loading estimates for a parameter. The overall approach was to obtain minimal estimates which would be consistent with the majority of the data. Hence, when a few stations had averages far greater (about 1 – 2 orders of magnitude) than the other maximums these data were deleted. In addition, results for snow months were compared with results for the entire period. Unfortunately, incomplete sampling records throughout the year required the use of the average of the entire record most of the time. Table 3.4 summarizes that portion of the data file which was used to obtain estimates and compile contour maps of loading values.

Figures 3.3 (a) through 3.3 (l) are contour maps of loadings of the parameters. These maps were compiled using the criteria summarized in Table 3.3 and the contouring procedure discussed above. Stations from which data were available are shown on each map. Three general patterns are discernible for these loading maps:

(a) The loading decreases toward the north or northwest.

(b) The loading decreases toward the south or southeast.

(c) There is no overall trend, but high loadings are found coincident with some industrialized areas.



GRID SCALE USED FOR COMPUTATION
OF PRECIPITATION CHEMISTRY LOADING ESTIMATES

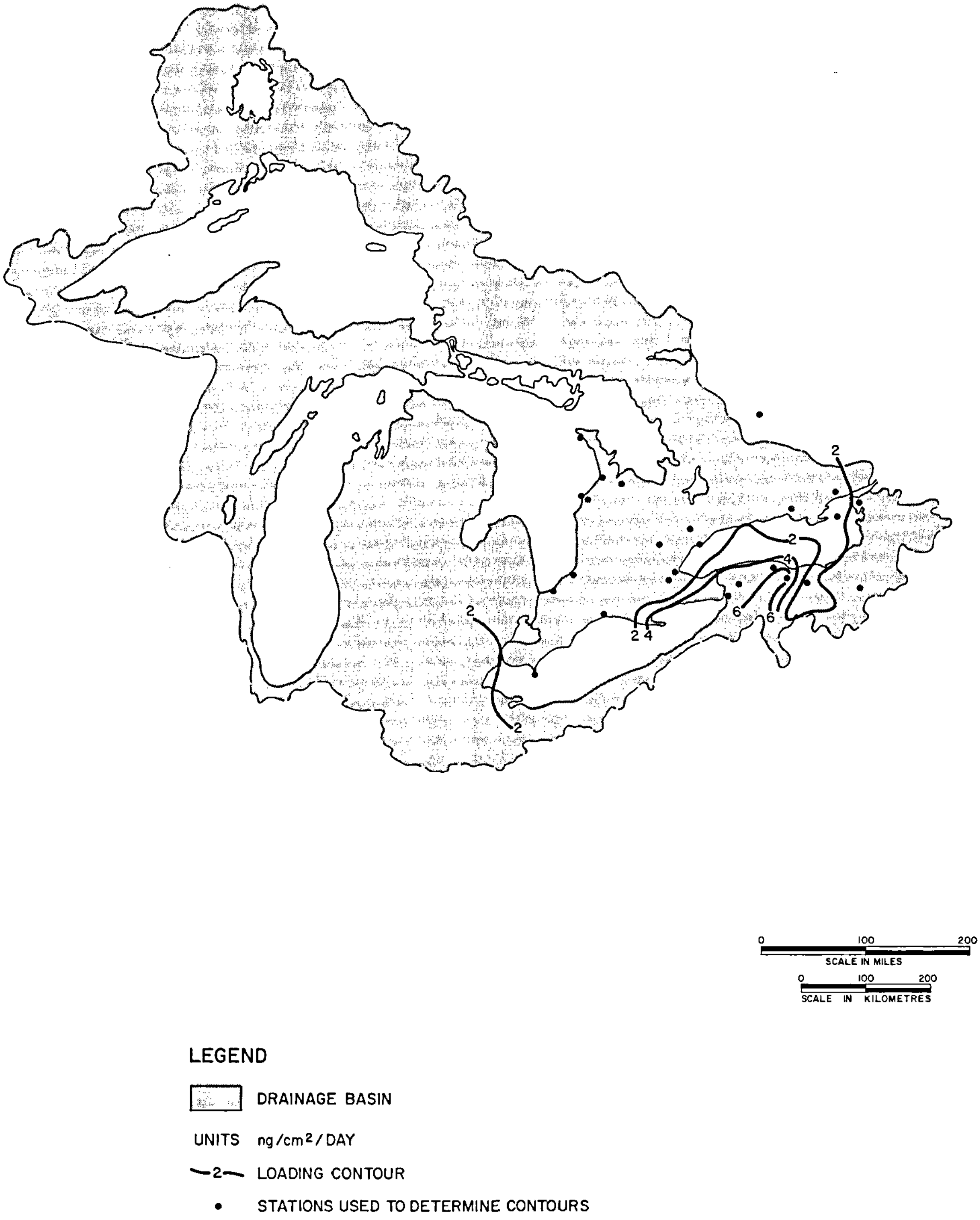
FIGURE 3.2

ATMOSPHERIC LOADING OF THE LOWER GREAT LAKES

TABLE 3.4

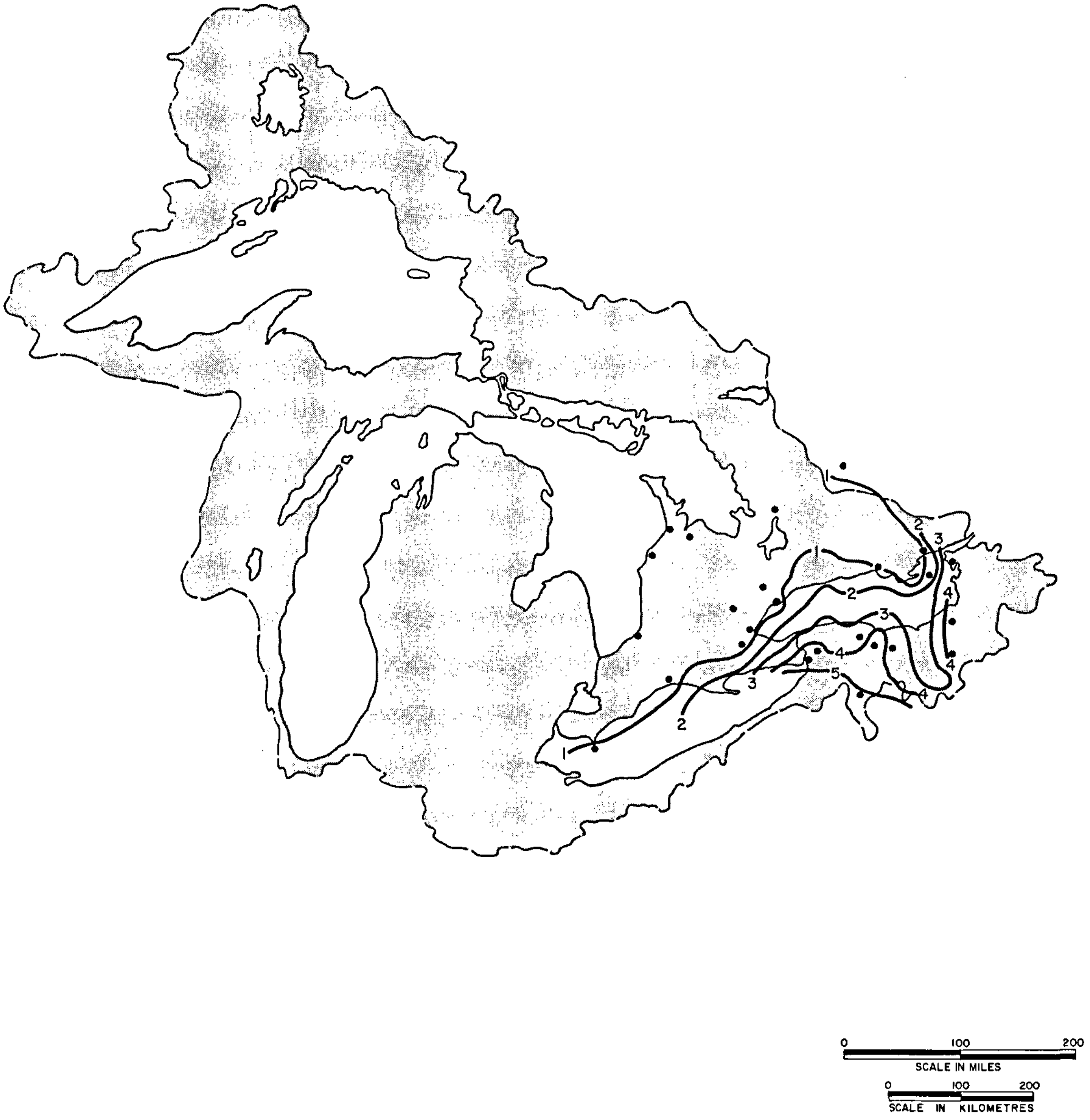
MODIFICATIONS MADE TO DATA TO OBTAIN CONSERVATIVE ESTIMATES OF ATMOSPHERIC DEPOSITION FROM FIELD DATA

Parameter	Acronym	Data Considered
101	Cd T	All data
107	Cu T	All data
110	Fe T	All data
113	Pb T	All data
116	Ni T	Minus all 200 series
127	SO_4	All data
222	Na F	All data
224	K F	All data
226	Mg F	All data
228	Ca F	All data
240	P T	Minus stations 167, 170
242	N T	All data



PRECIPITATION CHEMISTRY
CADMIUM LOADING 1973 - 1974

FIGURE 3.3(a)



LEGEND

▨ DRAINAGE BASIN

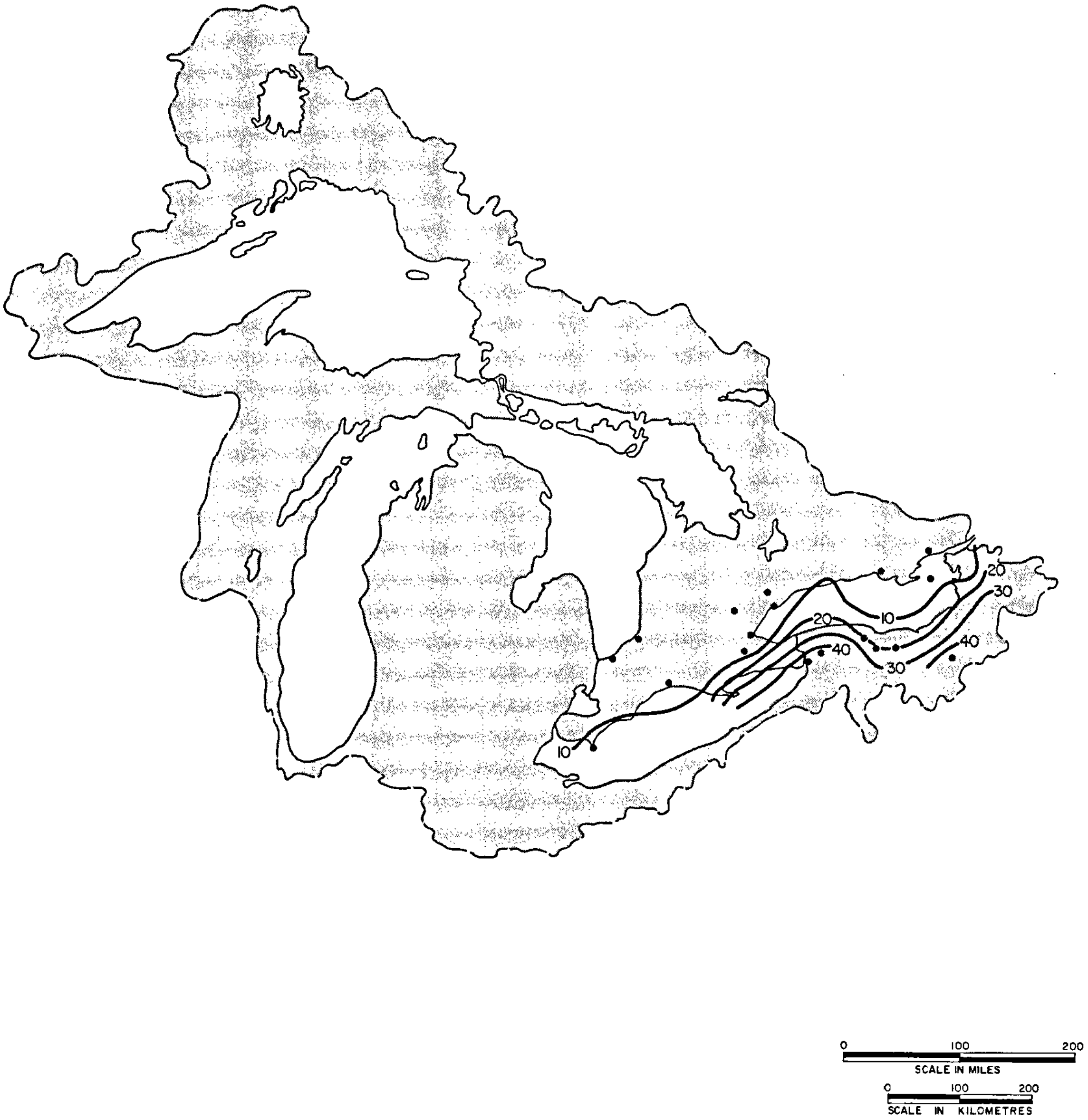
UNITS ng/cm^2/DAY

—1— LOADING CONTOUR

• STATIONS USED TO DETERMINE CONTOURS

PRECIPITATION CHEMISTRY
COPPER LOADING 1973-1974

FIGURE 3.3(b)



LEGEND

▨ DRAINAGE BASIN

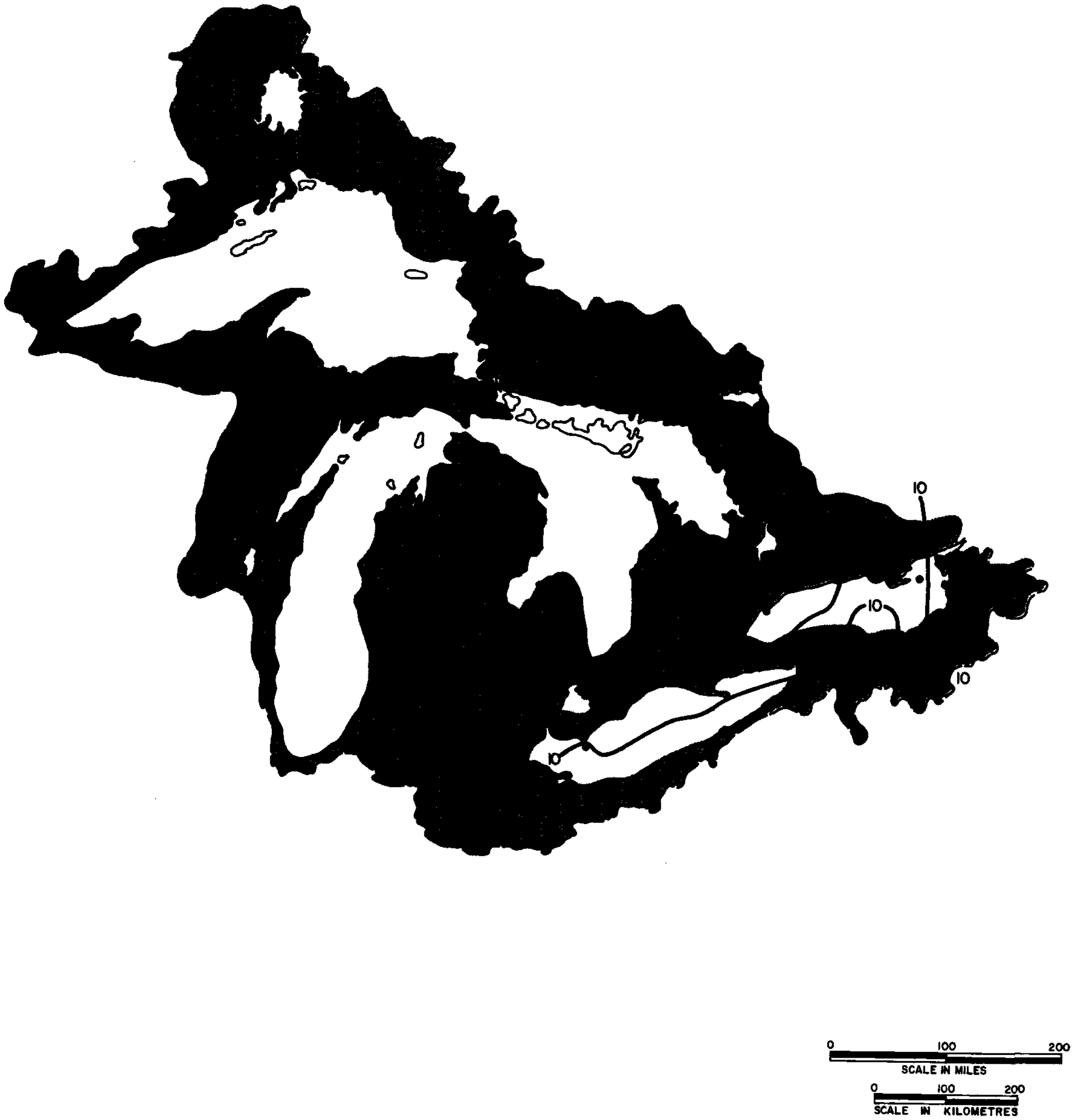
UNITS $ng/cm^2/DAY$

—10— LOADING CONTOUR

● STATIONS USED TO DETERMINE CONTOURS

PRECIPITATION CHEMISTRY
IRON LOADING 1973 - 1974

FIGURE 3.3 (c)



LEGEND

■ DRAINAGE BASIN

UNITS ng/cm²/DAY

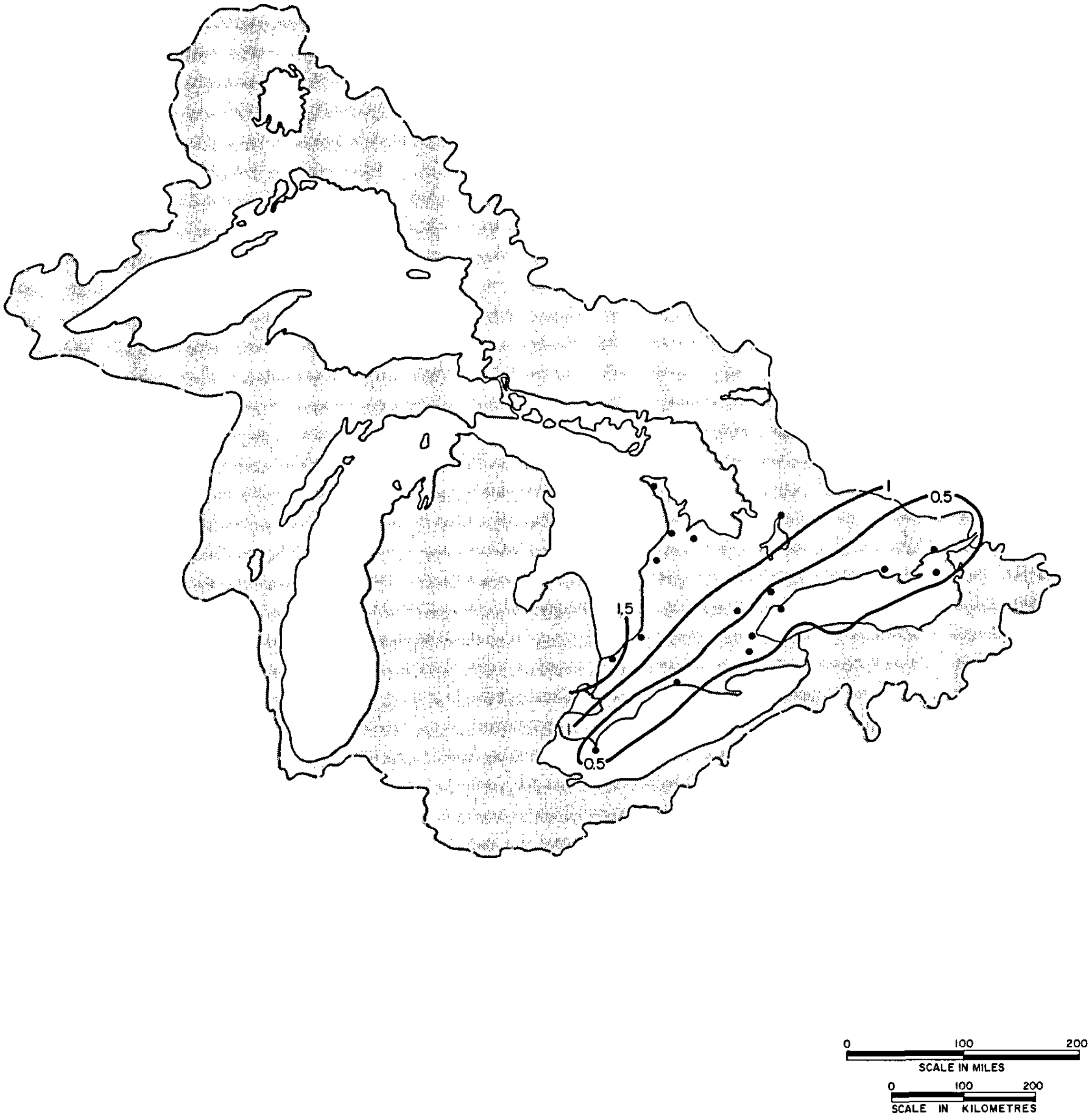
—10— LOADING CONTOUR

● STATIONS USED TO DETERMINE CONTOURS

PRECIPITATION CHEMISTRY
LEAD LOADING 1973 - 1974

FIGURE 3.3 (d)

ATMOSPHERIC LOADING OF THE LOWER GREAT LAKES



LEGEND

☐ DRAINAGE BASIN

UNITS ng/cm2 / DAY

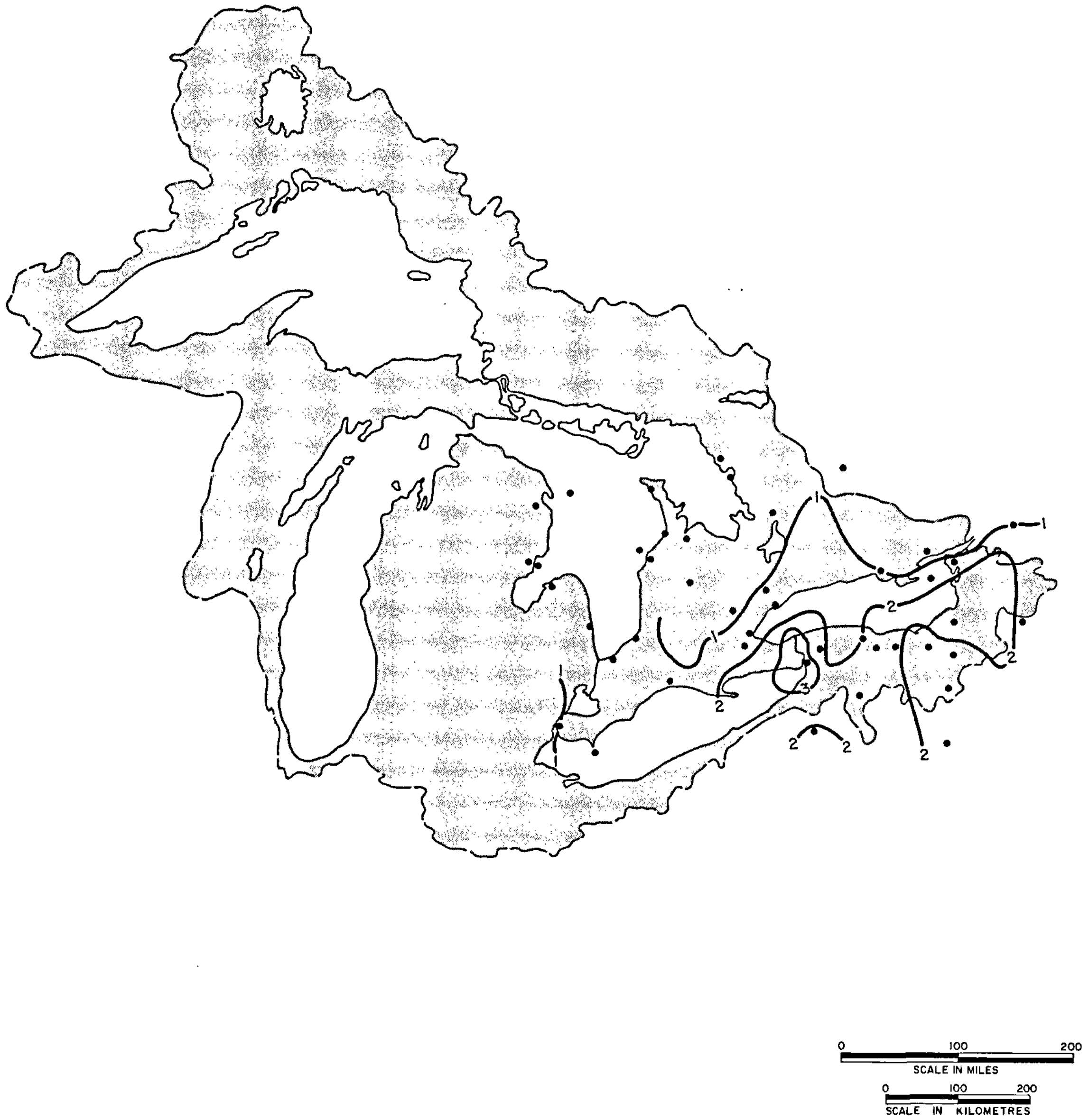
—1— LOADING CONTOUR

● STATIONS USED TO DETERMINE CONTOURS

PRECIPITATION CHEMISTRY
NICKEL LOADING 1973-1974

FIGURE 3.3(e)

ATMOSPHERIC LOADING OF THE LOWER GREAT LAKES



LEGEND

▒ DRAINAGE BASIN

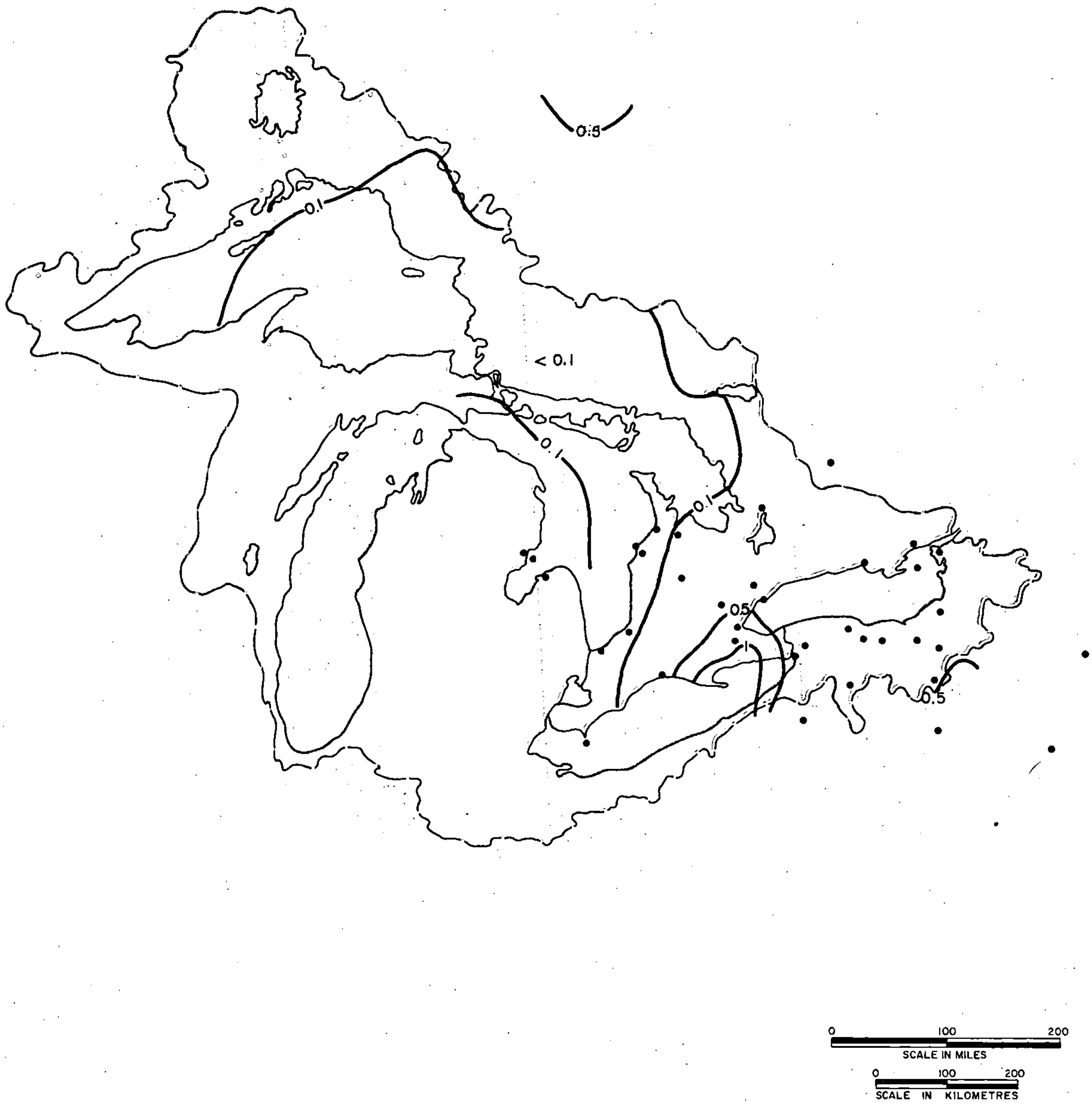
UNITS ug/cm^2/DAY

—2— LOADING CONTOUR

● STATIONS USED TO DETERMINE CONTOURS

PRECIPITATION CHEMISTRY
SULPHATE LOADING 1973 - 1974

FIGURE 3.3(f)



LEGEND

▭ DRAINAGE BASIN

UNITS ug/cm^2 / DAY

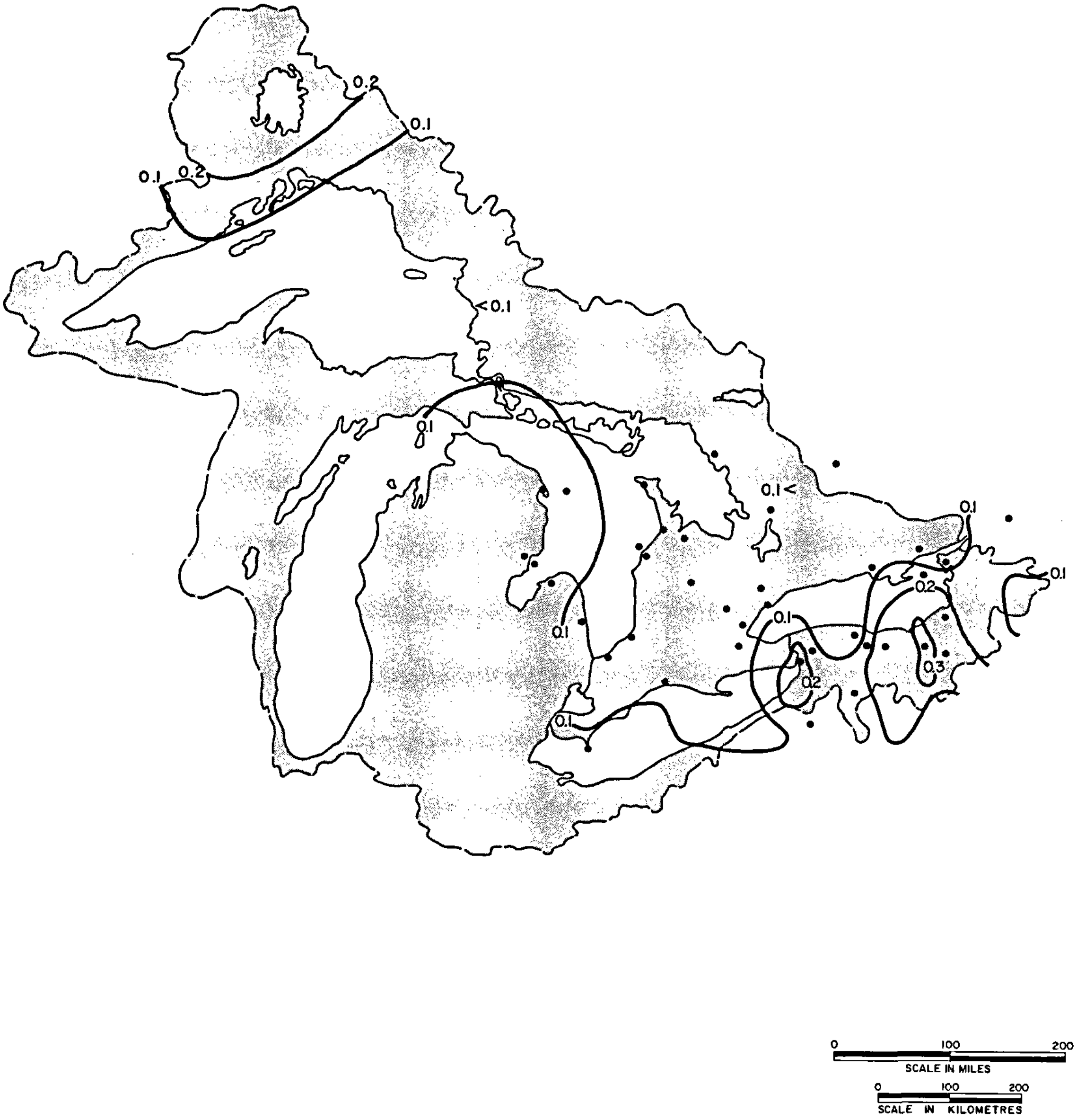
—1— LOADING CONTOUR

● STATIONS USED TO DETERMINE CONTOURS

PRECIPITATION CHEMISTRY
SODIUM LOADING 1973 - 1974

FIGURE 3.3(g)

ATMOSPHERIC LOADING OF THE LOWER GREAT LAKES



LEGEND

▨ DRAINAGE BASIN

UNITS ug/cm² / DAY

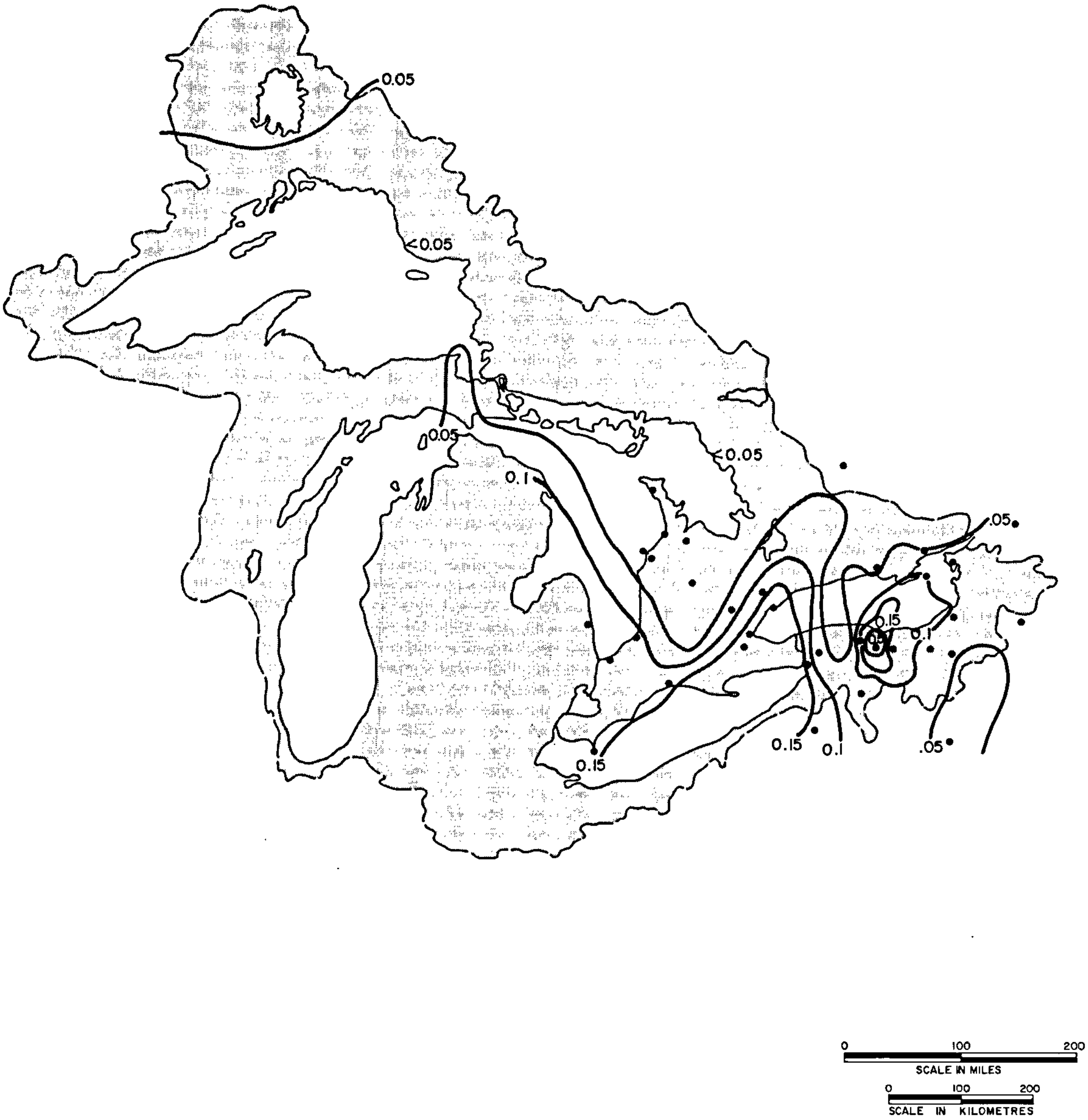
—0.1— LOADING CONTOUR

● STATIONS USED TO DETERMINE CONTOURS

PRECIPITATION CHEMISTRY
POTASSIUM LOADING 1973 - 1974

FIGURE 3.3(h)

ATMOSPHERIC LOADING OF THE LOWER GREAT LAKES



LEGEND

▨ DRAINAGE BASIN

UNITS ug/cm²/DAY

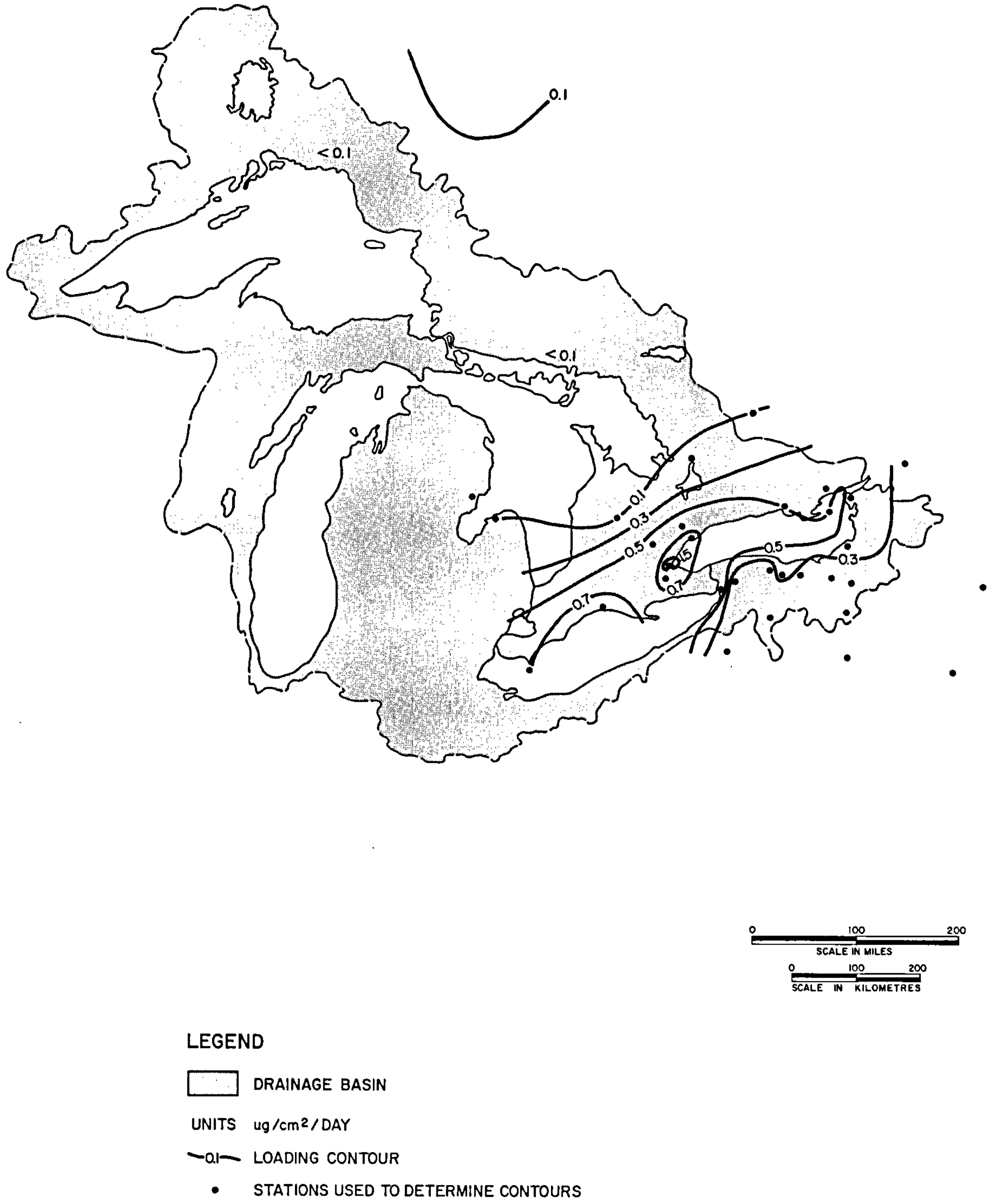
—0.1— LOADING CONTOUR

● STATIONS USED TO DETERMINE CONTOURS

PRECIPITATION CHEMISTRY
MAGNESIUM LOADING 1973 - 1974

FIGURE 3.3(i)

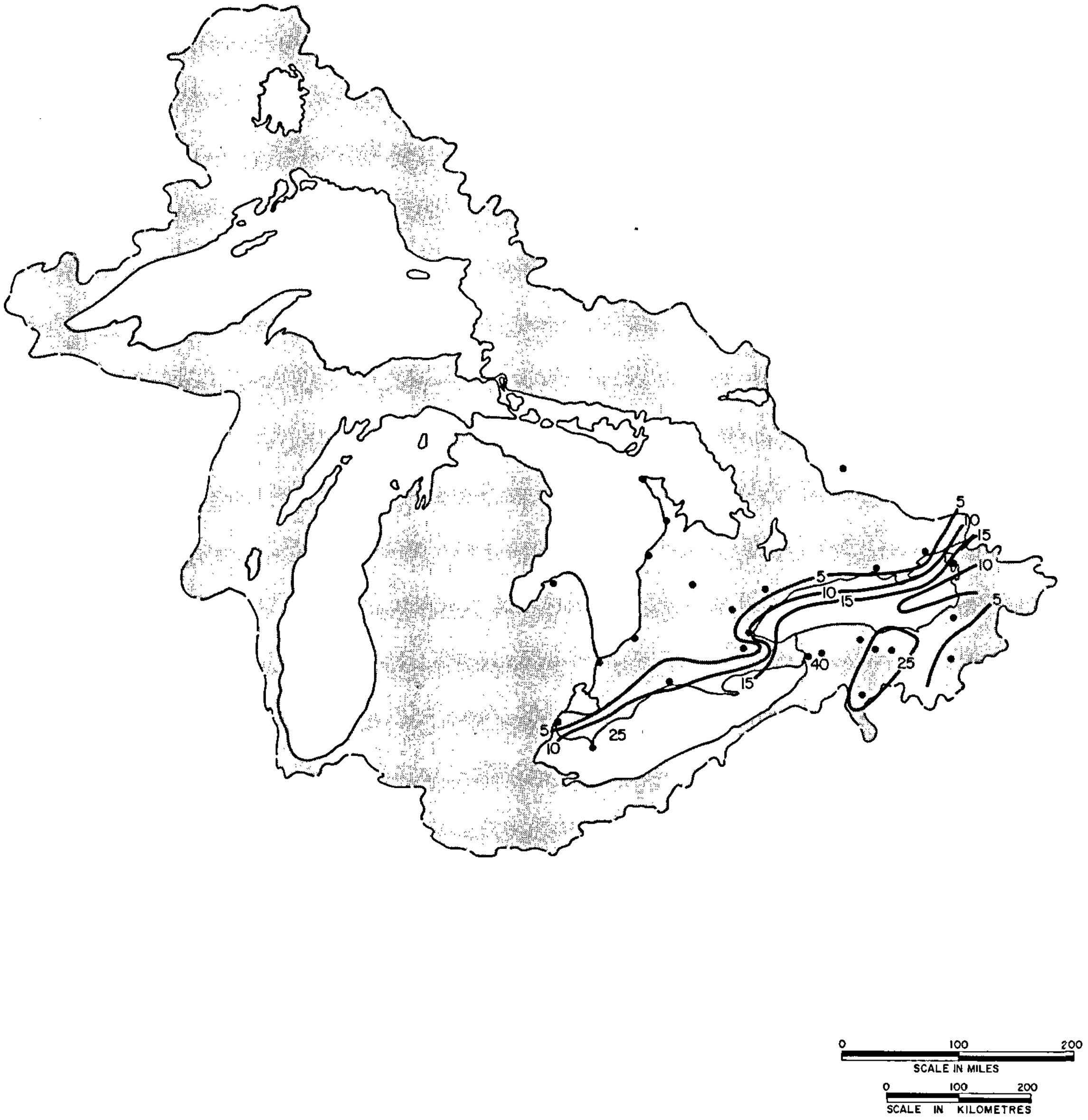
ATMOSPHERIC LOADING OF THE LOWER GREAT LAKES



PRECIPITATION CHEMISTRY
CALCIUM LOADING 1973 - 1974

FIGURE 3.3(j)

ATMOSPHERIC LOADING OF THE LOWER GREAT LAKES



LEGEND

▭ DRAINAGE BASIN

UNITS ng/cm^2/DAY

—5— LOADING CONTOUR

● STATIONS USED TO DETERMINE CONTOURS

PRECIPITATION CHEMISTRY
TOTAL PHOSPHORUS LOADING 1973-1974

FIGURE 3.3(k)

ATMOSPHERIC LOADING OF THE LOWER GREAT LAKES

LEGEND

▬ DRAINAGE BASIN

UNITS ug/cm^2/DAY

—0.1— LOADING CONTOUR

● STATIONS USED TO DETERMINE CONTOURS

PRECIPITATION CHEMISTRY
TOTAL NITROGEN LOADING 1973 - 1974

FIGURE 3.3(l)

ATMOSPHERIC LOADING OF THE LOWER GREAT LAKES

Cadmium [Figure 3.3 (a)], copper [Figure 3.3 (b)], iron [Figure 3.3 (c)], calcium [Figure 3.3 (j)], and phosphorus [Figure 3.3 (k)] fit into category (a), showing clear decreases in loading from south to north. Lead [Figure 3.3 (d)], sodium [Figure 3.3 (g)], potassium [Figure 3.3 (h)], magnesium [Figure 3.3 (i)], and nitrogen [Figure 3.3 (l)] also fit into category (a), but they show a less obvious trend. Nickel [Figure 3.3 (e)] alone fits into category (b), showing a decrease from northwest to southeast. Sulphate [Figure 3.3 (f)] is placed in category (c), showing no regional trend but a maximum in the Buffalo, New York area.

Loading estimates for Lake Ontario, Lake Erie, areas 21, 22, 16 and 17 are compiled in Table 3.5. These results are obtained from the product of the area and the average loading estimate. The average loading estimate is the geometric mean of all acceptable data from grid intersects (Figure 3.2) within the specified area. In some cases, data varied in no consistent manner; in others, only a few values were acceptable. These cases arise from poor data control, and have been noted in Table 3.5.

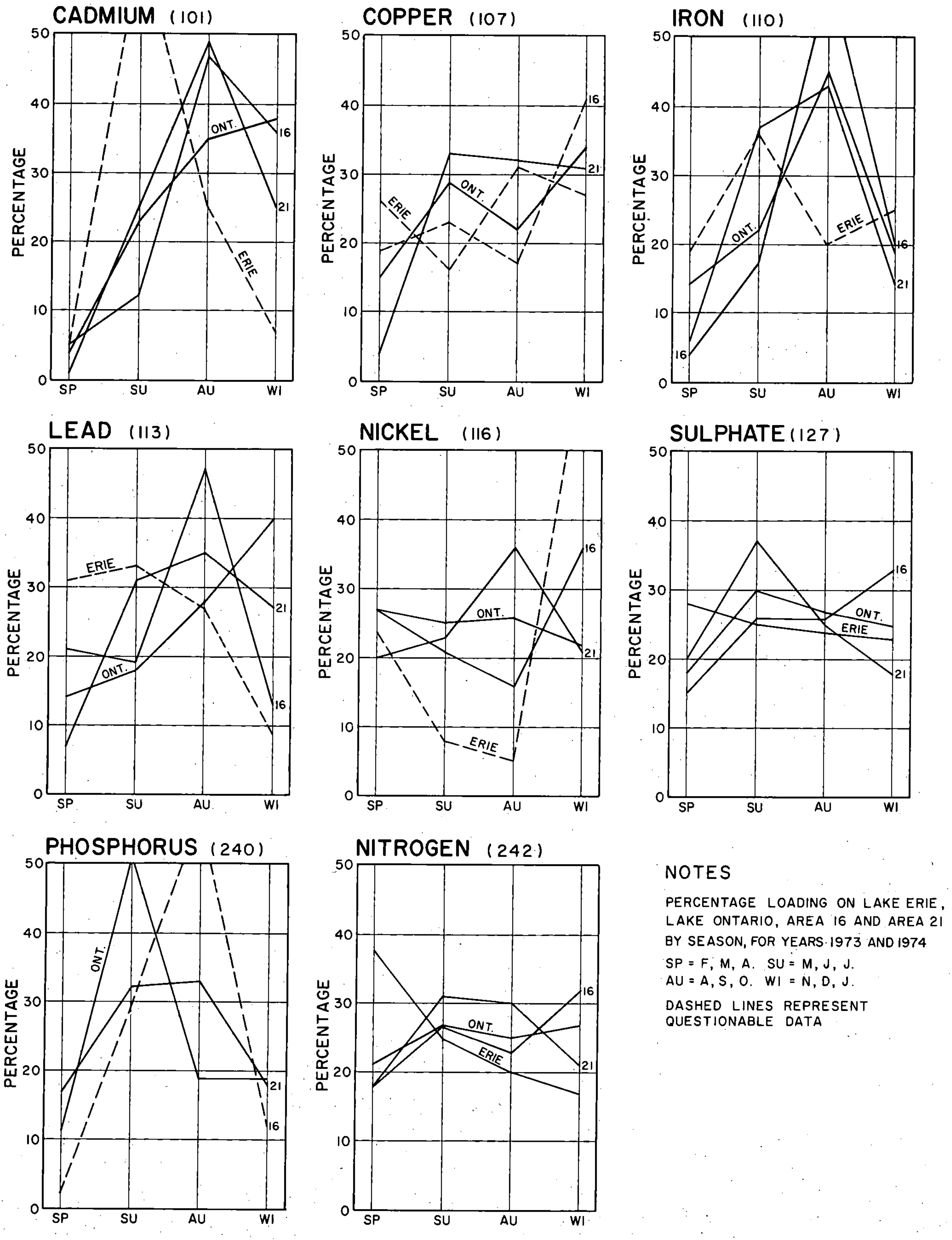
3.3 Trends in Data

Long-term and seasonal trends in the loading data were investigated. All of the data were compiled to investigate seasonal and longer-term patterns, whereas data from grid intersections of contour maps were compiled and compared as to seasonal patterns during 1973 and 1974.

The geometric mean for all data was compiled for each sampling period and plotted. All data were used, and no weighting of data points with respect to number of data was carried out. In addition, a linear least squares fit was forced onto the period averages in order to obtain the average longer-term trend. In some cases, data for the entire Great Lakes basin existed from 1972 to 1976 to establish the overall slope, whereas the seasonal patterns shown for 1973 and 1974 are based only on Lower Great Lakes data. Plots of these data are shown in Appendix 1.

Estimates of seasonal loading for Lakes Ontario and Erie, areas 16, 17, 21 and 22 were made by compiling average loadings for spring, summer, autumn and winter for all available data for 1973 and 1974. Matrices of loading estimates for grid intersections of the contouring routine were obtained for these seasonal categories and mean loadings were obtained. These are shown in Table 3.6 as percentages of the total loadings. They are also plotted on Figure 3.4 for cases where there were sufficient data to warrant inclusion for Lakes Erie and Ontario and areas 16 and 21.

Comparison of seasonal patterns for the study regions (Figure 3.4, Table 3.6) and seasonal trends for all the data are summarized in Table 3.7. In addition, the overall trend of the data established from a linear least squares fit is shown. The two sets of compilation of seasonal trends show good agreement. Cadmium, iron and phosphorus show maximums in summer and autumn; copper and sulphate show more subtle maximums in autumn, whereas lead shows a subtle maximum in winter for all the data and a subtle maximum in autumn for the study areas. Nickel and nitrogen show no seasonal patterns of loading. The slope of the least squares fit shows no overall change except for cadmium. It is quite probable that the decrease in cadmium is due to analytically questionable data from early years.



NOTES

PERCENTAGE LOADING ON LAKE ERIE, LAKE ONTARIO, AREA 16 AND AREA 21 BY SEASON, FOR YEARS 1973 AND 1974

SP = F, M, A. SU = M, J, J.
AU = A, S, O. WI = N, D, J.

DASHED LINES REPRESENT QUESTIONABLE DATA

SEASONAL LOADING VARIATIONS

FIGURE 3.4

ATMOSPHERIC LOADING OF THE LOWER GREAT LAKES

TABLE 3.5

BASIN LOADINGS FOR LAKE ONTARIO, LAKE ERIE AND AREAS 21, 22, 16 AND 17
(Where blanks occur, no acceptable data were available to make an estimate)

Code	Parameter	Lake Ontario	Lake Erie	21	22	16	17
			x 10^6 kg/yr				
127	Sulphate	88	120	110	34	45	25
242	Nitrogen	21	19	22	4.3	0.89	4.7
			x 10^3 kg/yr				
240	Phosphorus	480	800*	1,400	210	110	68
228	Calcium	32,000	23,000	37,000	3,600	24,000	7,000
226	Magnesium	4,100	6,600	7,300	890	3,300	1,500
222	Sodium	19,000	13,000	16,000	3,700	7,000	6,300
224	Potassium	3,300	22,000	4,700	1,900	3,600	5,300
101	Cadmium	45	150*	180*		13	50**
113	Lead	280	2,200*	280	260*	110	250*
116	Nickel	19	140*	13*	23**	10	20*
107	Copper	72	330*	130*	85	48	110**
110	Iron	530	5,900*	940*		220	4,200*

Note

Areas used were	$10^3 km^2$
Lake Ontario	19.5
Lake Erie	25.8
Area 21	14.8
Area 22	5.0
Area 16	8.8
Area 17	6.3

*Some questionable data or some problems in data control.

**Approximate value. Poor data control.

TABLE 3.6

SEASONAL LOADINGS FOR LAKE ONTARIO, LAKE ERIE AND AREAS 16, 17, 21 AND 22

Spring = Feb, Mar, Apr	Summer = May, June, July
Autumn = Aug, Sept, Oct	Winter = Nov, Dec, Jan

		Percentage of Total Loadings					
Parameter	Season	Lake Ontario	Lake Erie	16	17	21	22
101	Spring	4	5*	5	3**	1	4
Cadmium	Summer	23	63*	12	51**	25	8
	Autumn	35	25*	47	30**	49	38
	Winter	38	7*	36	16**	25	50
107	Spring	15	26*	19*	67*	4	
Copper	Summer	29	16*	23*	10*	33	
	Autumn	22	31*	17*	15*	32	
	Winter	34	27*	41*	8*	31	
110	Spring	14	19**	4	25**	6	
Iron	Summer	22	36**	17	26**	37	
	Autumn	45	20**	59	26**	43	
	Winter	19	25**	20	23	14	
113	Spring	14	31*	21	15**	7	14
Lead	Summer	18	33*	19	25**	31	28
	Autumn	28	27*	47	38**	35	26
	Winter	40	9*	13	22**	27	32
116	Spring	27	24**	27		20	
Nickel	Summer	25	8**	21		23	
	Autumn	26	5**	16		36	
	Winter	22	63**	36		21	
127	Spring	18	28	15	20	20	17
Sulphate	Summer	30	25	26	30	37	22
	Autumn	27	24	26	27	25	24
	Winter	25	23	33	23	18	37

TABLE 3.6 (Cont'd)

		Percentage of Total Loadings					
Parameter	Season	Lake Ontario	Lake Erie	16	17	21	22
240	Spring	11		2**		17	6*
Phosphorus	Summer	51		29**		32	66*
	Autumn	19		57**		33	13*
	Winter	19		12**		18	15*
242	Spring	21	38	18	28	18	27
Nitrogen	Summer	27	25	27	31	31	19
	Autumn	25	20	23	23	30	12
	Winter	27	17	32	18	21	42

*Some questionable data or some problems in data control.

**Approximate value. Poor data control.

TABLE 3.7

COMPARISON OF SEASONAL MAXIMUMS FOR STUDY AREAS (FIGURE 3.4) WITH ALL OF THE DATA (APPENDIX 1) THE SLOPE OF THE LINEAR LEAST SQUARES FIT TO ALL OF THE DATA IS ALSO SHOWN

	Maximum		
Parameter	From Figure 3.4	Appendix 1	Slope
Cadmium	Autumn	Autumn	Decrease
Copper	Autumn?	Variable	None
Iron	Summer-Autumn	Variable	None
Lead	Autumn?	Winter?	None
Nickel	None	None	None
Sulphate	None	Spring-Summer-Autumn	None
Phosphorus	Summer-Autumn	Summer-Autumn	None
Nitrogen	None	None	None

4 LOWER LAKES LOADING ESTIMATES

4 LOWER LAKES LOADING ESTIMATES

4.1 Comparison of Results

Table 4.1 summarizes the loading estimates made from the mathematical model for Lakes Michigan, Erie and Ontario compared with precipitation chemistry loading estimates for Lakes Erie and Ontario. Only model estimates are available for Lake Michigan with the exception of the total phosphorus loading (EPA, 1975).

In the Upper Great Lakes study (Acres–ESC 1975), comparison of mathematical model and precipitation chemistry loading estimates gave differences for sulphate and total phosphorus by a factor of 2 and for total nitrogen by a factor of 3. In this study, the differences are for sulphate and total nitrogen by a factor of 2 and for total phosphorus by a factor of about 4. These comparisons are consistent between the two studies except that estimates of total phosphorus loadings now differ by a factor of 4 instead of 2. It should be pointed out that in the Upper Great Lakes study phosphorus loadings estimated from precipitation chemistry were based for the most part on data for the nongrowing season, to minimize local contamination of the samples. In this study it was not possible to use that same procedure because all the available phosphorus data were required to make a statistically valid geometric average.

In the previous study, differences in the results from the two methods for some heavy metals were cadmium by a factor of 2, lead by a factor of less than 2, iron by a factor of just over 2, and nickel by a factor of 3. In this study, for Lake Ontario, differences for cadmium are a factor of 3, for lead a factor of 2, for iron a factor of 4, and for nickel a factor of 3. Except for iron, these differences are about the same as previously found. The comparison for iron loadings is now different by a factor of 4 instead of 2, and it is not apparent why this should be. It is noted that the relatively low iron loading rate estimated from precipitation chemistry data for Lake Ontario is markedly influenced by relatively low iron concentrations measured at the CCIW precipitation chemistry stations.

For Lake Erie, the comparison of heavy metal loading values calculated by the model with those calculated from precipitation chemistry data is considerably more erratic. As noted in the footnote to Table 3.5 and as commented on in the accompanying text, the reliability of the precipitation chemistry loading estimates for Lake Erie was restricted due to lack of data south of the lake. This same restriction applied to phosphorus loadings.

PARAMETERS	LAKE MICHIGAN	LAKE ERIE	LAKE ONTARIO
LAKE AREA 10^3 km^2	58.2	25.8	19.5

10^6 kg / YEAR

SO_4	MM	*330*	*270*	*120*
	PC	NA	*120*	*88*
N	MM	*42*	*29*	*14*
	PC	NA	*19*	*21*
PART.	MM	*56*	*41*	*21*
	PC	NA	NA	NA

10^3 kg / YEAR

TP	MM	350	190	110
	PC	1000*	800	480
Ca	MM	1800	1200	620
	PC	NA	23000	32000
Mg	MM	810	550	290
	PC	NA	6600	4100
Na	MM	500	370	190
	PC	NA	13000	19000
K	MM	1500	1100	550
	PC	NA	22000	3300
Cd	MM	*48*	*25*	*18*
	PC	NA	150	*45*
Pb	MM	*1100*	*650*	*440*
	PC	NA	2200	*280*
Ni	MM	71	50	51
	PC	NA	140	*19*
Cu	MM	55	32	21
	PC	NA	330	*72*
Fe	MM	*5500*	*4300*	*2100*
	PC	NA	5900	530

NOTE

MM - MATHEMATICAL MODEL
PC - PRECIPITATION CHEMISTRY
NA - NOT AVAILABLE
PREFERRED VALUE - eg *220*
WHEN BOTH VALUES OF A PAIR ARE MARKED PREFERRED, USE THE LARGER ONE TO BE CONSERVATIVE

* U.S. EPA 1975

LOADING ESTIMATES

TABLE 4.1

The large differences found between the two estimates for calcium, magnesium, sodium and potassium for the Upper Great Lakes again appear in this report for the Lower Great Lakes. The model estimates are consistently very low compared with the precipitation chemistry estimates; since these elements are common constituents of soil, entrainment of soil into the gauges and into the atmosphere as airborne particulates probably accounts for much of the difference. At the same time, there is available only limited information on which to base a breakdown of the percentage component of these elements in the total particulate emissions from the anthropogenic sources used in the model. Agricultural and natural sources or transport into the model region are not considered, both being possible significant sources of these materials.

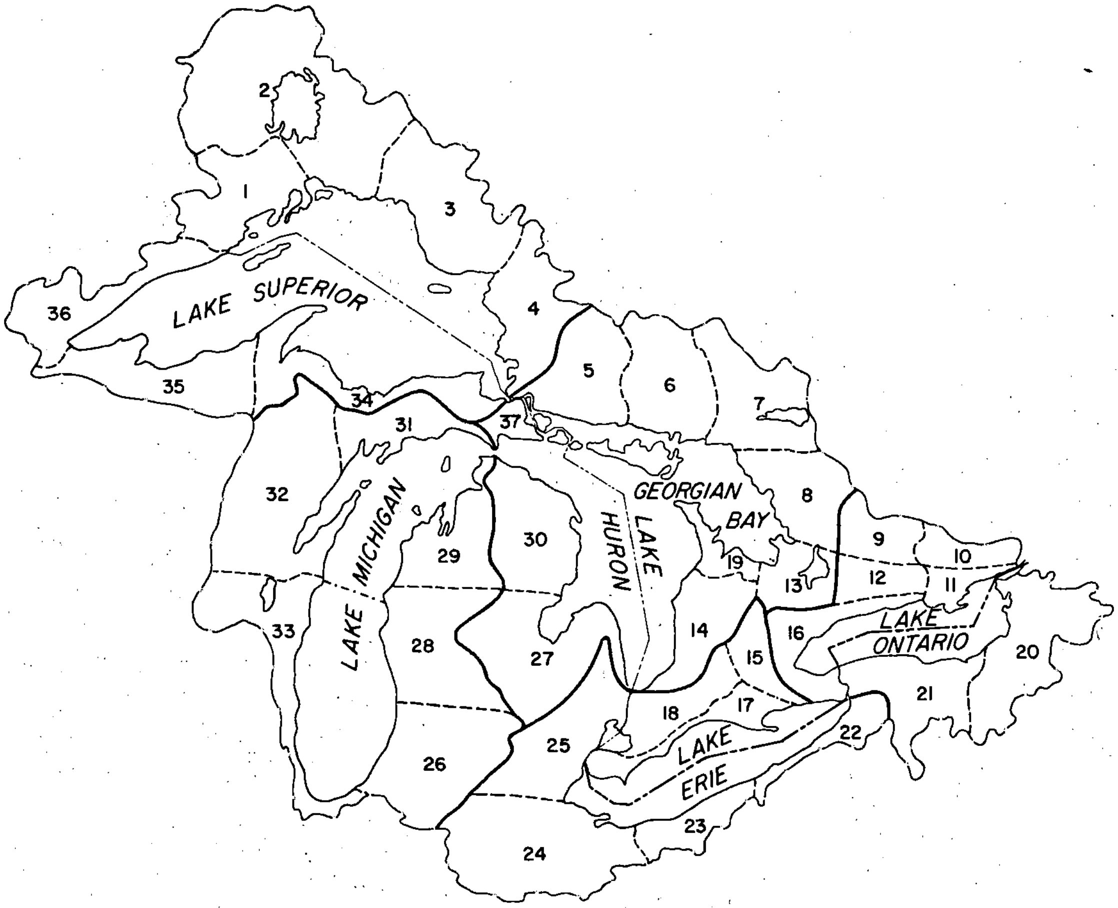
4.2 Drainage Basin Loading Estimates

The Great Lakes drainage basin has been divided into 37 subareas, as shown in Figure 4.1. Yearly loadings were calculated from the model for each of these subareas, using a Thiessen polygon weighting technique. These loadings, shown in Figure 4.1, have been calculated only for those parameters for which no large differences were found between the model and precipitation chemistry estimates. Since the model results seriously underestimate loadings of calcium, magnesium, sodium and potassium, no model estimates have been included for these parameters. Instead, the loading rate contours estimated from precipitation chemistry data in the Upper Great Lakes study have been added to the Lower Great Lakes contours in Figures 3.3 (g) to 3.3 (j) to provide data on drainage area loading rates for these parameters.

4.3 Transboundary Movement

Tables 4.2, 4.3 and 4.4 present the transboundary movement and loading of Lakes Michigan, Erie and Ontario for sulphates, total phosphorus and trace metals.

As would be expected, Lake Michigan loadings are dominated by the large American sources to the west and south of the lake. Chicago, Indiana—Cincinnati, St. Louis, Milwaukee, Illinois—Iowa and Green Bay together produce 66, 69 and 63 percent of the total loading of sulphates, total phosphorus and trace metals respectively. Canadian sources vary between a high of 10.6 percent in the case of sulphate, where the influence of Sudbury is felt, to a low of 3.1 percent for trace metals.



LOADING ZONE	10^3 km^2	10^6 kg/YEAR			10^3 kg/YEAR			
	AREA	SO_4	TOTAL N	PARTICULATES	TOTAL P	Cd	Pb	Fe
1	13.6	23	2	5	35	5	100	510
2	43.3	62	4	12	90	11	250	1200
3	20.5	49	3	8	53	7	150	830
4	15.1	57	4	9	57	7	170	930
5	14.3	69	5	11	62	8	200	1100
6	15.4	140	5	11	61	8	190	1100
7	18.2	130	6	14	75	10	240	1700
8	13.1	68	5	11	55	8	190	1700
9	7.1	27	3	5	26	4	88	660
10	5.3	25	3	5	26	4	99	990
11	3.2	21	2	4	19	3	74	740
12	5.3	29	3	5	25	4	9	900
13	7.9	45	4	7	35	5	120	1100
14	11.0	76	8	13	63	9	230	2000
15	6.8	50	5	8	39	5	130	1100
16	8.8	65	7	10	51	7	180	1600
17	6.3	60	7	9	44	6	150	1500
18	10.5	93	10	13	62	9	220	1800
19	4.1	26	2	4	19	3	66	470
20	17.4	90	10	17	100	16	370	3700
21	14.8	110	12	19	96	14	360	3600
22	5.0	51	5	8	39	5	140	1300
23	8.1	97	10	15	70	9	230	2300
24	23.6	180	21	32	160	21	530	4800
25	15.0	130	16	20	95	14	360	2200
26	23.2	160	20	28	150	21	510	2900
27	20.4	160	19	23	110	18	440	2400
28	21.3	130	16	23	120	17	430	2300
29	12.7	53	7	9	55	8	180	950
30	16.9	74	8	13	71	10	240	1300
31	9.0	31	4	7	41	6	130	680
32	32.1	100	13	20	140	18	390	2000
33	16.2	110	14	17	110	15	360	1700
34	12.7	35	4	8	48	6	150	780
35	13.6	27	3	6	38	5	110	550
36	17.6	29	3	6	51	6	130	620
37	2.7	11	1	2	13	2	44	230

DRAINAGE BASIN LOADINGS IN 1974

FIGURE 4.1

For Lake Erie, American sources contribute 89, 91 and 97 percent of the sulphate, total phosphorus and trace metals, respectively, with the largest contribution coming from Cleveland. The Sarnia and Sudbury sources are the largest Canadian contributors of sulphate; Toronto and Montreal contribute the most phosphorus and trace metals. Variations according to source region contributions between the American and Canadian portions of the lake are insignificant.

The Lake Ontario loadings result, to a much greater extent, from the general industrial activity in the study area as a whole, and are less dominated by specific sources. The Canadian sources contribute 27.5, 20.9 and 6.5 percent of the total loading of sulphate, total phosphorus and trace metals, respectively. Once again, the variations according to source region contributions between the American and Canadian portions of the lake is insignificant.

To obtain an estimate of the transboundary loadings of the 37 land drainage areas in the Great Lakes basin (Figure 4.1), the percentage contributions from American and Canadian sources can be taken as the percentage contributions to the closest lake area. The percentage contributions to the Upper Great Lakes are reproduced in Appendix 3 from the Acres–ESC 1975 report.

4.4 Loading Distribution of Polychlorinated Biphenyls

Substantial effort was made to obtain data on emissions of PCB's, both in Canada and the United States. Limited emission estimates by the Ontario Research Foundation were obtained for southern Ontario, but no specific data were available for the United States. Model calculations using emissions data were not possible, and it was decided to use population statistics for each major emission region as a rough indicator of possible PCB emission levels on a nonquantified basis. Population totals were compiled for each of the thirty regional sources used in the model from published population statistics for cities of 25,000 and over. Assuming these population figures are proportional to PCB emissions, the distribution pattern of PCB loadings shown in Figure 4.2 results.

P C B LOADING DISTRIBUTION BASED ON REGIONAL POPULATIONS FIGURE 4.2

ATMOSPHERIC LOADING OF THE LOWER GREAT LAKES

SOURCE	LAKE MICHIGAN		
	NORTH	SOUTH	TOTAL
CHICAGO	10.5	34.9	26.9
SAGINAW	7.5	3.2	4.7
DETROIT	4.4	2.9	3.4
GREEN BAY	10.5	3.0	5.5
DULUTH	.6	.2	.3
MINNEAPOLIS	1.9	1.3	1.5
WISCONSIN	2.1	.4	1.0
MILWAUKEE	5.3	8.9	7.8
ILLINOIS – IOWA	5.5	6.4	6.1
ST. LOUIS	8.1	9.7	8.8
INDIANA – CINCINNATI	8.7	12.5	11.1
MICHIGAN	2.8	.6	1.3
TOLEDO	2.4	1.2	1.6
CLEVELAND	2.3	2.0	2.1
OHIO	2.3	2.3	2.3
PITTSBURGH	4.5	3.4	3.8
PENNSYLVANIA	1.1	0.7	.9
WESTERN NEW YORK	.1	.1	.1
ROCHESTER	.1	.1	.1
BUFFALO	.1	<.1	.1
AMERICAN TOTAL	80.9	93.8	89.4
TORONTO	.9	.4	.6
SUDBURY	11.5	2.9	5.7
THUNDER BAY	.1	<.1	.1
SAULT ST. MARIE	.4	<.1	.1
MONTREAL	.1	.1	.1
SARNIA	1.6	1.6	1.6
NORTHERN ONTARIO	1.4	.3	.7
SOUTHERN ONTARIO	.3	.2	.2
NORANDA	2.1	.4	1.0
MANITOBA	.7	.3	.4
CANADIAN TOTAL	19.1	6.2	10.6
NOTE LOADINGS ARE PRESENTED AS PERCENTAGES OF THE FOLLOWING TOTAL LOADINGS (10^6 kg PER YEAR)	110	220	330

TRANSBOUNDARY LOADING OF SO_4

TABLE 4.2(a)

SOURCE	LAKE ERIE			LAKE ONTARIO			
	AMERICAN	CANADIAN	TOTAL	AMERICAN	CANADIAN	TOTAL	
CHICAGO	3.2	3.1	3.2	2.9	2.7	2.8	W
SAGINAW	3.8	3.7	3.8	2.8	2.9	2.9	W
DETROIT	10.9	10.8	10.8	5.7	6.1	5.9	SW
GREEN BAY - WISCONSIN	.4	.4	.4	.5	.5	.5	W
DULUTH *	.1	.1	.1	.1	.1	.1	W
MINNEAPOLIS	.4	.4	.4	.4	.4	.4	W
MILWAUKEE	.7	.6	.6	.7	.6	.7	W
ILLINOIS - IOWA	1.6	1.5	1.6	1.8	1.6	1.7	SW
ST. LOUIS	3.2	3.1	3.2	2.9	2.8	2.8	SW
INDIANA - CINCINNATI	5.5	5.2	5.4	3.5	3.3	3.4	SW
MICHIGAN	.4	.4	.4	.6	.5	.5	W
TOLEDO	5.9	5.3	5.7	1.8	1.8	1.8	SW
CLEVELAND	21.6	23.1	22.2	7.2	7.7	7.5	SW
OHIO	4.9	5.0	5.0	5.3	4.9	5.1	SW
PITTSBURGH	11.8	11.6	11.7	17.2	16.4	16.7	SW
PENNSYLVANIA	6.6	6.6	6.6	4.9	5.1	5.0	SW
WESTERN NEW YORK	.9	.8	.9	1.5	1.6	1.6	SW
ROCHESTER	.2	.2	.2	5.2	3.0	4.1	S
BUFFALO	.3	.3	.3	2.0	2.2	2.1	SW
ALBANY	.1	.1	.1	.7	.5	.6	SE
PHILADELPHIA	1.0	1.0	1.0	4.3	3.4	3.8	S
NEW YORK	.6	.6	.6	2.7	2.1	2.4	SE
BOSTON	<.1	<.1	<.1	.1	.1	.1	SE
AMERICAN TOTAL	84.1	83.9	84.1	74.8	70.4	72.5	
TORONTO	1.6	1.5	1.5	5.8	8.1	7.0	
SUDBURY	4.7	4.5	4.5	5.7	7.9	6.9	
THUNDER BAY *	.1	.1	.1	<.1	<.1	<.1	
EAST SUPERIOR	.2	.2	.2	.8	.5	.7	
MONTREAL	.2	.2	.2	1.1	.8	1.0	
SARNIA	7.2	7.9	7.4	3.5	3.9	3.7	
SOUTHERN ONTARIO	.9	.8	.9	5.5	6.2	5.7	
NORANDA	1.1	1.0	1.1	2.8	2.2	2.5	
CANADIAN TOTAL	15.9	16.1	15.9	25.2	29.6	27.5	

NOTE

LOADINGS ARE PRESENTED AS PERCENTAGES
OF THE FOLLOWING TOTAL LOADINGS
(10^6 kg PER YEAR) 147 123 270 57 63 120

* COMBINED AS SINGLE SOURCE FOR MODEL RUNS - THEN APPORTIONED FOR THIS TABLE

TRANSBOUNDARY LOADING OF SO_4

TABLE 4.2(b)

SOURCE	LAKE MICHIGAN		
	NORTH	SOUTH	TOTAL
CHICAGO	18.9	43.3	34.6
SAGINAW	3.2	1.4	2.1
DETROIT	3.5	2.2	2.7
GREEN BAY	10.7	3.7	6.2
DULUTH	3.4	1.6	2.3
MINNEAPOLIS	2.2	1.6	1.9
WISCONSIN	5.6	1.2	2.8
MILWAUKEE	6.8	8.1	7.6
ILLINOIS - IOWA	3.4	3.1	3.2
ST. LOUIS	5.7	6.6	6.3
INDIANA - CINCINNATI	9.4	12.2	11.1
MICHIGAN	4.6	.8	2.1
TOLEDO	3.2	1.7	2.2
CLEVELAND	2.5	2.3	2.4
OHIO	2.8	3.0	2.9
PITTSBURGH	1.4	1.2	1.3
PENNSYLVANIA	1.1	.8	.9
WESTERN NEW YORK	.2	.1	.1
ROCHESTER	.2	.2	.2
BUFFALO	.2	.3	.3
AMERICAN TOTAL	89.0	95.4	93.2
TORONTO	1.4	.8	1.0
SUDBURY	1.0	.3	.5
THUNDER BAY	.7	.2	.4
SAULT ST. MARIE	1.9	.2	.8
MONTREAL	.6	1.1	.9
SARNIA	<.1	<.1	<.1
NORTHERN ONTARIO	.2	<.1	<.1
SOUTHERN ONTARIO	.6	.3	.4
NORANDA	.4	.1	.2
MANITOBA	4.2	1.6	2.6
CANADIAN TOTAL	11.0	4.6	6.8
NOTE LOADINGS ARE PRESENTED AS PERCENTAGES OF THE FOLLOWING TOTAL LOADINGS (10^3 kg PER YEAR)	125	225	350

TRANSBOUNDARY LOADING OF TOTAL PHOSPHORUS

TABLE 4.3(a)

SOURCE	LAKE ERIE AMERICAN	LAKE ERIE CANADIAN	LAKE ERIE TOTAL	LAKE ONTARIO AMERICAN	LAKE ONTARIO CANADIAN	LAKE ONTARIO TOTAL	
CHICAGO	10.1	10.0	10.1	8.1	8.1	8.1	
SAGINAW	2.2	2.2	2.2	1.6	1.8	1.7	
DETROIT	6.8	6.7	6.7	4.9	4.9	4.9	
GREEN BAY - WISCONSIN	2.0	2.0	2.0	2.0	1.8	1.9	
DULUTH*	1.0	.9	.9	.9	.9	.9	
MINNEAPOLIS	1.0	.9	.9	.9	.9	.9	
MILWAUKEE	1.8	1.9	1.8	1.6	1.6	1.6	
ILLINOIS - IOWA	1.8	1.7	1.8	1.6	1.6	1.6	
ST. LOUIS	3.7	3.6	3.6	2.7	2.7	2.7	
INDIANA - CINCINNATI	8.6	8.7	8.6	5.0	5.2	5.1	
MICHIGAN	.7	.7	.7	1.1	1.1	1.1	
TOLEDO	6.9	6.4	6.6	2.9	3.0	3.0	
CLEVELAND	21.4	22.9	22.2	8.1	9.2	8.5	
OHIO	7.2	7.5	7.4	7.0	7.0	7.0	
PITTSBURGH	4.0	3.8	3.9	5.4	5.4	5.4	
PENNSYLVANIA	6.3	6.1	6.3	4.7	5.2	5.0	
WESTERN NEW YORK	.9	.9	.9	1.4	1.6	1.5	
ROCHESTER	.4	.5	.4	5.0	3.2	4.0	
BUFFALO	.9	.8	.8	4.7	5.2	5.0	
ALBANY	.5	.5	.5	1.8	1.3	1.5	
PHILADELPHIA	1.5	1.4	1.4	4.3	3.8	4.1	
NEW YORK	1.1	1.2	1.1	3.6	3.1	3.4	
BOSTON	<.1	<.1	<.1	.2	.2	.2	
AMERICAN TOTAL	90.8	91.3	90.8	79.5	78.8	79.1	
TORONTO	2.4	2.3	2.4	6.3	8.3	7.3	
SUDBURY	.6	.6	.6	.5	.7	.5	
THUNDER BAY*	.3	.2	.3	.4	.4	.4	Ont
EAST SUPERIOR	.2	.1	.2	.5	.4	.5	Ont
MONTREAL	3.9	3.9	3.9	11.2	9.0	10.0	
SARNIA	.4	.3	.4	.2	.2	.2	Ont
SOUTHERN ONTARIO	1.1	1.0	1.1	1.4	1.8	1.6	Ont
NORANDA	.3	.3	.3	.5	.4	.4	
CANADIAN TOTAL	9.2	8.7	9.2	20.5	21.2	20.9	
NOTE LOADINGS ARE PRESENTED AS PERCENTAGES OF THE FOLLOWING TOTAL LOADINGS (10^3 kg PER YEAR)	104	86	190	55	55	110	

* COMBINED AS SINGLE SOURCE FOR MODEL RUNS - THEN APPORTIONED FOR THIS TABLE

TRANSBOUNDARY LOADING OF TOTAL PHOSPHORUS

TABLE 4.3 (b)

SOURCE	LAKE MICHIGAN		
	NORTH	SOUTH	TOTAL
CHICAGO	12.7	31.1	24.5
SAGINAW	6.8	3.1	4.5
DETROIT	5.1	3.4	4.0
GREEN BAY	7.8	2.9	4.7
DULUTH	1.3	.6	.9
MINNEAPOLIS	2.3	1.7	1.9
WISCONSIN	2.4	.6	1.2
MILWAUKEE	5.1	6.5	5.9
ILLINOIS-IOWA	3.8	3.8	3.8
ST. LOUIS	7.6	9.3	8.6
INDIANA - CINCINNATI	12.2	16.7	15.2
MICHIGAN	7.1	1.4	3.5
TOLEDO	4.9	2.7	3.5
CLEVELAND	3.6	3.4	3.5
OHIO	4.9	5.5	5.3
PITTSBURGH	3.6	3.0	3.2
PENNSYLVANIA	2.3	1.8	2.0
WESTERN NEW YORK	.2	.3	.2
ROCHESTER	.3	.3	.3
BUFFALO	.3	.2	.2
AMERICAN TOTAL	94.3	98.3	96.9
TORONTO	.4	.3	.3
SUDBURY	.6	.1	.3
THUNDER BAY	.4	.1	.2
SAULT ST. MARIE	2.6	.3	1.2
MONTREAL	.1	.3	.2
SARNIA	.1	.1	.1
NORTHERN ONTARIO	.4	.1	.2
SOUTHERN ONTARIO	.5	.3	.3
NORANDA	.2	<.1	.1
MANITOBA	.4	.1	.2
CANADIAN TOTAL	5.7	1.7	3.1

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

	NORTH	SOUTH	TOTAL
(10^3 kg PER YEAR)	2500	4300	6800

CONSTITUENT	Fe	Pb	Ni	Cu	Cd
% OF TOTAL	80.9	16.6	1.0	.8	.7

TRANSBOUNDARY LOADING OF TRACE METALS

TABLE 4.4 (a)

SOURCE	LAKE ERIE			LAKE ONTARIO		
	AMERICAN	CANADIAN	TOTAL	AMERICAN	CANADIAN	TOTAL
CHICAGO	5.2	5.1	5.2	4.8	4.7	4.8
SAGINAW	3.6	3.6	3.6	2.9	3.1	3.1
DETROIT	7.5	7.2	7.3	5.9	6.4	6.2
GREEN BAY - WISCONSIN	.9	.9	.9	1.0	1.0	1.0
DULUTH*	.3	.3	.3	.4	.4	.4
MINNEAPOLIS	.7	.7	.7	.7	.7	.7
MILWAUKEE	1.1	1.0	1.0	1.1	1.1	1.1
ILLINOIS - IOWA	1.6	1.5	1.6	1.7	1.6	1.6
ST. LOUIS	3.7	3.6	3.6	2.9	3.0	3.0
INDIANA - CINCINNATI	8.6	8.5	8.6	5.5	5.8	5.7
MICHIGAN	.9	.9	.9	1.7	1.4	1.6
TOLEDO	7.9	7.4	7.8	3.9	4.1	4.0
CLEVELAND	23.3	24.6	23.8	9.9	11.1	10.5
OHIO	9.7	9.9	9.8	10.7	10.5	10.5
PITTSBURGH	7.4	7.3	7.4	11.4	11.3	11.3
PENNSYLVANIA	9.9	9.9	9.9	8.5	9.2	8.9
WESTERN NEW YORK	1.3	1.3	1.3	2.3	2.6	2.4
ROCHESTER	.4	.4	.4	5.8	3.6	4.7
BUFFALO	.6	.6	.6	3.7	4.2	3.9
ALBANY	.1	.1	.1	.5	.4	.4
PHILADELPHIA	1.5	1.4	1.4	4.8	4.2	4.5
NEW YORK	.9	.9	.9	3.3	2.8	3.0
BOSTON	<.1	<.1	<.1	.2	.2	.2
AMERICAN TOTAL	97.1	97.1	97.1	93.6	93.4	93.5
TORONTO	.5	.5	.5	1.6	2.1	1.9
SUDBURY	.3	.3	.3	.2	.3	.3
THUNDER BAY*	.1	.1	.1	.1	.1	.1
EAST SUPERIOR	.2	.2	.2	.8	.5	.6
MONTREAL	.7	.7	.7	2.3	1.9	2.1
SARNIA	.3	.3	.3	.2	.2	.2
SOUTHERN ONTARIO	.7	.7	.7	1.0	1.3	1.1
NORANDA	.1	.1	.1	.2	.2	.2
CANADIAN TOTAL	2.9	2.9	2.9	6.4	6.6	6.5
NOTE: LOADINGS ARE PRESENTED AS PERCENTAGES OF THE FOLLOWING TOTAL LOADINGS (10^3 kg PER YEAR)	2700	2300	5000	1300	1300	2600

CONSTITUENT	Fe	Pb	Ni	Cu	Cd
% OF TOTAL	83.2	14.2	1.3	.7	.6

* COMBINED AS SINGLE SOURCE FOR MODEL RUNS - THEN APPORTIONED FOR THIS TABLE

TRANSBOUNDARY LOADING OF TRACE METALS

TABLE 4.4(b)

5 PROJECTIONS TO THE YEAR 2000

5 PROJECTIONS TO THE YEAR 2000

5.1 Industrial Growth Rates

The happenings of the last 4 years have made energy demand forecasting difficult in both Canada and the United States. The potential for massive intervention of government in the energy situation, the problem of large price increases for energy, and the impact of environmental restrictions have created doubts as to the validity of the indicators traditionally used in projecting patterns of energy consumption.

At least through 1985, however, Canada and the United States are basically committed to present patterns of energy consumption because of the long time lags involved in changing our industrial system, our transportation system, and ultimately our way of life. After 1985, options can be developed which will allow the altering of present energy consumption patterns. Successful development of those options will demand new technologies in the supply and use of energy sources, new emission control methods, and heightened awareness and practice of energy conservation. Meanwhile, it is necessary to forecast economic developments based on the best information available.

The summary of annual growth rates presented in Table 5.1 is based on many references and reflects the best judgments of its participants. A principal reference has been the document *United States Energy Through the Year 2000* (revised) published in December 1975 by the U.S. Bureau of Mines, Department of the Interior, and coauthored by Walter G. Dupree, Jr. and John S. Corsentino. Mr. Dupree was contacted personally and provided new insights to that document which have been incorporated into our projections.

Table 5.1 summarizes the annual growth rates to year 2000 in fuel consumption as discussed in Subsubsection 5.1.1, as well as growth rates for transportation, incineration and for those industrial processes that are major sources of air pollutant emissions, i.e. production of primary metals, mineral products and petroleum. These categories combined account for about 90 percent of total emissions in most of the regional emission sources shown in Figure 2.2 and are discussed in Subsubsection 5.1.2.

In the tables to follow, units have been converted to SI but are consistent with the above reference documents.

TABLE 5.1

PERCENT ANNUAL GROWTH RATES TO THE YEAR 2000

	United States	Canada (Ontario)
Fuel Consumption		
Coal	3.8	3.8
Petroleum	1.6	1.6
Natural gas	-.5	-.5
Industrial Production		
Primary metals	3.0	4.0
Mineral products	4.5	4.5
Petroleum	1.6	1.6
Transportation Fuel	2.2	2.5
Incineration of Waste	.9	1.5

5.1.1 Fuel Consumption

The forecast growth rates for the United States fuel consumption are based on the Bureau of Mines document updated by Mr. Dupree's comments. The gross energy consumption is forecast to grow from 73,121 x 10^{12} Btu in 1974 to 163,430 x 10^{12} Btu in 2000. The portion that is obtained from coal, petroleum and natural gas is displayed in Table 5.2. The same growth rates in the consumption of these fuels have been assumed for Canada.

As a percentage of the total energy consumption, these fuels will reduce from 94.2 in 1974 to 64.6 in 2000, with natural gas reducing from 30.4 percent to 12.0 percent, petroleum reducing from 45.8 to 31.3 percent, and coal increasing from 18.0 to 21.3 percent.

The Bureau of Mines original forecast for the year 2000 expected that the total installed electrical generating capacity of 1,887,000 Mw would include 900,000 Mw of nuclear-fueled plants. Most recently, the nuclear capacity in year 2000 is seen to be only 650,000 Mw. The difference, if demand in the electrical energy sector achieves the total forecast, must be made up by fossil-fueled plants—much of which will be coal fired. However, in making the atmospheric loading projections the earlier estimate of nuclear energy growth was used.

5.1.2 Industrial Processes

The forecast growth rate for production of primary metals and mineral products in the United States was obtained by extrapolating data in the United States Department of Commerce, *Statistical Abstract of the United States, 1975*. Production levels have varied widely over the past 20 years as a function of general economic activity and correlate fairly closely to the forecast of general economic growth in the United States. The annual growth rates are 3.0 percent and 4.5 percent respectively.

In Canada, annual growth rates of 4.0 percent for primary metals production and 4.5 percent for mineral products have been used. The growth rate for primary metals was arrived at following discussions on data available at CCIW which suggest a higher growth rate than that in the United States. Production of Canadian mineral products is expected to follow the United States.

TABLE 5.2

UNITED STATES FUEL CONSUMPTION PRESENT AND PROJECTED (10^{12}Btu)

	Coal	Petroleum	Natural Gas
1974			
Household and commercial	291	6,390	7,116
Industrial	4,208	6,044	11,129
Transportation	2	17,608	664
Electric generation	8,668	3,448	3,328
Synthetic gas	–	–	–
Synthetic liquids	–	–	–
TOTALS	13,169	33,490	22,237
2000			
Household and commercial	–	7,960	9,000
Industrial	5,910	10,370	9,000
Transportation	–	28,170	600
Electric generation	20,700	4,700	1,000
Synthetic gas	6,000	–	–
Synthetic liquids	2,140	–	–
TOTALS	34,750	51,200	19,600
Annual growth rate (percent)	3.8	1.6	-.5

Data from Dupree and Corsentino, 1975

The 1.6 percent anuual growth in the petroleum industry has been based on the total United States petroleum consumption indicated in Table 5.2, which was assumed to apply equally in Canada.

5.1.3 Transportation

Table 5.3 from the Bureau of Mines study shows that energy input to the United States transportation sector would increase at a 2.2 percent annual rate, and that the petroleum share of the market would increase from 96.3 percent to 97.8 percent. Meanwhile, the transportation energy consumption as a percentage of gross energy consumption would fall from 25.0 percent to 19.7 percent.

Although the 2.2 percent growth may be high because of recently legislated mileage standards for the United States auto fleet entering service by the 1980's, it does incorporate an overall trend to the use of smaller and more efficient automobiles.

Given the higher population annual growth rate forecast in Canada (see Subsubsection 5.1.4), the growth in energy consumption by the transportation sector was assumed to exceed that of the United States, viz, 2.5 percent versus 2.2 percent.

5.1.4 Incineration

The Bureau of Mines forecast of annual population growth rate is 0.9 percent for the entire United States. Based on data available at CCIW on population projections in the Great Lakes basin, this rate was adjusted to 0.8 percent. The 1.3 percent forecast of annual Canadian population growth was based on the Statistics Canada *Population Projection B* and the Government of Ontario Provincial Planning Document (TEIGA 1976). This, combined with studies by CCIW, indicates a 1.4 percent growth rate in the Canadian portion of the Great Lakes basin.

The growth in incineration was assumed to follow population growth in both the United States and Canada. A factor of 0.1 percent was then added to reflect current trends to greater yields of refuse per individual in the population and trends to increased refuse burning in urban areas. This forecast is very sensitive to achievements in conservation and recycling of materials.

TABLE 5.3

TRANSPORTATION SECTOR

	1974	2000	Annual Growth (percent)
Liquid Hydrocarbons*			
10^6 bbl	3,274.7	5,708	2.2
Percentage of total energy	96.3	97.8	
Natural Gas			
10^9 cf	650	580	-.4
Percentage of total energy	3.6	1.9	
Electricity Purchases			
10^9 kwh	3	28	9.0
Percentage of total energy	0.6	0.3	
Total sector energy inputs (10^{12} Btu)	18,290	32,200	2.2
Percentage of national total	25.0	19.7	

*Includes all synthetics from tar sands, shale, coal, etc.

5.2 Sulphur Oxides – Control Technology

Sulphur oxides are formed during combustion of sulphur-containing fuels, by industrial processing of minerals, ores or other sulphur-bearing raw materials and by natural discharges such as volcanic action. By far the largest amount is generated by combustion processes as SO_2.

In recent years there has been a trend to reduction of SO_2 emissions by use of low-sulphur fuels including natural gas, light oils, selected residual oils, as well as low-sulphur coals.

Because of the concern over available reserves of liquid fuels and natural gas, it is expected that many future large combustion sources will use coal, and that some existing plants will convert to coal. This trend is apparent in the fuel consumption growth rates shown in Table 5.2.

Surveys conducted by EPA (Ponder, 1976) indicate that only about 50 percent of the coals used in utility type combustion systems are of the low-sulphur type. In addition to fuel economics, other factors mitigate against the use of low-sulphur coal, such as

- low heat value of the coal
- increased hardness requiring a different approach to milling
- different requirements of combustion volume and heat release within the furnace
- high ash content.

It can be expected, therefore, that the growth in demand for electrical energy to the year 2000 will increasingly be met by coal-fired steam electric generating stations, utilizing a range of sulphur content coals. It is anticipated that by 1980 less than 50 percent of all coal used will be of the low-sulphur type. This in turn will require removal of sulphur either from the fuel or combustion gases in an effort to maintain ambient air quality standards.

A variety of approaches to SO_2 emissions control has been investigated and are still being developed. The most common are

- physical cleaning of coal
- flue gas cleaning
- coal gasification
- coal liquefaction
- liquidized bed combustion.

Physical cleaning of coal removes only pyrites, at best representing 60 to 75 percent of the sulphur content. The remaining sulphur is in organic form and requires chemical processing.

Flue gas cleaning systems historically have had high operating costs and high maintenance requirements, although some improvements have been made during the past decade, resulting in a number of systems in the pilot plant stage at present. It is expected that existing pilot plants will be available for commercial testing by 1980 and for full-scale application by 1986. Systems at present being developed include

- limestone injection with a sulphur collection efficiency of 40 to 60 percent
- limestone injection followed by wet scrubbing with a sulphur collection efficiency of 80 to 90 percent
- alkalized alumina sorption with a sulphur collection efficiency of approximately 90 percent
- catalytic oxidation with a sulphur collection efficiency of approximately 90 percent.

Coal gasification has reached commercial feasibility. A number of plants are in operation with sulphur removal efficiency of approximately 95 percent, but much larger plants would be required to meet a significant portion of the energy demand with this fuel.

Coal liquefaction under development at present might be expected to reach commercial feasibility by 1986.

Fluidized bed combustion systems at present offer the most economical approach to SO_2 emissions control for new installations. Pilot plant operations are under study with full-scale testing anticipated by 1980. This would likely provide a commercial system by 1986.

Other means of SO_2 emissions control include selective blending of liquid fuels. The more economically priced residual oils normally contain an average of 2 percent sulphur. Blending with oil from low-sulphur wells or light distillates will lower that concentration, although at increased cost.

Without prejudging which approach(es) may ultimately be adopted, we have postulated for purposes of model illustration that a 50 percent reduction in SO_2 emissions will be achieved in 1985 by retrofitting all plants in service at that time, and that an 80 percent reduction will be achieved for all new sources installed between 1986 and 2000.

5.3 Projected Growth of SO_2 and Particulates

The following procedures were used for estimating the emissions to the atmosphere of SO_2 and particulates in the year 2000 as input to the mathematical model. Three specific situations were considered.

Case I Projected increases in emissions assuming no full-scale SO_2 controls.

Case II Projected increases in emissions assuming full-scale SO_2 controls.

Case III Projected increases in emissions assuming that all electric generation after 1985 will result from coal-fired plants. SO_2 controls are the same as Case II.

5.3.1 Case I – No Removal of SO_2

As indicated in the Upper Great Lakes report, Acres–ESC 1975, the emission data for each air quality region are subdivided into fuel combustion, industrial processes, transportation and solid wastes (incineration) emissions. These in turn were grouped into large area source regions incorporating as many as seven air quality control regions (AQCR). The total emissions in the year 2000 are calculated by multiplying the 1974 emissions in each category by the appropriate growth factor determined from the annual growth rates previously presented in Table 5.1.

$$\text{Emission (2000)} = \left(1 + \frac{GR}{100}\right)^{26} \times \text{Emission (1974)}$$

Where GR is the growth rate from Table 5.1.

This procedure has been illustrated in Table 5.4 for the Chicago area source.

The industrial process category consists of many industries, each exhibiting a different growth rate. However, of these, the primary metals, mineral products and petroleum industries produce the majority of the atmospheric emissions of SO_2 and particulates. In the case of Chicago, 80 percent of the SO_2 and over 90 percent of the particulates emitted from all industrial processes come from these three categories. The growth factor indicated in Table 5.4 for industrial processes is based on a weighted average of the growth rates for these three industries as illustrated in Table 5.5.

The only exceptions to the procedure described above are the single industrial sources of Wawa and Noranda which were assumed to remain constant through to the year 2000. It was assumed that the Sudbury sources will comply with Ontario Ministry of the Environment Amending Control Orders and that the SO_2 emissions will decrease to approximately 30 percent of the 1974 level.

5.3.2 Case II – SO_2 Removal

The following assumptions concerning the level of SO_2 controls to the year 2000 have been based on the conclusions presented in Subsection 5.2.

(a) Control technology will apply only to that portion of emissions resulting from industrial processes and the combustion of coal and petroleum.

(b) All growth to the year 1985 will be retrofitted with control equipment having a 50 percent recovery efficiency.

(c) All new installations after 1985 will be fitted with new control equipment having an 80 percent recovery efficiency.

TABLE 5.4

EMISSION BREAKDOWN FOR THE SOURCE REGION OF CHICAGO
(10^3 tons per year)

	Air Quality Control Regions					1974	Growth Factor	2000
	67	71	73	81	82			
SO_2								
Fuel Combustion								
Coal	693.0	18.1	53.9	18.8	151.6	935.4	(2.64)	2,469.5
Petroleum	137.6	1.2	2.8	3.5	6.5	151.6	(1.53)	231.9
Natural gas	1.9	0.0	0.0	0.0	0.0	1.9	(.88)	1.7
Industrial processes	137.6	7.8	0.0	0.0	0.0	145.4	(1.73)*	251.5
Transportation	19.2	0.7	1.4	1.5	3.0	25.8	(1.76)	45.4
Solid wastes (Incineration)	3.9	0.1	0.2	0.1	0.2	4.5	(1.26)	5.7
Source Totals						1,264.6		3,005.7
Particulate								
Fuel Combustion								
Coal	126.7	5.8	14.9	10.8	54.2	212.4	(2.64)	560.7
Petroleum	13.0	0.3	0.6	0.8	1.3	16.0	(1.53)	24.5
Natural gas	4.1	0.1	0.3	0.2	0.3	5.0	(.88)	4.4
Industrial processes	258.9	33.0	3.7	21.6	8.0	325.2	(2.75)*	894.3
Transportation	28.3	1.3	2.6	2.8	5.2	40.2	(1.76)	70.8
Solid wastes (Incineration)	33.6	1.2	2.1	1.5	1.9	40.3	(1.26)	50.8
Source Totals						639.1		1,605.5

*See Table 5.5.

TABLE 5.5

INDUSTRIAL PROCESS EMISSION BREAKDOWN FOR THE SOURCE REGION OF CHICAGO

(10^3 tons per year)

	Air Quality Control Regions					Total
	67	71	73	81	82	
SO_2						
Primary metals	19.3	–	–	–	–	19.3
Mineral products	5.8	6.3	–	–	–	12.1
Petroleum	84.5	–	–	–	–	84.5
						115.9

$$\text{Weighted growth rate} = \left(\frac{19.3}{115.9} \times 3.0\right) + \left(\frac{12.1}{115.9} \times 4.5\right) + \left(\frac{84.5}{115.9} \times 1.6\right) = 2.135$$

$$\text{Equivalent growth factor to year 2000} = (1.02135)^{26} = 1.73$$

	Air Quality Control Regions					Total
	67	71	73	81	82	
Particulate						
Primary metals	87.7	–	1.9	1.2	2.2	93.0
Mineral products	150.3	32.3	1.8	11.3	3.8	199.5
Petroleum	6.0	–	–	–	0.2	6.2
						298.7

$$\text{Weighted growth rate} = \left(\frac{93.0}{298.7} \times 3.0\right) + \left(\frac{199.5}{298.7} \times 4.5\right) + \left(\frac{6.2}{298.7} \times 1.6\right) = 3.973$$

$$\text{Equivalent growth factor to year 2000} = (1.03973)^{26} = 2.75$$

The Bureau of Mines report, cited in Subsection 5.1, contains data on the increase in fuel combustion to the year 1985. These data were used to produce the following growth factors. For coal combustion the growth factors from 1974 to 1985 and 1986 to 2000 are 1.614 and 1.635 respectively. For petroleum combustion these growth factors become 1.362 and 1.122.

The growth factors that apply to industrial processes have been based on a uniform growth rate. For example, the estimated growth rate for Chicago based on the industrial breakdown presented in Table 5.5 is 2.135 percent per year.

Therefore,

$$\text{the growth factor from 1974 to 1985} = (1.02135)^{11} = 1.26$$

Similarly,

$$\text{the growth factor from 1985 to 2000} = (1.02135)^{15} = 1.37$$

and

$$\text{the combined growth factor from 1974 to 2000} = 1.26 \times 1.37 = 1.73$$

as indicated in Table 5.4.

Using these growth factors, the SO_2 emissions for the year 2000 were calculated as follows.

Assuming a 50 percent efficiency on retrofits to the year 1985 and 80 percent efficiency on new installations after 1985, the emissions in 2000 are

$$\text{Emission (2000)} = \frac{20}{100} \times \left\{ [\text{Emission (1985)} \times \text{B}] - \text{Emission (1985)} \right\} + \frac{50}{100} \times \left\{ \text{Emission (1985)} \right\}$$

where

B is the growth factor from 1985 to 2000.

But,

Emission (1985) = A x Emission (1974)

where

A is the growth factor from 1974 to 1985.

Therefore,

$$\text{Emission (2000)} = \left\{ \frac{A}{2} + \left[\frac{A \times (B-1)}{5} \right] \right\} \times \text{Emission (1974)}$$

Based on this equation the growth factors appropriate for the Chicago emissions of SO_2 in the year 2000 are

$$\text{coal} \quad = \left[\frac{1.614}{2} + 1.614 \times \left(\frac{1.635 - 1}{5} \right) \right]$$

$$= 1.012$$

$$\text{petroleum} \quad = \left[\frac{1.362}{2} + \frac{1.362 \times (1.122 - 1)}{5} \right]$$

$$= .714$$

and

$$\text{industrial processes} = \left[\frac{1.26}{2} + 1.26 \times \left(\frac{1.37 - 1}{5} \right) \right]$$

$$= .723$$

The growth factors for all other emissions are the same as for the uncontrolled case.

5.3.3 Case III – No Increase in Nuclear Plants After 1985

As indicated in Subsection 5.1, the most variable aspect of forecasts relating to coal combustion is the uncertainty in the electric generation sector as to the use of nuclear power plants. Case III assumes the extreme condition in which all new thermal electric generation after 1985 is produced by coal-fired plants. The nuclear energy estimates from the Bureau of Mines report were converted to coal consumption assuming a 33 percent conversion efficiency for nuclear plants and a 40 percent conversion efficiency for fossil-fueled plants. When this additional consumption is added to the previously calculated coal growth factor, the modified growth factor from 1985 to 2000 is 2.978. This represents an annual growth rate during this period of 7.5 percent.

Since the assumptions concerning SO_2 control levels are identical to those used in Case II, the final SO_2 emissions from coal combustion can be calculated from the equation

$$\text{Emission (2000)} = \left\{\frac{A}{2} + \left[\frac{A \times (C - 1)}{5}\right]\right\} \times \text{ Emission (1974)}$$

where

A is the growth factor from 1974 to 1985

and

C is the modified growth factor indicated above.

All other emission categories are the same as those used in Case II.

5.4 Projected Loadings

The projected loadings of particulates and sulphates are presented in Table 5.6. The particulate loadings have been given for 1974 and 2000 with and without nuclear power. The sulphate loadings are for 1974 and 2000 for the three cases presented in Subsection 5.3.

	PARTICULATES 10^6 kg PER YEAR			SULPHATES 10^6 kg PER YEAR			
	1974	2000^1	2000^2	1974	2000^3	2000^4	2000^5
LAKE SUPERIOR	41	103	138	215	409	171	219
AMERICAN DRAINAGE	20	50	64	91	199	76	106
CANADIAN DRAINAGE	35	88	128	191	354	158	190
LAKE HURON	53	133	190	379	679	289	376
AMERICAN DRAINAGE	38	97	145	244	553	229	300
CANADIAN DRAINAGE	67	173	243	558	848	377	480
LAKE MICHIGAN	56	143	194	326	771	298	417
DRAINAGE	104	268	368	585	1395	539	752
LAKE ERIE	41	104	148	271	656	250	350
AMERICAN DRAINAGE	75	190	273	461	1180	435	597
CANADIAN DRAINAGE	30	77	112	203	490	194	259
LAKE ONTARIO	21	52	76	121	277	114	148
AMERICAN DRAINAGE	37	93	124	201	468	175	249
CANADIAN DRAINAGE	28	71	102	167	373	152	199

NOTE

2000^1 - BASED ON PROJECTED INCREASE OF EMISSION SOURCES TO THE YEAR 2000

2000^2 - GROWTH RATES ARE IDENTICAL TO 2000^1 EXCEPT THAT ALL PROJECTED ELECTRICAL ENERGY AFTER 1985 HAS BEEN ASSUMED TO BE COAL FIRED

2000^3 - BASED ON PROJECTED INCREASE OF EMISSION SOURCES TO THE YEAR 2000 ASSUMING NO SO_2 REMOVAL

2000^4 - ASSUMING 50% REMOVAL OF SO_2 ON INCREASE OF EMISSION SOURCES UP TO 1985 AND 80% REMOVAL BETWEEN 1986 AND 2000

2000^5 - IN ADDITION TO THE SAME SO_2 REMOVAL AS 2000^4, ALL PROJECTED ELECTRICAL ENERGY AFTER 1985 HAS BEEN ASSUMED TO BE COAL FIRED

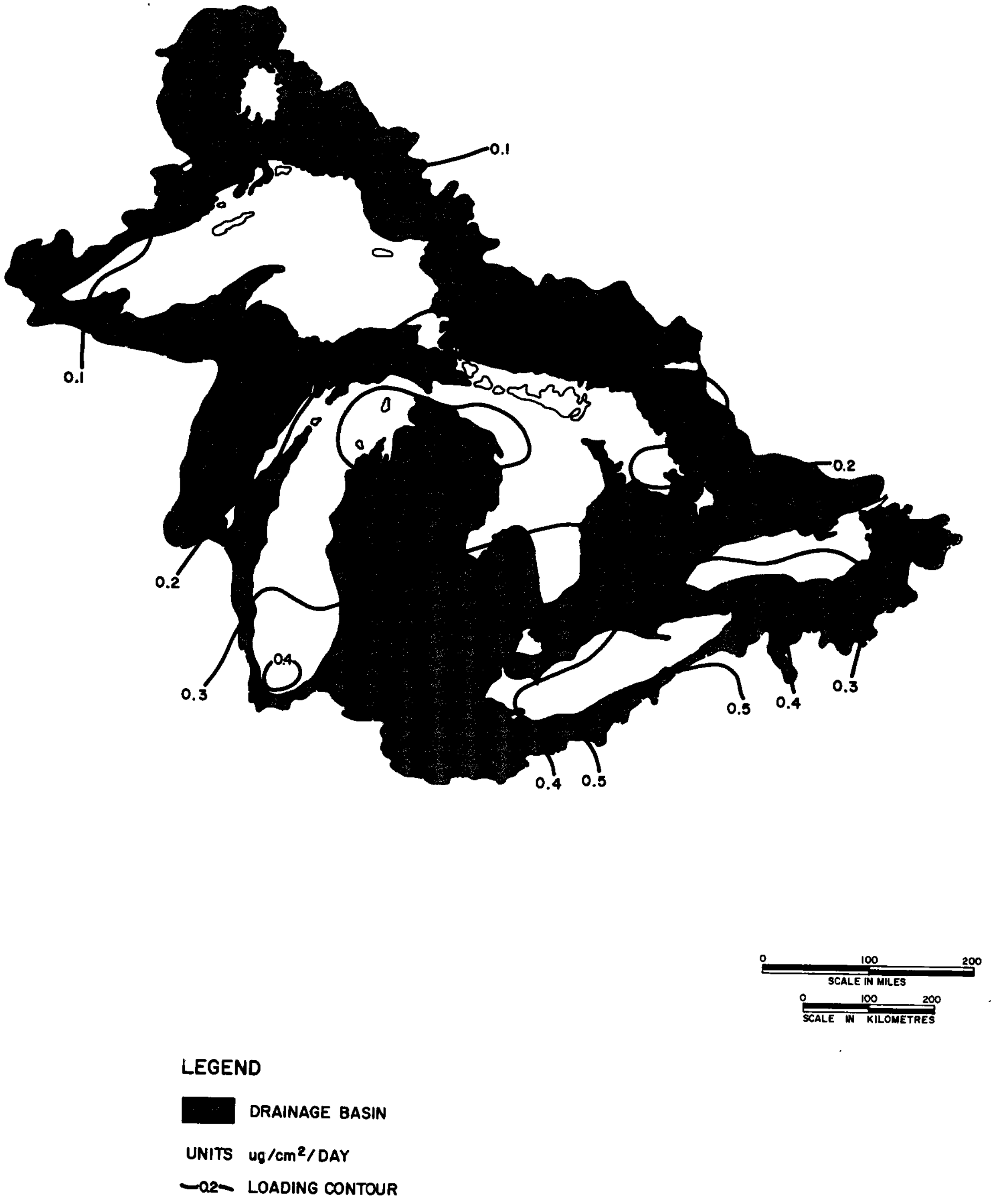
PROJECTED LOADINGS

TABLE 5.6

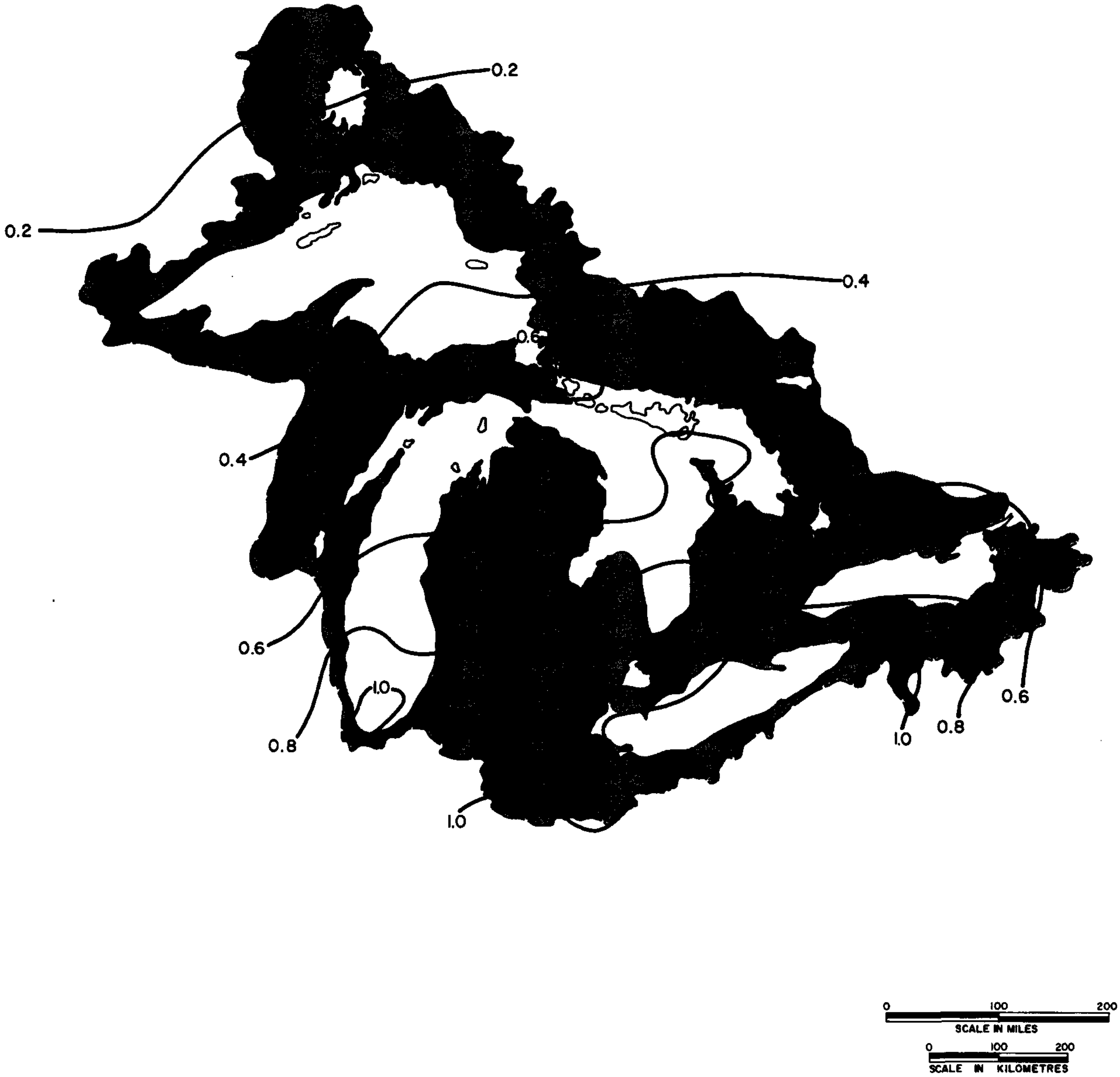
Assuming that SO_2 emissions are controlled to the degree indicated in Case III, the most significant effect of switching to coal from nuclear would be the increase in particulate loadings. Particulates are presently controlled to a high degree, thus allowing little scope for improvement.

Loading contours for all but the no-nuclear power situations have been presented in Figures 5.1 to 5.5. The general gradient from south to north is apparent in all cases. The high sulphate loadings generated in the Sudbury region during 1974 become less significant in the year 2000, assuming that proposed control measures are instituted at the same time as there is a general increase in SO_2 emissions to the south. When SO_2 controls are applied throughout the study region the sulphate loadings in the vicinity of Sudbury actually show an improvement.

In considering the contour maps it is important to note that there has been no redistribution of industry within the study area in the year 2000. For this reason Case III was considered too speculative to justify contouring.



TOTAL PARTICULATE LOADING IN THE YEAR 1974 FIGURE 5.1
ATMOSPHERIC LOADING OF THE LOWER GREAT LAKES



LEGEND

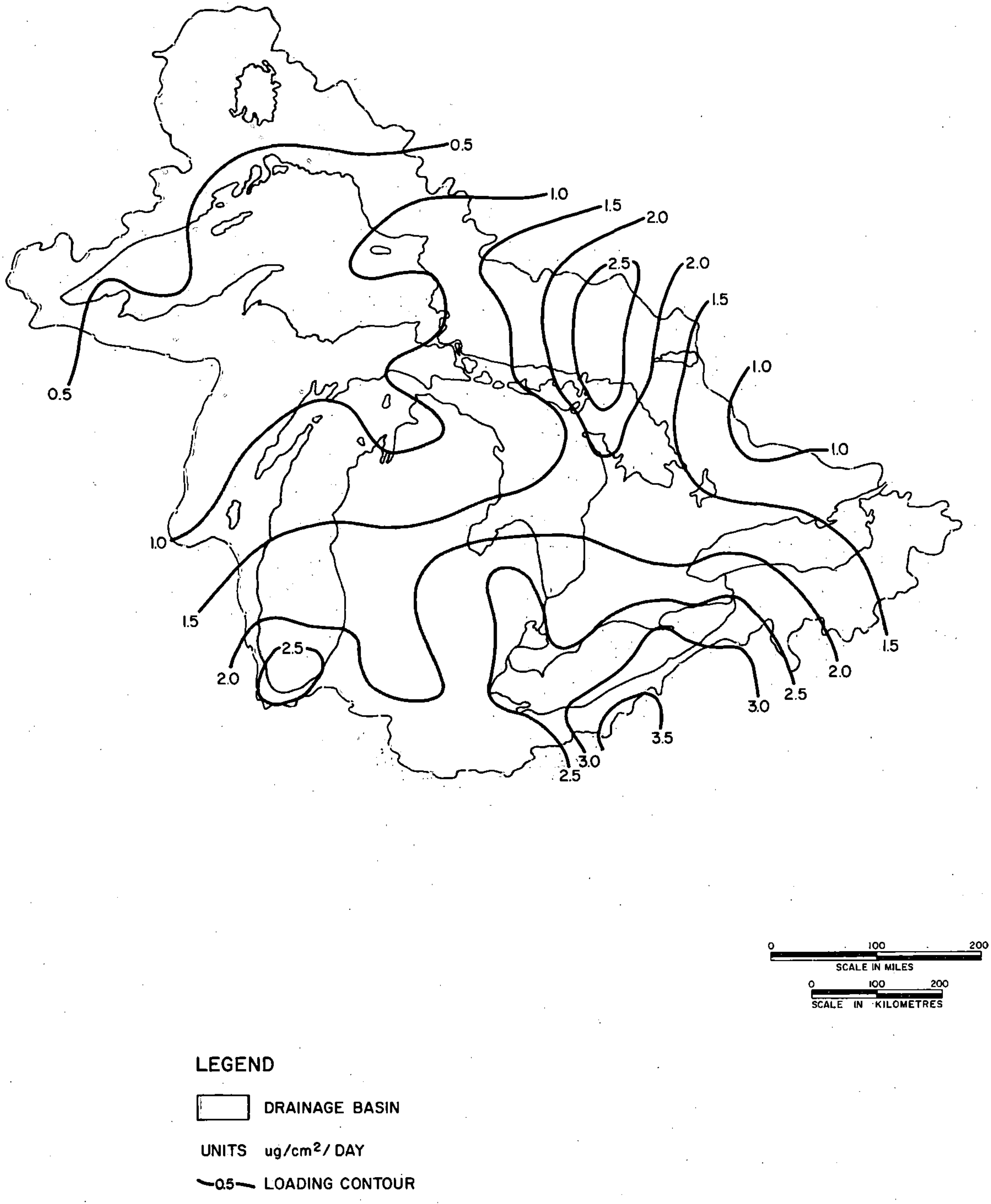
■ DRAINAGE BASIN

UNITS ug/cm²/ DAY

—0.6— LOADING CONTOUR

TOTAL PARTICULATE LOADING IN THE YEAR 2000 **FIGURE 5.2**

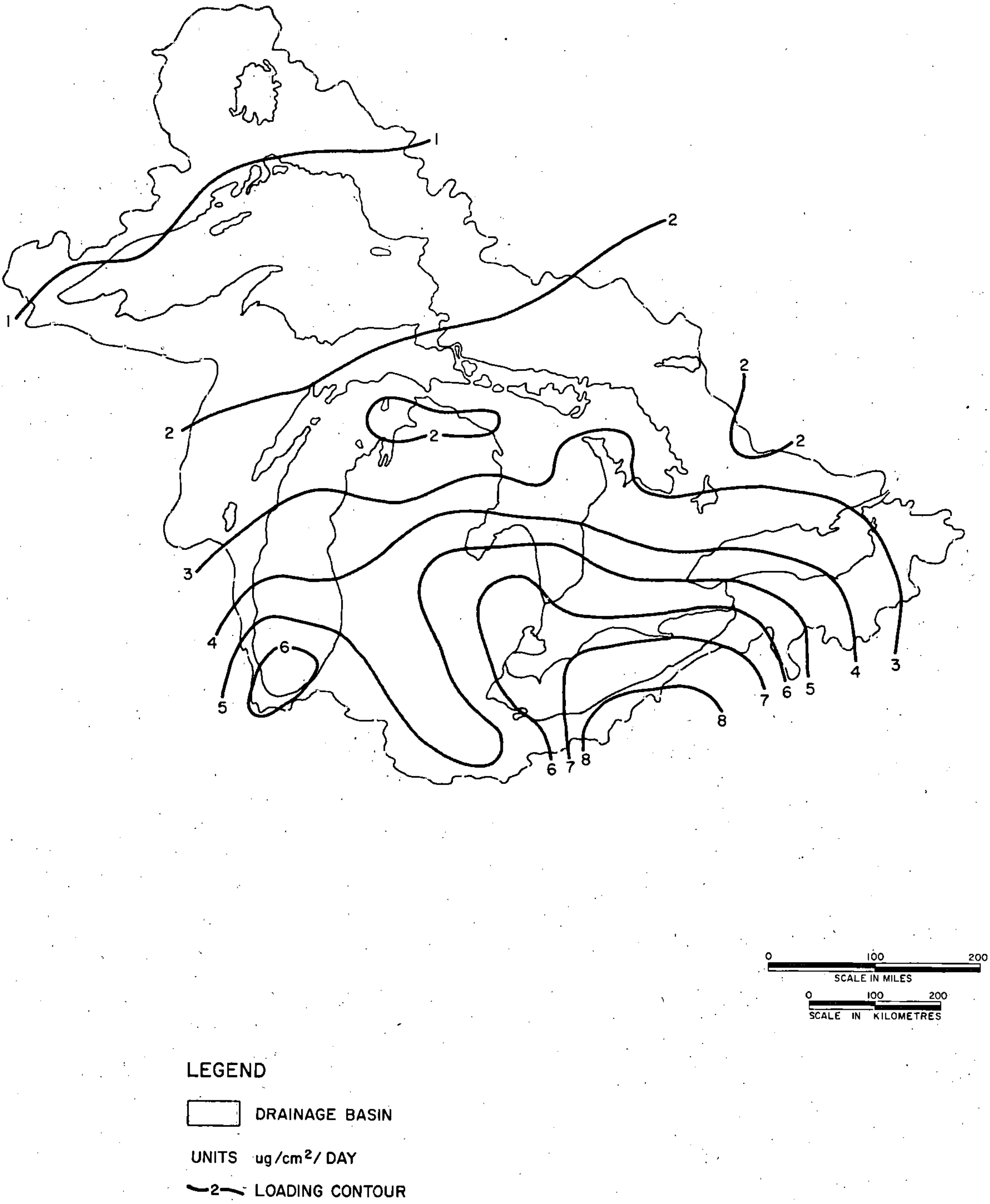
ATMOSPHERIC LOADING OF THE LOWER GREAT LAKES



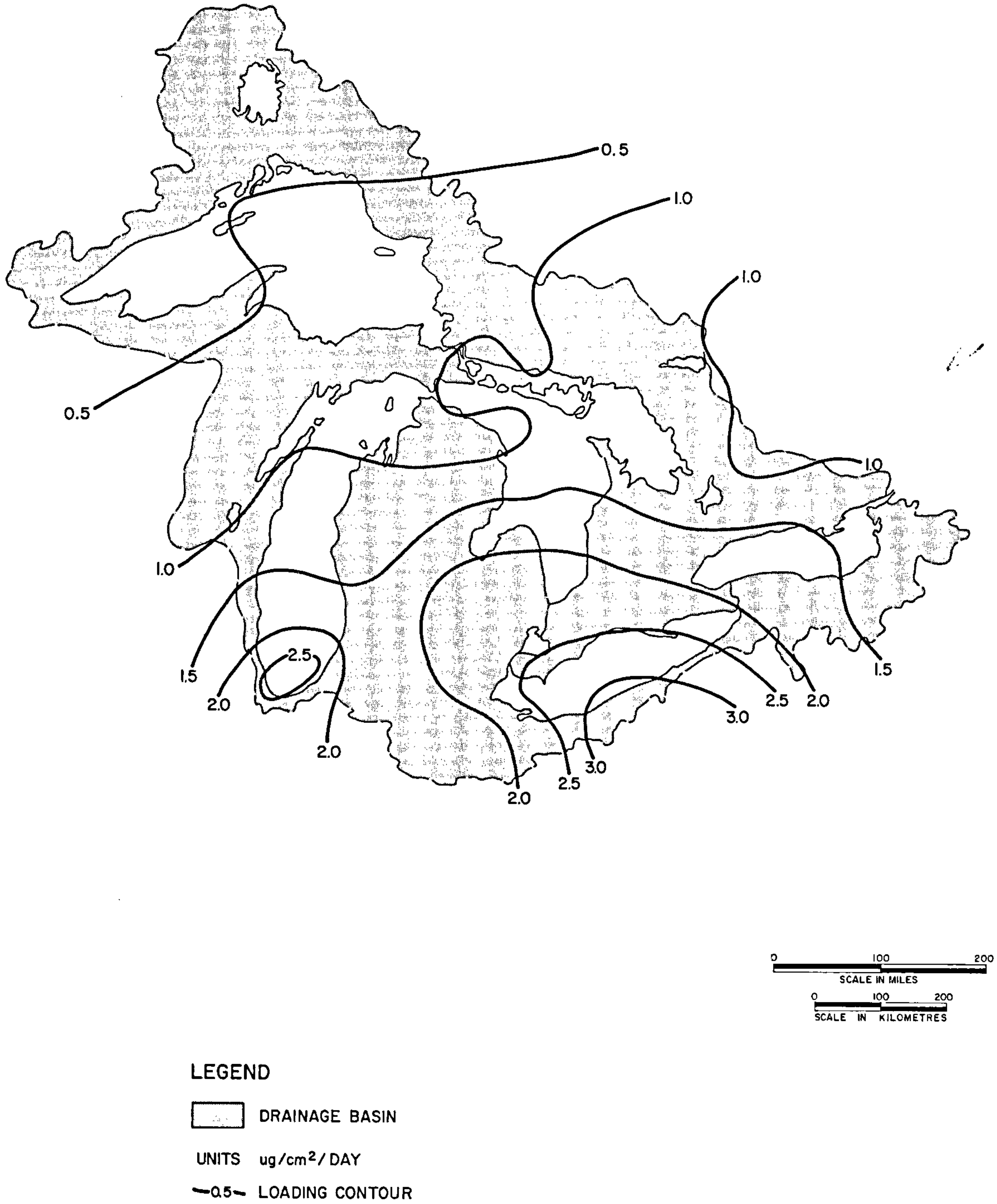
SULPHATE LOADING IN THE YEAR 1974

FIGURE 53

ATMOSPHERIC LOADING OF THE LOWER GREAT LAKES



SULPHATE LOADING IN THE YEAR 2000 WITHOUT SO_2 REMOVAL FIGURE 5.4
ATMOSPHERIC LOADING OF THE LOWER GREAT LAKES



SULPHATE LOADING IN THE YEAR 2000 WITH SO_2 REMOVAL FIGURE 5.5

ATMOSPHERIC LOADING OF THE LOWER GREAT LAKES

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BIBLIOGRAPHY

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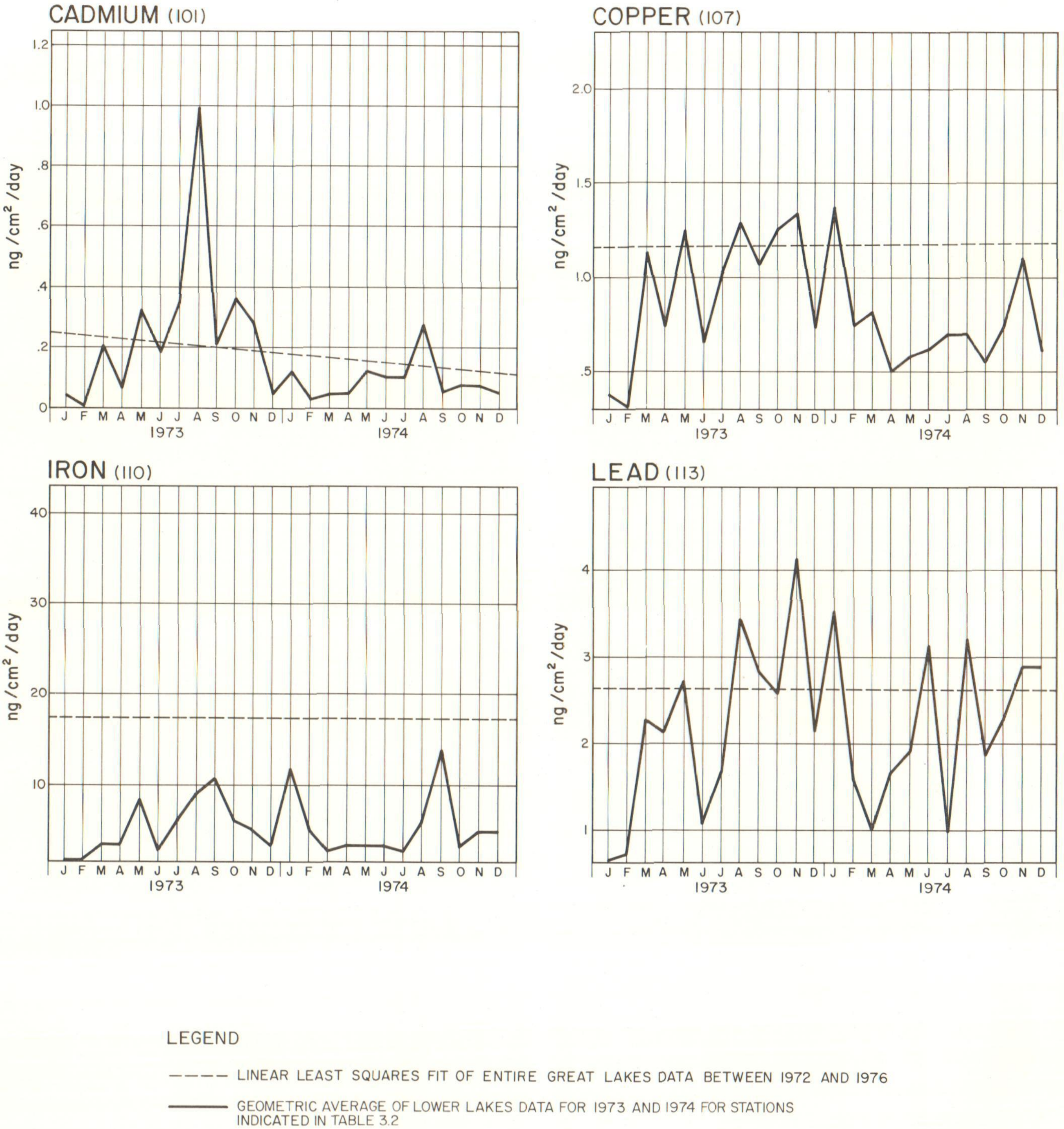
APPENDIXES

APPENDIX 1

SPECIAL VARIATIONS IN LOADING RATES – PRECIPITATION CHEMISTRY

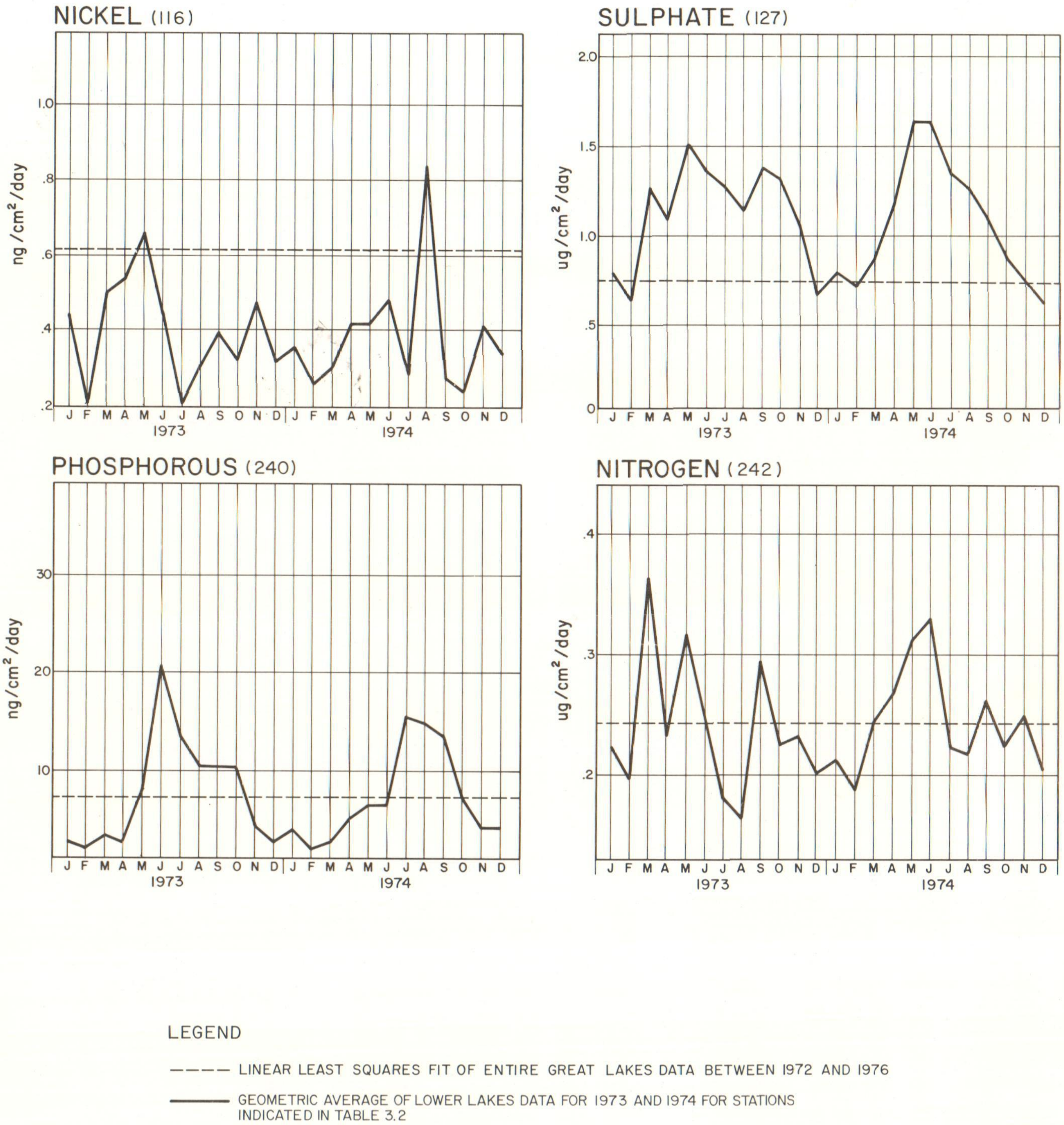
Seasonal and long-term trends of all loading data are plotted in Figures A1.1 and A1.2. Geometric averages of all available data are plotted for each sampling period during 1973/1974 for stations listed in Table 3.2. The dashed line is the linear least squares fit of the averages for all data available throughout the Great Lakes basin between 1972 and 1976. This line gives an indication of longer-term trends. Loading units are found in Table 3.1.



SEASONAL VARIATIONS IN LOADING RATES

FIGURE A1.1

ATMOSPHERIC LOADING OF THE LOWER GREAT LAKES



SEASONAL VARIATIONS IN LOADING RATES

FIGURE A1.2

ATMOSPHERIC LOADING OF THE LOWER GREAT LAKES

APPENDIX 2

SEASONAL VARIATIONS IN LOADING RATES – MATHEMATICAL MODEL

Seasonal loading rates for SO_4 NO_x and particulates have been presented in Tables A2.1 through A2.3. It is important to note that emission rates as input to the model are yearly average values and as such do not represent the seasonal variations that are likely to occur as a result of winter heating requirements, changes in industrial productions, etc. The variations that appear in these tables are merely a function of the seasonal changes in meteorology for the year 1974. The drainage areas to which these rates apply are given in Subsection 4.2 of the main report.

TABLE A2.1

SEASONAL VARIATIONS IN SO_4 LOADING RATES ($\mu g/cm^2/day$) BY DRAINAGE ZONES

Zone No.	Spring	Summer	Autumn	Winter
1	.4	1.0	.6	.4
2	.3	.6	.5	.3
3	.5	1.2	.8	.6
4	.5	1.1	1.4	1.0
5	1.3	.9	1.6	1.3
6	1.8	1.9	3.7	2.2
7	1.5	1.7	2.9	1.8
8	1.3	1.4	1.8	1.1
9	1.0	1.1	1.0	1.0
10	1.1	1.4	1.3	1.4
11	1.5	2.0	1.6	1.9
12	1.4	1.9	1.4	1.4
13	1.5	1.9	1.4	1.4
14	1.7	2.1	1.8	1.9
15	1.9	2.3	1.8	1.9
16	1.9	2.4	1.8	1.9
17	2.5	3.1	2.4	2.6
18	2.3	2.9	2.0	2.4
19	1.7	1.8	1.8	1.6
20	1.2	1.6	1.4	1.4
21	1.8	2.2	2.1	2.1
22	2.4	3.1	3.0	2.7
23	3.2	3.7	3.2	3.1
24	2.2	2.2	1.9	2.1
25	2.6	2.4	1.9	2.6
26	2.0	2.1	1.6	2.0
27	2.2	2.2	1.9	2.2
28	1.6	2.0	1.5	1.6
29	1.0	1.2	1.3	1.0
30	1.1	1.2	1.4	1.0
31	.7	.9	1.4	.8
32	.7	1.2	1.2	.7
33	1.7	2.0	1.8	1.6
34	.6	1.6	1.1	.6
35	.5	2.4	.7	.4
36	.4	1.2	.5	.4
37	1.0	1.0	1.6	1.0

TABLE A2.2

SEASONAL VARIATIONS IN NO_x LOADING RATES ($\mu g/cm^2/day$) BY DRAINAGE ZONES

Zone No.	Spring	Summer	Autumn	Winter
1	.09	.09	.11	.10
2	.06	.06	.08	.07
3	.08	.09	.13	.10
4	.14	.25	.28	.18
5	.20	.39	.38	.24
6	.20	.38	.34	.25
7	.20	.35	.33	.27
8	.24	.36	.38	.32
9	.24	.42	.32	.35
10	.32	.46	.44	.49
11	.49	.70	.61	.69
12	.38	.53	.50	.50
13	.37	.54	.48	.47
14	.49	.69	.61	.64
15	.53	.73	.57	.65
16	.55	.76	.63	.67
17	.78	1.00	.86	.88
18	.70	.89	.74	.81
19	.35	.53	.51	.47
20	.43	.56	.48	.50
21	.57	.73	.69	.72
22	.70	.95	.91	.86
23	.97	1.08	1.07	.97
24	.72	.77	.78	.71
25	.88	.93	.83	.95
26	.67	.76	.71	.76
27	.72	.86	.81	.82
28	.55	.70	.68	.61
29	.35	.50	.56	.40
30	.32	.45	.55	.37
31	.26	.34	.46	.29
32	.27	.38	.46	.29
33	.66	.80	.84	.64
34	.18	.26	.33	.20
35	.16	.20	.22	.15
36	.13	.17	.17	.12
37	.22	.39	.48	.27

TABLE A2.3

SEASONAL VARIATIONS IN PARTICULATE LOADING RATES ($\mu g/cm^2/day$) BY DRAINAGE ZONES

Zone No.	Spring	Summer	Autumn	Winter
1	.08	.12	.13	.08
2	.06	.09	.11	.06
3	.08	.13	.16	.08
4	.10	.17	.29	.11
5	.12	.20	.33	.14
6	.13	.21	.28	.14
7	.14	.22	.29	.16
8	.16	.26	.30	.18
9	.15	.25	.17	.17
10	.19	.26	.23	.29
11	.24	.36	.29	.36
12	.19	.33	.20	.22
13	.19	.34	.20	.20
14	.25	.41	.29	.29
15	.26	.45	.27	.29
16	.26	.46	.26	.28
17	.35	.50	.34	.41
18	.29	.44	.26	.36
19	.18	.31	.29	.20
20	.21	.30	.27	.29
21	.29	.41	.35	.38
22	.35	.55	.47	.46
23	.47	.59	.46	.50
24	.37	.40	.30	.39
25	.39	.39	.24	.42
26	.33	.40	.24	.35
27	.30	.37	.26	.32
28	.26	.38	.24	.28
29	.16	.26	.25	.15
30	.15	.26	.27	.13
31	.14	.22	.32	.14
32	.12	.19	.25	.12
33	.27	.35	.26	.27
34	.11	.19	.26	.11
35	.09	.13	.15	.08
36	.08	.12	.12	.07
37	.13	.24	.40	.15

APPENDIX 3

UPPER GREAT LAKES LOADING ESTIMATES AND TRANSBOUNDARY LOADING OF SO_4, PHOSPHATE AND TRACE METALS

From Acres–ESC 1975.

10^6 kg PER YEAR

PARAMETERS		LAKE SUPERIOR			LAKE HURON			
		EASTERN	WESTERN	TOTAL	NORTHERN	SOUTHERN	GEORG. BAY	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								
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*	*2600*	*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*	*9 700*	*1 300*	*900*	*2400*	*4600*
	MM	*2500*	*1 600*	*4 100*	*2 100*	*1700*	*1500*	*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 4.5

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 5.1

SOURCE	LAKE SUPERIOR			LAKE HURON		
	AMERICAN	CANADIAN	TOTAL	AMERICAN	CANADIAN	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)	174	86	260	100	180	280

TRANSBOUNDARY LOADING OF PHOSPHATE

TABLE 5.2

SOURCE	LAKE SUPERIOR			LAKE HURON		
	AMERICAN	CANADIAN	TOTAL	AMERICAN	CANADIAN	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 5.3