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Loading Estimates to Lake Erie, 1967 — 1976

A. S. Fraser and K. E. Willson

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Abstract

This report presents the authors' best estimate of the loading for several chemical variables to Lake Erie. Every effort has been made to obtain original raw data as accepted by local agencies so that a truly independent assessment of loadings could be made. The raw data, once obtained, were treated uniformly to eliminate the difficulties that arise from the comparison of loads calculated by various techniques. However, because of the limitations of sampling a highly variable natural system in the environment, the results included in this study must be called estimates and hence may be subject to unknown or unaccountable errors, which make placement of confidence limits difficult. Nevertheless, the following document is presented with the belief that the results represent the most comprehensive, independent study of loadings to Lake Erie presently available.

Résumé

Nous présentons ici les meilleures estimations qu'il est possible d'obtenir de l'apport de plusieurs matières chimiques dans le lac Érié. Pour affranchir l'évaluation des données de tous les facteurs possibles, nous nous sommes efforcés d'obtenir les données originales brutes acceptées par les organismes locaux, puis nous les avons traitées de façon uniforme pour faciliter la comparaison des apports, opération rendue compliquée par l'existence de diverses techniques de calcul. Toutefois, les limites de l'échantillonnage d'un milieu naturel très variable font qu'il faut tenir les résultats comme des estimations auxquelles il est difficile d'attribuer des seuils de confiance à cause d'erreurs insoupçonnées ou inexplicables. Malgré tout, nous croyons que ces données constituent les résultats les plus détaillés et les plus fiables de l'étude des apports dans le lac Érié.

Acknowledgments

The authors wish to thank all those who cooperated so readily in providing access to the extensive and detailed raw data files required for the successful completion of this project. Thanks also to Mrs. N. Snelling for her tirelessness in typing the manuscript and Mr. W. Finn and the drafting section at the National Water Research Institute for providing the final figures included herein.

Loading Estimates to Lake Erie, 1967 — 1976

A. S. Fraser and K. E. Willson

INTRODUCTION

This report contains the results of an exhaustive search to obtain, collate, and evaluate loading data from all sources to Lake Erie for the period 1967-1976. The underlying purpose of obtaining this information is the requirement for input data of the mathematical simulation models being developed and applied by the Government of Canada. Specifically, activities currently under way for the stabilization and amelioration of the trophic condition of Lake Erie include the development of simulation models that will have predictive capabilities. These models can be of several types ranging from complex systems of interrelated differential equations to simple input-output balances. No matter which kind of approach is used, data sets that contain reliable input data are required.

The emphasis in this study has been placed upon obtaining, where possible, both the flow and concentration data rather than accepting previously computed loads. Once obtained and evaluated, the data sets were uniformly subjected to the loading calculation procedures. Thus for the first time, loading data have been treated uniformly and independently. In some instances where data were not sampled or available, alternative estimation techniques had to be employed. Where this was necessary, a notation of the estimation technique is made in the text.

Much of the attention paid to the Great Lakes since the late 1960's has been related to the trophic condition of the lower lakes (Erie and Ontario). The condition of Lake Erie has been of particular concern owing to the reductions of dissolved oxygen in the hypolimnetic waters of the central basin during the late summer. It has been shown that part of this problem can be related to biological production, which in turn is related to phosphorus loadings to the lake. The importance of knowing as accurately as possible the loadings of total phosphorus leads to the emphasis placed upon this variable in the study. Other variables included are soluble reactive phosphorus, total nitrogen, nitrate plus nitrite nitrogen, Kjeldahl nitrogen, ammonia, and chloride.

DATA SOURCES

To obtain the raw data required in this study, it was necessary to tap many sources of information. A listing of the major tributaries, municipal plants, and industries for which data were obtained is given in Appendix B. The municipal plants listed in Appendix B are the sources considered for the 10-year study even though some of them were not in operation for the entire period. These data could not have been obtained without a high degree of assistance and cooperation from the agencies and individuals contacted by the authors. The primary agencies involved in the data-gathering phase are listed:

(1) Environment Canada/National Water Research Institute
(2) Michigan Department of Natural Resources
(3) New York Department of Environmental Conservation
(4) Ohio Environmental Protection Agency
(5) Ontario Ministry of the Environment
(6) U.S. Environmental Protection Agency
(7) U.S. Geological Survey
(8) U.S. National Oceanic and Atmospheric Administration.

METHODS

To obtain raw data and successfully calculate the loadings to Lake Erie, it was necessary to define the protocol by which sources would be identified and accepted. The following are the operative definitions.

Tributaries

These were considered to be rivers and streams which flow directly into Lake Erie. Concentration data were obtained from the closest water quality monitoring station to the mouth of the river, and the corresponding flow data were obtained from the closest gauging station to the water quality sampling site. No attempt was made to distinguish and identify separately any sources such as municipal plants or industrial outfalls that flowed into a tributary upstream from the water quality site.

The connecting channels associated with Lake Erie, i.e., the Detroit and Niagara Rivers, were considered separately as special cases and will be discussed in detail in the section on computational techniques.

Data for the Canadian tributaries were obtained from the Ontario Ministry of the Environment (MOE) for 1967 to 1974. To fill out and supplement these data for the years 1975 and 1976, additional data were acquired from the information gathered by Pollution from Land Use Activities Reference Group (PLUARG) Canadian Task D. Similarly, data on flows and concentrations for the 14 U.S. tributaries studied were obtained from the water resources publications for New York, Michigan, and Ohio (U.S. Geological Survey 1966-1976). These data were also supplemented by information retrieved directly from the U.S. STORET system, which contains concentration and flow data for specified tributaries in the United States.

Municipal and Industrial

These sources were considered to be either direct point source dischargers to the lake or plants that discharged to a tributary downstream from the selected tributary water quality sampling station. In all cases both the concentration and the flow data were obtained from the closest monitoring point to the plant discharge.

Data for the eight Canadian municipal plants identified for the study were obtained for 1967, 1975, and 1976 from the International Joint Commission reports (1969; 1976). Additional data were obtained for 1968, 1972, 1973, and 1974 from a report by Appelby (1977). Some of these data were incomplete and required estimations to be made prior to usage. The techniques employed to estimate data are discussed in detail in another section.

The U.S. direct municipal dischargers included in this study are those identified in a report by the U.S. Corps of Engineers (1975). Flow and concentration data for the six plants in New York State were abstracted from the operating and maintenance files of the New York State Department of Environmental Conservation (NYDEC). Similarly, the data for 22 municipal dischargers from Ohio were obtained from the records on file with the Ohio Environmental Protection Agency Northeast and Northwest district offices. The data for the three plants located in Michigan were released by the Michigan Department of Natural Resources (MDNR).

The availability of industrial nutrient and chloride data was severely limited, leading to the use of the published material of the International Joint Commission (IJC 1973, 1974, 1975, 1976). The industrial data obtained for the individual sites noted in Appendix A were included in the computations; the State of Ohio in particular maintained excellent records, with the major variable studied being chloride.

Atmospheric

Reliance was placed on published loads with respect to this component. The total yearly loads for total phosphorus, chloride, and total nitrogen were taken from a study by Elder *et al.* (1977). Ammonia, nitrate plus nitrite, and Kjeldahl nitrogen were obtained from the work of Kuntz (1978). Atmospheric loadings were taken to be constant over the 10-year period and were considered to be spatially homogeneous. No doubt these assumptions are not fully applicable but can be reasonably upheld (Elder *et al.* 1977; Canada Centre for Inland Waters 1977).

COMPUTATIONAL TECHNIQUE

In all of the cases under investigation (excepting atmospheric) the availability of a mean annual flow either by direct acquisition or calculated from the monthly flow led to the selection of the loading estimator attributed to E.M.L. Beal and used by the International Joint Commission since 1976 for the computation of the loadings. The properties of the technique were discussed in detail by Tin (1965) and by Kendall and Stuart (1968). The chosen estimator technique uses the additional information, where available, for annual and monthly flows in the computation. Thus, some of the variance associated with perturbations in flow is removed, yielding an estimate with minimized variance associated with the flow component.

The estimator $\tilde{\mu}$ is expressed as follows:

$$\tilde{\mu}_y = \mu_x \cdot \frac{m_y}{m_x} \cdot \frac{\left(1 + \frac{1}{n}\,\frac{S_{xy}}{m_y m_x}\right)}{\left(1 + \frac{1}{n}\,\frac{S_x^2}{m_x^2}\right)} \qquad (1)$$

where μ_x = mean daily flow for the year

m_y = mean daily loading for the days concentrations were determined

m_x = mean daily flow for the days concentrations were determined

n = number of days concentrations were determined

$$S_{xy} = \frac{\sum_{i=1}^{n} X_i Y_i - n \cdot m_y \cdot m_x}{n-1}$$

$$S_x^2 = \frac{\sum_{i=1}^{n} X_i^2 - n \cdot m_x^2}{n-1}$$

and the X_i and Y_i are the individual measured flow and calculated loading, respectively, for each day concentrations were determined. The mean-square-error of this estimator may be estimated to terms of the order n^{-2}, assuming the population size is very large, by

$$\hat{E}\left[({}^{\backprime}\mu - \mu_y)^2\right] = m_y^2 \cdot$$
$$\left[\frac{1}{n} \cdot \left(\frac{S_x^2}{m_x^2} + \frac{S_y^2}{m_y^2} - 2\frac{S_{xy}}{m_x m_y}\right)\right.$$
$$+ \frac{1}{n^2} \cdot \left(2 \cdot \left(\frac{S_x^2}{m_x^2}\right)^2 - 4\frac{S_x^2}{m_x^2}\frac{S_{xy}}{m_x m_y}\right.$$
$$\left.\left. + \left(\frac{S_{xy}}{m_x m_y}\right)^2 + \frac{S_x^2}{m_x^2}\frac{S_y^2}{m_y^2}\right)\right] \qquad (2)$$

where S_y^2 is calculated analogously to S_x^2.

CONNECTING CHANNELS

Detroit River

The Detroit River exhibits a complex structure with respect to water quality variable concentrations. In the region chosen for the computation of the loads out of the river (range DT 3.9) the horizontal concentration gradients for phosphorus and chloride, for example, are quite strong and opposite in direction across the transect (Fig. 1). This situation necessitates the subdivision of the transect into panels and a weighting of the flow regime in order to compute representative loadings from the river. The panel weighting was made by considering a uniformly distributed flow at range DT 3.9 and proportioning this flow by the panel areas.

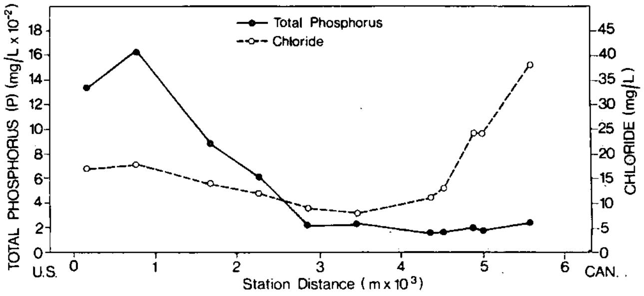

Figure 1. Detroit River range 3.9 showing changes in total phosphorus and chloride concentrations.

The Detroit River range 3.9, which stretches between Lee Point in the United States and Bar Point in Canada, has been segmented into 20 panels in a report by the U.S. Army Corps of Engineers (1975). For the purposes of this study a comparison was made between the sampling locations used over the 10-year period by the Ontario Ministry of the Environment and the Michigan Department of Natural Resources relative to the river segmentation. In this study the river range was segmented into 13 panels so that two water quality sampling sites would be located in each panel and over the 10-year study period there would always be at least one sampled station in each panel for each year (Fig. 2).

Daily flow records for the Detroit River from 1968 to 1976 were obtained from the U.S. Geological Survey, using the computation made by the National Oceanic and Atmospheric Administration based on variations in river and lake levels. These data were supplemented by additional records of flow for 1967 estimated from the mean monthly calculations reported by Dercki (1975).

The Canadian chemical data analyzed by the Ontario Ministry of the Environment for 1967-1976 were supplied by PLUARG Canadian Task D. Similarly, data for the U.S. component were obtained from the U.S. STORET system operated by the U.S. Environmental Protection Agency.

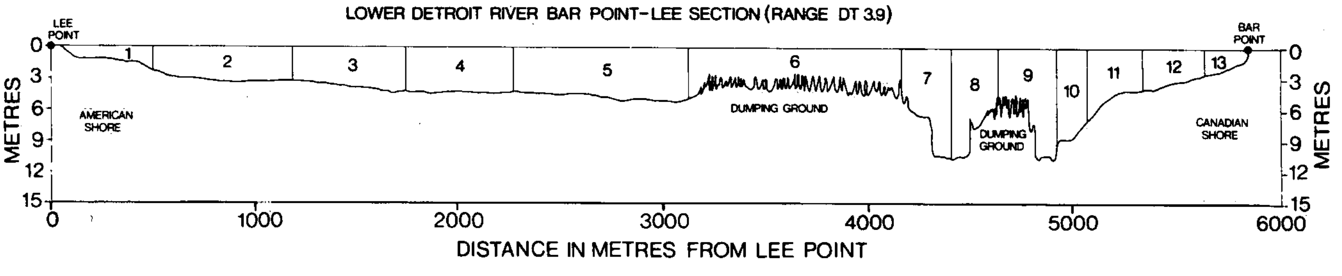

Figure 2. Detroit River range 3.9 showing panel structure.

When these data sets were combined, a total of 22 sampling stations were available over the 10-year period.

Computation of the river load was made by summing the contribution from each of the panels, which were treated as independent sections with their own variable concentrations and flow. The unbiased estimator (Equation 1) was used in all cases to obtain the panel load.

Niagara River

A procedure similar to that used for the Detroit River was adopted for the outflow channel with the difference being that the transect between Fort Erie, Ontario, and Buffalo, New York, was subdivided into nine area weighted panels. Flow data were obtained from the U.S.G.S. water resources publications for the State of New York (U.S. Geological Survey 1966-1976). The flows were measured as power-plant discharges plus an estimated flow over the falls at Niagara. The chemical concentrations were obtained from the MOE and PLUARG Canadian Task D. The panels were structured so that each segment had one sampling station at the mid-point of the horizontal surface. As was the case with the Detroit River, each panel load was calculated independently using Equation 1. The nine panel loads were summed to obtain the total outgoing load.

ESTIMATION TECHNIQUES

Because of the size and scope of the data set required for this study, and in some cases only partial data availability owing to limitations in the historical data records, several estimation strategies were developed to fill in, where possible, the holes in the comprehensive data matrix. On occasion, some data of questionable quality were also obtained and hence were selectively edited. Missing data of this category were also subject to estimation. The following is a description of the techniques used in this study for estimation.

Tributary Data

For the 10 major and 5 minor tributaries identified from the Canadian drainage area for 1967-1974 only 9 had adequate flow and concentration data. The remaining 6 tributaries reported only concentration data. To compute the required flows for association with tributary concentrations, the estimation scheme proposed by Ongley (1974) was applied, with subsequent estimation of the daily flow from the annual. The relationship is as follows:

$$\log Q = 0.11106 + 0.91414 \log A \qquad (3)$$

where Q = mean annual discharge (cfs)
A = basin area (mi^2)

For 1975 and 1976, loadings computed using Equation 1 were obtained on a water year (October-September) basis for nine of the major Canadian tributaries. It was necessary therefore to convert these to calendar year values. The ratio between calendar and water year loads for the U.S. tributaries described by Sonzogni *et al.* (1978) was used for this purpose. Applying these ratios to the Canadian data yielded the required calendar year loads. The remaining six minor tributaries were estimated for 1975 and 1976 by using the ratio between the total load and the loading for the six rivers during 1974, followed by the application of the results to the 1975/76 data. The net effect was to produce a full 10-year data matrix for the Canadian tributaries.

With respect to the tributaries identified for the U.S. drainage area, two major techniques were used for estimation of missing data. Where data for loads existed for a specific tributary in adjacent years to a missing year, an interpolation based on the ratio of the flows between the years was made. Where no prior loads were reported, the ratio between load and flow was determined for the closest year for which a load was available and subsequently the ratio was applied to the flow obtained for the missing year.

In some instances soluble reactive phosphorus data for U.S. tributaries were missing owing to sampling strategies. Data were estimated by computing the ratio between total phosphorus and soluble reactive phosphorus for the Canadian tributaries and applying it to the total phosphorus data for the U.S. tributaries. This procedure was considered justifiable based on the general similarities in sub-basin characteristics displayed within the study region.

As a consequence of the limitations of sampling strategy, large areas of the nitrogen-related loadings had to be estimated for the contribution from the U.S. tributaries. For total nitrogen, the ratio of the U.S. tributary total phosphorus to the Canadian tributary total phosphorus was applied to the Canadian total nitrogen loading from tributaries, thereby generating a value for the U.S. tributary load. Similarly, with nitrate plus nitrite for the U.S. tributaries between 1967 and 1973 the ratio of U.S. to Canadian tributary total nitrogen was applied to the Canadian nitrite plus nitrate loadings. For ammonia, data for the U.S. tributaries were available for only 1974-1976. To obtain the 1967-1973 estimates, the ratio between ammonia and Kjeldahl nitrogen was computed for 1974-1976 and applied to the Kjeldahl data for the U.S. tributaries during the missing period.

Municipal Data

Concentrations for the Canadian municipal plants with direct discharge to Lake Erie for the years 1968-1974 did not have corresponding flow data available. Therefore, estimates for these years were made by applying the percentage change in effluent concentration for total phosphorus during the missing years to the years for which full data were available and then back-calculating the flow data. This procedure assumes a direct proportional relationship between flow and total phosphorus concentration for municipal effluents. In this manner, 10 years of loads could be calculated for total phosphorus.

Total phosphorus and soluble reactive phosphorus data were obtained for the U.S. municipal plants, with missing areas in the data filled by techniques similar to those described in the section on tributaries. Where loads existed in adjacent years for a specific plant, the missing loads were interpolated based on flow ratios. In cases where no prior load was available, the ratio between flow and load for the closest year was applied to the reported flow for the plant and a load estimate generated.

One major change in sampling occurred during the 10-year study period. Before 1975 the municipal plant outfall for the city of Toledo, Ohio, was located upstream from the Maumee River water quality sampling site and hence this load was included as part of the load from the tributary. In 1975 the water quality site was shifted upstream from the plant outfall, necessitating the inclusion of the Toledo municipal outfall as a point source load for 1975 and 1976.

Some municipal sources included in this study did not report any data for total phosphorus. Since these sources were considered to be significant (flow $>$ 1 MGD*) and flow data alone were available, a percentage increment in load based on flow was calculated and added to the final U.S. municipal plant load figures.

No data for soluble reactive phosphorus were available for Canadian plants so estimates were made on a year-to-year basis by using the ratio (TP:SRP) for the U.S. plants and applying this to the Canadian total phosphorus loads, thus producing estimates for the Canadian soluble reactive phosphorus loads.

As was the situation with the U.S. tributaries concerning the lack of nitrogen data, some of the nitrogen had to be estimated. A good record of BOD_5 (5-day biological oxygen demand) data was obtained for the U.S. municipal plants studied, which permitted the proportional relationship between the total nitrogen load reported by the IJC (1969) and the BOD_5 to be applied to the remaining 9 years of BOD_5 data, producing estimates of the total nitrogen loads from the U.S. municipal plants. For the Canadian plants, the relationship derived for the U.S. plants was in like manner applied as the ratio (Can. Municipal:U.S. municipal) for the years 1968-1976.

The nitrate plus nitrite estimates for some of the Canadian municipal plants were calculated by taking the ratio of the total nitrogen loads between the U.S. and Canadian municipal plants and applying this ratio to the nitrate plus nitrite loads computed from empirical data for the U.S. municipal plants. Similarly, since data were obtained for ammonia loading from U.S. municipal plants, the ratio (U.S. Municipal:Can. Municipal) for Kjeldahl nitrogen was applied to the U.S. municipal data, yielding estimates of the municipal ammonia loadings for Canadian plants.

Industrial Data

As was noted previously, industrial nutrient data were extremely limited, particularly with respect to the nitrogen parameters. For both the Canadian and U.S. total nitrogen data, the ratio for 1967 total phosphorus:total nitrogen available from the IJC (1969) was applied to the total phosphorus industrial loads for 1968-1976. Similarly, for nitrate plus nitrite the ratio (industrial:municipal) for total nitrogen was applied to the municipal nitrate plus nitrite data for both the Canadian and the U.S. industries, yielding estimates for the nitrate plus nitrite loads. With respect to ammonia from industrial sources there was insufficient data either to compute a load or to establish a ratio for estimation purposes. Since Kjeldahl nitrogen is essentially the sum of the organic nitrogen component and ammonia, a percentage (90%) was applied to the Kjeldahl nitrogen to yield an estimate for ammonia. The high percentage of ammonia was considered reasonable, as the sources considered were industries that would normally have low levels of organic nitrogen output.

Limitations in the availability of Kjeldahl nitrogen data for U.S. tributaries and both the U.S. and Canadian municipal and industrial sources forced the use of the relationship:

$$TKN = TN - NO_3 - NO_2$$

for estimating these inputs. Kjeldahl nitrogen for the remaining sources was either computed from raw data or obtained from literature.

Connecting Channels

Owing to the technique of panel segmentation and subsequent flow weighting for both the Detroit and Niagara Rivers, estimation procedures for missing data were twofold. For a given panel for which data were missing in a particular year, an interpolation using the flow ratios of the

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*MGD = Million gallons per day

adjacent years was applied to the missing point. This procedure was employed first, followed by the interpolation using flow ratios between adjacent panels within the same year. As the river segmentation was designed to minimize any estimations at the river ranges with respect to the primary variable, total phosphorus, these procedures were only used in a few cases for secondary variables.

Diffuse Tributary Load

The load from unmonitored tributary sources, estimated as 30% of the total tributary load by the International Joint Commission, was added to the computed load for tributaries. The estimate was made by comparing basin area and load of known and monitored basins with the basin area of unmonitored regions of similar land type and proximity.

DISCUSSION

Comprehensive annual load estimates for the computations of the variables—total phosphorus, soluble reactive phosphorus, total nitrogen, nitrate plus nitrite, Kjeldahl nitrogen, ammonia, and chloride—are provided in Appendix A of this report (Tables A1-A7). No attempt has been made at this time to provide monthly estimates for the loadings; they will be the subject of a separate report.

The variable of major significance in this study, total phosphorus, has shown a marked decrease in the order of 50% over the study period (Fig. 3). The importance and dominance of the influence of the Detroit River component (see Appendix A) is noteworthy here, using the variable total phosphorus as an example. This source alone represented an average of 56% of the total loading to the system. Between 1967 and 1976, the total phosphorus loadings from the river itself dropped from 14 309 to 7991 metric tonnes. Similarly, reductions of approximately 50% can be seen in the contributions from municipal plants and industrial sources, however, reductions in load cannot be seen in the tributary component. These show some variability but no significant reduction. Since tributaries represent and reflect the activities occurring within their respective drainage basins, they cannot be expected to show signs of reduction unless and until control measures on land use activities are implemented.

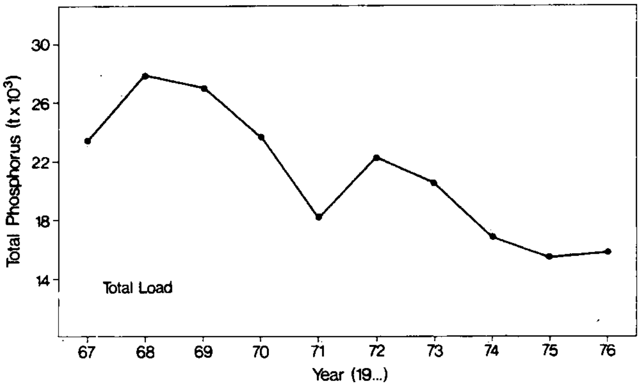

Figure 3. Total loading of Total Phosphorus to Lake Erie.

Soluble reactive phosphorus, which may be considered the soluble inorganic form of phosphorus most readily available for biological use, showed a pattern of reduction similar to total phosphorus. This form represented an average of 34% of the total phosphorus load. The Detroit River again was strongly dominant, with additional reductions noted in the tributary loads as well as the municipal and industrial sources. The downward trend in the total loading results was quite clear, particularly between 1967 and 1969. In the later years of the study, reductions in load continued but at a lesser rate (Fig. 4).

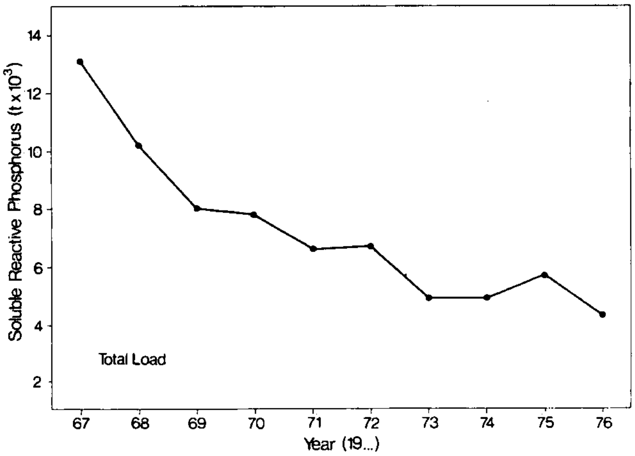

Figure 4. Total loading of Soluble Reactive Phosphorus to Lake Erie.

The four nitrogen variables—total nitrogen, nitrate plus nitrite, Kjeldahl nitrogen, and ammonia—although related, displayed somewhat varied behaviour over the 10 years studied (Figs. 5-8). Nitrate plus nitrite, which constitutes the major soluble inorganic component of total nitrogen, has increased since 1967 with a reasonably stable slope of +7800 metric tonnes per year. Examination of the loading breakdown for nitrate plus nitrite (Table 4) indicates increases in the contributions from the Detroit River and tributary sources corresponding with reductions in the municipal and industrial component. This factor can be related to the installation of municipal treatment plants, which although they are designed to reduce organics and remove phosphorus, also remove an amount of nitrogen in the process. Thus, treated effluents are likely to show reductions, whereas untreated sources may display increases.

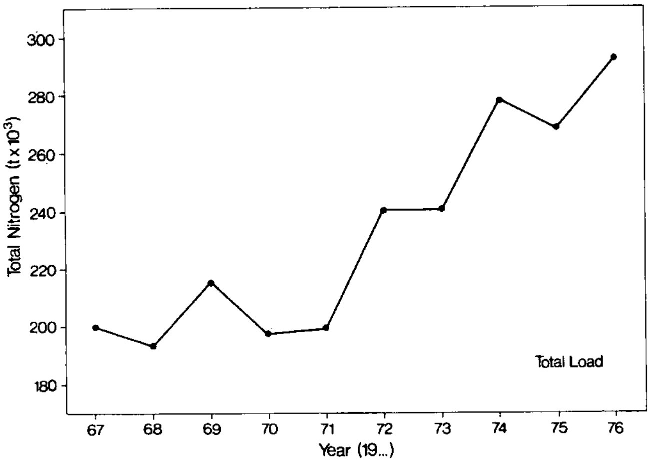

Figure 5. Total loading of Total Nitrogen to Lake Erie.

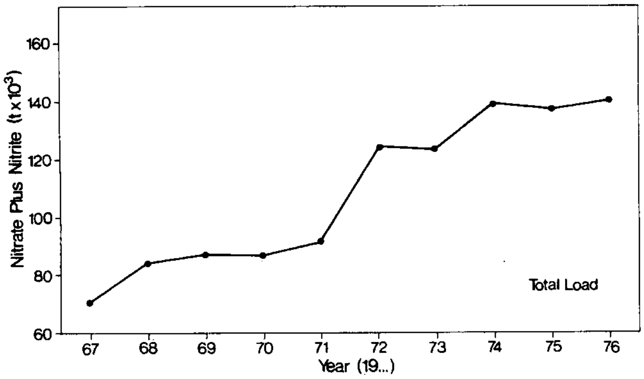

Figure 6. Total loading of Nitrate plus Nitrite to Lake Erie.

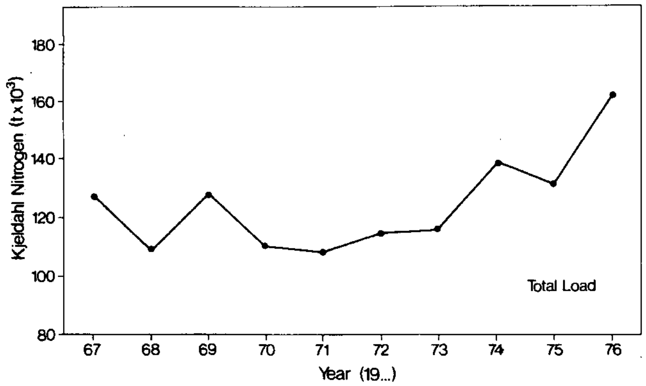

Figure 7. Total loading of Kjeldahl Nitrogen to Lake Erie.

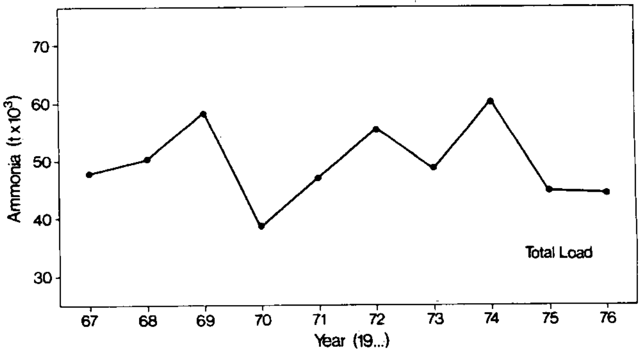

Figure 8. Total loading of Ammonia to Lake Erie.

Kjeldahl nitrogen, which is a combined measure of the organic nitrogen and ammonia component, showed some variability from 1967 to 1970, a leveling up to and including 1973, followed by an increase to 1976. The ammonia loads also showed a great deal of variability, with an average loading of approximately 47 000 metric tonnes per year over the study period. Of note here is the increase in the contribution of organic nitrogen from 1974 to 1976 attributed to the Detroit River and tributaries to Lake Erie.

Considering these three variables of the nitrogen loading together as components of the total nitrogen yields an overall picture of increasing nitrogen loadings to the lake beginning significantly in 1972. The implications and effects of this increase are beyond the scope of this report but it is hoped that the topic will be addressed in other research.

As was outlined in the section entitled "Estimation Techniques," the nitrogen variables required significant estimation in some areas; therefore, with the exception of total nitrogen and nitrate plus nitrite, less confidence can be attributed to the loadings in this section.

The variable included in this study to act as a conservative substance was chloride (Fig. 9), which displayed some variability over the 10-year period, with no significant trend to increasing loadings except for 1975 and 1976, which appear to have reached higher than average loads. This increase is attributed primarily to the tributary contribution. Notable in the breakdown of the chloride loading is the negative sign of the net loading figures, which are obtained by subtracting the outflow loading of the lake (upper Niagara River) from the total input loading. This indicates the presence of an unmonitored source of chloride loading. One major source of chloride to Lake Erie not included thus far in this study was the contribution from winter road salting, with the subsequent natural land runoff and channeled storm sewer point sources. If, as a point of exercise, the concentration of chloride in Lake

Table 1. Additional Chloride Loading Attributed to Road Salting (Chloride, t x 10^6)

Year	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
Load	0.73	1.14	1.06	0.66	0.90	1.05	0.77	1.18	0.40	0.25

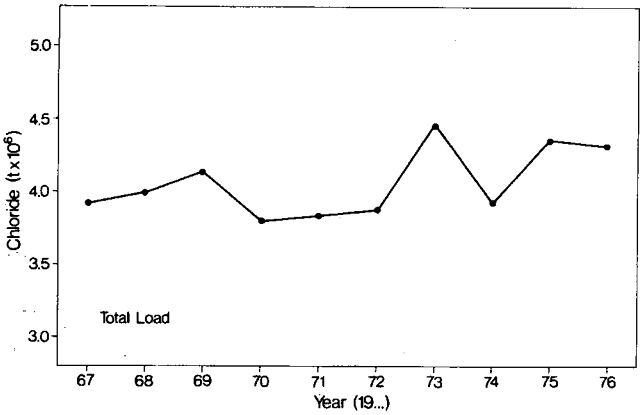

Figure 9. Total loading of Chloride to Lake Erie.

Erie were assumed to be constant over the 10-year study period, an input/output balance would yield additional loads primarily attributed to road salting activities, as shown in Table 1.

If changes in lake concentration that are related to water level changes and retention of chloride in the lake system were taken into account, the figures in Table 1 would be somewhat different. To pursue this issue would be beyond the scope of this study, and therefore it should be noted that on the average, an additional 0.8 x 10^6 tonnes of chloride is loaded to the lake each year.

Over the past few years, several groups and agencies have worked upon the complex task of estimating the loading of total phosphorus to Lake Erie. The four major contributors have been the U.S. Army Corps of Engineers, the International Joint Commission (IJC), Task Group III on the 5th year review of the Great Lakes Water Quality Agreement (IJC, 1978a) and the Pollution from Land Use Activities Reference Group (PLUARG) (IJC, 1978b). Results from these studies have been compared with the total loading estimates from the present study (Fig. 10).

Excellent agreement has been found with the U.S. Army Corps of Engineers estimates for the 4 years 1970-1973, with less than 5% deviation. Similarly, for 1973 to 1976 the IJC estimates are within 5% deviation. With respect to the PLUARG and the Task Group load estimates, which are considered for 1976 only, the deviations are somewhat larger, with values of 10% and 24% respectively.

The major deviation from the estimates presented for this study is seen in the 1974 and 1975 loads given by the U.S. Army Corps of Engineers, which differ by about 8000 metric tonnes (50%). However, as can be seen, good agreement was achieved between the three studies reporting data for 1973. It has been shown in the comprehensive breakdown of phosphorus loads (Table A-1) that the major factor responsible for the reduction in load between 1973 and 1974 is a reduction in the contribution from the Detroit River. As a result, the increase in load reported for 1974 is difficult to explain.

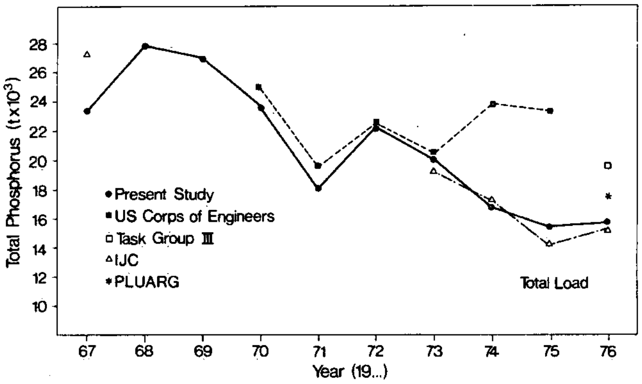

Figure 10. Comparison of Total Phosphorus loads to Lake Erie.

Examination of the entire 10-year period indicates that, in general, good agreement has been achieved by those studying Lake Erie loadings and that there has been a general but significant reduction in the load of total phosphorus entering the system.

The expansion of this study to obtain and compute loads for additional years up to 1979 is presently under way and will indicate whether or not the reductions in load calculated for the past 10 years have continued.

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NOTES TO THE TABLES

*The loads were estimated based on less than the identified number of significant contributing sources.

R—As no soluble reactive phosphorus data were available for the U.S. tributaries, these loads were estimated in the manner described in the text.

E—Flow data were not available for these years, requiring estimation techniques as described in the text.

Appendix A
Loading Results

PARAMETER TOTAL PHOSPHORUS TOTAL ANNUAL LOAD (METRIC TONNES)

	CANADIAN TRIBUTARY	U. S. TRIBUTARY	CANADIAN MUNICIPAL	U. S. MUNICIPAL	CANADIAN INDUSTRIAL	U. S. INDUSTRIAL	ATMOSPHERIC	DETROIT RIVER	TOTAL	UPPER NIAGARA	NET LOAD
1967	1473	4684	23	2112*	15	47	774	14309	23437	3479	19958
1968	1234	4464*	20^E	3575*	9	46	774	17822	27944	5352	22592
1969	792	5886*	20^E	2061*	9	46	774	17389	26977	4408	22569
1970	1511	4291*	20^E	1652*	9	45	774	15422	23724	7016	16708
1971	770	4385*	19^E	1639*	9	45	774	10436	18077	3421	14656
1972	966	6803*	19^E	1658*	7	44	774	12000	22271	3554	18717
1973	1430	6518*	11^E	1163*	9	32	774	10548	20485	5141	15344
1974	711	5699	8^E	1118*	7	12	774	8492	16821	5262	11559
1975	728	5161	6	1332*	1	11	774	7521	15534	3806	11728
1976	983	4937*	6	1106*	14	20	774	7991	15831	5071	10760

PARAMETER SOLUBLE REACTIVE PHOSPHORUS TOTAL ANNUAL LOAD (METRIC TONNES)

	CANADIAN TRIBUTARY	U. S. TRIBUTARY	CANADIAN MUNICIPAL	U. S. MUNICIPAL	CANADIAN INDUSTRIAL	U. S. INDUSTRIAL	ATMOSPHERIC	DETROIT RIVER	TOTAL	UPPER NIAGARA	NET LOAD
1967	887	2820[R]	13	1157*	8	26	-	8163	13074	1953	11121
1968	744	2691[R]	13	2320*	5	25	-	4373	10171	2009	8162
1969	372	2764[R]	11	1081*	5	25	-	3759	8017	2031	5986
1970	915	2569[R]	10	842*	5	25	-	3428	7794	4602	3192
1971	402	2288[R]	11	943*	5	25	-	2938	6612	920	5692
1972	425	2994[R]	10	871*	4	24	-	2395	6723	1023	5700
1973	376	1712[R]	6	617*	5	18	-	2113	4847	1654	3193
1974	213	1708[R]	4	592*	4	7	-	2341	4869	1480	3389
1975	177	1547[R]	3	699*	1	6	-	3243	5676	904	4772
1976	291	1481[R]	4	638*	8	11	-	1884	4317	998	3319

PARAMETER TOTAL NITROGEN TOTAL ANNUAL LOAD (METRIC TONNES)

	CANADIAN TRIBUTARY	U. S. TRIBUTARY	CANADIAN MUNICIPAL	U. S. MUNICIPAL	CANADIAN INDUSTRIAL	U. S. INDUSTRIAL	ATMOSPHERIC	DETROIT RIVER	TOTAL	UPPER NIAGARA	NET LOAD
1967	11423	36324	97	8442	87	118	35088	108851	200430	83251	117179
1968	9335	33769	96	8381	52	115	35088	105816	192652	105815	86837
1969	8059	59893	96	8381	52	115	35088	103637	215321	72841	142480
1970	9493	26644	94	8165	52	113	35088	117100	196749	76883	119866
1971	7071	40268	98	8507	52	113	35088	108231	199428	71460	127968
1972	12929	91052	89	7782	41	110	35088	93340	240431	68655	171776
1973	14257	64984	79	6909	52	80	35088	118670	240119	109117	131002
1974	12714	101909	79	6880	41	30	35088	121390	278133	144313	133820
1975	13317	94408	88	7638	6	28	35088	118311	268884	136647	132237
1976	21585	108408	81	7059	81	50	35088	119458	291810	130026	161784

PARAMETER NITRATE PLUS NITRITE TOTAL ANNUAL LOAD (METRIC TONNES)

	CANADIAN TRIBUTARY	U. S. TRIBUTARY	CANADIAN MUNICIPAL	U. S. MUNICIPAL	CANADIAN INDUSTRIAL	U. S. INDUSTRIAL	ATMOSPHERIC	DETROIT RIVER	TOTAL	UPPER NIAGARA	NET LOAD
1967	4013	12761*	25	2164*	22	30	17000	34604	70619	5665	64954
1968	5555	20095*	18	1556*	10	21	17000	40491	84746	8598	76148
1969	4256	31630*	21	1869*	11	26	17000	32488	87301	8266	79035
1970	7112	19961*	15	1263*	8	17	17000	41485	86862	6454	80408
1971	3959	22546*	15	1340*	8	18	17000	46491	91377	11013	80364
1972	7830	55142	29	2568*	13	36	17000	42113	124713	11350	113381
1973	8579	39103	30	2602*	20	30	17000	56260	123623	33970	89653
1974	8652	62824	12	1067*	6	5	17000	49822	139387	64381	75006
1975	9143	56475*	15	1282*	1	5	17000	53550	137471	70626	66845
1976	16358	52585*	13	1173*	13	8	17000	53211	140361	56255	84106

PARAMETER KJELDAHL NITROGEN TOTAL ANNUAL LOAD (METRIC TONNES)

	CANADIAN TRIBUTARY	U. S. TRIBUTARY	CANADIAN MUNICIPAL	U. S. MUNICIPAL	CANADIAN INDUSTRIAL	U. S. INDUSTRIAL	ATMOSPHERIC	DETROIT RIVER	TOTAL	UPPER NIAGARA	NET LOAD
1967	5204	23563	72	6278	65	88	18000	74247	127517	77586	49931
1968	4389	13674	78	6825	42	94	18000	65325	108427	96217	12210
1969	3856	28263	75	6512	41	89	18000	71149	127985	64575	63410
1970	3322	6683	79	6902	44	96	18000	75615	110741	70429	40312
1971	3125	17722	83	7167	44	95	18000	61740	107976	60447	47529
1972	3983	35910	60	5214	28	74	18000	51227	114496	57305	57191
1973	5381	25881	49	4307	32	50	18000	62410	116110	75147	40963
1974	3916	39085	67	5813	35	25	18000	71570	138511	79932	58579
1975	4198	37933	73	6356	5	23	18000	64761	131349	66021	65328
1976	5246	55823	68	5886	68	42	18000	77284	162417	63203	99214

PARAMETER AMMONIA TOTAL ANNUAL LOAD (METRIC TONNES)

	CANADIAN TRIBUTARY	U. S. TRIBUTARY	CANADIAN MUNICIPAL	U. S. MUNICIPAL	CANADIAN INDUSTRIAL	U. S. INDUSTRIAL	ATMOSPHERIC	DETROIT RIVER	TOTAL	UPPER NIAGARA	NET LOAD
1967	724	11441	43	3726*	59	79	8500	23113	47703	10833	36870
1968	1346	13299	43	3784*	38	85	8500	22978	50073	11657	38414
1969	764	21413	37	3241*	37	80	8500	24556	58628	10744	47884
1970	865	8191	33	2862*	40	86	8500	17948	38531	7671	37770
1971	801	14486	35	2981*	40	86	8500	20004	46933	9485	37448
1972	619	24599	46	3970*	25	67	8500	17580	55406	4583	50823
1973	788	17095	36	3181*	29	45	8500	18547	48221	9105	39116
1974	741	31054*	31	2676*	32	23	8500	17199	60256	8245	52011
1975	404	15227*	47	4080*	5	21	8500	16659	44943	5783	39160
1976	386	14554*	47	4043*	61	38	8500	16665	44294	2326	41968

PARAMETER CHLORIDE TOTAL ANNUAL LOAD (METRIC TONNES)

	CANADIAN TRIBUTARY	U. S. TRIBUTARY	CANADIAN MUNICIPAL	U. S. MUNICIPAL	CANADIAN INDUSTRIAL	U. S. INDUSTRIAL	ATMOSPHERIC	DETROIT RIVER	TOTAL	UPPER NIAGARA	NET LOAD
1967	90424	500058*	986	28008*	496	35000	20124	3228092	3903188	4627756	-724568
1968	93093	763370	1566	44477*	491	34677	20124	3074453	4032251	5167232	-1134981
1969	87074	1019088	1443	40977*	495	34938	20124	2943825	4147964	5205519	-1057555
1970	78381	948307*	1627	46207*	454	32013	20124	2671961	3799074	4455620	-656546
1971	78914	712726*	1604	45557*	403	28410	20124	2960767	3848505	4746531	-898026
1972	113075	1043410	2525	71719*	353	24908	20124	2605927	3882041	4928428	-1046387
1973	80746	1103890	2397	68088*	357	25158	20124	3165226	4465985	5240321	-774336
1974	112200	858406	1022	29033*	354	25000	20124	2881108	3927247	5106014	-1178767
1975	150717	1573519*	1688	47962*	354	25000	20124	2542438	4361802	4766073	-404272
1976	136000	1381702	1649	46854*	354	25000	20124	2722626	4334309	4583503	-249194

Appendix B
Data Sources

TRIBUTARIES

State of Ohio

Maumee R.
Portage R.
Sandusky R.
Huron R.
Vermilion R.
Black R.
Cuyahoga R.
Rocky R.
Chagrin R.
Grand R.
Ashtabula R.
Conneaut Cr.

State of Michigan

River Raisin
Huron R.

Province of Ontario

Sturgeon Cr.
Kettle Cr.
Catfish Cr.
Big Otter Cr.
South Otter Cr.
Big Cr.
Dedrick Cr.
Lynn R.
Nanticoke Cr.
Grand R.

State of New York

Buffalo R.
Cattaragus Cr.
Eighteen Mile Cr.

INDUSTRIAL DISCHARGERS

State of Ohio

Gulf Oil—Toledo
Interlake Steel—Toledo
Sun Oil—Toledo
Standard Oil—Oregon
Routh Packing—Sandusky
U.S. Steel—Lorain
U.S. Steel—Cleveland
Jones & Loughlin Steel—Cleveland
Harshaw Chemicals—Cleveland
Republic Steel Corp.—Cleveland
Union Carbide—Ashtabula
R.M.I. Sodium Chloride—Ashtabula
Olin Corp.—Ashtabula

State of New York

Bethlehem Steel

Province of Ontario

Omstead Foods—Wheatley
Omstead Fisheries—Wheatley
H.J. Heinz Co.—Leamington
Mallory Hardware Products—Blenheim
Inco—Port Colborne
Algoma Steel—Port Colborne

MUNICIPAL DISCHARGERS

State of Ohio

Camp Perry
Port Clinton
Oak Harbor
Clyde
Bellevue
Sandusky
Vermilion
Amherst
Lorain
Rocky River, S.D. #6
Avon Lake
Lakewood
Brookport
Middleburg Heights S.D. #8
North Olmstead
Cleveland—Westerly
—Easterly
—Southerly
Euclid
Willoughby—Eastlake
—Greater Mentor
Geneva-On-The-Lake
Lake County—Madison
Ashtabula
Conneaut
Toledo

State of New York

Erie County #2 South
Dunkirk
Fredonia
Westfield
Hamburg Master
Lackawanna

State of Michigan

Monroe
Wayne County—Flat Rock
—Rockwood

State of Pennsylvania

Erie

Province of Ontario

Port Dover
Fort Erie—Crystal Beach
Ontario Hospital
Port Stanley
Port Burwell
Kingsville
Leamington
Dutton