

Environment Canada Environnement Canada Atmospheric Bulk Precipitation in the Great Lakes Basin

K. W. Kuntz



SCIENTIFIC SERIES NO. 115

INLAND WATERS DIRECTORATE ONTARIO REGION WATER QUALITY BRANCH BURLINGTON, ONTARIO, 1980 Environment Canada

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Contents

ABSTRACT	١
RÉSUMÉ	١
	1
EXPERIMENTAL PROCEDURES	1
Site selection	1
Sampling methods	3
DISCUSSION	4
Atmospheric precipitation concentration data.	4
Lake Superior Basin concentration data	5
Lake Huron Basin concentration data	5
Lake Erie Basin concentration data	6
Lake Ontario Basin concentration data	7
Loading calculations	8
SUMMARY	ε
ACKNOWLEDGMENTS	ç
REFERENCES	ç

Tables

1.	Great Lakes precipitation chemistry stations
2.	Precipitation analysis methods summary 14
3.	Concentration data at Thunder Bay 14
4.	Concentration data at Schreiber
5.	Concentration data at Coldwell 15
6.	Concentration data at Copper Harbor
7.	Concentration data at Isle Royale
8.	Accumulated concentration data, Lake Superior
9.	Concentration data at Gore Bay
10.	Concentration data at Parry Sound
11.	Concentration data at Beausoleil Island
12.	Concentration data at Wiarton
13.	Concentration data at Douglas Point
14.	Concentration data at Sarnia
15.	Concentration data at Grand Bend 20
16.	Accumulated concentration data, Lake Huron
17.	Concentration data at Rockwood
18.	Concentration data at Port Stanley

Page

Tables (Cont.)

19.	Concentration data at Pelee Island
20.	Accumulated concentration data, Lake Erie
21.	Concentration data at Burlington
22.	Concentration data at Ancaster
23.	Concentration data at Toronto Island
24.	Concentration data at Woodbridge
25.	Concentration data at Trenton
26.	Concentration data at Kingston
27.	Accumulated concentration data, Lake Ontario
28.	Great Lakes areal deposition rates
29.	Atmospheric loadings to the Great Lakes

Page

Illustrations

Figure 1.	Great Lakes precipitation chemistry stations, 1969-76	2
Figure 2.	Bulk precipitation Type A sampler	3
Figure 3.	Bulk precipitation Type A sampler interior	3
Figure 4.	Bulk precipitation Type B sampler	4

Abstract

Résumé

A wide variety of chemical constituents of atmospheric bulk precipitation have been analyzed on a monthly basis since 1969 in the Great Lakes Basin. These include total phosphorus, forms of nitrogen (nitrate, ammonia, total and total Kjeldahl), trace metals (copper, iron, lead and zinc) and major ions (calcium, magnesium, sodium, potassium, sulphate and chloride). All of the data contained in this report are bulk precipitation, i.e., wet plus dry precipitation. It includes rain, snow and any dry fallout that was collected between precipitation events.

Concentration data are compared between stations within each basin and between sampler types for each basin. A Student's t test was performed on the data to test for significant variations within each basin and also between sampler types.

Areal loading rates are calculated for each of the Great Lakes basins, and a correlation between the chemical composition of atmospheric bulk precipitation and the population of the basin was observed for many of the parameters measured. Atmospheric loadings expressed as percentages of total loadings to the Great Lakes for total phosphorus, total nitrogen and chloride show that atmospheric inputs are increasingly important as one proceeds up the interconnected Great Lakes system from Lake Ontario to Lake Superior. Depuis 1969, sur le bassin des Grands lacs, une grande variété de constituants chimiques contenus dans les précipitations totales ont été analysés sur une base mensuelle. Il s'agit du phosphore total, des diverses formes d'azote (nitrate, ammoniac, azote total et azote total de Kjeldahl) des métaux à l'état de traces (cuivre, fer, plomb et zinc), et des principaux ions (calcium, magnésium, sodium, potassium, sulfates et chlorures). Toutes les données fournies dans ce rapport correspondent aux précipitations totales, c'est-à-dire à *la somme des précipitations sèches et humides*. Cela comprend la pluie, la neige et toutes les matières sèches recueillies entre les précipitations.

Les valeurs des concentrations ont été comparées entre les stations et les types d'échantillonneurs de chaque bassin. Ces valeurs ont été soumises au test du t de Student, en vue de déceler les variations significatives à l'intérieur de chaque bassin et aussi, entre les types d'échantillonneurs.

La charge par unité de surface a été calculée pour chaque bassin des Grands lacs, et on a pu observer une corrélation entre la composition chimique des précipitations atmosphériques totales et la population du bassin pour plusieurs des paramètres mesurés. Les charges atmosphériques exprimées en pourcentages des charges totales des Grands lacs pour le phosphore total, l'azote total et le chlorure montrent que les apports atmosphériques sont de plus en plus importants au fur et à mesure que l'on remonte le système des Grands lacs, du lac Ontario au lac Supérieur.

Atmospheric Bulk Precipitation in the Great Lakes Basin

K. W. Kuntz

INTRODUCTION

One of the early major tasks of the Canada Centre for Inland Waters (CCIW) was to provide technical input for the report to the International Joint Commission (IJC) on the "Pollution of Lake Erie, Lake Ontario and the International Section of the St. Lawrence River" (IJC, 1969). This report indicated that less than 10%, or 12 000 tons per year, of total nitrogen was added to the surface of Lake Ontario by atmospheric inputs. The same report stated that about 8%, or 16 000 tons per year, of total nitrogen was added to the surface of Lake Erie by atmospheric inputs. It was also pointed out that in 1969, very little information about the contribution of atmospheric inputs to the chemical budgets of Lakes Ontario and Erie was available.

Few studies of precipitation chemistry were carried out in the Great Lakes Basin prior to 1969. These include the work of Shutt and Hedley (1925) in the Ottawa region, Matheson (1951) in the Hamilton area, Junge and Werby (1958) in the United States portion of the Great Lakes Basin, and Weibel *et al.* (1966) and Rutherford (1967) in the Kingston area. Lodge *et al.* (1968) carried out their work in the U.S. portion of the Great Lakes Basin.

In response to the lack of information regarding the importance of precipitation inputs to the chemical budgets of the Great Lakes Basin, the CCIW Atmospheric Precipitation Program was initiated in 1969. As a result of this and other studies carried out since 1969, a great deal of data have been collected.

Winchester and Nifong (1971) have concluded that a sizeable fraction of the loading of zinc and copper to Lake Michigan comes from the atmosphere. Shiomi and Kuntz (1973) calculated that 13% to 14% of the nitrogen as well as 6% to 14% of the phosphorus loaded by the Niagara River into Lake Ontario is a result of atmospheric deposition. Murphy (1975) determined that 20% to 33% of the total input of phosphorus to Lake Michigan is a result of atmospheric inputs. Conroy *et al.* (1975) found that many lakes in the Sudbury area contained nickel, iron and copper concentrations well above expected levels even though there were no direct discharges to these lakes. They concluded that atmospheric deposition was the most probable source. Numerous other reports have appeared in the literature for the Great Lakes Basin area. A report by Acres Consulting Services (1975) presents loadings for all available data for the years 1972-74 for Lakes Huron and Superior. Matheson (1975) summarized methods of sampling atmospheric inputs to the Great Lakes. Elder *et al.* (1976) calculated the atmospheric loading for nutrients, major ions and trace metals to Lakes Superior and Huron for 1973-74. Another report by Acres Consulting Services (1977) calculated loadings for all available data for Lakes Ontario and Erie for 1973-74.

An excellent assessment of the ecological effects of long-term atmospheric material deposition is found in a report by Applied Earth Science Consultants, Inc. (1976) for the Department of the Environment.

There have been many studies of precipitation chemistry conducted in other countries. Perhaps the most widely known and quoted investigations in this field are those of Egner and Eriksson and co-workers in Scandinavia and northern Europe (Egner and Eriksson, 1949, 1955; Eriksson, 1952a, b, 1955).

Similar studies were carried out in the United States by Junge and Gustafson in 1957, Junge and Werby in 1958 and Junge in 1963. Reviews of work in this field are found in papers by Gore (1968), Whitehead and Feth (1964) and Feth *et al.* (1964). Gambell and Fisher (1966) carried out a study similar to this one in North Carolina and Virginia in which they estimated nutrient and major ion inputs from atmospheric precipitation to various river drainage basins.

An excellent review of the importance of nitrogen and phosphorus in precipitation was written by Vollenweider (1968) and is published in Organization for Economic Cooperation and Development Report No. DAS/CSI/68.27.

EXPERIMENTAL PROCEDURES

Site Selection

Initially, the CCIW Atmospheric Precipitation Chemistry Program consisted of six stations in the Lake Ontario drainage basin in 1969. The locations chosen in the Lake Ontario Basin were Toronto Island, Kingston, Trenton, Woodbridge, Ancaster and Burlington.

In 1970, the program was expanded to include each of the other Great Lakes basins. Three stations were established at Port Stanley, Pelee Island and Rockwood in the Lake Erie Basin. Two stations were established in the Lake Huron Basin at Gore Bay and Wiarton. Two stations were established in the Lake Superior Basin at Schreiber and Thunder Bay. In 1971, an additional station at Sarnia was added to the Lake Huron Basin network.

When the Great Lakes Water Quality Agreement was signed between Canada and the United States in 1972, there was great concern for the present and future water quality of Lakes Superior and Huron. Consequently, the agreement was used as a basis for a request to the IJC by the Canadian and U.S. governments for a comprehensive study of pollution problems of Lakes Superior and Huron.

In November 1972, the IJC appointed the Upper Lakes Reference Group to undertake appropriate studies and report its findings to the IJC, which would in turn report to the Canadian and U.S. governments.

As a result of this requirement for information, the Atmospheric Precipitation Chemistry Program was again expanded. Two stations in the state of Michigan, one at Copper Harbor and one on Isle Royale, as well as one at Coldwell were added to the Lake Superior Basin network in 1973. Also in 1973, four stations were added to the Lake Huron Basin network at Grand Bend, Parry Sound, Beausoleil Island and Douglas Point.



Figure 1. Great Lakes precipitation chemistry stations, 1969-76.

All of the station locations are shown in Figure 1. A detailed listing of stations, their latitudes and longitudes, description, and dates of operation are given in Table 1.

Attempts to select station locations were usually based on the availability of basic meteorological observations, i.e., rainfall gauges. As a result, most stations were located at Atmospheric Environment Service weather stations. Those in this category are at Toronto Island, Woodbridge, Trenton, Kingston, Port Stanley, Pelee Island, Gore Bay, Wiarton, Sarnia, Thunder Bay and Schreiber.

Other stations were located in federal or provincial parks which volunteered cooperation and which had rainfall measuring capabilities. This group included stations at Parry Sound, Beausoleil Island, Douglas Point, Grand Bend and Coldwell.

Cooperation was also obtained from the Michigan Department of Natural Resources, and as a result, two stations were established in the state of Michigan at Copper Harbor and Isle Royale.

As well, Professor J.R. Kramer of McMaster University volunteered to look after a sampler for this program on his



Figure 2. Bulk precipitation Type A sampler.

property in Ancaster. Professor H. Whitley of the University of Guelph offered his cooperation in this program by operating a sampler near Rockwood.

In most cases people operating the sampling stations were volunteers. They were required to change the sample bottles each month and to send in the samples collected to CCIW.

Stations were always installed on undisturbed land, preferably covered with grass and not overhung with trees, wires or towers, etc. Attempts were made to keep the samplers at least 30 m from the nearest buildings, trees or towers. An effort was made to keep the samplers at least 100 m away from local sources of pollution such as routine air, ground and water traffic.

Sampling Methods

Two types of bulk precipitation samplers have been used throughout this study. The first type, shown in Figures 2 and 3, is similar to that used by Gambell and Fisher (1966) in their studies in North Carolina and Virginia. This sampler will be referred to as a "Type A" sampler in this report.



Figure 3. Bulk precipitation Type A sampler interior.

3

The Type A sampler employs a glass collection funnel, which is connected to a 2-L polyethylene storage bottle with a plastic pour spout, Tygon tubing and a neoprene stopper. All storage bottles were washed with 50% HCl and then rinsed three times with distilled water.

In the earlier stage of this program, a prewashed (in boiling distilled water prior to use) glass wool prefilter was used in the bottom end of the glass funnel. This filter was used to filter out insects and large particulates. After July 1974, however, the use of this filter was discontinued, because elevated concentrations of calcium, magnesium, sodium and sulphate, and reduced concentrations of ammonia, total phosphorus, zinc and chloride were observed (Kuntz, 1978).

Since the Type A sampler designed by Gambell and Fisher (1966) proved to be inefficient for collecting snowfall, an additional sampler with an "alter" shield was installed at most stations by 1972. This sampler, shown in Figure 4, will be referred to as a "Type B" sampler.

The Type B sampler consists of a large, hollow cylinder (10-in. diameter) with a polyethylene bag liner surrounded by an "alter" shield. The "alter" shield is used as a deflector to protect the cylinder orifice from crosswinds which decrease the sampling efficiency, particularly for snow.



Figure 4. Bulk precipitation Type B sampler.

All of the samples were collected on a monthly integrated basis and sent to CCIW for analysis. A full range of chemical analyses including total phosphorus, species of nitrogen (ammonia, nitrate, total and total Kjeldahl), trace metals (copper, iron, lead and zinc) and major ions (calcium, magnesium, sodium, potassium, sulphate and chloride) were carried out on these samples.

The addition of a preservative to the storage bottle was considered, but no one preservative could be found which would effectively prevent sample deterioration over the long storage period (one month) and at the same time not interfere with the many different analytical tests being performed on these samples. Thus no preservative was used.

Analytical methods used for these samples have been summarized by Traversy (1971) and by Philbert and Traversy (1973). A summary of range, detection limit and standard deviation of each analytical method is given in Table 2.

DISCUSSION

Atmospheric Precipitation Concentration Data

Initial examination of these data shows that large variations between stations and sampler types exist. Other investigators have also observed this problem in precipitation sampling (Shiomi and Kuntz, 1973; Acres Consulting Services, 1975, 1977; Kuntz, 1978). Moreover, the number of observations at each station, the time interval and number of analyses of each parameter are different. As a result, the data are grouped into basins, stations and sampler types. The data from each drainage basin are discussed separately and insufficient observations (i.e., <10) at any particular station have been omitted.

Since almost all of the parameters measured in atmospheric precipitation have a lognormal distribution, a geometric mean is considered to be more representative of the true mean than an average value. An average value is usually high. For this reason the calculations and discussion in this report are based on geometric means. Average values are shown for comparative purposes.

In addition, a Student's t test of significance of difference between means was calculated for each basin, using the following equation (Mode, 1966):

$$t = \frac{(\bar{x} - \bar{y}) - (U_{x} - U_{y})}{\sqrt{\left(\frac{N_{x}S_{x}^{2} + N_{y}S_{y}^{2}}{N_{x} + N_{y}-2}\right)\left(\frac{1}{N_{x}} + \frac{1}{N_{y}}\right)}$$

where \overline{x} = mean of sample size X, $\overline{\mathbf{v}} = \text{mean of sample size } \mathbf{Y},$ U_x = mean of population X,

 U_{v} = mean of population Y_{r}

- N_x = population size of X,
- $N_V = population size of Y_{\nu}$
- S_x = standard deviation of sample size X, and
- S_v = standard deviation of sample size Y.

In this formula, the null hypothesis is that $u_X - u_V = 0$

The geometric means were compared for each parameter in each basin to determine whether significant (at the 95% confidence level) differences occurred within the basin. In this test, the highest and lowest geometric mean value for each parameter within the basin was tested for significant difference (at the 95% confidence level). Then the data from one to two stations with high values (depending on the basin) were eliminated and the t test was performed again to determine whether the remaining data were significantly different (at the 95% confidence level) within the basin.

A Student's t test was performed to determine whether any significant (at the 95% confidence level) differences existed between data collected with the Type A and Type B samplers. For this test, all the data from each type of sampler were grouped together and tested for each basin.

Lake Superior Basin Concentration Data

Concentration data (mg/L) for this basin are given for sampling stations at Thunder Bay, Schreiber, Coldwell, Copper Harbor and Isle Royale in Tables 3 to 7. Mean concentrations for all of the data collected in the basin are given in Table 8.

Comparisons of data within the basin show some interesting trends. The approximate order of the stations with respect to increasing local urbanization would be Isle Royale, Copper Harbor, Coldwell, Schreiber and Thunder Bay. This trend is shown in the increasing concentrations of most parameters as one compares Isle Royale data with Thunder Bay data.

Of the parameters measured, Thunder Bay had the highest geometric mean concentrations for total nitrogen; nitrate nitrogen; extractable copper, iron and lead (shared with Coldwell); sodium; potassium and sulphate. The highest total phosphorus, ammonia nitrogen and total Kieldahl nitrogen concentrations were observed at Copper Harbor. Coldwell had the highest extractable lead (shared with Thunder Bay) and zinc concentrations; Isle Royale

had the highest magnesium and chloride concentrations; and Schreiber had the highest calcium concentrations.

The lowest geometric mean concentrations for ammonia and nitrate nitrogen, extractable copper, iron and lead as well as sodium and sulphate were observed at Isle Royale, Coldwell had the lowest concentrations of total phosphorus, total Kjeldahl nitrogen, calcium, potassium and extractable zinc. Copper Harbor had the lowest magnesium concentration and Schreiber had the lowest chloride concentration. The Student's t test performed on all of the data within the Lake Superior Basin showed that ammonia. total Kjeldahl and total nitrogen species were not significantly different within the basin at the 95% confidence level. This is a good indication that these parameters are not locally influenced and that they are good indicators of long-range transport of atmospheric pollutants. All other parameters showed significant variation throughout the basin.

When the station considered to be the most urbanized (i.e., Thunder Bay) within the basin was eliminated, potassium and sulphate showed no significant variation within the basin. Hence, these parameters are somewhat affected by local sources but are more widely dispersed than the remaining parameters measured.

When the geometric mean values for the Type A and B samplers were compared for the Lake Superior Basin, in the Type B samples extractable and total lead were significantly higher, and extractable and total zinc, calcium, magnesium and sodium were lower. These high concentrations of lead and low concentrations of calcium, magnesium and sodium in the Type B samplers can be explained by the use of the glass wool prefilter in the Type A sampler prior to July 1974 (Kuntz, 1978). This filter most likely filtered out many of the lead particulates and also contaminated the samples with calcium, magnesium and sodium. No reason is known why the zinc concentrations in the Type B samples are significantly lower than those in the Type A samples.

Lake Huron Basin Concentration Data

Concentration data (mg/L) for this basin are given for sampling stations at Gore Bay, Parry Sound, Beausoleil Island, Wiarton, Douglas Point, Sarnia and Grand Bend in Tables 9 to 15. Mean concentrations for all of the data collected in the basin are given in Table 16.

The approximate order of the stations with respect to increasing degree of urbanization is Beausoleil Island, Douglas Point, Gore Bay, Parry Sound, Grand Bend, Wiarton and Sarnia.

The highest geometric mean concentrations of nitrate and total nitrogen, total iron and lead, calcium, magnesium and sulphate were observed at Sarnia. Wiarton had the highest geometric mean concentrations of ammonia and total Kjeldahl nitrogen, extractable copper (shared with Gore Bay), total copper and zinc, potassium and extractable lead (shared with Parry Sound). The highest geometric mean concentrations of extractable copper (shared with Wiarton), extractable iron and sodium were observed at Gore Bay. Grand Bend had the highest geometric mean concentration of total phosphorus. Douglas Point had the highest geometric mean concentration of extractable zinc and Parry Sound had the highest geometric mean concentrations of extractable lead (shared with Wiarton) and chloride.

The lowest geometric mean concentrations for total phosphorus, calcium, magnesium and potassium were observed at Beausoleil Island. Douglas Point shared the lowest geometric mean value of extractable copper with Grand Bend. Grand Bend also had the lowest nitrate nitrogen value. The lowest chloride value was observed at Gore Bay. The lowest values for total nitrogen, total copper (shared with Sarnia), total zinc and sulphate were recorded at Wiarton. Sarnia recorded the lowest values of total copper (shared with Wiarton), total iron and lead, ammonia, and extractable iron and zinc.

From these observations, there is no clear trend toward higher concentrations at increasingly urbanized stations, although Wiarton and Sarnia do exhibit high values for 14 of the 19 parameters measured. One reason for this trend is that all of the stations are located in relatively similar local geographic areas. The differences between stations in degree of urbanization are probably not marked enough. The only station that could show some effects owing to local urbanization was Sarnia. The station, however, is located to the northeast of the city and hence misses the major effects of the city, since the predominant wind direction is northwest.

The Student's t test performed on all of the data collected within the Lake Huron Basin showed that total Kjeldahl and total nitrogen, and extractable copper did not vary significantly at the 95% confidence level throughout the basin. This is a good indication that these parameters, especially total Kjeldahl and total nitrogen, are not locally influenced and that they are good indicators of long-range transport of atmospheric pollutants. All of the other parameters measured showed significant variation throughout the basin.

When the stations considered to be the most urbanized (i.e., Sarnia and Wiarton) within the basin were eliminated,

ammonia nitrogen and extractable iron showed no significant variation throughout the basin. Hence these parameters are somewhat affected by local sources but are more widely distributed than the remaining parameters.

When the geometric mean values for the Type A and B samplers were compared for the Lake Huron Basin, ammonia nitrogen, extractable and total zinc, sodium and sulphate were significantly lower in the Type B samples. Extractable and total lead and total copper and iron were significantly higher in the Type B samples. These low concentrations of sodium and sulphate and high concentrations of lead and total copper and iron in the Type B samples can be explained by the use of the glass wool prefilter prior to July 1974 (Kuntz, 1978) with the Type A samplers. This filter most likely filtered out many of the lead, iron and copper particulates and also contaminated the Type A samples with sodium and sulphate. No reason is known why the ammonia nitrogen and zinc are significantly lower in the Type B samples.

Lake Erie Basin Concentration Data

Concentration data (mg/L) are given for sampling stations at Rockwood, Port Stanley and Pelee Island in Tables 17 to 19. Mean concentrations for all of the data collected in the basin are given in Table 20.

Ranking these stations in order of increasing local urbanization would place them in the approximate order of Pelee Island, Port Stanley and Rockwood. Pelee Island data, however, are probably greatly influenced by effects from Toledo, Ohio, which is about 80 km upwind. This could explain why many of the observed high concentrations occur at Pelee Island.

The lowest geometric mean concentrations of total phosphorus and calcium and the highest concentrations of extractable copper (shared with Pelee Island), extractable iron, extractable lead, extractable zinc and sodium were observed at Rockwood.

The lowest geometric mean concentrations of ammonia, nitrate, total Kjeldahl and total nitrogen; extractable copper, lead and zinc; magnesium; sodium; potassium; sulphate and chloride were observed at Port Stanley.

The lowest geometric mean concentrations of extractable iron and the highest geometric mean concentrations of total phosphorus; ammonia, nitrate, total Kjeldahl and total nitrogen; extractable copper (shared with Rockwood) as well as calcium, magnesium, potassium, sulphate and chloride were observed at Pelee Island. These high concentrations of total phosphorus; ammonia, nitrate, total Kjeldahl and total nitrogen; and potassium may be the result of the high agricultural activity around this section. Artificial fertilizers used for agricultural purposes contain high concentrations of nitrogen, phosphorus and potassium. The high calcium and magnesium concentrations at this station may also be associated with soil particle contamination owing to agricultural activity. The high sulphate concentrations observed may result from inputs from industrial activity at Toledo, Ohio.

The Student's t test performed on all of the data collected within the Lake Erie Basin showed that total nitrogen, extractable iron, sodium and chloride did not vary significantly at the 95% confidence level throughout the basin. Of these three parameters, only total nitrogen is considered to be a good indicator of long-range transport of atmospheric pollutants. The fact that extractable iron, sodium and chloride did not vary significantly throughout the basin may show that they are indicators of long-range transport but more likely indicates that each station in the basin is similarly affected by local effects.

When the station considered to be affected the most by urbanization (i.e., Pelee Island) was eliminated, nitrate and total Kjeldahl nitrogen, calcium and magnesium showed no significant variation throughout the basin. Hence, these parameters are somewhat affected by local sources but are more widely distributed than the remaining parameters.

When the geometric mean values for the Type A and B samplers were compared for the Lake Erie Basin, ammonia nitrogen, extractable copper, extractable zinc, sodium, potassium and sulphate values were significantly lower in the Type B samples, while total iron and lead were significantly higher in the Type B samples. No reason is known why the ammonia nitrogen and extractable copper and zinc are lower in the Type B samples. The low concentrations of sodium, potassium and sulphate in the Type B samplers are readily explained by the contamination of the Type A samples by the glass wool prefilter used prior to July 1974 in the Type A sampler (Kuntz, 1978). Also, this glass wool prefilter probably filtered out many of the iron and lead particulates in the Type A samplers, thus making the Type B samples appear significantly higher.

Lake Ontario Basin Concentration Data

Concentration data (mg/L) are given for sampling stations located at Burlington, Ancaster, Toronto Island, Woodbridge, Trenton and Kingston in the Lake Ontario drainage basin in Tables 21 to 26. Mean concentrations for all of the data collected in the basin are given in Table 27. Ranking these stations in order of increasing local urbanization would place them in the following approximate order: Trenton, Kingston, Ancaster, Woodbridge, Burlington and Toronto Island.

At Trenton, the lowest concentrations of total phosphorus, nitrate and total Kjeldahl nitrogen, and magnesium were found, while the highest concentrations of potassium were observed.

At Kingston, the lowest concentrations of ammonia and total nitrogen, extractable iron and zinc, calcium, sulphate and chloride were found, while the highest concentrations of extractable copper (shared with Toronto Island) were observed.

At Ancaster, the lowest concentrations of extractable lead and the highest concentrations of extractable zinc were found.

At Woodbridge, the lowest concentrations of extractable copper, total iron, sodium and potassium were observed.

At Burlington, the lowest concentrations of total copper and lead and the highest concentrations of total phosphorus, ammonia, total Kjeldahl and total nitrogen, total zinc, calcium, magnesium, sodium, sulphate and chloride were observed.

At Toronto Island, the lowest concentrations of total zinc and the highest concentrations of nitrate nitrogen; extractable copper (shared with Kingston); total copper, iron and lead; and extractable iron and lead were observed.

The Student's t test performed on all of the data collected within the Lake Ontario Basin showed that all of the parameters varied significantly within the basin at the 95% confidence level. This probably indicates that each station within this basin is similarly affected by its local sources.

When the two stations considered to be most affected by urbanization (i.e., Burlington and Toronto Island) were eliminated, only total nitrogen and extractable iron did not show significant variation within the basin. Once again, total nitrogen is probably an indicator of long-range transport of atmospheric pollutants.

When the geometric mean values for Type A and B samplers were compared for the Lake Ontario Basin, nitrate and total Kjeldahl nitrogen, extractable copper and zinc, and total zinc were significantly lower in the Type B samplers. Total copper, total iron, total lead, extractable lead, calcium, magnesium and chloride were significantly higher in the Type B samplers. No reason is known why the nitrate and total Kjeldahl nitrogen, extractable copper, extractable zinc and total zinc are lower in the Type B samplers. Higher values of total copper, iron and lead and extractable lead in the Type B samplers may be explained by the filtering out of particulates in the Type A samplers by the glass wool prefilter prior to July 1974, thus making the Type B samples appear significantly higher. The high calcium, magnesium and chloride concentrations observed in the Type B samplers may be due to greater soil particle contamination in the Type B sampler than in the Type A sampler. The glass wool prefilter may have filtered out many of these soil particles in the Type A sampler.

Loading Calculations

Since concentration, sample volume, surface area for each sampler type and time interval of collection were. measured for each sample collected, a deposition per day was calculated for each parameter and expressed in milligrams per square metre per day. The geometric means of these areal deposition rates were calculated and then the units were converted to kilograms per square kilometre per year by multiplying by 365.25.

A sample calculation for Lake Ontario total phosphorus would be:

Geometric mean total phosphorus deposition is $0.052 \text{ mg/m}^2/\text{day}$.

Total phosphorus deposition = $0.052 \times 365.25 = 19 \text{ kg/km}^2/\text{yr}$

Surface area of Lake Ontario = 19.5×10^3 km²

...Total phosphorus loading to Lake Ontario surface from atmospheric sources = $19.5 \times 10^3 \times 19$ = 370×10^3 kg/yr = 370 metric tonnes/yr

Calculated areal deposition rates for each of the Great Lakes basins are given in Table 28. This table also shows population figures for each basin taken from "Population Estimates for the Great Lakes Basins and their Major Tributaries" (CCIW, 1973).

These data show a consistent decreasing trend for many parameters as population in the basin decreases. Those parameters showing a consistent decrease in areal loading rates as the population in the basin decreases are total phosphorus; ammonia, total Kjeldahl, nitrate and total nitrogen (calculated from total Kjeldahl plus nitrate nitrogen); calcium; magnesium; potassium and sulphate.

Extractable copper, iron, lead and zinc; total copper, lead and zinc; and chloride have relatively similar deposition rates in all four basins. This indicates that either local sources are insignificant, local sources are nearly identical throughout the four basins or these parameters are indicators of long-range transport of atmospheric pollutants.

In Table 29, a comparison of atmospheric loadings and total loadings is given for total phosphorus, total nitrogen and chloride for each lake basin. This table shows the increasing importance of atmospheric loadings as one progresses up the chain of the Great Lakes drainage basin from Lakes Ontario and Erie to Lakes Huron and Superior.

These percentages of total loadings to Lakes Superior and Huron are even more important when one considers that of the total drainage basins for Lakes Superior and Huron, 40% and 31%, respectively, consist of the lake surface itself (Elder *et al.*, 1976). Lake Superior has no upstream lakes and hence most of the water supply to the lake is derived from atmospheric precipitation. For Lake Huron, the overall importance of atmospheric precipitation is less because upstream flows are received from both Lakes Michigan and Superior.

For Lakes Erie and Ontario, although 33% and 22%, respectively, of their total drainage basins (Rainey, 1967) consist of their surface areas, upstream inputs are much greater than atmospheric inputs. Industrial and municipal inputs to these lakes are also much larger than for Lakes Superior and Huron.

SUMMARY

The data have been analyzed on a station and basin basis. When tests of significance were completed for each basin, ammonia, total Kjeldahl and total nitrogen did not vary significantly within the Lake Superior Basin; total Kjeldahl and total nitrogen and extractable copper did not vary significantly in the Lake Huron Basin; and total nitrogen, extractable iron, sodium and chloride did not vary significantly in the Lake Erie Basin. In the Lake Ontario Basin, all of the parameters showed significant variations throughout the basin.

This is one of the major problems encountered in sampling atmospheric precipitation. Concentrations of samples collected vary greatly, depending on wind direction; amount of rainfall; agricultural, industrial or urban activities; local terrain; time since the last rainfall; and numerous other variables. Different types of samplers also give different results. In this study, calcium, magnesium, sodium, sulphate and potassium analyses were often higher in the Type A samplers due to contamination by the glass wool prefilter used prior to July 1974. Total lead, iron, copper and zinc were generally lower in Type A samplers because the glass wool prefilter probably filtered out many of the particulates containing these parameters.

There is an apparent correlation between the chemical composition of atmospheric bulk precipitation and the population of the basin. Basin geometric mean concentrations of total phosphorus; nitrate, total Kjeldahl and total nitrogen; calcium; magnesium; sodium and sulphate were appreciably higher in the Lake Ontario and Erie basins than in the Lake Huron and Superior basins.

The following have relatively similar deposition rates in all four basins: extractable copper, iron, lead and zinc; total copper, lead and zinc; and chloride.

The percentage of total loadings for total phosphorus, total nitrogen and chloride to Lakes Huron and Superior contributed by atmospheric inputs is much greater than that contributed by atmospheric precipitation to Lakes Erie and Ontario. Atmospheric inputs are very important in Lakes Superior and Huron because the surface areas of these lakes are large in relation to their drainage basin areas. Lake Superior receives few or no upstream inputs from other lakes and industrial and municipal inputs. Lake Huron receives industrial and municipal inputs via the St. Marys River, some from Lake Michigan and greater inputs via the Saginaw River into Saginaw Bay. These inputs, however, are smaller than the industrial and municipal inputs to the lower Great Lakes.

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Tables

					Туре А		Туре В	
Station	Latitude	Longitude	Description	Installation date	Discontinued	Installation date	Discontinued	
Toronto Island	43° 37′ 54″	79°23'48″	Toronto Island Airport beside weather office, Toronto, Ont.	69-07-28	76-12-01	72-12-01	76-12-30	
Kingston	44°13'05″	76° 35' 46″	Kingston Airport near weather office, Kingston, Ont.	69-07-29	76-12-02	72-12-01	76-12-01	
C.F.B. Trenton	44°06'40″	77° 32' 38″	Trenton Armed Forces Base near weather office, Trenton, Ont.	69-08-01	76-12-06	72-12-01	76-11-02	
Woodbridge	43°47'36″	79° 34'09″	Near Woodbridge, Ont., at Meteorological Research Station	69-07-31	76-12-01	72-12-01	76-12-01	
Burlington	43°17′56″	79°47'58″	At CCIW, Burlington, Ont.	69-08-18	76-12-30	71-12-31	76-12-01	
Ancaster	43°10'31″	79° 57'00″	Near Ancaster, Ont., on J.R. Kramer property	69-11-28	76-12-01	_	_	
Port Stanley	42°40′14″	81°13'28″	Near Port Stanley, Ont., on Marr Bros. Farm	70-06-09	76-11-01	72-12-01	75-10-01	
Pelee Island	41°45′02″	82°41'13″	Pelee Island, SW corner in western Lake Erie on farm of C. Pierce	70-06-09	76-04-02	72-12-01	74-06-04	
Gore Bay	45°53'06"	82° 34' 28"	Gore Bay Airport, Gordon Township, Ont., on Manitoulin Island	70-07-13	75-11-01	73-12-01	75-10-01	
Schreiber	48°48′00″	87°16'00″	Schreiber, Ont., on D.L. Wilson property	70-07-15	73-03-31	_	_	
Thunder Bay	45°22'27"	89°18'38″	Thunder Bay Airport in meteorological compound, Thunder Bay, Ont.	70-07-16	76-10-31	73-05-15	76-10-31	
Wiarton	44°44'48"	81°06′46″	Wiarton Airport near weather office, Wiarton, Ont.	70-07-12	77-01-01	72-12-01	77-01-01	
Rockwood	4 3° 38'04″	80°06′52″	Farm at Blue Springs Creek International Hydrological Decade station near Rockwood, Ont.	70-07-01	75-05-14	72-12-06	74-03-01	
Sarnia	42° 59′ 48″	82°18'25″	Sarnia Airport near weather station, Sarnia, Ont.	71-02-04	76-11-01	72-12-01	77-01-01	
Copper Harbor	47°28′12″	87° 52' 54"	Fort Wilkins State Park near Copper Harbor, Michigan	73-03-15	75-07-01	73-03-15	75-07-01	
Isle Royale	47°55'15″	89°08'30″	Windigo Ranger Station on Isle Royale off Thunder Bay, Ont.	73-05-16	75-07-01	73-05-16	75-07-01	
Coldwell	48°46′38″	86° 35' 12"	Near park entrance in clearing near railroad track near Coldwell, Ont.	73-05-31	76-12-01	73-05-17	76-12-01	
Grand Bend	43°15′26″	81°49′38″	Pinery Provincial Park near Grand Bend, Ont.	73-10-25	76-11-06	73-10-25	76-02-03	
Douglas Point	44°18'03″	81° 35'25″	Inverhuron Provincial Park near Douglas Point, Ont.	73-10-25	76-11-01	73-10-25	76-11-01	
Beausoleil Island	44° 50' 50″	79° 51' 50″	Beausoleil Island in Georgian Bay Islands National Park near Honey Harbour, Ont.	73-11-28	76-12-01	73-11-28	76-12-01	
Parry Sound	45°21′46″	80°49'38″	Killbear Provincial Park near Park entrance near Nobel, Ont.	73-10-30	76-12-01	73-10-30	76-12-01	

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Table 1. Great Lakes Precipitation Chemistry Stations

Method	Range	Detection limit	Standard deviation
Total phosphorus	0-50 μg/L	0.2 µg/L	0.41 at 10 µg/L-P
Ammonia nitrogen	0-1000 μg/L	1 μg/L	0.60 at 45 µg/L-N
Nitrate nitrogen	0-500 μg/L	$1 \mu g/L$	4.5 at 375 µg/L-N
Total Kjeldahl nitrogen	$0-1000 \ \mu g/L$	$10 \mu g/L$	2.8 at 60 µg/L-N
Total nitrogen	0-1000 µg/L	$10 \mu g/L$	10 at 145 µg/L-N
Copper, extractable	$0-40 \ \mu g/L$	$0.2 \ \mu g/L$	0.10 at 0.90 µg/L
Copper, total	0-80 µg/L	$0.2 \ \mu g/L$	0.20 at 0.90 µg/L
Iron, extractable	0-40 µg/L	$0.2 \ \mu g/L$	0.10 at 5.6 µg/L
Iron, total	0-80 µg/L	$0.2 \ \mu g/L$	0.20 at 5.6 µg/L
Lead, extractable	0-40 μg/L	$0.2 \ \mu g/L$	0.10 at 0.90 µg/L
Lead, total	$0-80 \ \mu g/L$	$0.2 \ \mu g/L$	0.20 at 0.90 µg/L
Zinc, extractable	0-40 µg/L	0.5 µg/L	0.20 at 7.9 µg/L
Zinc, total	0-80 µg/L	$0.5 \mu g/L$	0.40 at 7.9 µg/L
Calcium	0-20 mg/L	0.05 mg/L	0.05 at 8.7 mg/L
Magnesium	0-10 mg/L	0.01 mg/L	0.10 at 6.3 mg/L
Sodium	0-10 mg/L	0.02 mg/L	0.11 at 2.11 mg/L
Potassium	0-10 mg/L	0.02 mg/L	0.04 at 0.20 mg/L
Sulphate	0-20 mg/L	0.20 mg/L	0.05 at 5.0 mg/L
Chloride	0-10 mg/L	0.05 mg/L	0.04 at 6.2 mg/L

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	т	ype A sampler		Т	ype B sampler	
Parameter	No. observations	Arithmetic mean	Geometric mean	No. observations	Arithmetic mean	Geometric mean
Total phosphorus	66	0.033	0.023	42	0.067	0.038
Ammonia nitrogen	69	0.61	0.44	14	0.57	0.39
Nitrate nitrogen	70	0.77	0.57	15	0.47	0.33
Total Kjeldahl nitrogen	30	0.92	0.78	33	0.96	0.80
Total nitrogen	12	1.15	1.03	13	1.07	0.86
Copper, extractable	46	0.005	0.004	14	0.018	0.010
Iron, extractable	46	0.037	0.018	13	0.081	0.046
Lead, extractable	46	0.008	0.006	13	0.024	0.018
Zinc, extractable	48	0.107	0.064	13	0.046	0.037
Calcium	61	3.73	1.70	13	1.33	1.04
Magnesium	56	0.58	0.32	13	0.17	0.15
Sodium	56	2.95	1.24	14	1.00	0.52
Potassium	61	0.34	0.23	14	0.33	0.26
Sulphate	65	4.95	4.16	13	4.52	4.35
Chloride	65	4.86	1.64	14	2.56	1.50

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Table 4.	Concentration	Data	(mg/L)	at Schreiber
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		Туре А	sampler
Parameter	No. observations	Arithmetic mean	Geometric mean
Total phosphorus	24	0.024	0.019
Ammonia nitrogen	26	0.50	0.41
Nitrate nitrogen	26	0.67	0.49
Copper, extractable	21	0.008	0.006
Iron, extractable	22	0.035	0.022
Lead, extractable	21	0.010	0.007
Zinc, extractable	22	0.058	0.049
Calcium	23	2.66	1.96
Magnesium	23	0.43	0.33
Sodium	24	1.16	0.82
Potassium	24	0.30	0.19
Sulphate	24	4.86	3.85
Chloride	25	1.57	0.58

Table 5. Concentration Data (mg/L) at Coldwell

	Т	ype A sampler		Type B sampler		
Parameter	No. observations	Arithmetic mean	Geometric mean	No. observations	Arithmetic mean	Geometric mean
Total phosphorus	36	0.022	0.016	40	0.025	0.012
Ammonia nitrogen	34	0.52	0.41	13	0.66	0.55
Nitrate nitrogen	34	0.47	0.37	13	0.49	0.46
Total Kjeldahl nitrogen	28	0.72	0.61	33	0.72	0.57
Total nitrogen	10	1.11	0.89	10	1.25	1.01
Copper, extractable	19	0.004	0.003	10	0.004	0.003
Iron, extractable	25	0.037	0.021	10	0.053	0.033
Lead, extractable	23	0.009	0.006	10	0.021	0.018
Zinc, extractable	27	0.204	0.123	10	0.021	0.016
Calcium	27	0.92	0.75	10	0.49	0.42
Magnesium	27	0.19	0.15		-	_
Sodium	21	0.37	0.25	_	_	_
Potassium	31	0.32	0.12	10	0.11	0.09
Sulphate	33	3.86	3.50	11	3.64	3.34
Chloride	32	2.99	2.01	10	3.31	1.50

	Т	ype A sampler		Type B sampler			
Parameter	No. observations	Arithmetic mean	Geometric mean	No. observations	Arithmetic mean	Geometric mean	
Total phosphorus	18	0.166	0.039	28	0.072	0.029	
Ammonia nitrogen	16	0.93	0.57	15	0.65	0.38	
Nitrate nitrogen	16	0.39	0.36	15	0.37	0.30	
Total Kjeldahl nitrogen	10	1.03	0.83	17	0.94	0.71	
Total nitrogen	_		_	14	1.23	0.92	
Copper, extractable	14	0.003	0.003	15	0.136	0.003	
Iron, extractable	14	0.010	0.007	15	0.015	0.010	
Lead, extractable	15	0.004	0.004	14	0.024	0.011	
Zinc, extractable	15	0.057	0.035	15	0.049	0.025	
Calcium	15	1.53	1.07	14	0.66	0.54	
Magnesium	15	0.27	0.22	11	0.12	0.10	
Sodium	13	0.81	0.49	13	0.20	0.15	
Potassium	15	0.25	0.17	14	0.29	0.19	
Sulphate	16	3.57	3.51	15	3.34	2.82	
Chloride	16	1.79	1.21	15	1.65	1.15	

Table 6. Concentration Data (mg/L) at Copper Harbor

Table 7. Concentration Data (mg/L) at Isle Royale

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	т	'ype A sampler		Type B sampler		
Parameter	No. observations	Arithmetic mean	Geometric mean	No. observations	Arithmetic mean	Geometric mean
Total phosphorus	15	0.033	0.016	21	0.068	0.025
Ammonia nitrogen	15	0.38	0.29	12	0.58	0.35
Nitrate nitrogen	15	0.24	0.17	12	0.31	0.25
Total Kjeldahl nitrogen	_	_	_	13	0.95	0.68
Total nitrogen	_	-	-	10	1.14	0.97
Copper, extractable	14	0.002	0.002	11	0.002	0.002
Iron, extractable	14	0.011	0.005	12	0.011	0.009
Lead, extractable	14	0.004	0.003	12	0.006	0.005
Zinc, extractable	14	0.155	0.092	12	0.015	0.011
Calcium	12	2.08	1.61	_	_	_
Magnesium	13	0.48	0.37	_		_
Sodium	11	0.99	0.70	10	0.10	0.08
Potassium	13	0.31	0.19	11	4.61	0.22
Sulphate	15	2.89	2.73	12	3.32	2.97
Chloride	14	4.46	3.12	12	2.58	1.54

Parameter	No.	Arithmetic	Geometric
Total phosphorus	290	0.049	0.022
Ammonia nitrogen	214	0.59	0.42
Nitrate nitrogen	216	0.56	0.40
Total Kjeldahl nitrogen	173	0.85	0.69
Total nitrogen	87	1.18	0.96
Copper, extractable	164	0.018	0.003
Copper, total	37	0.011	0.007
Iron, extractable	171	0.033	0.016
Iron, total	41	0.416	0.135
Lead, extractable	168	0.011	0.007
Lead, total	39	0.026	0.015
Zinc, extractable	176	0.095	0.049
Zinc, total	40	0.128	0.053
Calcium	184	2.22	1.16
Magnesium	170	0.39	0.23
Sodium	169	1.43	0.52
Potassium	193	0.55	0.18
Sulphate	204	4.19	3.62
Chloride	203	3.28	1.46

Table 8. Accumulated Concentration Data (mg/L), Lake Superior

Table 9. Concentration Data (mg/L) at Gore Bay

	Type A sampler			Type B sampler		
Parameter	No. observations	Arithmetic mean	Geometric mean	No. observations	Arithmetic mean	Geometric mean
Total phosphorus	57	0.062	0.022	25	0.026	0.018
Ammonia nitrogen	58	0.65	0.45	12	0.56	0.48
Nitrate nitrogen	58	1.08	0.87	12	1.01	0.92
Total Kjeldahl nitrogen	19	1.00	0.87	19	0.87	0.72
Total nitrogen	11	1.56	1.44			_
Copper, extractable	51	0.007	0.004	11	0.006	0.005
Copper, total	-	_		10	0.008	0.007
Iron, extractable	53	0.022	0.012	11	0.044	0.027
Iron, total		_	_	10	0.088	0.059
Lead, extractable	49	0.010	0.006	-	_	_
Zinc, extractable	53	0.095	0.063	10	0.066	0.046
Calcium	55	2.54	1.87	11	1.74	1.35
Magnesium	52	0.47	0.37	10	0.50	0.36
Sodium	49	1.27	0.85	_	_	_
Potassium	58	0.31	0.19	11	0.18	0.16
Sulphate	57	5.77	5.23	10	5.11	4.53
Chloride	58	1.52	0.79	11	1.97	1.35

	Т	ype A sampler		Type B sampler		
Parameter	No. observations	Arithmetic mean	Geometric mean	No. observations	Arithmetic mean	Geometric mean
Total phosphorus	35	0.027	0.017	37	0.036	0.017
Ammonia nitrogen	34	0.51	0.41			
Nitrate nitrogen	35	0.72	0.67			
Total Kjeldahl nitrogen	32	0.79	0.67	33	0.94	0.75
Copper, extractable	31	0.004	0.003			
Iron, extractable	33	0.044	0.017			
Lead, extractable	31	0.013	0.011			
Zinc, extractable	33	0.306	0.168			
Calcium	33	1.04	0.91			
Magnesium	31	0.22	0.18			
Sodium	24	0.36	0.24			
Potassium	32	0.18	0.13			
Sulphate	35	4.52	4.18			
Chloride	35	3.08	2.15			

Table 10. Concentration Data (mg/L) at Parry Sound

Table 11. Concentration Data (mg/L) at Beausoleil Island

	Т	ype A sampler		Type B sampler		
Parameter	No. observations	Arithmetic mean	Geometric mean	No. observations	Arithmetic mean	Geometric mean
Total phosphorus	36	0.024	0.016	33	0.086	0.026
Ammonia nitrogen	33	0.52	0.46			
Nitrate nitrogen	33	0.77	0.72			
Total Kjeldahl nitrogen	33	0.77	0.69	33	2.32	0.83
Copper, extractable	31	0.004	0.004			
Iron, extractable	32	0.027	0.019			
Lead, extractable	30	0.013	0.011			
Zinc, extractable	32	0.202	0.152			
Calcium	31	1.05	0.83			
Magnesium	27	0.22	0.17			
Sodium	19	0.58	0.34			
Potassium	31	0.14	0.11			
Sulphate	34	4.75	4.54			
Chloride	32	2.11	1.37			

	Т	ype A sampler		Type B sampler		
Parameter	No. observations	Arithmetic mean	Geometric mean	No. observations	Arithmetic mean	Geometric mean
Total phosphorus	74	0.056	0.018	41	0.039	0.024
Ammonia nitrogen	74	0.63	0.53	11	0.48	0.40
Nitrate nitrogen	74	0.97	0.82	12	0.78	0.70
Total Kjeldahl nitrogen	34	0.99	0.87	34	0.89	0.78
Total nitrogen	15	1.36	1.29	_	_	_
Copper, extractable	65	0.025	0.005	11	0.006	0.003
Copper, total	12	0.005	0.004	13	0.077	0.013
Iron, extractable	66	0.017	0.011	11	0.016	0.012
Iron, total	13	0.105	0.060	13	0.202	0.086
Lead, extractable	63	0.008	0.006	11	0.013	0.011
Lead, total	13	0.012	0.010	13	0.021	0.019
Zinc, extractable	67	0.129	0.085	10	0.042	0.036
Zinc, total	13	0.123	0.096	13	0.059	0.044
Calcium	71	2.21	1.73	10	4.56	2.50
Magnesium	67	0.41	0.31	10	0.79	0.45
Sodium	63	1.25	0.74	_	-	_
Potassium	72	0.45	0.22	11	0.23	0.12
Sulphate	73	5.65	5.24	10	4.52	3.69
Chloride	73	1.99	1.18	11	1.83	1.32

Table 12. Concentration Data (mg/L) at Wiarton

Table 13. Concentration Data (mg/L) at Douglas Point

	Т	ype A sampler		Type B sampler		
Parameter	No. observations	Arithmetic mean	Geometric mean	No. observations	Arithmetic mean	Geometric mean
Total phosphorus	35	0.223	0.025	36	0.039	0.018
Ammonia nitrogen	32	0.58	0.48			
Nitrate nitrogen	33	0.73	0.69			
Total Kjeldahl nitrogen	31	1.24	0.78	32	0.89	0.65
Copper, extractable	27	0.004	0.002			
Iron, extractable	31	0.018	0.013			
Lead, extractable	31	0.009	0.007			
Zinc, extractable	31	0.293	0.200			
Calcium	33	1.67	1.37			
Magnesium	32	0.44	0.35			
Sodium	22	0.42	0.27			
Potassium	31	0.24	0.13			
Sulphate	33	5.07	4.77			
Chloride	33	3.26	1.82			

	Т	ype A sampler		Type B sampler		
Parameter	No. observations	Arithmetic mean	Geometric mean	No. observations	Arithmetic mean	Geometric mean
Total phosphorus	61	0.036	0.024	40	0.040	0.023
Ammonia nitrogen	62	0.65	0.53	12	0.38	0.32
Nitrate nitrogen	63	1.25	1.04	12	0.97	0.84
Total Kjeldahl nitrogen	31	0.96	0.80	34	0.81	0.71
Total nitrogen	13	2.23	1.89	-	_	_
Copper, extractable	54	0.004	0.003	_	-	
Copper, total	12	0.005	0.004	14	0.017	0.009
Iron, extractable	55	0.022	0.010	11	0.009	0.003
Iron, total	13	0.062	0.034	14	0.731	0.167
Lead, extractable	52	0.010	0.006	10	0.005	0.003
Lead, total	12	0.007	0.006	14	0.060	0.028
Zinc, extractable	56	0.110	0.076	11	0.023	0.018
Zinc, total	13	0.080	0.059	14	0.081	0.055
Calcium	60	4.36	3.71	11	7.16	5.56
Magnesium	60	0.66	0.56	11	0.95	0.78
Sodium	53	1.52	0.76	10	0.50	0.46
Potassium	58	0.21	0.16	11	0.16	0.13
Sulphate	61	8.18	7.42	10	8.68	7.52
Chloride	63	3.06	1.75	11	2.69	1.73

Table 14. Concentration Data (mg/L) at Sarnia

Table 15. Concentration Data (mg/L) at Grand Bend

	Т	ype A sampler		Type B sampler		
Parameter	No. observations	Arithmetic mean	Geometric mean	No. observations	Arithmetic mean	Geometric mean
Total phosphorus	28	0.067	0.030	21	0.087	0.027
Ammonia nitrogen	27	0.60	0.46			
Nitrate nitrogen	27	0.65	0.59			
Total Kjeldahl nitrogen	25	0.91	0.77	17	0.98	0.82
Copper, extractable	22	0.003	0.002			
Iron, extractable	26	0.020	0.014			
Lead, extractable	25	0.009	0.007			
Zinc, extractable	26	0.196	0.142			
Calcium	26	2.06	1.45			
Magnesium	26	0.48	0.31			
Sodium	19	0.44	0.27			
Potassium	25	0.28	0.19			
Sulphate	27	5.11	4.63			
Chloride	27	2.79	1.87			

	No.	Arithmetic	Geometric
Parameter	observations	mean	mean
Total phosphorus	559	0.058	0.021
Ammonia nitrogen	388	0.58	0.46
Nitrate nitrogen	392	0.93	0.79
Total Kjeldahl nitrogen	407	1.04	0.76
Total nitrogen	125	1.44	1.28
Copper, extractable	340	0.009	0.003
Copper, total	122	0.015	0.005
Iron, extractable	359	0.023	0.012
Iron, total	127	0.193	0.073
Lead, extractable	340	0.011	0.008
Lead, total	121	0.022	0.014
Zinc, extractable	359	0.147	0.082
Zinc, total	124	0.127	0.064
Calcium	370	2.51	1.71
Magnesium	355	0.47	0.33
Sodium	298	0.94	0.50
Potassium	368	0.27	0.16
Sulphate	381	5.75	5.14
Chloride	381	2.37	1.41

Table 16. Accumulated Concentration Data (mg/L), Lake Huron

Table 17. Concentration Data (mg/L) at Rockwood

		Туре А	sampler
	No.	Arithmetic	Geometric
Parameter	observations	mean	mean
Total phosphorus	51	0.064	0.022
Ammonia nitrogen	49	0.81	0.58
Nitrate nitrogen	50	1.20	0.96
Total nitrogen	15	2.43	2.04
Copper, extractable	44	0.007	0.005
Iron, extractable	43	0.034	0.015
Lead, extractable	43	0.017	0.011
Zinc, extractable	44	0.129	0.096
Calcium	46	2.46	2.12
Magnesium	46	0.57	0.47
Sodium	46 ⁺	2.03	1.16
Potassium	47	0.37	0.25
Sulphate	47	9.09	8.10
Chloride	47	1.65	1.16

	Т	ype A sampler		Type B sampler		
Parameter	No. observations	Arithmetic mean	Geometric mean	No. observations	Arithmetic mean	Geometric mean
Total phosphorus	76	0.081	0.036	39	0.088	0.045
Ammonia nitrogen	75	0.66	0.47	11	0.39	0.27
Nitrate nitrogen	76	1.14	1.02	12	0.94	0.77
Total Kjeldahl nitrogen	34	1.25	0.95	33	1.16	0.96
Total nitrogen	14	1.54	1.33	-	—	-
Copper, extractable	73	0.004	0.003	11	0.002	0.002
Copper, total	12	0.005	0.004	—		_
Iron, extractable	72	0.027	0.012	10	0.024	0.012
Iron, total	13	0.147	0.063		-	_
Lead, extractable	68	0.008	0.005	10	0.017	0.008
Lead, total	13	0.010	0.008	_		
Zinc, extractable	75	0.089	0.057	11	0.023	0.016
Zinc, total	12	0.072	0.048	_	_	
Calcium	74	4.04	3.09	11	4.77	3.21
Magnesium	74	0.59	0.47	11	0.85	0.64
Sodium	65	1.30	0.80	-	-	_
Potassium	75	0.41	0.28	10	0.14	0.12
Sulphate	73	6.86	6.36	10	5.87	4.81
Chloride	74	1.95	1.19	11	1.25	1.15

Table 18. Concentration Data (mg/L) at Port Stanley

Table 19. Concentration Data (mg/L) at Pelee Island

	Type A sampler			Type B sampler		
Parameter	No. observations	Arithmetic mean	Geometric mean	No. observations	Arithmetic mean	Geometric mean
Total phosphorus	68	0.351	0.095	31	0.301	0.102
Ammonia nitrogen	67	1.01	0.60	10	0.42	0.32
Nitrate nitrogen	68	1.61	1.32	10	1.46	1.12
Total Kjeldahl nitrogen	25	3.00	1.61	25	2.16	1.23
Total nitrogen	15	2.66	2.18	_	-	-
Copper, extractable	59	0.029	0.005	-	_	-
Iron, extractable	62	0.024	0.012	10	0.018	0.009
Lead, extractable	59	0.011	0.006		-	-
Zinc, extractable	62	0.065	0.048	10	0.028	0.018
Calcium	68	5.62	4.56	10	7.99	5.08
Magnesium	68	0.85	0.72	10	0.98	0.68
Sodium	64	1.65	0.91	-		_
Potassium	67	0.91	0.42	10	0.28	0.17
Sulphate	66	9.25	8.43		-	
Chloride	68	1.76	1.27	10	1.89	1.66

	No.	Arithmetic	Geometric
Parameter	observations	mean	mean
Total phosphorus	272	0.170	0.048
Ammonia nitrogen	219	0.77	0.50
Nitrate nitrogen	223	1.30	1.07
Total Kjeldahl nitrogen	127	1.77	1.13
Total nitrogen	66	1.99	1.64
Copper, extractable	203	0.012	0.004
Copper, total	38	0.016	0.006
Iron, extractable	204	0.027	0.013
Iron, total	39	0.580	0.149
Lead, extractable	196	0.012	0.007
Lead, total	39	0.022	0.015
Zinc, extractable	209	0.082	0.052
Zinc, total	38	0.063	0.048
Calcium	216	4.47	3.31
Magnesium	215	0.71	0.56
Sodium	199	1.47	0.80
Potassium	216	0.54	0.29
Sulphate	211	8.10	7.21
Chloride	217	1.78	1.23

Table 20. Accumulated Concentration Data (mg/L), Lake Erie

Table 21. Concentration Data (mg/L) at Burlington

	Т	ype A sampler		Т	'ype B sampler	
	No.	Arithmetic	Geometric	No.	Arithmetic	Geometric
Parameter	observations	mean	mean	observations	mean	mean
Total phosphorus	86	0.140	0.061	52	0.161	0.076
Ammonia nitrogen	82	0.99	0.78	27	0.72	0.54
Nitrate nitrogen	86	1.50	1.28	28	1.21	1.12
Total Kjeldahl nitrogen	35	2.60	2.08	28	1.58	1.32
Total nitrogen	15	2.45	2.25	14	2.07	1.96
Copper, extractable	73	0.005	0.004	29	0.004	0.004
Copper, total	12	0.008	0.006		-	_
Iron, extractable	78	0.033	0.017	27	0.051	0.016
Iron, total	13	0.269	0.124	_	_	_
Lead, extractable	75	0.018	0.010	28	0.030	0.017
Lead, total	12	0.031	0.021	_	-	_
Zinc, extractable	77	0.133	0.095	29	0.074	0.061
Zinc, total	11	0.199	0.123	_	-	_
Calcium	82	5.58	4.68	28	9.74	7.46
Magnesium	82	1.03	0.87	28	2.17	1.62
Sodium	80	13.27	3.17	26	8.51	2.87
Potassium	83	0.45	0.34	-28	0.50	0.35
Sulphate	81	11.07	9.71	27	13.48	12.09
Chloride	81	16.76	3.92	28	13.02	5.67

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		Туре А	sampler
	No.	Arithmetic	Geometric
Parameter	observations	mean	mean
Total phosphorus	77	0.205	0.034
Ammonia nitrogen	74	0.73	0.60
Nitrate nitrogen	75	1.27	1.02
Total Kjeldahl nitrogen	30	1.63	1.05
Copper, extractable	65	0.003	0.003
Iron, extractable	69	0.025	0.014
Lead, extractable	67	0.012	0.007
Zinc, extractable	70	0.164	0.100
Calcium	72	4.08	2.61
Magnesium	72	0.78	0.58
Sodium	65	1.26	0.80
Potassium	73	0.26	0.18
Sulphate	72	7.81	7.23
Chloride	72	2.10	1.25

Table 22. Concentration Data (mg/L) at Ancaster

Table 23. Concentration Data (mg/L) at Toronto Island

	Type A sampler			Type B sampler		
Parameter	No. observations	Arithmetic mean	Geometric mean	No. observations	Arithmetic mean	Geometric mean
Total phosphorus	87	0.090	0.041	43	0.082	0.047
Ammonia nitrogen	81	0.67	0.54	18	0.58	0.48
Nitrate nitrogen	83	1.60	1.35	18	1.05	0.88
Total Kjeldahl nitrogen	33	1.84	1.29	30	1.08	0.92
Total nitrogen	14	2.63	2.10	14	1.56	1.46
Copper, extractable	76	0.007	0.005	17	0.006	0.005
Copper, total	14	0.008	0.007	13	0.012	0.009
Iron, extractable	78	0.041	0.024	16	0.040	0.015
Iron, total	14	0.161	0.074	13	0.410	0.185
Lead, extractable	75	0.036	0.020	17	0.051	0.026
Lead, total	14	0.044	0.027	11	0.106	0.070
Zinc, extractable	77	0.118	0.079	17	0.059	0.050
Zinc, total	14	0.132	0.084	13	0.070	0.060
Calcium	84	5.45	3.97	17	6.01	5.17
Magnesium	84	0.80	0.62	16	0.81	0.76
Sodium	77	2.31	1.25	15	1.18	0.62
Potassium	82	0.40	0.27	17	0.26	0.21
Sulphate	84	10.59	9.21	16	9.17	7.09
Chloride	86	5.98	2.12	17	2.69	1.97

	Type A sampler			Type B sampler		
Parameter	No. observations	Arithmetic mean	Geometric mean	No. observations	Arithmetic mean	Geometric mean
Total phosphorus	82	0.253	0.024	48	0.038	0.023
Ammonia nitrogen	81	0.56	0.42	21	0.54	0.42
Nitrate nitrogen	82	1.43	1.13	21	1.18	1.05
Total Kjeldahl nitrogen	32	0.91	0.79	34	0.95	0.68
Total nitrogen	13	1.97	1.61	16	1.79	1.54
Copper, extractable	68	0.005	0.004	20	0.002	0.002
Iron, extractable	74	0.039	0.017	20	0.022	0.011
Lead, extractable	67	0.024	0.013	20	0.027	0.016
Zinc, extractable	72	0.134	0.079	20	0.057	0.043
Calcium	79	3.55	2.72	19	4.17	3.69
Magnesium	79	0.71	0.57	20	0.88	0.74
Sodium	69	1.71	0.98	18	0.88	0.48
Potassium	77	0.39	0.19	19	0.19	0.11
Sulphate	79	7.43	6.66	19	6.95	6.67
Chloride	79	3.30	1.64	20	2.12	1.74

Table 24. Concentration Data (mg/L) at Woodbridge

Table 25. Concentration Data (mg/L) at Trenton

	Type A sampler			Type B sampler			
Parameter	No. observations	Arithmetic mean	Geometric mean	No. observations	Arithmetic mean	Geometric mean	
Total phosphorus	84	0.060	0.022	38	0.047	0.020	
Ammonia nitrogen	84	0.61	0.53	11	0.61	0.44	
Nitrate nitrogen	84	1.17	1.06	11	0.92	0.56	
Total Kjeldahl nitrogen	32	0.84	0.76	32	0.73	0.66	
Total nitrogen	15	1.59	1.48	_	-	_	
Copper, extractable	77	0.006	0.004	10	0.016	0.004	
Iron, extractable	79	0.030	0.014	10	0.021	0.013	
Lead, extractable	77	0.012	0.008	10	0,035	0.017	
Zinc, extractable	80	0.106	0.071	10	0.039	0.033	
Calcium	82	3.33	2.57	10	4.59	4.07	
Magnesium	71	0.37	0.28	-	_	-	
Sodium	72	1.43	0.87		_		
Potassium	81	0.44	0.26	10	0.62	0.37	
Sulphate	83	6.83	6.08	-	-	_	
Chloride	82	1.65	1.15	10	4.23	2.70	

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	Type A sampler			Type B sampler		
Parameter	No. observations	Arithmetic mean	Geometric mean	No. observations	Arithmetic mean	Geometric mean
Total phosphorus	84	0.097	0.030	38	0.097	0.043
Ammonia nitrogen	83	0.62	0.47	11	0.77	0.34
Nitrate nitrogen	84	1.10	0.98	11	0.99	0.66
Total Kjeldahl nitrogen	32	1.35	0.95	33	1.24	0.95
Total nitrogen	14	1.89	1.73		_	_
Copper, extractable	75	0.005	0.003	10	0.012	0.005
Iron, extractable	77	0.030	0.014	10	0.013	0.008
Lead, extractable	74	0.013	0.008	_	_	-
Zinc, extractable	79	0.114	0.070	10	0.035	0.027
Calcium	80	3.13	2.34	10	5.83	3.34
Magnesium	76	0.41	0.29	10	0.91	0.40
Sodium	72	1.38	0.80	-	_	-
Potassium	79	0.31	0.22	10	0.32	0.22
Sulphate	82	6.10	5.35	10	7.00	4.95
Chloride	82	1.62	0.96	10	2.97	1.52

Table 26. Concentration Data (mg/L) at Kingston

Table 27. Accumulated Concentration Data (mg/L), Lake Ontario

Parameter	No. observations	Arithmetic mean	Geometric mean
Total phosphorus	719	0.123	0.035
Ammonia nitrogen	573	0.69	0.53
Nitrate nitrogen	583	1.31	1.09
Total Kjeldahl nitrogen	351	1.35	0.99
Total nitrogen	146	1.98	1.71
Copper, extractable	520	0.006	0.004
Copper, total	105	0.024	0.007
Iron, extractable	538	0.033	0.016
Iron, total	105	0.341	0.130
Lead, extractable	519	0.021	0.011
Lead, total	102	0.047	0.029
Zinc, extractable	541	0.116	0.074
Zinc, total	103	0.140	0.096
Calcium	563	4.57	3.29
Magnesium	547	0.77	0.54
Sodium	511	3.77	1.14
Potassium	559	0.38	0.24
Sulphate	562	8.48	7.27
Chloride	567	5.43	1.77

	Lake	Lake	Lake	Lake
	Erie	Ontario	Huron	Superior
Total phosphorus	30	20	13	10
Ammonia nitrogen	330	300	295	200
Nitrate nitrogen	690	630	500	200
Total Kjeldahl nitrogen	710	610	480	300
Total nitrogen*	1400	1240	980	500
Copper, extractable	3	2	2	2
Copper, total	5	4	4	5
Iron, extractable	8	9	8	10
Iron, total	100	75	58	110
Lead, extractable	4	7	5	4
Lead, total	10	15	10	10
Zinc, extractable	40	50	60	40
Zinc, total	40	60	60	50
Calcium	2140	1830	1060	680
Magnesium	360	310	210	130
Sodium	550	660	300	390
Potassium	200	140	100	90
Sulphate	4870	4140	3200	1800
Chloride	800	960	850	720
Basin population	11.6×10^{6}	6.7 × 10 ⁶	2.3 × 10 ⁶	0.6 × 10 ⁶

Table 28. Great Lakes Areal Deposition Rates (kg/km²/yr)

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*Total-N = NO_3 + total Kjeldahl-N

Table 29. Atmospheric Loadings to the Great Lakes

Basin	Parameter	Atmospheric loading (metric tonnes/yr)	Total loading (metric tonnes/yr)	Atmospheric loading as % of total
Lake Ontario	Total phosphorus	370	12 700*	3
	Total nitrogen†	24 300	197 400*	12
	Chloride	18 700	6 675 300*	<1
Lake Erie	Total phosphorus	740	32 000‡	2
	Total nitrogen†	36 100	_	
	Chloride	20 700	4 652 700‡	<1
Lake Huron	Total phosphorus	800	5 500 §	14
	Total nitrogen+	59 100	159 000 §	37
	Chloride	51 400	1 280 000 §	4
Lake Superior	Total phosphorus	850	4 100**	21
· · · ·	Total nitrogen†	41 400	95 200**	43
	Chloride	59 900	312 000**	19

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27

* From K.E. Willson (Unpublished).
† Total nitrogen - N = NO₃ + total Kjeldahl-N.
‡ From N.M. Burns (1976).
§ From IJC (1977a).
**From IJC (1977b).