1976-03-01

Assessment of the Effects of Nutrient Loadings on Lake Ontario Using a Mathematical Model of the Phytoplankton

Hydroscience Inc.

GREAT LAKES
WATER QUALITY BOARD

INTERNATIONAL
JOINT
COMMISSION

ASSESSMENT OF THE EFFECTS OF NUTRIENT LOADINGS ON LAKE ONTARIO USING A MATHEMATICAL MODEL OF THE PHYTOPLANKTON

International Joint Commission
Windsor, Ontario, Canada

ASSESSMENT OF THE EFFECTS OF NUTRIENT LOADINGS ON LAKE ONTARIO USING A MATHEMATICAL MODEL OF THE PHYTOPLANKTON

Prepared by:

Hydroscience, Inc.
363 Old Hook Road
Westwood, New Jersey 07675

March 1976

HYDROSCIENCE, INC.
Consultants in Water Pollution Control
363 OLD HOOK ROAD
WESTWOOD, NEW JERSEY 07675
201-666-2600

DONALD J. O'CONNOR
EDWIN L. BARNHART
JOHN L. MANCINI
THOMAS J. MULLIGAN

Associates
JOHN P. ST. JOHN
ROBERT V. THOMANN
EUGENE D. DRISCOLL

March 31, 1976

Dr. W.R. Drynan
International Joint Commission
Great Lakes Regional Office
100 Quellette Avenue
Eighth Floor
Windsor, Ontario, Canada

Dear Dr. Drynan:

In fulfillment of the terms of our agreement (DSS File: SS02.14001-5-0057), we are pleased to submit herewith our final report entitled, "Assessment of the Effects of Nutrient Loadings on Lake Ontario Using a Mathematical Model of the Phytoplankton".

The report summarizes work which was accomplished in five specific task areas:

I. Compilation and Evaluation of Historic (1967-1974) Nutrient Loads to Lake Ontario

II. Compilation of Present (1974) Nutrient Loads to Lake Ontario Using the Best Available Data

III. Review of the W.Q.A. Loads and the Preparation of Alternative Loading Scenarios for Simulation Purposes

IV. Reduction of the Alternative Loading Scenarios to Formats Required by the Lake 1 Model

V. Summarize and Evaluate Lake 1 Model Simulations Under Alternative Loading Scenarios and Draw Appropriate Conclusions from the Study Results

A summary of the Study's principal conclusions is presented in the Executive Summary at the beginning of this Report.

May we express our appreciation to you and other members of your staff and the signatory agency staffs for their cooperation and assistance. The contributions of Dr. Wu-Seng Lung who acted as Project Engineer and Ms. Gayle Higgins are also gratefully acknowledged.

Very truly yours,

HYDROSCIENCE, INC.

Daniel S. Szumski

Very truly yours,

HYDROSCIENCE, INC.

Robert V. Thomann

DSS/RVT:gah
Enclosure

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES
(Continued)

LIST OF FIGURES

LIST OF FIGURES
(Continued)

LIST OF FIGURES
(Continued)

E X E C U T I V E S U M M A R Y A N D C O N C L U S I O N S

A. SUMMARY

The International Joint Commission, as part of its broad based responsibility for water resource management on the Great Lakes, has adopted programs for the control of eutrophication processes in the Lower Great Lakes. The Water Quality Agreement (W.Q.A.) between the United States and Canada constitutes one of the major elements of these programs by providing for the systematic reduction of nutrient loadings to the lower Lakes. The foremost question raised by the W.Q.A. load reduction program is: What response, in terms of phytoplankton biomass levels, can be expected as a result of ongoing nutrient removal programs?

The present study attempts to put this question into perspective through an analysis of present and historical loadings to Lake Ontario, and through a series of mathematical modeling simulations designed to show trends in lakewide biomass levels as a function of alternative loading scenarios relative to the W.Q.A..

The input from this study is therefore focused on several key areas related to the water quality assessment:

a) an evaluation of the present (1974) phosphorus and nitrogen loads to Lake Ontario,

b) a compilation and evaluation of historical input loads from 1967-1974,

c) determination of nutrient input scenarios for simulation purposes including the IJC Water Quality Agreement loads, and

d) use of an existing whole lake phytoplankton model, to analyze and present the results of long term simulations.

Each of these components of the study is directed therefore to providing additional information on the present status of input nutrient loads, as well as, the possible range of responses that might be expected under different future scenarios of input conditions. It should be stressed that the results presented herein are in no way intended to be predictions of actual future phytoplankton biomass in Lake Ontario. Rather, the results are indications of trends and ranges only and are to be viewed as part of a planning process in contrast to formal predictions of events.

The first element of the study program, that of evaluating historic loadings to Lake Ontario was completed through a detailed analysis of flow and concentration measurements from tributaries to Lake Ontario, and a compilation of available data concerning municipal and industrial discharges direct to the Lake and to tributary streams. The analysis methods were directed toward separating controllable nutrient loads from the largely uncontrollable loadings so that realistic evaluations of basinwide load reduction programs could be addressed. One of the principal results of this task is an apparent discrepency in load reduction requirements stated in the W.Q.A..

In this regard, the municipal and industrial load established by the Water Quality Agreement, 16,300 pounds/day, represents an average effluent phosphorus concentration of about 2.2 mg P/l. The agreement stipulates in part that:

> 2. Effluent Requirements. The phosphorus concentrations on effluent from municipal waste treatment plants discharging in excess of one million gallons per day, and from smaller plants as required by regulatory agencies, shall not exceed a daily average of one milligram per liter into Lake Erie, Lake Ontario and the International Section of the St. Lawrence River.
>
> 3. Industrial Discharges. Waste treatment or control requirements for all industrial plants discharging wastes into the Great Lakes System shall be designed to achieve maximum practicable reduction of phosphorus discharges to Lake Erie, Lake Ontario and the International Section of the St. Lawrence River.

Hence, the W.Q.A. municipal and industrial mass load appears to be greater than the load dictated by effluent requirements. Even if the allowable 16,300 pound/day load is extrapolated to 2015 populations, the average effluent requirement is approximately 1.3 mg P/l. Therefore, there is some "slack" in the W.Q.A. loads in the sense that if technologically feasible phosphorus reduction is attained, the municipal and industrial mass load will probably be less than 16,300 pounds/day.

Figure 1 summarizes the present phosphorus loadings, those required by W.Q.A., and those that are technologically feasible for large scale treatment facilities.

The second element of the study program constructed a summary of present loadings to Lake Ontario. The results indicate that the phosphate detergent ban has had a significant impact in reducing the phosphorus load from municipal and industrial sources. However, the present high flow period on the Lakes, most notably in the Niagara River, precludes the identification of a significant reduction in the total phosphorus loading in the 1974 nutrient load estimate.

Alternative loading scenarios, which reflect various combinations of W.Q.A. implementation period, system kinetics, and Niagara River nutrient loading rate, were constructed to test the impacts of phosphorus load reduction on lakewide phytoplankton biomass. The LAKE 1 model was used to calculate trends in future phytoplankton biomass levels under each of these scenarios. The results of these loading scenarios is summarized in Figure 2.

Figure 2 presents a summary of computed chlorophyll concentrations ten years into an implementation program as a function of the phosphorus load reduction rate in pounds/day per year. The figure considers 3 kinetic assumptions and also shows the present range of peak annual chlorophyll

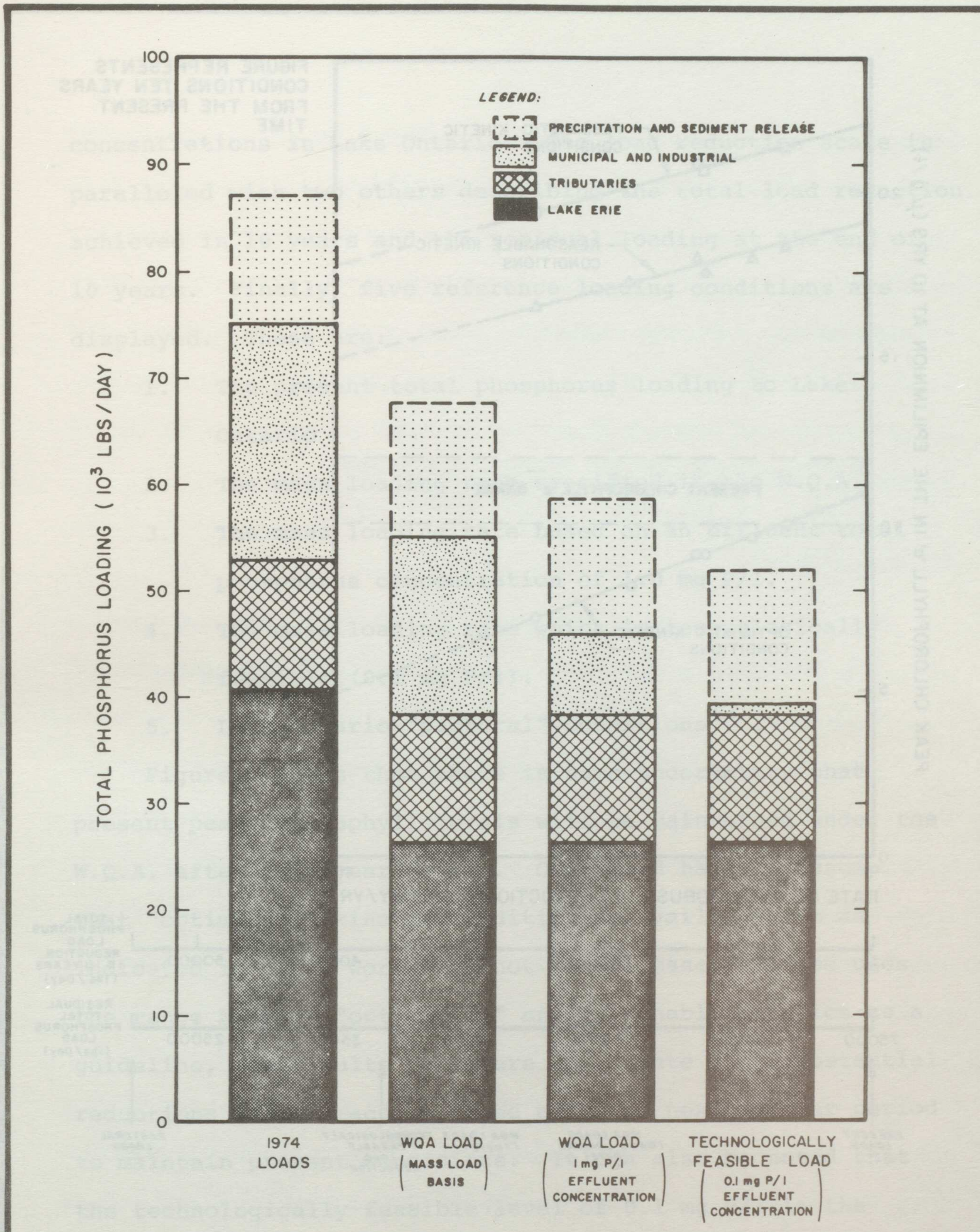

FIGURE 1

SUMMARY OF PHOSPHORUS LOADINGS TO LAKE ONTARIO

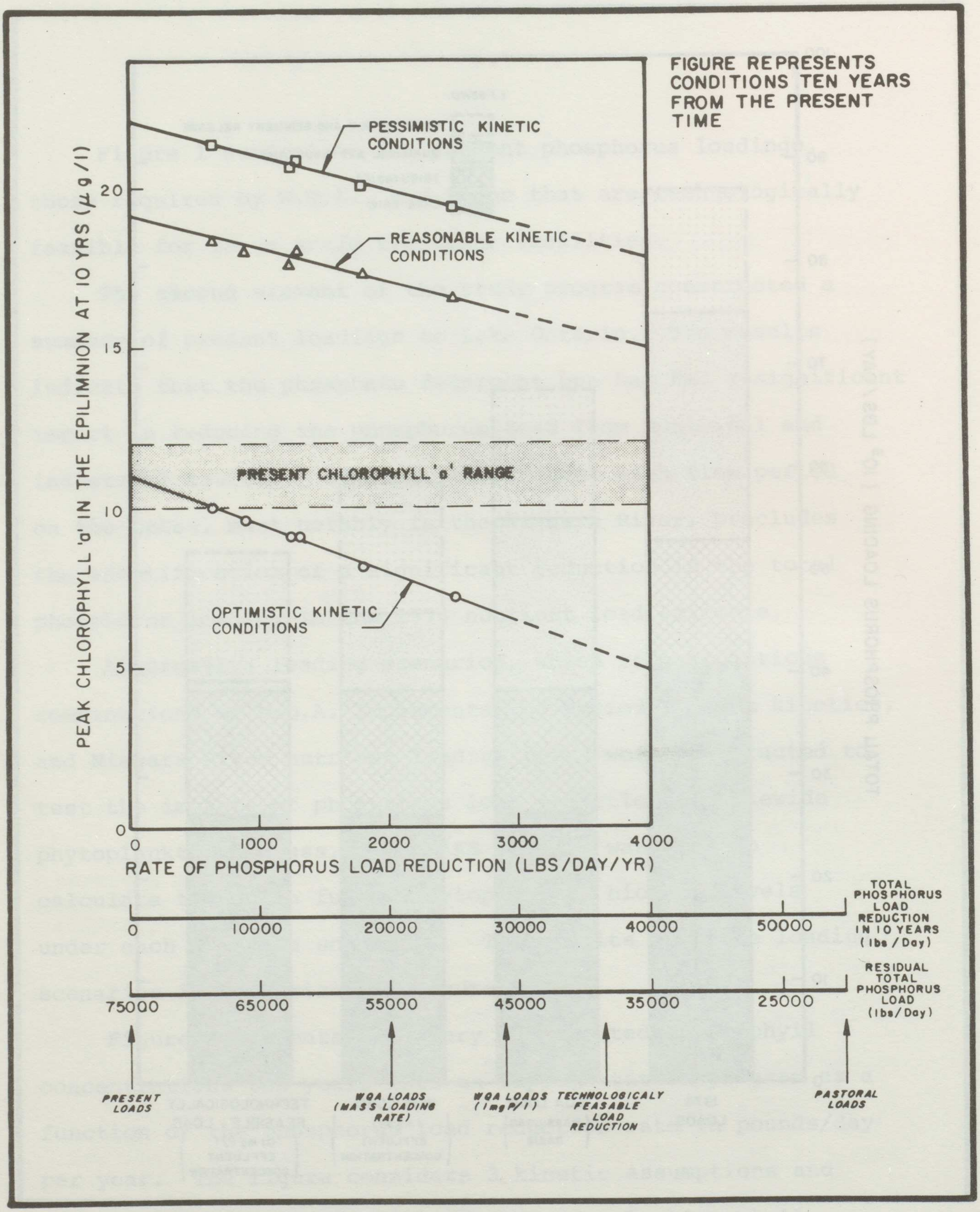

FIGURE 2
EFFECT OF PHOSPHORUS LOAD REDUCTION RATE

concentrations in Lake Ontario. The load reduction scale is paralleled with two others describing the total load reduction achieved in 10 years and the residual loading at the end of 10 years. Finally, five reference loading conditions are displayed. These are:

1. The present total phosphorus loading to Lake Ontario
2. The mass loading rate specified in the W.Q.A.
3. The mass loading rate based on an effluent total phosphorus concentration of 1.0 mg P/l.
4. The mass loading rate which is technologically feasible (0.1 mg P/l).
5. Lake Ontario "pastoral" conditions[(2)].

Figure 2 shows that there is some uncertainty that present peak chlorophyll levels will be maintained under the W.Q.A. after a 10 year period. One would have to assume that "optimistic" kinetic conditions prevailed which as indicated in other work, may not be the case. If one uses the range between "optimistic" and reasonable kinetics as a guideline, the results in Figure 2 indicate that substantial reductions must be accomplished over the next 10 year period to maintain present conditions. It can also be noted that the technologically feasible level of 0.1 mg P/l in the effluent does provide a greater degree of assurance that the present biomass level will be maintained. Thus, the rate of implementation appears to critically impact the degree to which the intended goals of the Water Quality Agreement are realized in terms of phytoplankton biomass in Lake Ontario. It appears that a load reduction rate of 2,000 to 3,000 pound/day of phosphorus per year for a ten year period is a sound objective if phytoplankton biomass in the Lake is to be maintained at its present level.

B. CONCLUSIONS

The following conclusions are presented, based on the analysis of loads to Lake Ontario and the LAKE 1 simulation results presented in this study.

1. The present and historic nutrient loads from Lake Erie to the Niagara River do not show any clear trends in nutrient loading over the period 1967 to 1974. Unusually high discharge rates at the Lake Erie outlet have persisted for this entire period cuasing the mean annual nitrogen and phosphorus loads to exceed the mean loading rate considered in this study.

2. Nutrient inputs from the Niagara River to Lake Ontario show a trend toward lower phosphorus loading rates. Analysis of pre- and post- phosphate detergent ban data show a significant reduction in phosphorus concentration in the lower Niagara River between 1967 and 1974. The load reduction

is calculated to be 5,400 pounds/day which is consistent with other estimates of post-ban phosphorus load reductions. The load reduction is not apparent in total load estimates from the Niagara River due to significant flow increased in the Niagara River since 1971. Similar analysis methods have indicated that the total nitrogen loading from the Niagara River outlet has not changed during that same period.

3. Municipal and industrial total phosphorus loads to the Lake Ontario Basin show a significant decline since 1971. This reduction, which amounts to more than 10,000 pounds/day reflects partial implementation of the Water Quality Agreement and implementation of the phosphate detergent ban. By contrast, total nitrogen loadings from municipal and industrial sources has grown steadily from 1967 to 1974.

4. The study results indicate that there are no strong trends in nutrient loadings from tributary discharges to Lake Ontario where such discharges include municipal point sources in the tributary basin. One would suspect that the phosphate detergent ban would have significantly decreased tributary phosphorus loads. The analysis in this regard is limited by the availability of adequate data with which to make long term trend assessments.

5. The present (1974) total loading condition to Lake Ontario is estimated to be 75,000 pounds/day of total

phosphorus and 1,043,000 pounds/day of total nitrogen. The following table presents a more detailed breakdown of the present phosphorus loading.

TABLE I

ESTIMATED 1974 PHOSPHORUS LOADS TO LAKE ONTARIO
(IN POUNDS/DAY)

Source	Total Phosphorus	% of Total
1. Uncontrollable		
Lake Erie	37,080	49
Biomass	3,300	5
Tributaries	12,200	16
Subtotal (uncontrollable)	52,590	70
2. Controllable		
Municipal		
Niagara River Basin	5,820	8
Lake Ontario (direct)	11,800	16
On tributaries to Lake	4,100	5
Total Municipal	(21,700)	(29)
Industrial	700	1
Subtotal (controllable)	22,400	30
TOTAL	75,000	100

---

6. The analyses conducted as part of the present study indicate that additional monitoring and surveillance are appropriate to better define nutrient loadings to Lake Ontario. Tributary loadings include largely uncontrollable background loads in addition to point source loads from municipal and industrial discharges. The relative magnitude

of these sources is estimated in the present study but should be more quantitatively defined in future surveillance programs to develop estimates of the effectiveness of W.Q.A. load reductions on total tributary loads to Lake Ontario. In this regard, the following steps may be considered appropriate:

a) Continue to inventory and measure controllable nutrient discharges to upbasin tributaries.

b) Investigate the effects of sampling frequency and number of tributaries sampled on tributary load estimates.

c) Explore statistical aggregation methods to develop reliable estimates of the total mean annual tributary nutrient load to Lake Ontario as well as the variance of that load.

d) Initiate efforts to explore the magnitude and potential for control of non-point source nutrient loads within the Lake Ontario Basin.

7. The study presents estimates of inputs to Lake Erie which reflect extreme loading conditions. These include estimates of high (95%) and low (5%) Lake Erie loadings, and estimates of phosphorus inputs from atmospheric and sediment sources. The high and low Niagara River loads are conditions which are properly viewed as short term load anomalies which probably would not persist for more than 10 years. Long

term evaluations of phytoplankton biomass using these loads are useful in establishing probable ranges around mean Niagara River load simulations. Atmospheric and sediment sources of phosphorus contribute significant loads to Lake Ontario. However, a significant technical question concerning the availability of this phosphorus source for phytoplankton growth, especially atmospheric phosphorus, remains at this time.

8. There appears to be a difference between the final W.Q.A. mass loading rate for phosphorus from municipal and industrial sources and that computed on the basis of the W.Q.A. 1 mg P/l effluent requirement. The equivilent effluent concentration at the allowable phosphorus load of 16,300 pounds/day is estimated to be 2.2 mg P/l, that is, greater than double the effluent concentration required by the agreement. The following table summarizes estimated municipal and industrial total phosphorus loads for three cases: The W.Q.A. mass loading rate, the W.Q.A. effluent requirement of 1 mg P/l, and the load reduction that is technologically feasible.

- -

TABLE 2

W.Q.A. LOAD COMPARISON

Loading Condition	Total Load (#/day)
W.Q.A. Mass Loading	16,300
W.Q.A. load- 1 mg P/l	7,400 (1)
Technologically feasible load (0.1 mg P/l)	740 (1)

(1) Under present population

- -

9. Lake 1 simulations utilizing a set of reasonable model kinetics indicate that the peak phytoplankton concentrations presently observed in Lake Ontario are not in equilibrium with the present nutrient loadings to the Lake. These results show a trend toward peak chlorophyll concentrations 50 to 100% higher than presently observed peak concentrations of 10-12 μg/l. The transition period over which these higher biomass levels will be achieved, even under W.Q.A. load reductions, is 10 to 15 years.

10. Under a set of "optimistic" kinetics which assume that the present peak biomass levels are in equilibrium with present nutrient loads, reductions of the peak chlorophyll concentrations to levels between 6.5 and 9.0 mg/l are indicated. These conditions represent the most optimistic estimates of biomass reduction under presently planned load

reductions. A simulation which includes estimated phosphorus loads from atmospheric and sediment sources show that, even under this most optimistic kinetic assumption, there is a loading condition which will merely maintain biomass concentrations at their present levels, even under the W.Q.A. loads.

11. Lake 1 model simulations using a set of "pessimistic" kinetic assumptions put an upper limit on peak biomass concentrations after W.Q.A. loads are achieved. These results show that the peak chlorophyll concentration could exceed 20 μg/l. If atmospheric and sediment sources of phosphorus are included in the calculations the peak chlorophyll concentration could exceed 30 μg/l.

12. The implementation period over which W.Q.A. load reductions are realized is a prime factor in achieving the intended goals of the agreement. The effect of a long (20 year) implementation period is to sustain a high phosphorus loading rate to the lake over a longer period of time. In effect nutrient concentrations in the lake continue to rise for a longer period, yielding higher peak chlorophyll levels than would be observed under a ten year implementation period. In addition, the model results indicate that the peak biomass levels may exceed, or at least approach equilibrium levels faster, for slow implementation of W.Q.A. phosphorus load reductions.

13. The study results indicate a high degree of variability in a number of factors which influence biomass levels in Lake Ontario. These include short and long term Niagara River and tributary load variability, hydraulic variations, and temperature variations. In aggregate these factors contribute to the variability of presently observed peak phytoplankton concentrations and those that might be expected under the W.Q.A. load reductions. Various Lake 1 simulations showed that the variability in peak biomass levels in Lake Ontario under W.Q.A. load reduction ranges from 1-4 μg/l for any single factor mentioned above, and will probably be greater for a combination of random variations in Lake Ontario inputs.

14. The analysis results show that there is some uncertainty that present peak chlorophyll levels will be maintained under the W.Q.A. load reductions. A ten year time horizon is used to illustrate this point in this study. To maintain present levels, one would have to assume that "optimistic" kinetic conditions prevailed, which as indicated in other work, may not be the case. If one uses a range of kinetics between "optimistic" to "reasonable" as a guideline, the results indicate that a substantial load reduction must be accomplished over the next 10 year period to maintain present conditions. It can also be noted that the

technologically feasible level of 0.1 mg P/l in the effluent provides a greater degree of assurance that the present biomass level will be maintained. On the basis of this analysis it would appear that a 2,000 to 3,000 pound/day reduction per year is a sound objective to reasonably assure the maintenance of present conditions.

CHAPTER I

INTRODUCTION

A. Objectives and Scope

The principal objective of this study is to provide additional input into the ongoing process of assessing the effects of nutrient loadings on Lake Ontario water quality. The assessment of the water quality of Lake Ontario is a continuing responsibility of the International Joint Commission (ISC) as well as its signatory parties. The present study is intended to develop specific results related to existing programs of phosphorus reduction to the Lake. The input from this study is therefore focused on several key areas related to the water quality assessment: a) an evaluation of the present (1974) phosphorus and nitrogen loads to Lake Ontario, b) a compilation and evaluation of historical input loads from 1967-1974, c) determination of nutrient input scenarios for simulation purposes including the IJC Water Quality Agreement loads and d) use of an existing whole lake phytoplankton model, to analyze and present the results of long term simulations.

Each of these components of the study is directed therefore to providing additional information on the present status of input nutrient loads as well as on the possible range of responses that might be expected under different future scenarios of input conditions. It should be stressed that the results presented herein are in no way intended to be predictions of actual future phytoplankton biomass in Lake Ontario. Rather, the results are indications of trends and ranges only and are to be viewed as part of a planning process in contrast to formal predictions of events.

The scope of the present study therefore, includes the utilization of a) an existing analysis tool, (the whole lake phytoplankton model), b) an existing data base on input nutrient loads and c) reasonable estimates of future levels of inputs under existing agreements. The preceding three items are considered as given for purposes of this study although, as will be noted at several points throughout the report, some discussion is appropriate on the utility of each of these main components of the study. The geographical scope of the study, by virtue of the analysis tool at hand, includes the main lake portion of Lake Ontario and is not directed towards describing water quality responses in the near-shore (within 10 km) region. Finally, the study scope does include the interaction of the key nutrients of nitrogen and phosphorus with phytoplankton biomass measured by chlorophyll 'a', but does not assess impacts on the attached algae such as claclophora.

The principal indicator then of the effects of nutrient discharges to Lake Ontario is the phytoplankton chlorophyll. From a water quality point of view, this variable is of significant interest since under "high" concentrations of chlorophyll, various water use interferences may occur, including ecological shifts to undesirable phytoplankton species and production of undesirable phytoplankton blooms. One of the additional purposes of this study therefore is to provide a "baseline" or a departure point from which potential future objectives of phytoplankton chlorophyll can be measured. In other words, the measure of the effectiveness of a nutrient control program ultimately has to be in terms of some measure of plant biomass, ideally at the species level. Failing that however, and recognizing the overall management problem, phytoplankton biomass, as measured by the chlorophyll 'a' content appears to be a useful water quality variable at this time.

B. Previous Work and Study Framework

As indicated, this study is accepting work that has previously been performed, principally a mathematical model of phytoplankton dynamics for the open lake water and input load information generated by a number of agencies and individuals. The latter data base is resident in a variety of reports and documents throughout the basin community and in the relevant sections below, detailed references are given for all published and unpublished work. The mathematical model, called Lake 1, is presently resident among other places at the New York University Courant Institute of Mathematical Sciences on a CDC 6600 computer and has been discussed and documented elsewhere[1].

The basic framework, therefore, of the study incorporates existing nutrient load information for use by a whole lake model. Figure 1 shows in a schematic fashion, the principal components of the assessment framework. The nutrient inputs are considered in three broad settings with additional breakdowns for the lake inputs. The input components are considered as:

1) Inputs from Lake Erie

2) Inputs to Niagara River

3) Inputs to Lake Ontario

   a) Municipal - Direct to Lake and to tributaries to Lake

   b) Non-point tributaries

   c) Industrial

   d) Atmospheric

   e) Sediment

Each of these components is discussed in some detail below.

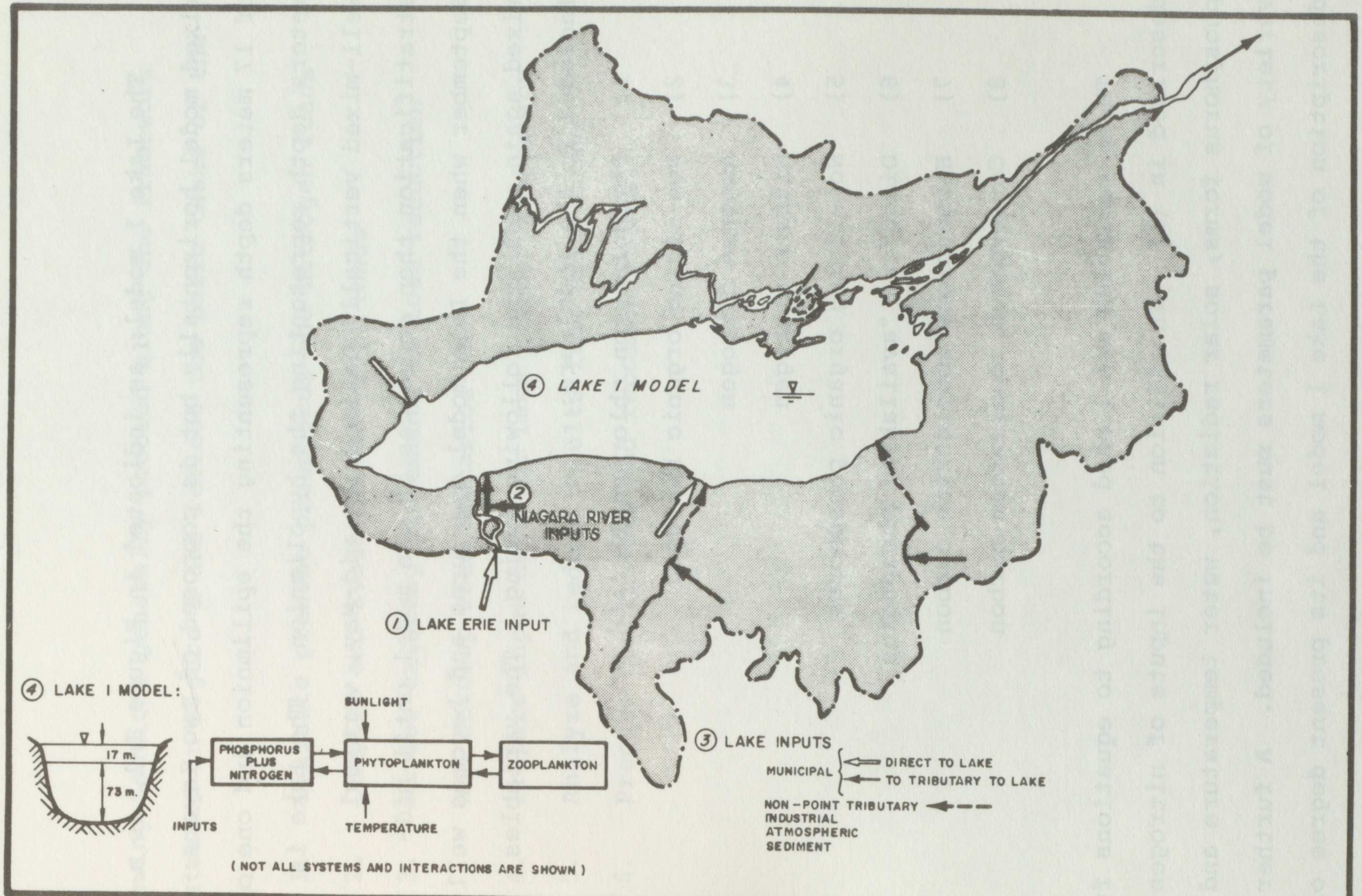

FIGURE I-1
GENERAL COMPONENTS OF ASSESSMENT FRAMEWORK

The Lake 1 model; as indicated in Figure I-1, is a well-mixed model horizontally but is composed of two layers; one of 17 meters depth representing the epilimnion and one of 73 meters depth representing the hypolimnion. The Lake is well-mixed vertically until about mid-May, vertical stratification then commences in the model until mid-September when the Lake model overturns and becomes well-mixed again until the following spring. The variables included in the model are:

1) Phytoplankton chlorophyll 'a'
2) Non-living organic nitrogen
3) Ammonia nitrogen
4) Nitrate nitrogen
5) Non-living organic phosphorus
6) Dissolved "available" phosphorus
7) Herbevorous zooplankton carbon
8) Carnevorous zooplankton carbon

These variables are linked according to equations fully described in (1). In addition to the inputs of nitrogen and phosphorus forms, solar radiation, water temperature and a variety of model parameters must be included. A further description of the Lake 1 model and its present degree of verification and credibility is given in Chapter IV. The following Sections generally proceed along the framework illustrated in Figure 1 and reflect the basic tasks of the study:

1. Evaluate present phosphorus and nitrogen loads
2. Compile and Evaluate 1967-1974 loads
3. Review existing agreements in load reduction and develop load scenarios
4. Prepare input data for Lake 1 model similation
5. Analyze and reduce results from simulations
6. Prepare conclusions and recommendations.

REFERENCES

[1] Thomann, R.V. et. al., "Mathematical Modeling of Phytoplankton in Lake Ontario, 1. Model Development and Verification, ORD, EPA Corvallis, Oreg., EPA - 660/3-75-005, March 1975, 177 pp.

CHAPTER II

EVALUATION OF PRESENT AND HISTORIC NUTRIENT LOADINGS TO LAKE ONTARIO

The first element of the study program is a detailed evaluation of present and historic phosphorus and nitrogen inputs to Lake Ontario. "Historic" in this case refers to the interval 1967 to 1974, the period for which data are available. This task focuses on evaluating data from numerous published and unpublished sources made available by:

- International Joint Commission
- Ontario Ministry of the Environment
- U.S. Environmental Protection Agency
- Canadian Center for Inland Waters
- United States Geological Survey
- New York State Department of Environmental Conservation

Information contained in these sources includes data listings, summary data reports and published estimates of nutrient loads to Lake Ontario. This chapter of the report discusses the methods and results of detailed analyses of these data according to the following sequence:

A. Inputs from Lake Erie

B. Tributary Inputs

C. Municipal/Industrial Inputs

D. Atmospheric Inputs

E. Sediment Inputs

A. Inputs From Lake Erie

Nutrient loads from Lake Erie constitute a large portion of the total loading to Lake Ontario. For example, it was estimated that in 1967 about 33% of the total phosphorus input introduced to Lake Ontario originated in the outflow from Lake Erie(1). Under the conditions of the U.S. - Canada Water Quality Agreement (discussed more fully in Chapter III) the Lake Erie input will constitute about 48% of the total load and therefore, will assume considerably more importance relative to lakewide loadings(2), and ultimately phytoplankton biomass levels. This section describes factors affecting the magnitude of the Lake Erie nutrient load, and presents trend analyses developed to describe its variability.

1. Lake Erie Load Variability

The Lake Erie nutrient load was estimated at 25,000 lbs/day of total phosphorus and 435,000 lbs/day of total nitrogen in 1967, and demonstrates a high degree of variability, a large part of which is attributed to Niagara River flow (or flow from Lake Erie) variation(3). All values of phosphorus and nitrogen are as phosphorus and nitrogen respectively. About 70% of the time, the average annual Niagara River flow is between about 180,000 to 220,000 cfs or a range of 40,000 cfs[(3)].

The variation of nutrient concentration also contributes to load variability. Figure II-1 shows that there is no clear trend in phosphorus concentration data from the Upper Niagara River on a long term basis, and that the annual mean concentrations vary considerably from year to year. The indicated within year variability reflects both seasonal variations and lateral variation across the Niagara River channel. The seasonal variability results from sampling variability as well as complex (and largely undefined) physical, chemical and biological processes. Figure II-2 shows the large lateral variability for the Niagara River and is believed to be principally the result of wastewater discharges from the Lackawana-Buffalo metropolitan area.

2. Loads from the Niagara River Basin

As the Niagara River flows downstream toward Lake Ontario, it receives nutrient discharges from a number of communities and industrial sources. As mentioned earlier, the phosphorus concentration at the Upper Niagara River does not show any significant trend from year to year during the last ten years. It is informative to compare the upper

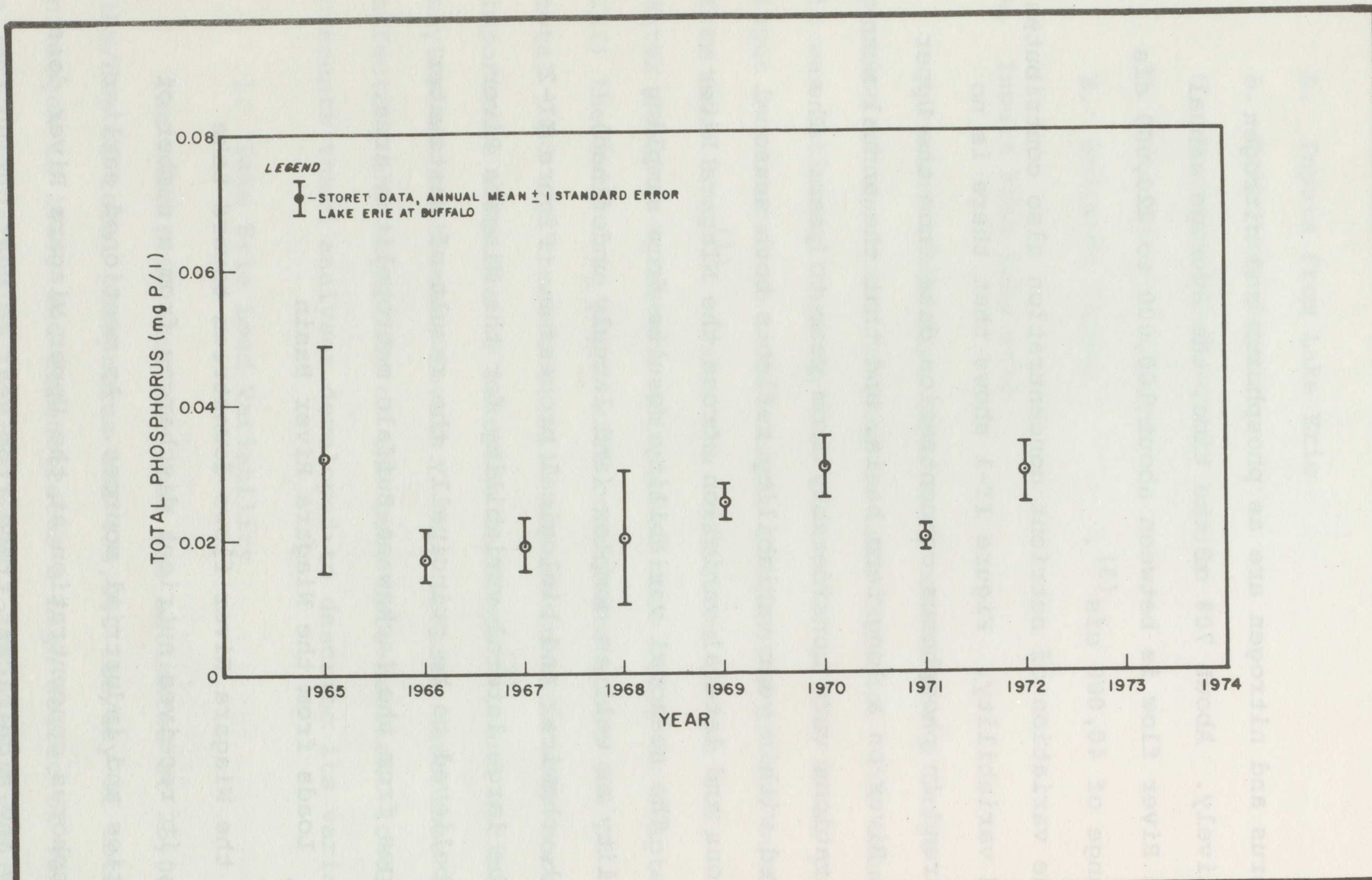

FIGURE II-1
TOTAL PHOSPHORUS AT UPPER NIAGARA RIVER

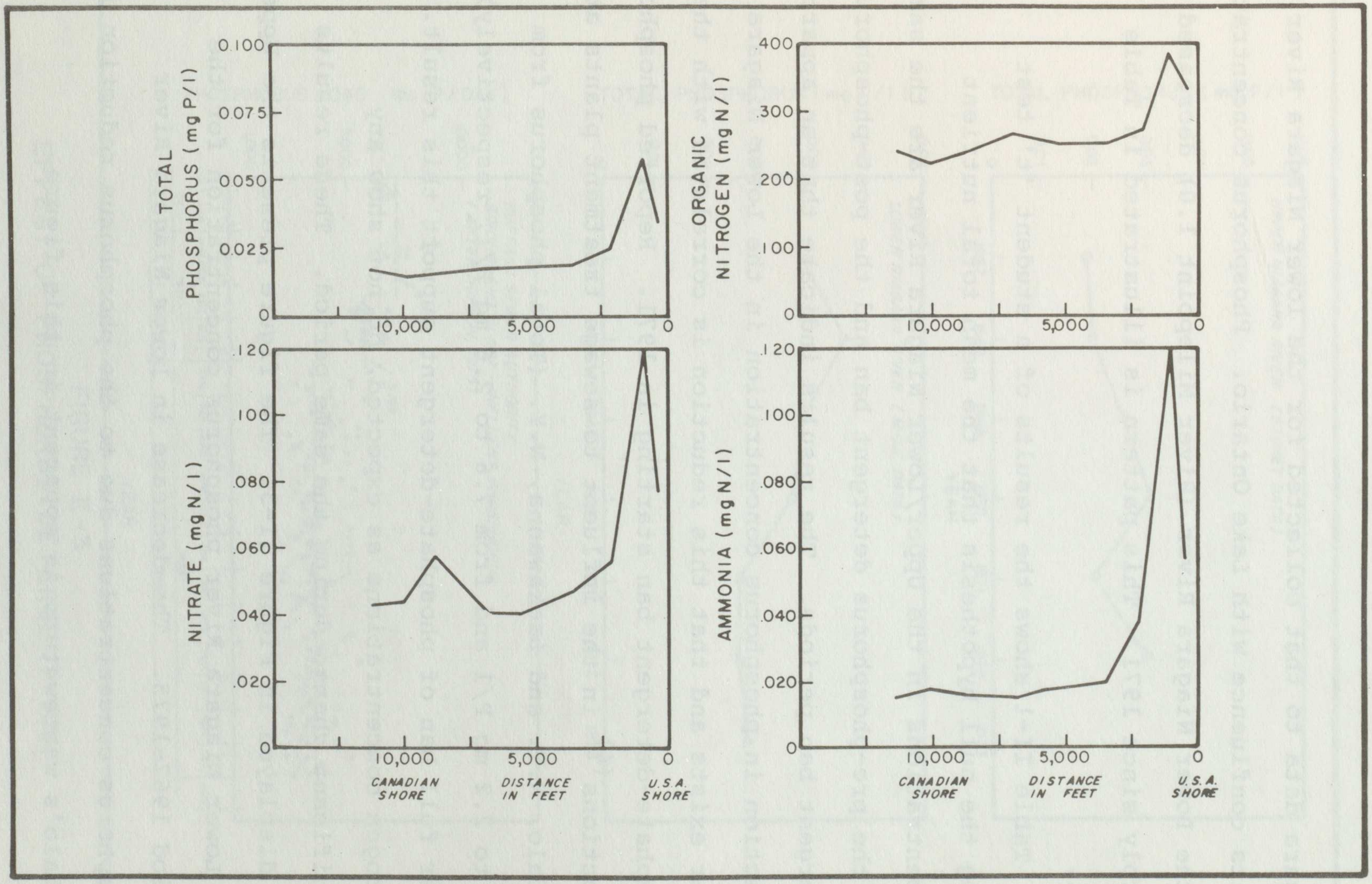

FIGURE II-2

VARIATION OF NUTRIENT CONCENTRATIONS ACROSS LAKE ERIE OUTLET-1972

(AFTER M.O.E.)

Niagara data to that collected for the lower Niagara River at its confluence with Lake Ontario. Phosphorus concentration in the Lower Niagara River (River Milepoint 1.0) decreased sharply since 1971. This pattern is illustrated in Table II-1.

Table II-1 shows the results of a student 't' test using the null hypothesis that the mean total nutrient concentrations in the Upper/Lower Niagara River are the same for the pre-phosphorus detergent ban and the post-phosphorus detergent ban periods. The results indicate that an apparent reduction in phosphorus concentration in the Lower Niagara River exists and that this reduction is correlated with the phosphate-detergent ban starting in 1971. Reported phosphorus reductions[4] in the influent to sewage treatment plants at Buffalo, N.Y. and Lackawanna, N.Y. (Total phosphorus from 5.5 to 2.2 mg P/l and from 7.6 to 2.6 mg P/l, respectively) after full ban of phosphate-detergent support this result. Nitrogen concentrations as expected, do not show any significant change during the same period. These results are displayed in Figure II-3. The figure presents the Upper and Lower Niagara River phosphorus concentration for the period 1967-1973. The decrease in Lower Niagara River phosphorus concentrations due to the phosphorus reduction in Buffalo's wastewaters is apparent in this figure.

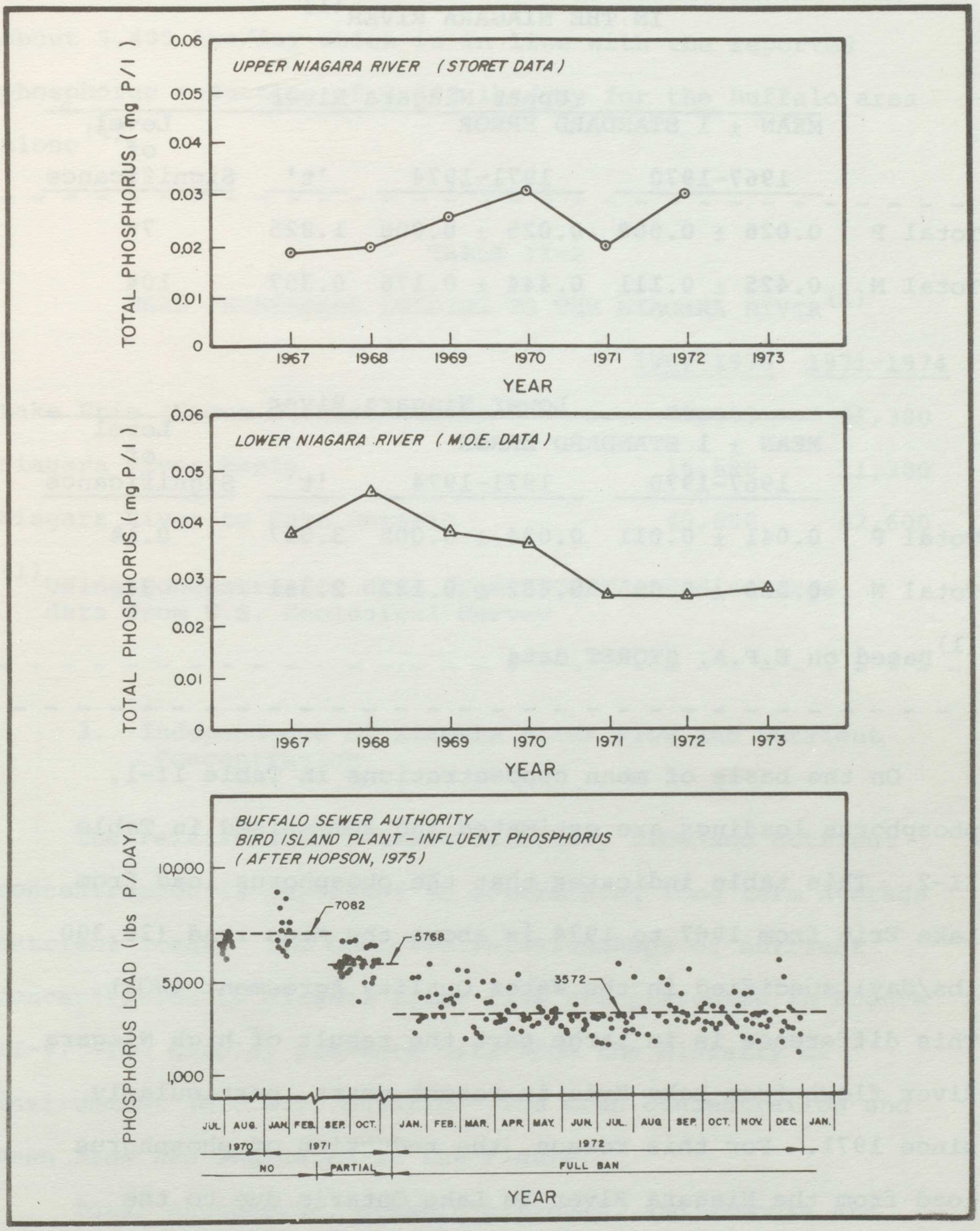

FIGURE II-3

EFFECT OF PHOSPHORUS DETERGENT BAN

TABLE II-1

MEAN ANNUAL PHOSPHORUS AND NITROGEN CONCENTRATIONS IN THE NIAGARA RIVER[(1)]

	Upper Niagara River			
	MEAN ± 1 STANDARD ERROR			Level of
	1967-1970	1971-1974	't'	Significance
Total P	0.026 ± 0.008	0.025 ± 0.006	1.825	7%
Total N	0.425 ± 0.111	0.444 ± 0.176	0.357	10%

	Lower Niagara River			
	MEAN ± 1 STANDARD ERROR			Level of
	1967-1970	1971-1974	't'	Significance
Total P	0.041 ± 0.011	0.034 ± 0.005	3.597	0.1%
Total N	0.520 ± 0.095	0.432 ± 0.122	2.361	3%

[(1)] Based on E.P.A. STORET data

On the basis of mean concentrations in Table II-1, phosphorus loadings are estimated and summarized in Table II-2. This table indicates that the phosphorus load from Lake Erie from 1967 to 1974 is above the mean load (26,300 lbs/day) specified in the Water Quality Agreement (WQA). This difference is in large part the result of high Niagara River flows from Lake Erie in recent years, particularly since 1971. For this reason, the reduction of phosphorus load from the Niagara River to Lake Ontario due to the phosphate-detergent ban is not immediately apparent. However, comparison of phosphorus loadings from the Niagara River basin before and after the ban indicate a load reduction of about 5,400 lbs/day which is in line with the reported phosphorus reduction of 3,500 lbs/day for the Buffalo area alone[4].

TABLE II-2

MEAN PHOSPHORUS LOADING TO THE NIAGARA RIVER[1]

	1967-1970	1971-1974
Lake Erie (Upper Niagara River)	29,000	31,300
Niagara River basin	16,680	11,300
Niagara River to Lake Ontario	45,680	42,600

[1] Using concentration data from STORET and discharge data from U.S. Geological Survey

3. Independence of Niagara River Flow and Nutrient Concentration

The relationship between tributary flow and nutrient concentration is important in determining long term average nutrient loads. The observed relationships of nutrient concentration to Niagara River flow are presented in Figure II-4. The display presents data from the Ministry of Environment (M.O.E.), Ontario. The mean concentration and mean flow are indicated in the Figure.

Total phosphorus, organic nitrogen, and ammonia are apparently independent of, or at least, not significantly correlated with river flow. The hypothesis that total phosphorus and flow are uncorrelated was tested in the

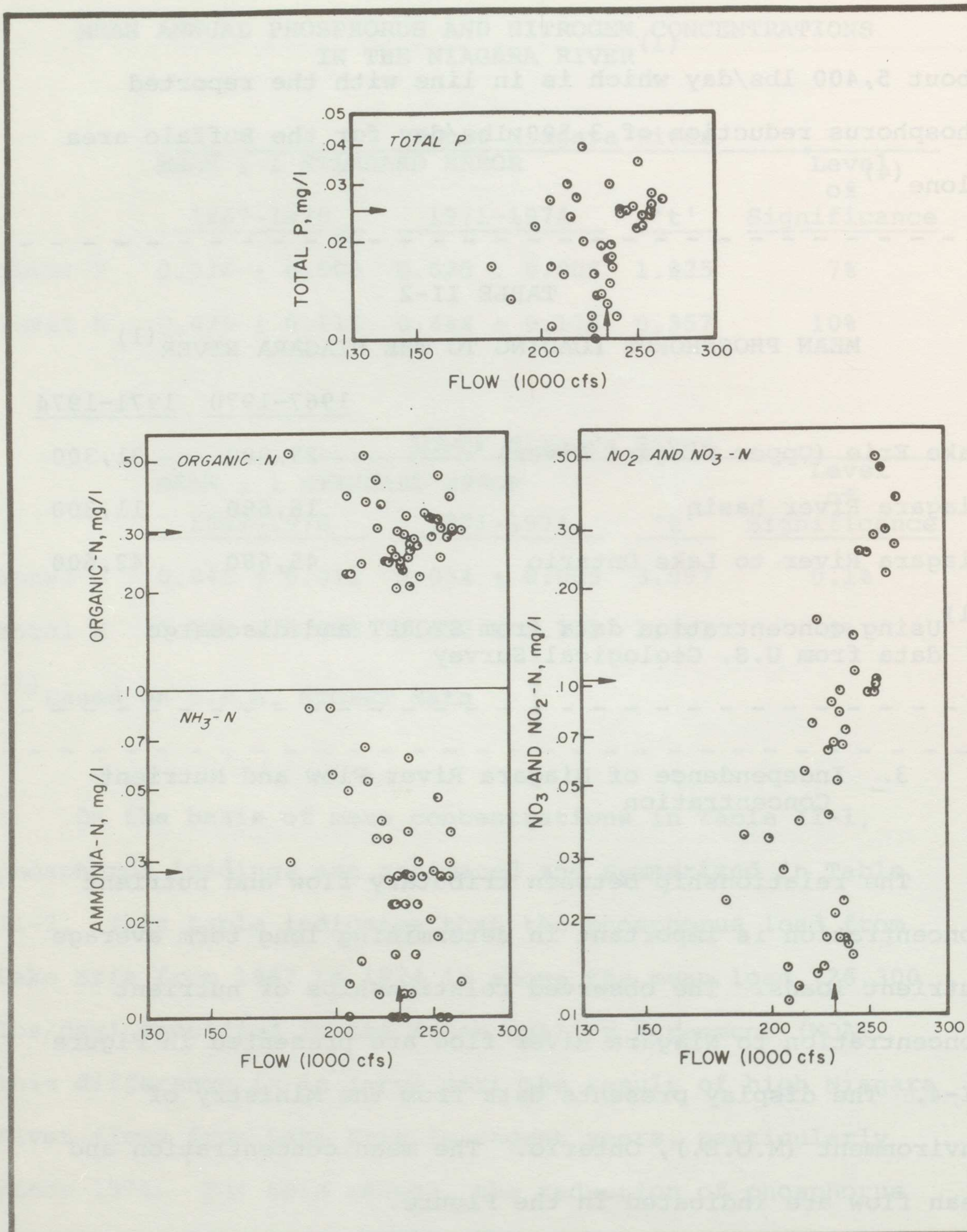

FIGURE II-4
RELATIONSHIP BETWEEN NUTRIENT CONCENTRATION
AND FLOW AT UPPER NIAGARA RIVER
(M.O.E. DATA, 1967-1974)

present study. The test procedure was to develop the simple correlation coefficient between Log flow and Log total phosphorus concentration for data collected at the Lake Erie outlet. The 95% confidence bands for a zero correlation coefficient and a sample size of 44 observations was determined to be 0.30 from "Tables Of The Ordinates And Probability Integral Of The Distribution Of The Correlation Coefficient In Small Samples"(15). The computed sample correlation coefficient, 0.226, when compared to that number indicates that the sample correlation coefficient is not significantly different from zero. Therefore, the logs of the two variables may be considered to be uncorrelated and independent.

Similar analyses were developed for four other tributaries to Lake Ontario. The analysis results show that Log flow and Log total phosphorus concentration are uncorrelated for the Genesee, Oswego, Black and Trent Rivers.

Nitrate and nitrite nitrogen appears to increase as Niagara River flows increase. However, an explanation for this relationship was not developed from the available data base. One should note that M.O.E. data are collected in a limited seasonal time span, the period from May to September so that the data obviously reflects seasonal temperature effects and are biased to source extent.

4. Nutrient Components And Estimate of Total Load From Lake Erie

Phosphorus concentration is often reported only as total phosphorus. As a result, the inorganic portion (orthophosphorus), which is available for phytoplankton growth, is estimated from the orthophosphorus to total phosphorus ratio developed from C.C.I.W. limnological data at the Lake Erie outlet. Concentrations of nitrogen components such as organic nitrogen, ammonia, and nitrite and nitrate are available from M.O.E. and STORET data files. A detailed description of historic load calculations using these data is presented later.

Inputs for the Lake 1 Model calculations require estimates of each nutrient component including that contained in the phytoplankton and zooplankton biomass. However, biological data collected at the Upper Niagara River are very limited and incomplete. The only reported chlorophyll 'a' data at this location are from the Ontario Ministry of Environment[4] (1972). The average chlorophyll 'a' concentration in 1972 is 1.76 μg/l with a standard deviation of 0.98 μg/l. Data files from other sources were also examined[6,7]. A summary of phytoplankton biomass data is presented in Table II-3.

TABLE II-3

AVERAGE PHYTOPLANKTON BIOMASS AT THE UPPER NIAGARA RIVER

Phytoplankton	Unit	Data Source	Period
1.76	μg Chl 'a'/l	Ontario M.O.E.[4]	1972
415.8	cell/ml	STORET[6]	1961-1972
220.3	cell/ml	STORET[6]	1969-1972
1274	cell/ml	USGS[7]	1973
1414	cell/ml	USGS[7]	1974

In the present study, the chlorophyll 'a' concentration data from M.O.E. is used in estimating the Lake Erie nutrient loads associated with phytoplankton biomass.

Data on zooplankton biomass are very limited. Total zooplankton biomass is not available because counts from individual groups of zooplankton are incomplete in STORET data files.

Traditionally, there are three methods used in loading calculations[8]. These are (1) product of the mean concentration and mean flow, (2) average of the product of instantaneous concentration and flow, and (3) same as (2) with scaling of the averages according to the ratio of instantaneous flow to average flow. In the present study, nutrient loads are calculated by the first method using the long term mean nutrient concentration for the period from 1967 to 1974 and the mean annual flow of each year, and also by another estimator empolyed by I.J.C.. According to method (1), the mean and standard deviation of the nutrient loading are calculated as follows:[16]

$$\bar{W} = \bar{Q}\bar{C} \qquad \text{(II-1)}$$

and

$$s_W = \sqrt{(\bar{Q})^2 (S_c)^2 + (\bar{C})^2 (S_Q)^2 + S_Q^{\,2} S_c^{\,2}} \qquad \text{(II-2)}$$

where $\bar{Q}$ is the mean flow, $\bar{C}$ is mean concentration, $\bar{W}$ is mean loading, S_Q, S_c and S_W are the standard deviations of flow, concentration and loading respectively.

Loading rates for total phosphorus, organic nitrogen, ammonia nitrogen, and nitrate - nitrite nitrogen are calculated in the above fashion. The total nitrogen loads are computed as the sum of the nitrogen components. The inorganic phosphorus portion is calculated according to the ratio of orthophosphorus to total phosphorus (0.14) derived from Lake Erie Limnological Data[9]. The method by which this ratio was developed is displayed in Figure II-4A. The Figure also demonstrates the annual variability of this ratio. In the winter months a larger portion (15-20 percent) of the total phosphorus is in an available nutrient form, while in the summer, the available nutrient concentration is generally less than 10 percent of the total phosphorus concentration.

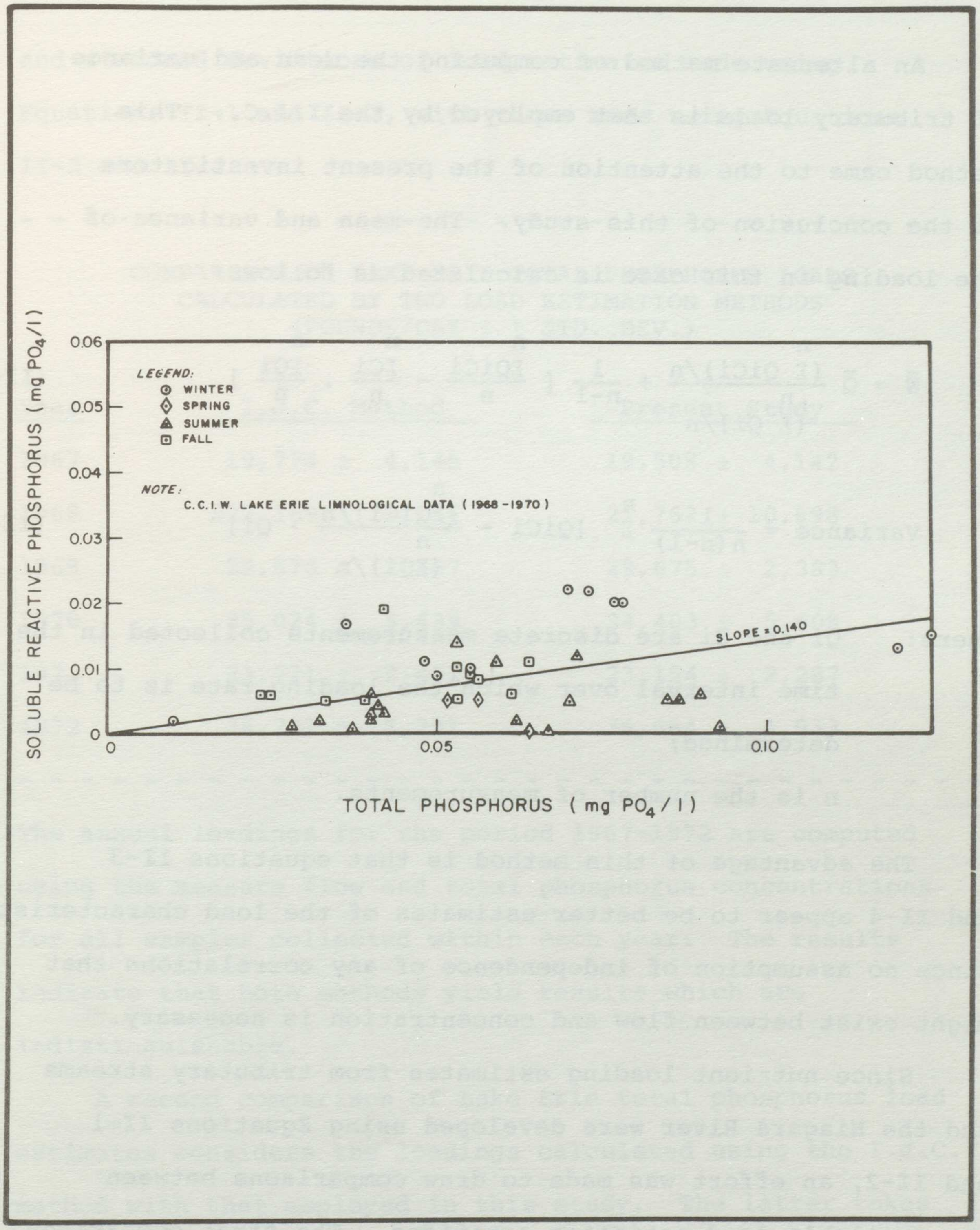

FIGURE II-4A

INORGANIC TO TOTAL PHOSPHORUS RATIO AT LAKE ERIE OUTLET

An alternate method of computing the mean and variance of tributary loads is that employed by the I.J.C.. This method came to the attention of the present investigators at the conclusion of this study. The mean and variance of the loading in this case is calculated as follows:

$$\bar{W} = \bar{Q} \frac{(\overset{n}{\Sigma} QiCi)/n}{\overset{n}{(\Sigma} Qi)/n} + \frac{1}{n-1} \left[\frac{\overset{n}{\Sigma}QiCi}{n} - \frac{\overset{n}{\Sigma}Ci}{n} \cdot \frac{\overset{n}{\Sigma}Qi}{n} \right] \qquad (II-3)$$

$$\text{Variance} = \frac{1}{n(n-1)} \overset{n}{\Sigma} \left[QiCi - \frac{\overset{n}{(\Sigma}QiCi)/n}{(\Sigma Qi)/n} \cdot Qi\right]^2 \qquad (II-4)$$

where: Qi and Ci are discrete measurements collected in the time interval over which the loading rate is to be determined;

n is the number of measurements.

The advantage of this method is that equations II-3 and II-4 appear to be better estimates of the load characteristics since no assumption of independence of any correlations that might exist between flow and concentration is necessary.

Since nutrient loading estimates from tributary streams and the Niagara River were developed using Equations II-1 and II-2, an effort was made to draw comparisons between the available load estimator equations. The first comparison, which is shown in the following table, compares the mean and standard deviations of load estimates made using Equations II-1 and II-2, with those made using Equations II-3 and II-4.

- -

COMPARISON OF LAKE ERIE TOTAL PHOSPHORUS LOADS
CALCULATED BY TWO LOAD ESTIMATION METHODS
(POUNDS/DAY ± 1 STD. DEV.)

Year	I.J.C. Method	Present Study
1967	19,774 ± 4,145	19,508 ± 4,142
1968	22,169 ± 11,156	21,762 ± 10,898
1969	29,676 ± 2,467	29,875 ± 2,383
1970	35,024 ± 5,439	34,403 ± 5,608
1971	23,721 ± 2,421	23,154 ± 2,287
1972	36,702 ± 5,291	36,664 ± 4,933

- -

The annual loadings for the period 1967-1972 are computed using the measure flow and total phosphorus concentrations for all samples collected within each year. The results indicate that both methods yield results which are indistinguishable.

A second comparison of Lake Erie total phosphorus load estimates considers the loadings calculated using the I.J.C. method with that employed in this study. The latter takes the mean loading as the product of the long term average total phosphorus concentration and the mean annual flow. The variance is computed using the long term statistics on concentrations and the measured within year statistics for flow, in Equation II-2. The comparison which is indicated in Figure II-4B shows that the difference in loading estimates between the two methods is generally small. The overlap between estimates as indicated by the ± 1 standard deviation range suggests that the estimates are the same within the accuracy of the analysis. A comparison of the tributary total phosphorus loads calculated by both methods is also shown in the display.

Chlorophyll 'a' inputs from Lake Erie are calculated using Ontario M.O.E. data (Table II-3). The zooplankton carbon concentration is assumed to be 0.025 mg/l in the calculation of zooplankton biomass related nutrient inputs.

Table II-4 and Figure II-5 summarize the nutrient loads from Lake Erie from 1967 to 1974. Data sources used in constructing this loading matrix are indicated.

As shown and discussed previously, there is no clear trend in the phosphorus and nitrogen loadings from Lake Erie and the fluctuation in mass input is directly related to the Niagara River flow variability. Also, it can be seen that the Lake Erie load has been above the load of 26,300 pounds/day given in the W.Q.A. for each of the eight years during the period 1967 to 1974.

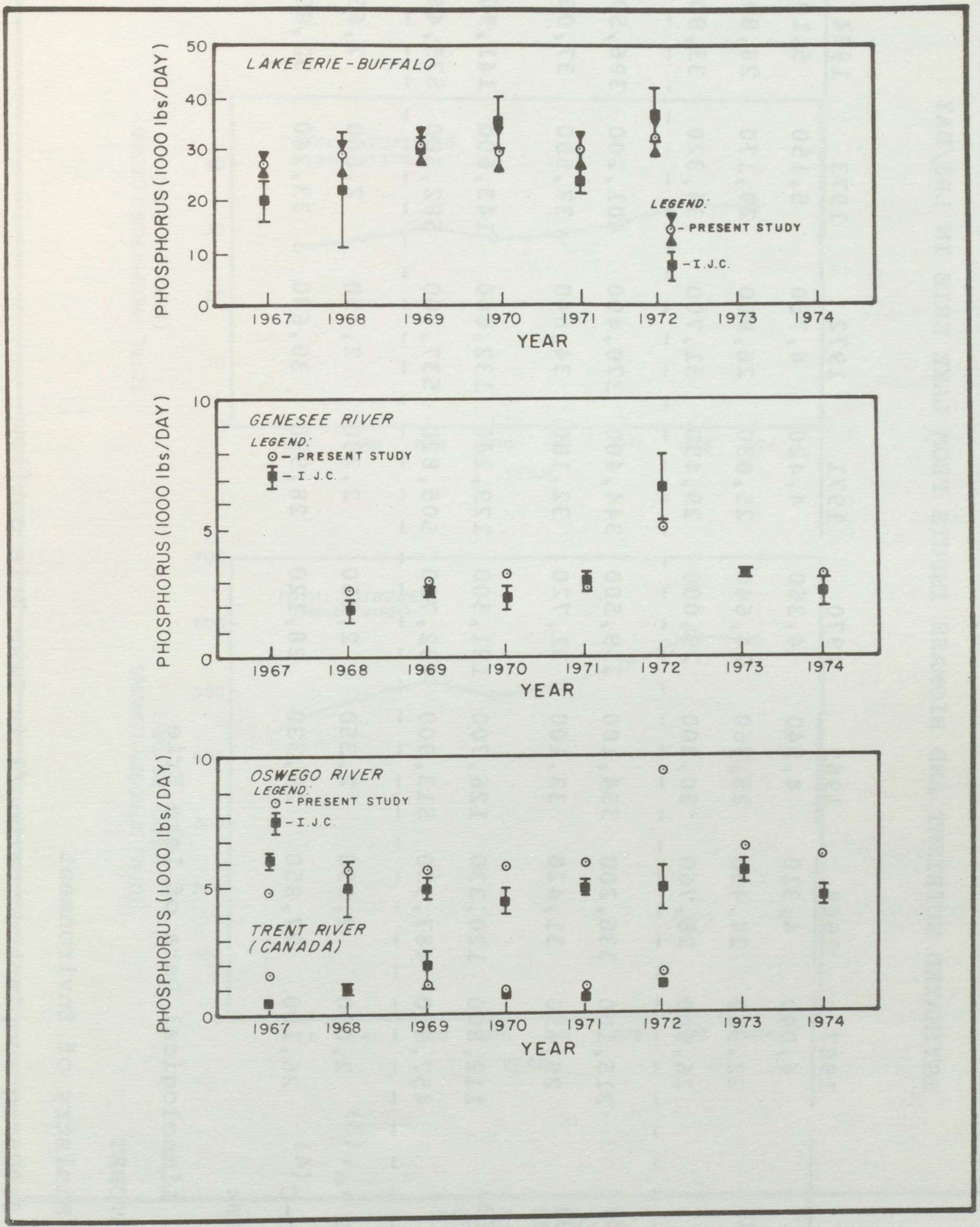

FIGURE II-4B
COMPARISON OF PHOSPHORUS LOADING ESTIMATES

TABLE II-4

ESTIMATED NUTRIENT AND BIOMASS INPUTS FROM LAKE ERIE IN LBS/DAY

	1967	1968	1969	1970	1971	1972	1973	1974
Ortho-P[1]	4,040	4,310	4,540	4,360	4,420	4,760	5,150	5,100
Organic P[1]	22,920	24,450	25,760	24,640	25,030	26,960	29,170	28,800
Total P[2]	26,960	28,760	30,300	29,000	29,450	31,700	34,320	33,900
Organic-N[3]	315,100	336,200	354,100	339,500	344,400	370,400	401,200	396,500
Ammonia-N[3]	29,450	31,420	33,100	31,720	32,180	34,640	37,500	37,050
Nitrate & Nitrite-N[3]	112,800	120,330	126,700	121,500	129,240	132,660	143,600	141,900
Total N	457,350	487,950	513,900	492,720	505,820	537,700	582,300	575,450
Chlorophyll 'a'[3]	2,090	2,230	2,350	2,250	2,280	2,450	2,660	2,630
Zooplankton-C[4]	26,100	27,850	29,330	28,120	28,530	30,680	33,240	32,850

Data Sources:

(1) C.C.I.W. Limnological Data of Lake Erie

(2) E.P.A. STORET

(3) Ontario Ministry of Environment

(4) Assumes 0.025 mg zooplankton carbon/l in Lake Erie outflow

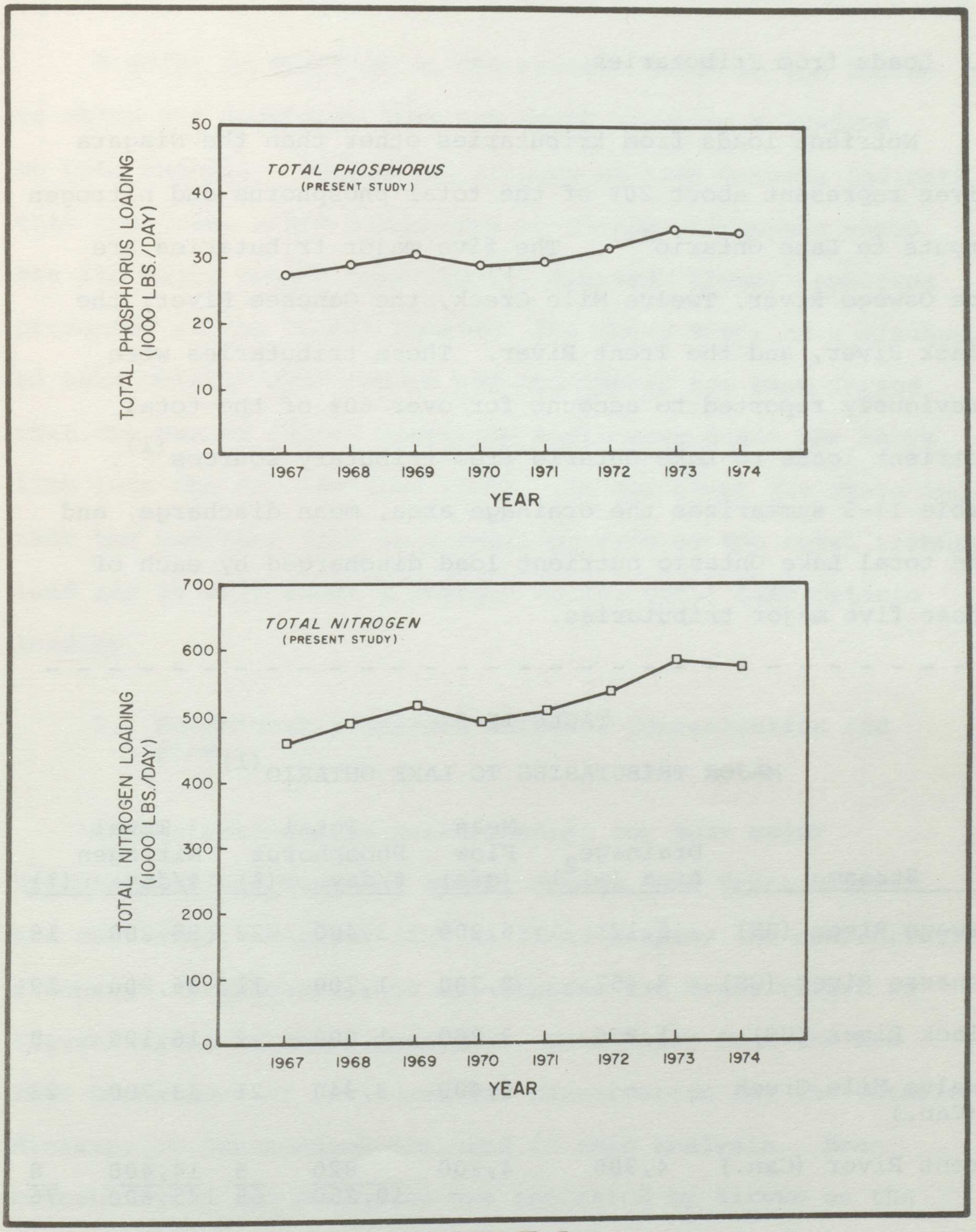

FIGURE II-5
MEAN NUTRIENT INPUTS FROM LAKE ERIE TO NIAGARA RIVER
(1967-1974)

B. Loads from Tributaries

Nutrient loads from tributaries other than the Niagara River represent about 20% of the total phosphorus and nitrogen inputs to Lake Ontario[1]. The five major tributaries are the Oswego River, Twelve Mile Creek, the Genesee River, the Black River, and the Trent River. These tributaries were previously reported to account for over 60% of the total nutrient loads to Lake Ontario from tributary sources[1]. Table II-5 summarizes the drainage area, mean discharge, and the total Lake Ontario nutrient load discharged by each of these five major tributaries.

TABLE II-5

MAJOR TRIBUTARIES TO LAKE ONTARIO[1]

Stream	Drainage Area (mi^2)	Mean Flow (cfs)	Total Phosphorus #/day	(%)	Total Nitrogen #/day	(%)
Oswego River (US)	5,121	6,200	3,400	22	35,200	18
Genesse River (US)	2,457	2,700	1,700	11	36,200	19
Black River (US)	1,876	3,800	1,000	7	16,100	8
Twelve Mile Creek (Can.)	-	6,400	3,340	21	43,700	23
Trent River (Can.)	4,900	4,200	820	5	14,400	8
			10,260	65	145,600	76
All other tributaries			5,340	34	45,400	24
TOTAL			15,600	100	191,000	100

(1) IJC Annual Report 1969 (Reference 1)

A point in question in the present study is the degree to which the discharge from the Trent River is a loading to Lake Ontario. Inspection of maps of Lake Ontario indicate that the Trent River discharges to the Bay of Quinte which has its major outlet near the St. Lawrence River. Analyses presented in the report consider the Trent River as a discharge to Lake Ontario even though the hypothesis has been raised that the Bay of Quinte discharge might move along the shore line into the St. Lawrence River. In any event the Table indicates that the nutrient load is a small portion of the total tributary load and is only about 1 percent of the total Lake Ontario loading.

1. Relationship between Nutrient Concentration and Flow

Concentration flow relationships for four major tributaries (the Genesee, Black, Oswego, and Trent Rivers) are evaluated. Figures II-6 to II-13 display the concentration discharge relationships in the Genesee and Trent rivers as illustrations of these analysis. Data files from the New York Department of Environmental Conservation and the Ontario Ministry of Environment are used in this analysis. Mean concentration and mean flow are indicated by arrows on the plots. The displays indicate that total phosphorus and nitrogen components are generally independent of the flow. The only exceptions in the four rivers analyzed are nitrate-

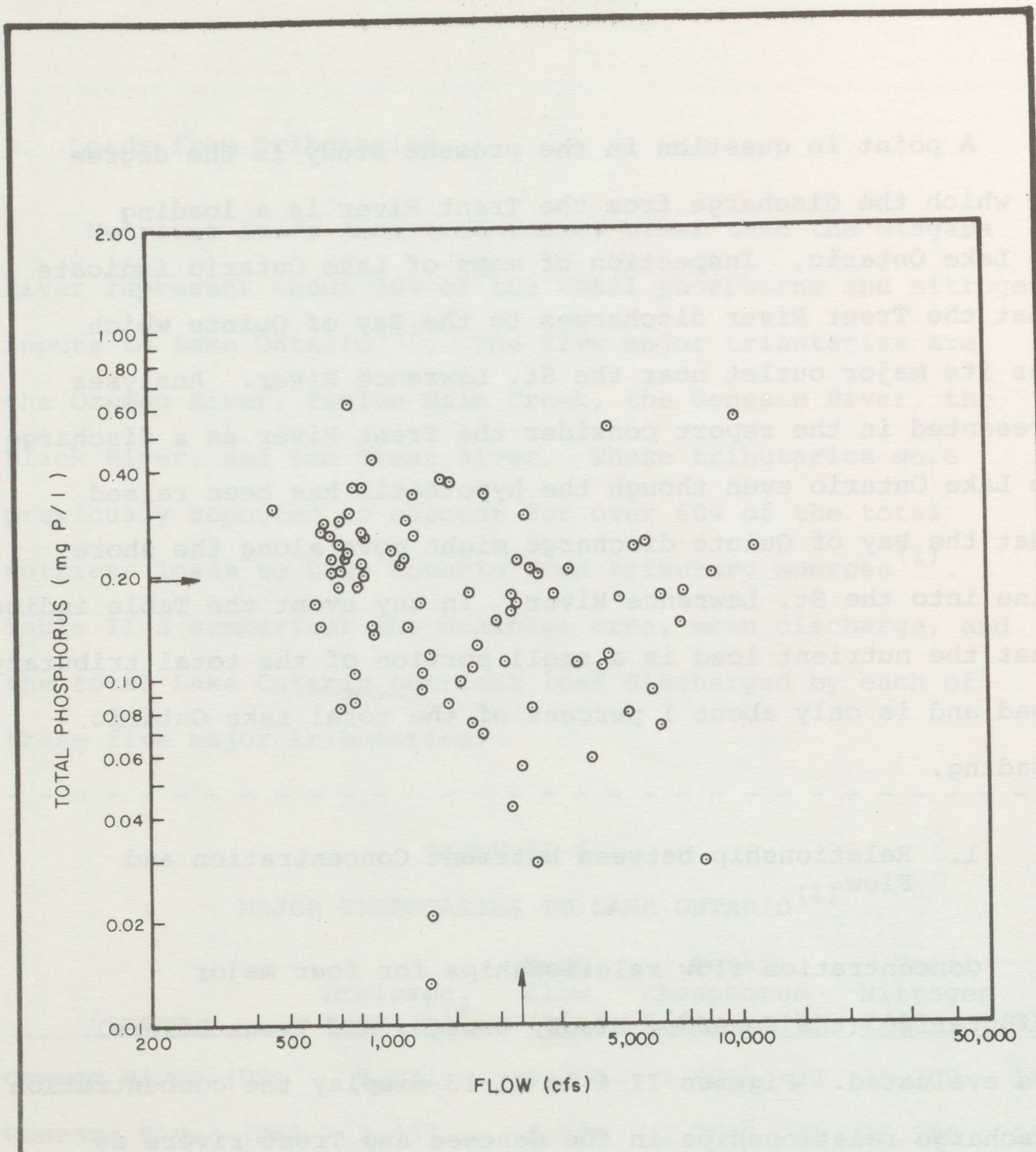

FIGURE II-6
RELATIONSHIP BETWEEN TOTAL PHOSPHORUS AND FLOW FOR GENESEE RIVER (1968–1974)

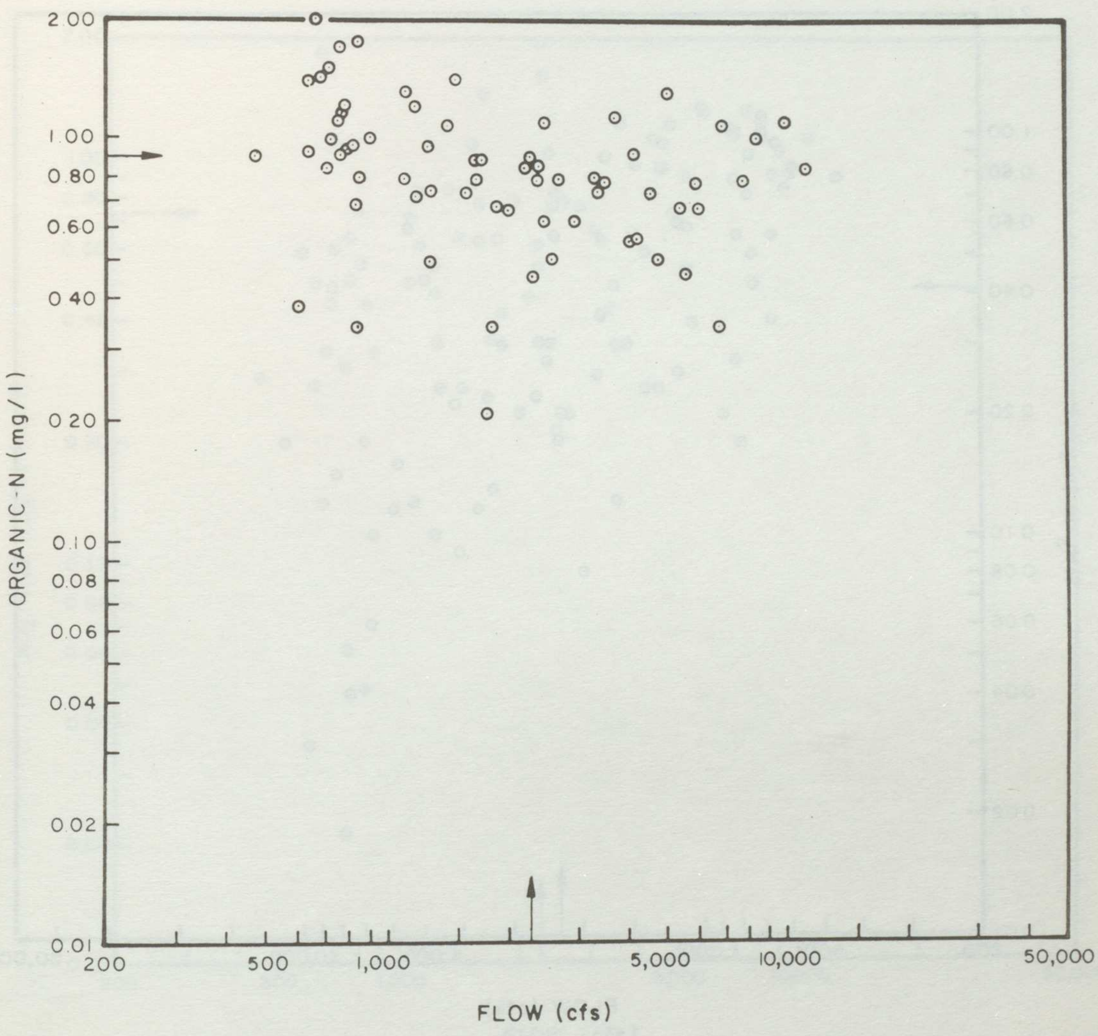

FIGURE II-7
RELATIONSHIP BETWEEN ORGANIC NITROGEN
AND FLOW FOR GENESEE RIVER
(1968 – 1974)

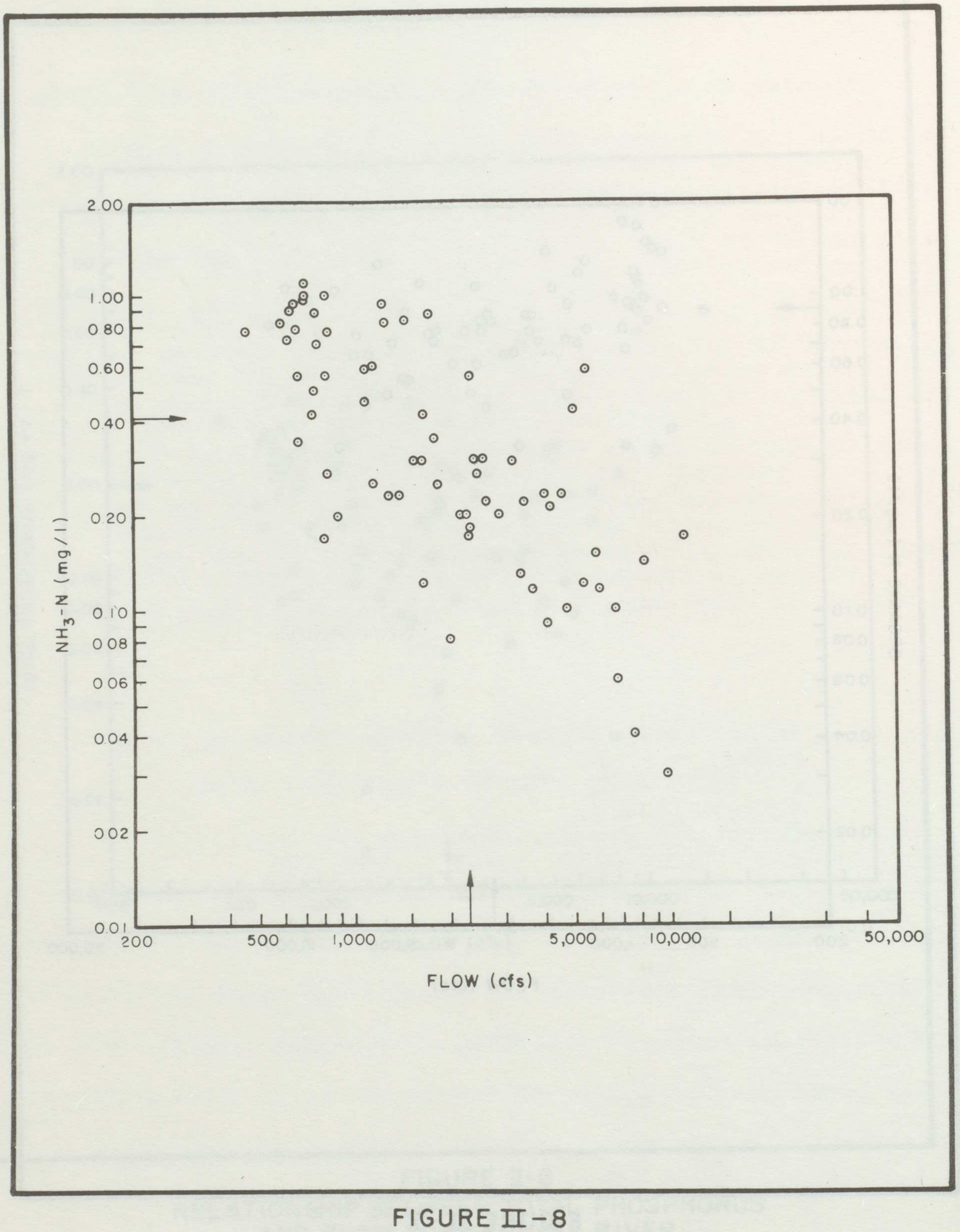

FIGURE II-8
RELATIONSHIP BETWEEN AMMONIA AND FLOW FOR GENESEE RIVER
(1968-1974)

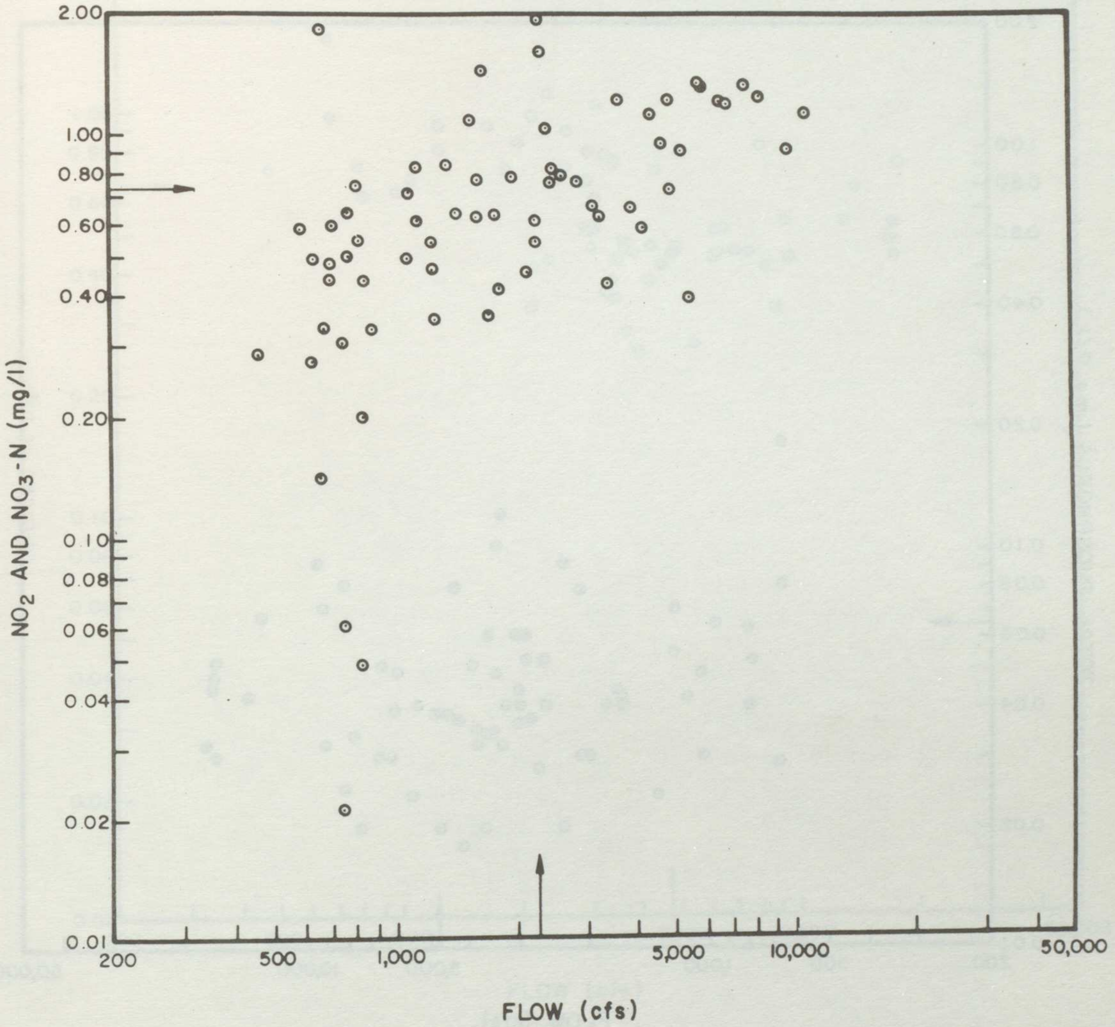

FIGURE II-9
RELATIONSHIP BETWEEN NITRATE AND NITRITE
AND FLOW FOR GENESEE RIVER
(1968-1974)

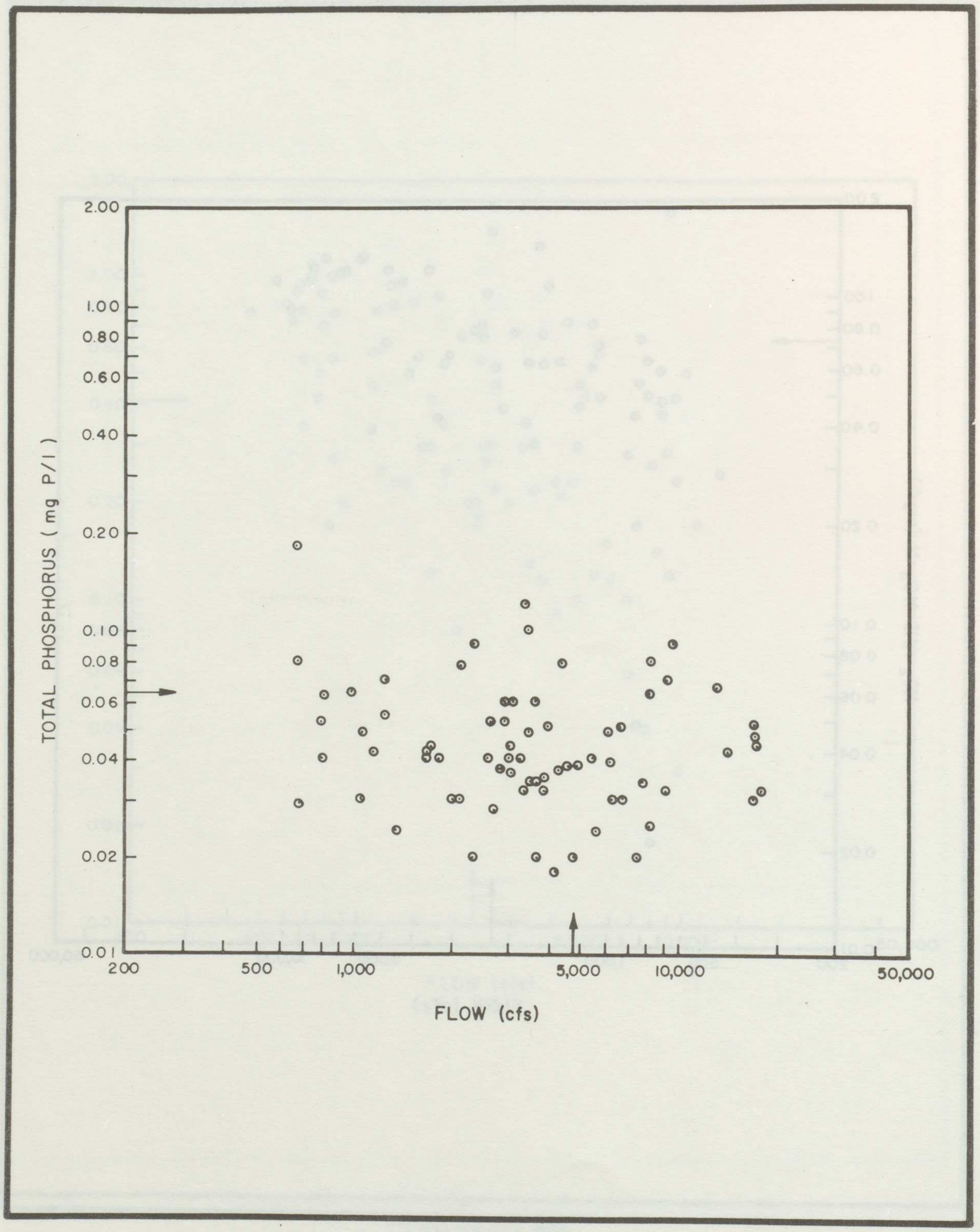

FIGURE II-10
RELATIONSHIP BETWEEN TOTAL PHOSPHORUS AND FLOW FOR TRENT RIVER
(1967–1973)

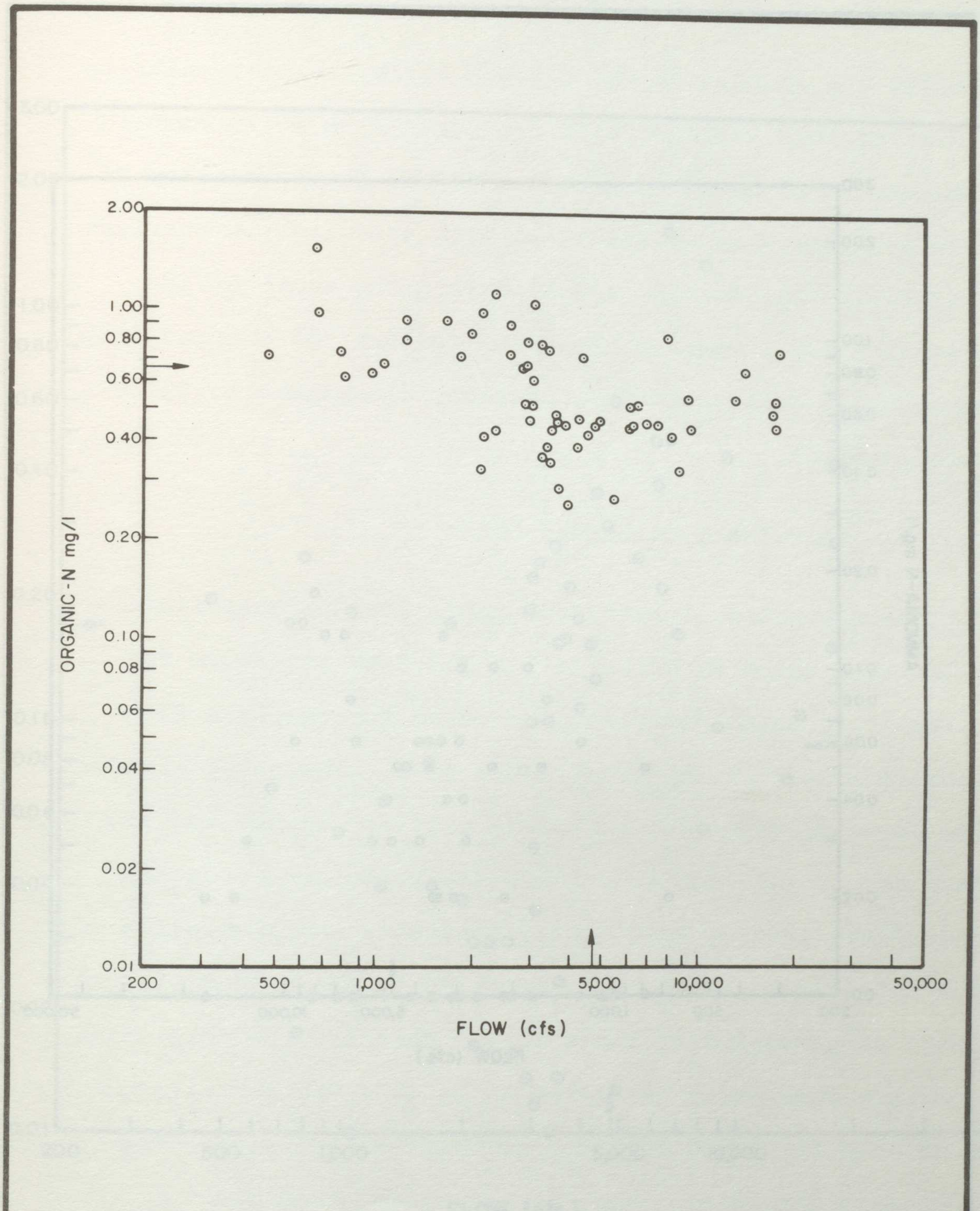

FIGURE II-11
RELATIONSHIP BETWEEN ORGANIC NITROGEN CONCENTRATION AND FLOW FOR TRENT RIVER
(1967-1972)

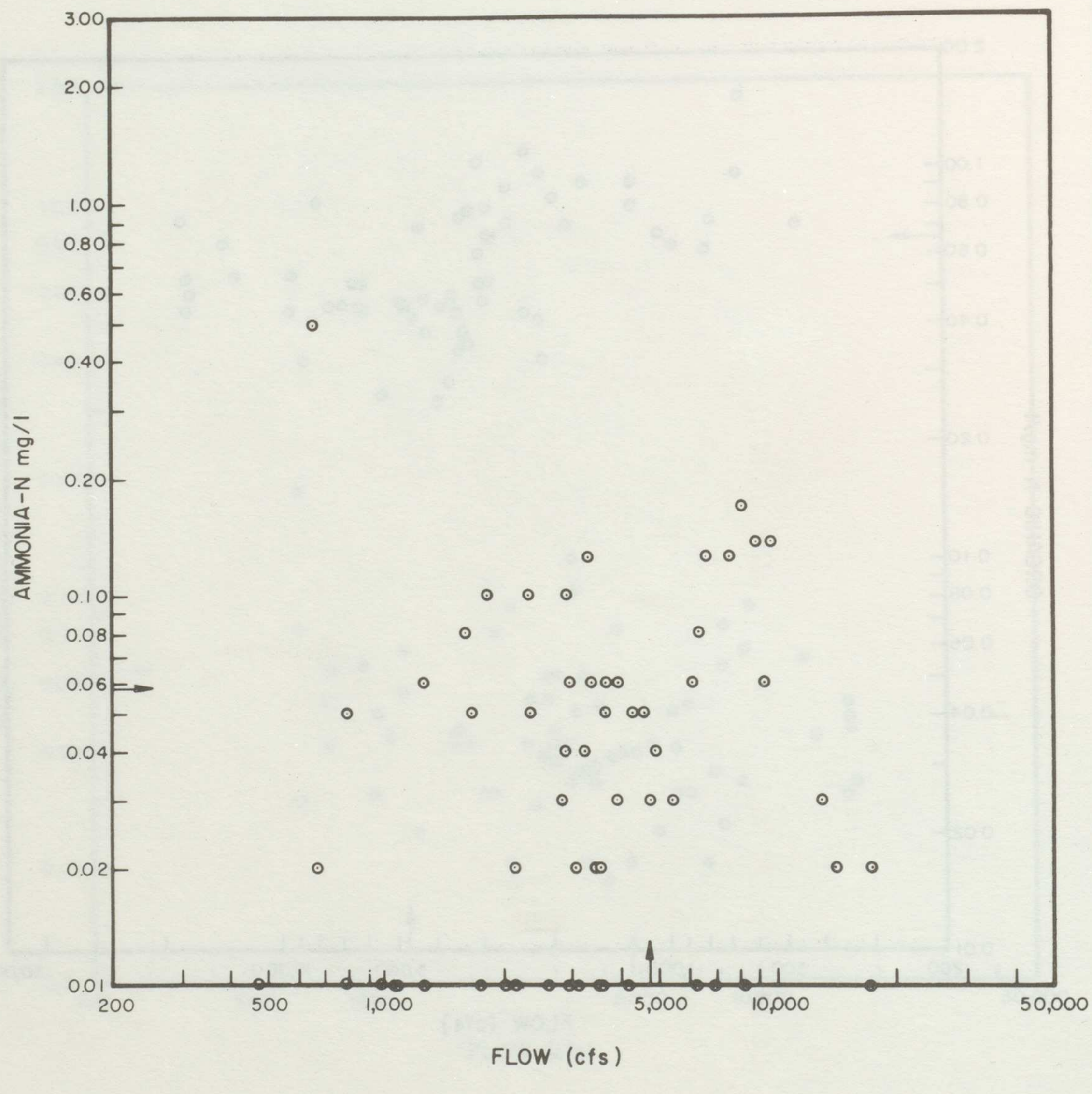

FIGURE II -12
RELATIONSHIP BETWEEN AMMONIA
AND FLOW FOR TRENT RIVER
(1967-1972)

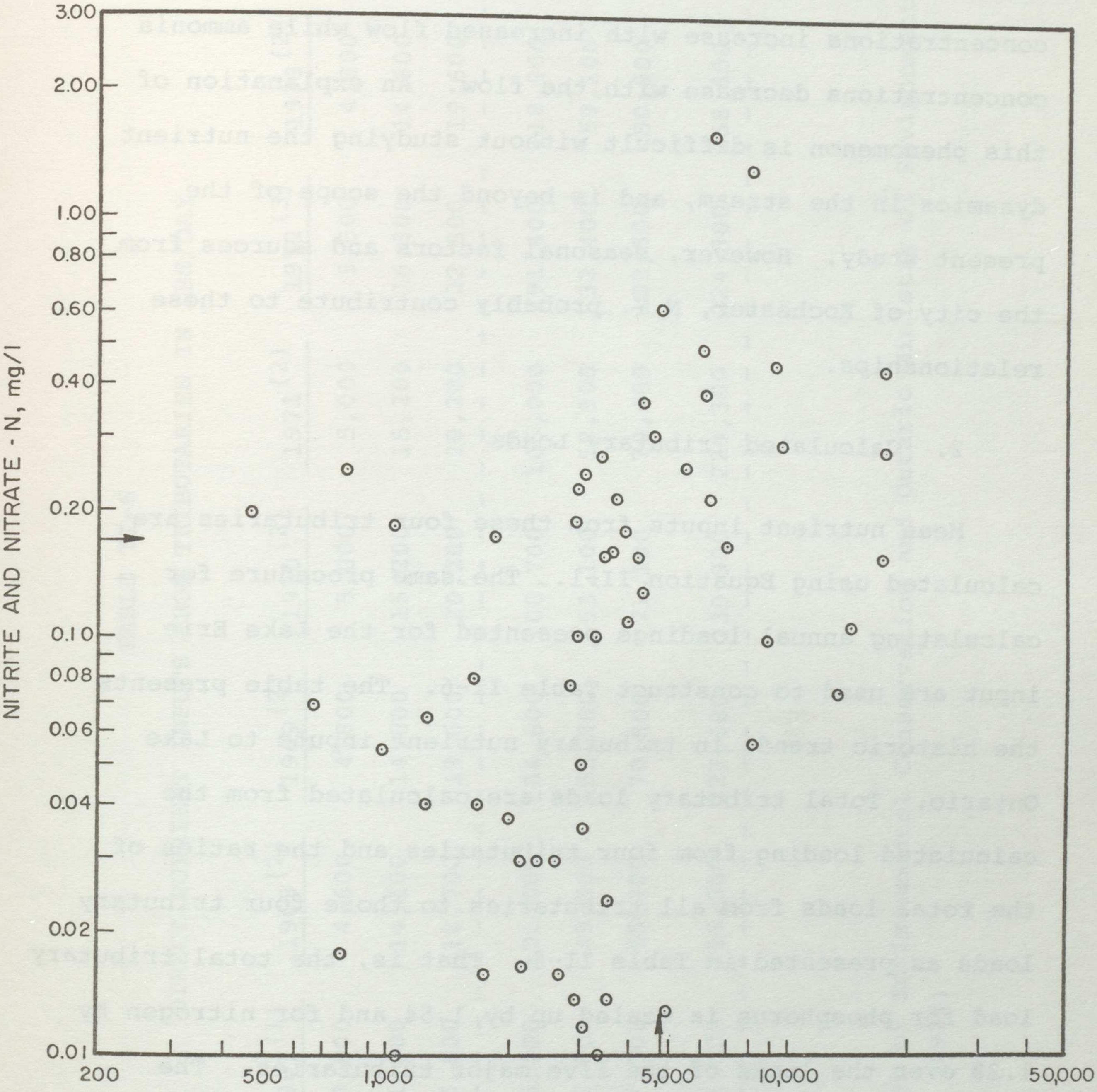

FIGURE II-13
RELATIONSHIP BETWEEN NITRATE AND NITRITE
AND FLOW FOR TRENT RIVER
(1967-1972)

nitrite and ammonia in the Genesee River. Nitrate-nitrite concentrations increase with increased flow while ammonia concentrations decrease with the flow. An explanation of this phenomenon is difficult without studying the nutrient dynamics in the stream, and is beyond the scope of the present study. However, seasonal factors and sources from the city of Rochester, N.Y. probably contribute to these relationships.

2. Calculated Tributary Loads

Mean nutrient inputs from these four tributaries are calculated using Equation II-1. The same procedure for calculating annual loadings presented for the Lake Erie input are used to construct Table II-6. The table presents the historic trends in tributary nutrient inputs to Lake Ontario. Total tributary loads are calculated from the calculated loading from four tributaries and the ratios of the total loads from all tributaries to those four tributary loads as presented in Table II-5. That is, the total tributary load for phosphorus is scaled up by 1.54 and for nitrogen by 1.38 over the loads of the five major tributaries. The inorganic phosphorus input is calculated from the orthophosphorus to total phosphorus ratio, 0.33, derived from Casey and Salbach[8]. The total nitrogen and total phosphorus loadings to Lake Ontario from 1967 to 1974 are displayed in Figure II-14.

TABLE II-6

DIRECT NUTRIENT INPUTS FROM TRIBUTARIES IN LBS/DAY

	1967 (1)	1968 (2)	1969 (2)	1970 (2)	1971 (2)	1972 (3)	1973 (2)	1974 (2)
Ortho-P	3,800	4,600	4,800	5,000	5,000	5,500	4,800	3,200
Organic P	11,800	14,100	14,800	15,200	15,200	16,800	14,800	9,800
Total P	15,600	18,700	19,600	20,200	20,200	22,300	19,600	13,000
Organic-N	76,400	101,000	104,800	106,700	106,000	191,400	118,900	56,300
Ammonia-N	27,600	49,800	52,000	53,100	52,900	32,400	59,100	39,000
Nitrate & Nitrite-N	87,000	65,700	70,800	71,100	70,400	102,500	80,600	72,400
Total N	191,000	216,500	227,600	230,900	229,300	224,900	258,600	167,700

Data Sources:

(1) 1969 IJC Report

(2) New York Department of Environmental Conservation and Ontario Ministry of Environment

(3) Casey and Salbach (1974)

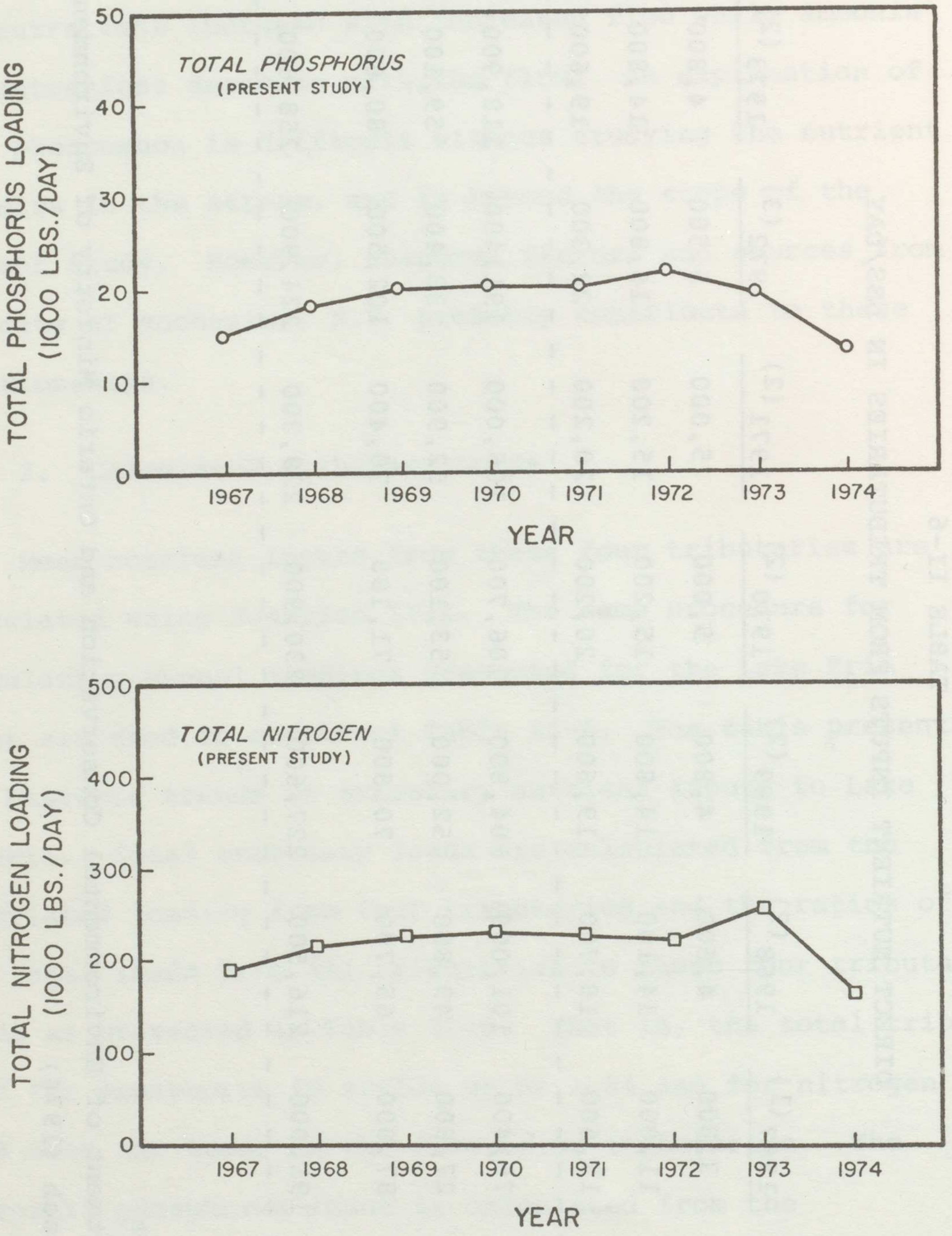

FIGURE II-14
MEAN NUTRIENT INPUT FROM
DIRECT TRIBUTARY DISCHARGES TO LAKE ONTARIO
(1967-1974)

As is the case with all loading estimates, the calculations are subject to a wide variability due to the structure of sampling programs, and estimates of municipal and industrial discharges which were extracted from the load estimates at the mouths of the rivers. Programs should be developed to define methods by which future estimates of nutrient loadings to Lake Ontario from tributary sources are calculated. Such methods, should attempt to answer questions regarding load variability as well as the breakdown of the total load into controllable and uncontrollable portions. Further comments in this regard are contained in the study conclusions.

C. Loads from Municipal and Industrial Sources

Direct municipal and industrial discharges contributed about 22% of the total phosphorus and 8% of the total nitrogen inputs into Lake Ontario in 1967 (1). Nutrient inputs from industries are small when compared with municipal inputs. The principal sources of municipal effluents are metropolitan Toronto, Rochester, and Hamilton. In addition, there is a significant discharge of municipal effluents to tributaries to Lake Ontario but the magnitude of this discharge has not been reported.

1. Method for Estimating the Municipal Loads

Municipal phosphorus loadings are calculated from the sewered population and the per capita contribution of nutrient forms in municipal wastewater effluents. An independent estimate of municipal phosphorus loads from the Niagara River basin was made for comparison with loadings developed on a per capita basis.

The total municipal phosphorus load from the Niagara River basin before the phosphate detergent ban is calculated to be 14,270 lbs/day (using a sewered population of 1.38 million). Considering some additional contribution from industries, land drainage, and non-point sources, this figure compares favorably with 16,680 lbs/day in Table II-2. A similar comparison is obtained for the post-ban period (i.e., 8,800 lbs/day vs. 11,300 lbs/day).

An orthophosphorus to total phosphorus ratio of 0.69 is developed from data presented by Casey and Salbach[8]. This ratio is used in calculating the inorganic phosphorus loads from municipal wastes. This ratio is consistent with literature values reported elsewhere[10].

Further reduction of municipal phosphorus loadings is expected when phosphorus removal facilities at major municipal treatment plants are completed.

Municipal loadings to tributaries to Lake Ontario are treated as controlable loadings in the context of the present study. An initial estimate of the magnitude of this load was developed by assuming that the municipal load accounts for 25 percent of the total tributary load. This estimate was tested by back calculating the population equivelant of this load assuming a 120 gallon per capita flow and an average phosphorus concentration of 3.0 mg P/l. On this basis the loading was determined to be a good estimator of total municipal nutrient inputs entering Lake Onatario on an annual basis.

2. Load Variability

A decreasing trend in municipal phosphorus loads has been observed in the Great Lakes basin and elsewhere following the phosphate-detergent ban and significant decreases in phosphorus concentration in municipal wastes has been reported since 1971[4,10]. A decrease in per capita phosphorus loadings in municipal wastewater were reduced by 50-60 percent in four cities for which data are available and a 60 percent reduction is reported at Buffalo. Some reported results are summarized in Table II-7.

TABLE II-7

PHOSPHORUS REDUCTIONS IN MUNICIPAL INFLUENTS/EFFLUENTS

Area	Units	Before Ban	After Ban	References
Buffalo, N.Y.	Total P mg/l	5.5	2.2	Hopson (1975)
Lackawanna, N.Y.[3]	Total P mg/l	7.6	2.6	Hopson (1975)
Checktowaga[3]	Total P mg/l	10.4	3.8	Hopson (1975)
Albany, N.Y.[3]	Total P lbs/cap/yr	3.2	1.6	Hetling (1973)
Lake Ontario Basin	Total P lbs/cap/yr	3.7[1]	2.2[2]	Present study

[1] 1969 IJC Annual Report - P load/pop.
[2] Casey and Salback - P load/pop.
[3] Out of Basin, Included for Basic Data Purposes Only

3. Industrial Sources

Nutrient inputs from industrial sources are difficult to estimate because of their high degree of variability. The 1969 IJC report[1] documents nutrient loads from individual industries including discharge volumes, treatment, and the nutrient loading rates. Overall, industrial phosphorus inputs constituted a minor portion (1.3%) of the total phosphorus inputs to the lake. A recent IJC report (1974) indicates a slight reduction of phosphorus loads from industries[11].

The nitrogen discharge from industrial sources was reported to be 97,300 lbs/day in 1967[1]. However, Casey and Salbach[8] estimated it to be about 20,300 lbs/day in 1972. This apparent load reduction, while questionable, is responsible for the decrease in municipal and industrial loads shown in Figure II-15.

The phosphorus load composition is calculated using the proportions reported by Casey and Salbach. According to the IJC report[1], 90% of the total nitrogen loading from industries is from steel mills. Since 95% of that loading is expected to be ammonia[2], the following industry-wide approximation is used: 90% ammonia, 5% organic nitrogen, and 5% nitrite-nitrate.

A tabular summary of estimated municipal and industrial nutrient loads to Lake Ontario for the period 1967 to 1974 is contained in Table II-8 and Figure II-15.

D. Other Sources

IJC estimated about 9,900 lbs/day of phosphorus and 137,000 lbs/day of nitrogen input to Lake Ontario from precipitation and dry fallout[1]. In a recent study, Shiomi and Kuntz[13] reported a loading rate of 4,250 lbs/day of atmospheric phosphorus to the lake. Ammonia and nitrate-nitrite inputs were estimated to be about 66,000 lbs/day and 70,000 lbs/day respectively. Variations of precipitation

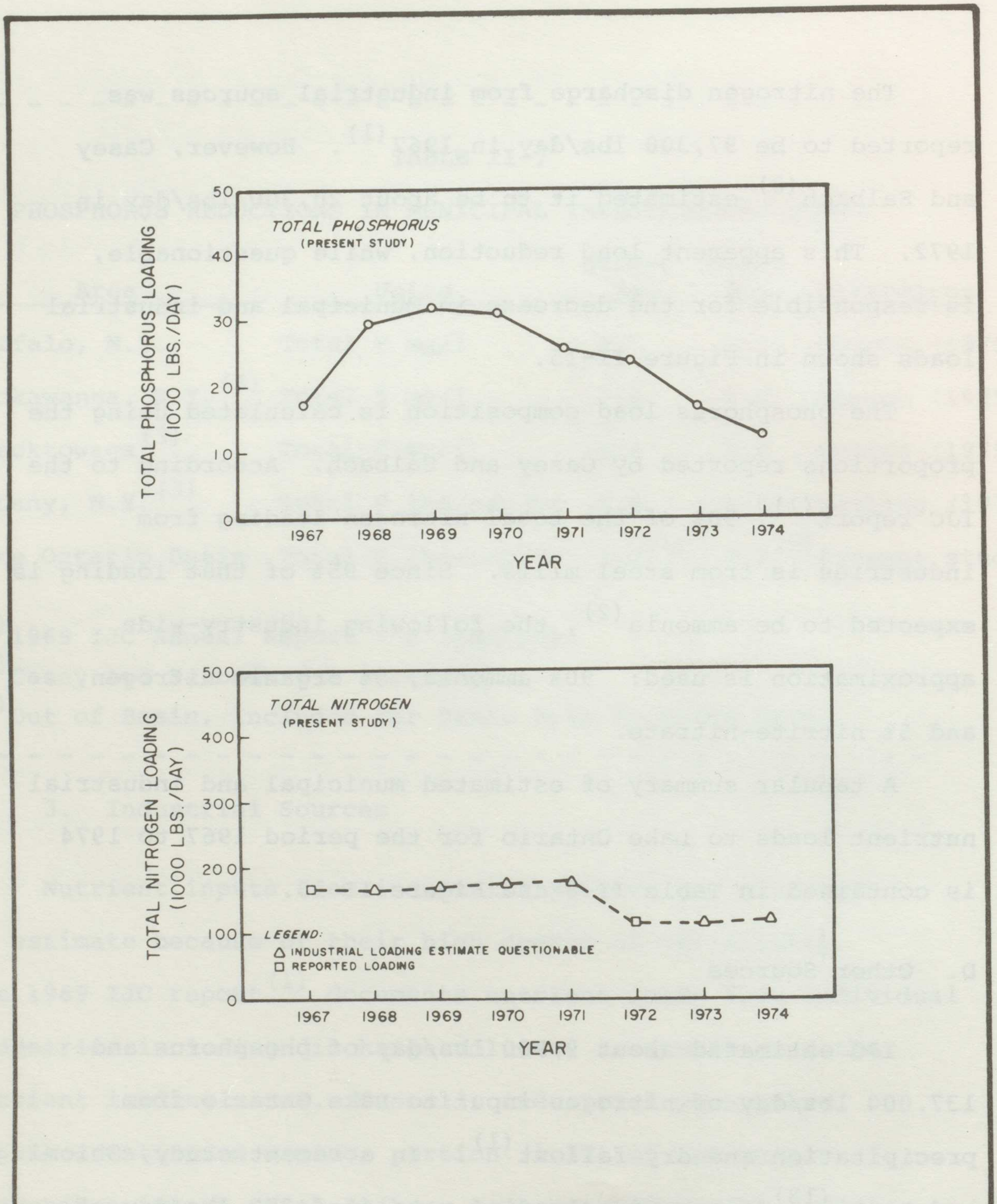

FIGURE II-15
MEAN NUTRIENT INPUT FROM DIRECT
MUNICIPAL AND INDUSTRIAL DISCHARGES TO LAKE ONTARIO
(1967-1974)

TABLE II-8

DIRECT NUTRIENT INPUTS FROM MUNICIPAL AND INDUSTRIAL SOURCES IN LBS/DAY

	1967 (1)	1968 (2)	1969 (2)	1970 (2)	1971 (2)	1972 (3)	1973 (2)	1974 (2)
Ortho-P	11,350	20,050	21,440	20,750	17,300	15,250	10,400	8,200
Organic P	5,850	9,450	10,560	10,250	8,700	8,550	5,900	4,300
Total P	17,200	29,500	32,000	31,000	26,000	23,800	16,300	12,500
Organic-N	21,850	22,500	23,400	24,400	25,300	22,900	24,000	24,900
Ammonia-N	139,000	155,300	138,200	141,100	144,100	84,000	87,300	90,200
Nitrate & Nitrite-N	9,050	8,900	9,300	9,500	9,800	6,600	6,900	7,100
Total N	169,900	166,700	170,900	175,000	179,200	113,600	118,300	122,300

Data Sources:

(1) 1969 IJC Report
(2) Ontario Ministry of Environment
(3) Casey and Salbach (1974)

inputs from year to year are expected but there is no data available in this regard.

Another potentially important source of phosphorus is the sediments. Attention has been directed to this source of phosphorus during the past 10 years because of growing concern over eutrophication control in the Lower Great Lakes. Bannerman et. al.[14], experimentally determined the inorganic phosphorus flux across the sediment water interface in Lake Ontario to be about 8,500 lbs/day. Other independent documentation of this flux, and the availability of the released phosphorus forms for algal growth are not conclusive at this time. In any case, this sediment release is a potential internal nutrient sources which would remain after controllable point source control is implemented. Table II-9 summarizes the atmospheric and sediment loadings to Lake Ontario.

TABLE II-9

OTHER NUTRIENT SOURCES

Nutrient Form	Precipitation	Sediment Release
Total Phosphorus	4,240[13]	8,500[14]
Inorganic Phosphorus	2,020[13]	8,500[14]
Ammonia Nitrogen	66,000[13]	-
Nitrate-Nitrite N	70,000[13]	-

E. Summary of Present and Historic Nutrient Loadings to Lake Ontario

A summary of nutrient loadings developed in the present study and from other published sources is displayed in Table II-10. The table is footnoted to indicate the source of each load, and the method of calculation used in its development.

Present nutrient loads to Lake Ontario are developed for 1974 which is the most recent year for which an adequate data base exists. These loadings are then utilized as initial conditions for model simulations of phytoplankton productivity under alternative future loading scenarios. The methods and results described in the previous section are extended to yield a finer breakdown of the 1974 load according to six nutrient source categories. These are:

1. Lake Erie Outflow to the Niagara River
   - Non-living organic and inorganic nutrient forms
   - Living biomass
2. Total uncontrollable tributary loads to Lake Ontario
3. Municipal discharge to:
   - Niagara River Basin
   - Lake Ontario (direct)
   - Tributaries to Lake Ontario
4. Industrial sources (direct to Lake)
5. Atmospheric (phosphorus)
6. Sediment Release (phosphorus)

Table II-11 presents a tabular summary of nutrient loadings to Lake Ontario for 1974. A graphical display of information contained in this table is presented in Figure II-16. Phosphorus loads from atmospheric and sediment sources are considered separately. These loading represent an additional loading which has not previously been included in I.J.C.'s evaluation of annual Lake Ontario loadings. Within the context of the present study these loads are employed to establish an upper bound on the phosphorus loadings to the lake for purposes of simulating future phytoplankton growth trends.

TABLE II-10

TOTAL PHOSPHORUS LOADING TO LAKE ONTARIO IN LBS/DAY

Source	1967	1968	1969	1970	1971	1972	1973	1974[a]	1974[b]
Niagara River Outlet	42,200[1]	40,100[3]	42,200[3]	40,500[3]	41,100[3]	41,000[2]	47,400[1]	46,200[3]	46,200
Tributaries	15,600[1]	18,700[5]	19,600[5]	20,200[5]	20,200[5]	22,300[2]	19,600[2]	13,000[2]	16,300
Municipal Direct	16,200[1]	28,500[4]	31,000[4]	30,000[4]	25,000[4]	22,000[2]	15,000[2]	11,800[2]	11,800
Industrial	1,000[1]	1,000[9]	1,000[9]	1,000[9]	1,000[9]	1,800[2]	1,300[2]	700[2]	700
Total	75,000[1]	88,300[10]	93,800[10]	91,700[10]	87,300[10]	87,100[2]	83,300[2]	71,700[10]	75,000

[a]Reported

[b]Present Study

NOTE: Footnotes appear at the conclusion of this table

TABLE II-10
(Continued)

TOTAL NITROGEN LOADING TO LAKE ONTARIO IN LBS/DAY

Source	1967	1968	1969	1970	1971	1972	1973	1974[a]	1974[b]
Niagara River Outlet	522,200[1]	506,000[3]	533,000[3]	511,000[3]	518,000[3]	482,400[6]	603,300[3]	550,000[3]	595,200
Tributaries	191,000[1]	216,500[5]	227,600[5]	230,900[5]	229,300[5]	224,900[6]	258,600[5]	167,700[5]	326,490
Municipal (Direct)	72,600[1]	76,700[4]	80,900[4]	85,000[4]	89,200[4]	93,300[6]	98,000[4]	102,000[4]	102,000
Industrial	97,300[1]	90,000[9]	90,000[9]	90,000[9]	90,000[9]	20,300[6]	20,300[9]	20,300[9]	20,200
Total	883,100[1]	889,200[10]	931,500[10]	916,900[10]	926,500[10]	820,900[6]	980,200[10]	840,000[10]	1,043,890

[a] Reported

[b] Present Study

NOTE: Footnotes appear at the conclusion of this table

TABLE II-10
(Continued)

ORTHO-PHOSPHATE PHOSPHORUS LOADING TO LAKE ONTARIO IN LBS/DAY

Source	1967	1968	1969	1970	1971	1972	1973	1974
Niagara River	5,000[7]	4,750[7]	5,010[7]	4,800[7]	4,900[7]	4,800[7]	5,500[7]	4,700[7]
Outlet Tributaries	3,800[7]	4,600[7]	4,800[7]	5,000[7]	5,000[7]	5,500[7]	4,800[7]	3,200[7]
Municipal (Direct)	11,300[7]	20,000[7]	21,390[7]	20,700[7]	17,250[7]	15,160[7]	10,335[7]	8,165[7]
Industrial	50[7]	50[7]	50[7]	50[7]	50[7]	90[7]	65[7]	35[7]
Total	20,150[10]	29,400[10]	31,250[10]	30,550[10]	27,200[10]	25,550[10]	20,700[10]	16,100[10]

NOTE: Footnotes appear at the conclusion of this table

TABLE II-10
(Continued)

ORGANIC NITROGEN LOADING TO LAKE ONTARIO IN LBS/DAY

Source	1967	1968	1969	1970	1971	1972	1973	1974
Niagara River Outlet	356,000[7]	348,800[3]	367,300[3]	352,100[3]	357,100[3]	380,000[7]	416,100[3]	400,000[3]
Tributaries	76,400[7]	101,000[5]	104,800[5]	106,700[5]	106,000[5]	191,400[7]	118,900[5]	56,300[5]
Municipal (Direct)	17,000[7]	18,000[7]	18,900[7]	19,900[7]	20,800[7]	21,800[7]	22,900[7]	23,800[7]
Industrial	4,850[9]	4,500[9]	4,500[9]	4,500[9]	4,500[9]	1,100[9]	1,100[9]	1,100[9]
Total	454,250[10]	472,300[10]	495,500[10]	483,200[10]	488,400[10]	594,300[10]	559,000[10]	481,200[10]

NOTE: Footnotes appear at the conclusion of this table

TABLE II-10
(Continued)

AMMONIA LOADING TO LAKE ONTARIO IN LBS/DAY

Source	1967	1968	1969	1970	1971	1972	1973	1974
Niagara River Outlet	47,000[7]	58,000[3]	61,000[3]	58,500[3]	59,300[3]	40,000[7]	69,100[3]	60,000[3]
Tributaries	27,600[7]	49,800[5]	52,000[5]	53,100[5]	52,900[5]	32,400[7]	59,100[5]	39,000[5]
Municipal (Direct)	51,400[7]	54,300[7]	57,200[7]	60,100[7]	63,100[7]	66,000[7]	69,300[7]	72,200[7]
Industrial	87,600[8]	81,000[8]	81,000[8]	81,000[8]	81,000[8]	18,000[8]	18,000[8]	18,000[8]
Total	213,600[10]	243,100[10]	251,200[10]	252,700[10]	256,300[10]	156,400[10]	215,500[10]	189,200[10]

NOTE: Footnotes appear at the conclusion of this table

TABLE II-10
(Continued)

NITRATE AND NITRITE LOADING TO LAKE ONTARIO IN LBS/DAY

Source	1967	1968	1969	1970	1971	1972	1973	1974
Niagara River Outlet	119,200[7]	99,000[3]	104,400[3]	100,100[3]	101,500[3]	62,400[9]	118,200[3]	90,000[3]
Tributaries	87,000[7]	65,700[5]	70,800[5]	71,100[5]	70,400[5]	102,500[7]	80,600[5]	72,400[5]
Municipal (Direct)	4,200[7]	4,400[7]	4,800[9]	5,000[7]	5,300[7]	5,500[7]	5,800[7]	6,000[7]
Industrial	4,850[9]	4,500[9]	4,500[9]	4,500[9]	4,500[9]	1,100[9]	1,100[9]	1,100[9]
Total	215,250[10]	173,600[10]	184,500[10]	180,700[10]	181,700[10]	171,500[10]	205,700[10]	169,500[10]

NOTE: Footnotes appear at the conclusion of this table

TABLE II-10 (continued)

LOADINGS TO LAKE ONTARIO

FOOTNOTES:

1. Report to the International Joint Commission on the Pollution of Lake Erie, Lake Ontario and the St.Lawrence River, Vol.3, 1969.

2. International Joint Commission, Great Lakes Water Quality, 1974 Annual Report.

3. Lower Niagara River nutrient inputs calculated from Eq.II-1 using the water quality data from the Ontario Ministry of Environment and the flow data from the U.S. Geological Survey.

4. Canadian direct municipal nutrient inputs are obtained from the Ontario Ministry of Environment and direct U.S. inputs are calculated from the sewered population.

5. Direct tributary nutrient loadings are calculated from Eq. II-1 using the data from the Ontario Ministry of Environment and the New York State Department of Environmental Conservation.

6. Using estimates from Casey and Salbach (1974).

7. Estimates are based on the ratios of the nutrient components to the total nutrient concentrations derived from Casey and Salbach (1974).

8. Nitrogen components from industrial sources are approximated by the following proportion: ammonia (90%), organic nitrogen (5%), and nitrite-nitrate (5%).

9. Best estimate--the present study.

10. Total nutrient inputs are summed from all the nutrient sources.

TABLE II-11

1974 NUTRIENT LOADS TO LAKE ONTARIO IN LBS/DAY
(INITIAL LOADING CONDITIONS FOR SIMULATION)

	Organic-N	Ammonia-N	Nitrite & Nitrate-N	Total N	Organic-P	Inorganic P	Total P
Lake Erie	376,470	32,890	113,740	523,100	31,430	5,650	37,080
Biomass	23,100			23,100	3,300		3,300
Tributaries	169,000	32,400	41,950	243,350	9,200	3,000	12,200
Municipal discharge to:							
Niagara River Basin	11,730	34,310	2,960	49,000	1,750	4,070	5,820
Lake Ontario (Direct)	23,800	72,200	6,000	102,000	3,540	8,260	11,800
Tributaries to Lake	20,650	62,490	-	83,140	3,075	1,025	4,100
Total Municipal	56,180	169,000	8,960	234,140	8,365	13,355	21,720
Industrial	1,100	18,000	1,100	20,200	200	500	700
Total Loads	625,850	252,290	165,750	1,043,890	52,495	22,505	75,000

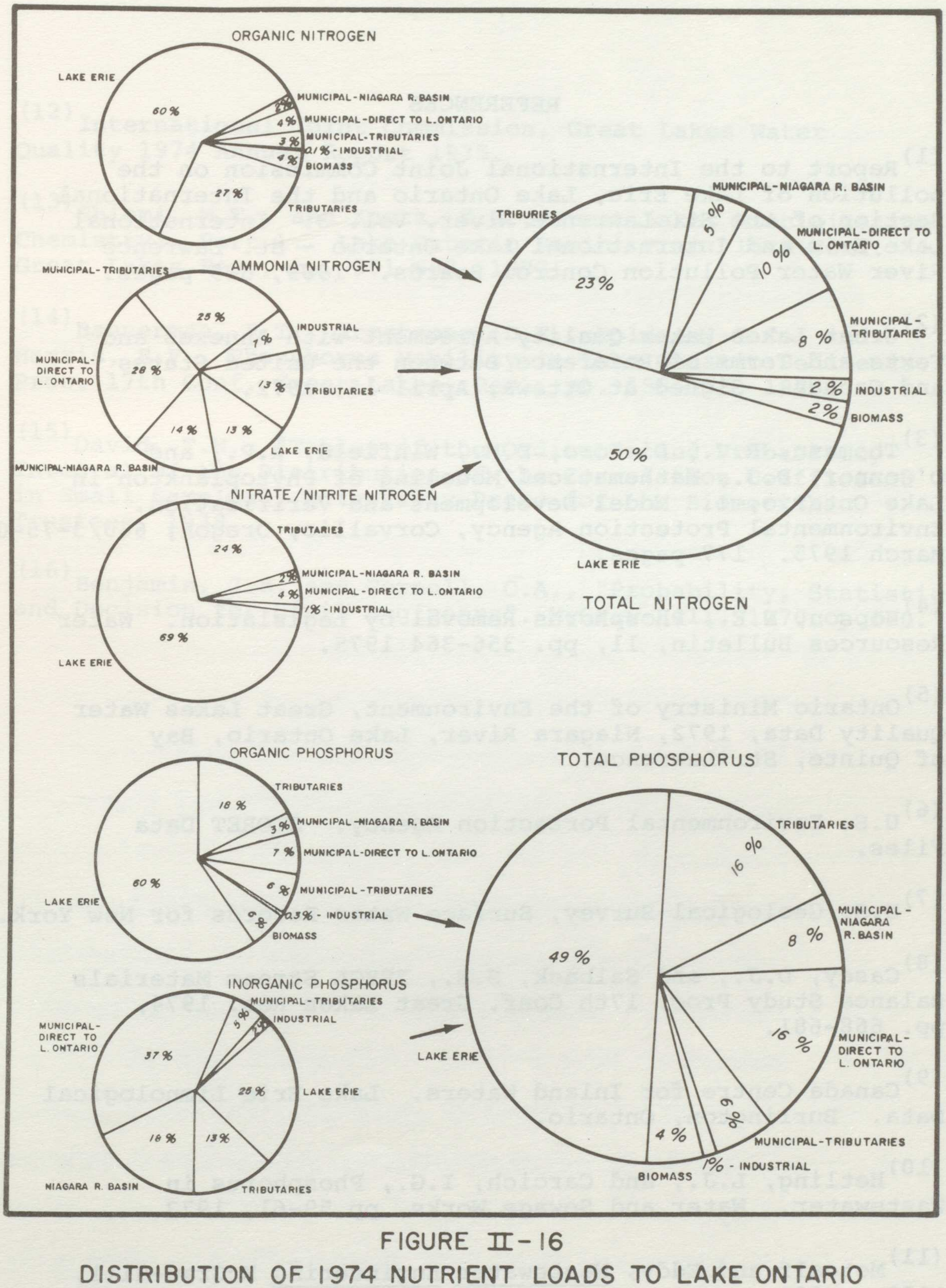

FIGURE II-16

DISTRIBUTION OF 1974 NUTRIENT LOADS TO LAKE ONTARIO

REFERENCES

[1] Report to the International Joint Commission on the pollution of Lake Erie, Lake Ontario and the International Section of the St. Lawrence River, Vol. 3. International Lake Erie and International Lake Ontario - St. Lawrence River Water Pollution Control Boards. 1969, 329 pages.

[2] Great Lakes Water Quality Agreement with Annexes and Texts and Terms of Reference Between the United States and Canada. Signed at Ottawa, April 15, 1972.

[3] Thomann, R.V., Di Toro, D.M., Winfield, R.P., and O'Connor, D.J., Mathematical Modeling of Phytoplankton in Lake Ontario, 1. Model Development and Verification. Environmental Protection Agency, Corvallio, Oregon, 660/3-75-005. March 1975. 177 pages.

[4] Hopson, N.E., Phosphorus Removal by Legislation. Water Resources Bulletin, 11, pp. 356-364 1975.

[5] Ontario Ministry of the Environment, Great Lakes Water Quality Data, 1972, Niagara River, Lake Ontario, Bay of Quinte, St. Lawrence.

[6] U.S. Environmental Portection Agency. STORET Data Files.

[7] U.S. Geological Survey, Surface Water Records for New York.

[8] Casey, D.J., and Salback, S.E., IFYGL Stream Materials Balance Study Proc. 17th Conf. Great Lakes Res. 1974, pp. 668-681.

[9] Canada Centre for Inland Waters. Lake Erie Limnological Data. Burlington, Ontario.

[10] Hetling, L.J., and Carcich, I.G., Phosphorus in Wastewater. Water and Sewage Works, pp.59-61, 1973.

[11] Metcalf and Eddy, Wastewater Engineering McGraw-Hill, 1972, p.231.

(12) International Joint Commission, Great Lakes Water Quality 1974 Annual Report 1975.

(13) Shiomi, M.T., and Kuntz, K.W., Great Lakes Precipitation Chemistry: Part 1. Lake Ontario Basin. Proc. 16th Conf. Great Lakes Res., pp. 581-602, 1973.

(14) Bannerman, R.T., Armstrong, D.E., Holdren, G.C., and Harris, R.F., Phosphorus Mobility in Lake Ontario Sediments. Proc. 17th Conf. Great Lakes. Res., pp. 158-178, 1974.

(15) David, F.N., "Tables of the Ordinates and Probability Integral of the Distribution of the Correlation Coefficient in Small Samples", University Press for the Biometrika Trustees, 1938.

(16) Benjamin, J.R. and Cornell, C.A., "Probability, Statistics, and Decision for Civil Engineers", McGraw-Hill, 1970, p.170.

CHAPTER III

DEVELOPMENT OF SOME FUTURE LOAD SCENARIOS

A principal objective of the present investigation is to develop an evaluation of lakewide phytoplankton biomass in Lake Ontario under alternate loading scenarios. The loading scenarios evaluated in this regard reflect both long term trends in loading due to planned load reductions and population growth factors, as well as short term variability in nutrient loads resulting from the natural variability of inputs to the Lake. The primary factors considered in developing loading scenarios to Lake Ontario are:

1. Planned point source reductions in phosphorus loading to levels specified in the Water Quality Agreement
2. The implementation period over which such load reductions are achieved
3. Projected population growth in the Lake Ontario Basin
4. Variability in natural hydrologic and water quality variables which effect the magnitude of the tributary load
5. Phosphorus loadings entering the Lake through precipitation or sediment release

Other factors which could potentially alter the magnitude of Lakewide nutrient loads but for which no quantitative estimates of loading trends have yet been established are not considered in the analysis. For example, nutrient concentrations in Lakes Erie, Huron, Michigan and Superior are probably not in equilibrium with their present loadings. Future loadings to the Niagara River from Lake Erie will undoubtedly change in the time scale of decades as nutrient concentrations in the upbasin lakes approach equilibrium levels. It is not clear how future loadings from Lake Erie will be affected without more detailed analyses of the Great Lakes basin which consider long term loading trends, times to equilibrium, and nutrient retention in those lakes. Another factor not considered in the present description of future loads is changes in land use patterns in the Lake Ontario Basin. An adequate basis for describing nutrient loadings due to future development does not exist at this time.

An earlier study also included some computations of the LAKE 1 Model response under different load inputs[(1)], but assumed that all load reductions would be instantaneous, a quite unrealistic assumption. In this study, therefore, a more realistic schedule of load reductions over 10 and 20 year periods are assumed and associated phytoplankton responses were computed.

The discussion of nutrient loadings to Lake Ontario which is presented in this chapter is conveniently viewed in terms of four major loading components discussed in Chapter II. These are loadings from:

1. Lake Erie;
2. Tributaries to Lake Ontario;
3. Municipal and Industrial point sources;
4. Phosphorus loadings from atmospheric sources and sediment release.

Within the context of this study loadings from Lake Erie, percipitation and sediment release are viewed as uncontrolable sources, that is sources that will not be influenced by man made control practices within the time scale of 20 to 40 years. The annual Lake Erie loading is dominated principally by variability in hydrologic inputs as discussed earlier, while precipitation and sediment release of phosphorus are natural occurring background loadings described by other investigators[2].

On the other hand, municipal and industrial nutrient discharges, and inputs from tributary streams are considered to be partially or totally controllable using control technologies available at the present time. Removal of phosphrous from municipal and industrial discharges is presently practical down to levels of 1.0 mg P/l and technologically feasible to 0.1 mg P/l. Nitrogen removal to low levels is also feasible but is not presently being considered for control of long term eutrophication processes.

That portion of the tributary load associated with point source discharge is assumed to be controllable and will undoubtedly be reduced under the provisions of the present Agreement. Other tributary inputs associated with distributed loadings from agricultural runoff, while controllable, are assumed constant in the analysis.

A. The Lake Erie Nutrient Loading

The Water Quality Agreement specifies the magnitude of the Lake Erie phosphorus loading to the Niagara River to achieve the WQA loads. This planned loading of 4,800 short tons per year (26,300 #/day) is 94% of the 28,000 pound/day mean annual load associated with the mean discharge from Lake Erie to the Niagara River, 207,000 cfs. As discussed in Chapter III, the variability in the average annual discharge from Lake Erie is the principal factor contributing to variability in the annual nutrient loading from Lake Erie. For this reason three Lake Erie nutrient input conditions are utilized in future laoding scenarios:

- Mean annual Lake Erie input
- High (95%) Lake Erie input
- Low (5%) Lake Erie input

The analysis of flow and nutrient concentration data for the Niagara River, presented in Chapter II, permits a quantitative description of the long term variability of the Lake Erie loading through application of equations II-1 and II-2. The Lake Erie input characteristics developed in this manner are displayed in Table III-1. The table was developed from an analysis of flow and concentration data at the O.M.E. sampling transect and the STORET NET station at the inlet to the Niagara River. Data were available for total phosphorus, organic nitrogen, ammonia nitrogen, and nitrite/nitrate nitrogen. The table presents the computed mean annual loading for each form as well as the standard error of the mean, and the estimated low (5%) and high (95%) nutrient loading rates. As indicated, the breakdown of total phsophorus into organic and inorganic (available) forms was accomplished by determining the average phosphorus composition of total phosphorus in Lake Erie from available C.C.I.W. data.

One additional breakdown of the Lake Erie nutrient loading data is required by the Lake 1 modeling framework. Chlorophyll and zooplankton biomass contains biological forms of nitrogen and phosphorus. The nutrients present in the Lake Erie outflow were estimated to have 2.5 μg P/l and 17.5 μg N/l tied up in biomass forms. Since the nutrient input in these forms is implicitly included in the

TABLE III-1

LAKE ERIE LOAD CHARACTERISTICS[1]

Water Quality Variable	Mean Annual Input	Standard Error of Annual Input	Extremes In Lake Erie Load Low (5%)	High (95%)
Total Phosphorus	28,050	3,176	21,700	34,400
Organic Phosphorus	24,120[2]	-	18,660[2]	29,580[2]
Available Phosphorus	3,930[2]	-	3,040[2]	4,820[2]
Total Nitrogen	478,610	-	356,845	600,374
Organic Nitrogen	330,525	33,330	263,870	397,184
Ammonia Nitrogen	30,660	4,050	22,565	38,755
Nitrate Nitrogen	117,425	23,510	70,410	164,435

(1) Based on analysis of STORET and O.M.E. Data collected at Buffalo, N.Y.

(2) Phosphorus components developed from ratios of phosphorus forms in C.C.I.W. Lake Erie Data (Available P = 0.14 Total P; Organic P = 0.85 Total P)

phytoplankton and zooplankton biomass inputs to the Lake 1 model, the loading associated with biomass nutrient forms was subtracted from the organic nutrient loadings from Lake Erie.

For purposes of extrapolating loadings to future conditions the Lake Erie loading is assumed to decrease to, and then remain constant at one of the three levels outlined above for the simulation period. The mean annual Lake Erie discharge is associated with each of the simulations with additional sensitivity analyses to describe the effect of other high (95%) and low (5%) discharge conditions on the time to equilibrium and peak phytoplankton concentration for the Lake. A description of the Lake Erie load relative to other loadings to Lake Ontario is presented in the loading summaries at the end of this chapter.

An additional Lake Erie loading condition was developed to assess the sensitivity of phytoplankton biomass in the Lake to naturally occurring variability in the Lake Erie input. In this regard, 40 years of historical Lake Erie discharge data (1930-1970) was used to develop a time history of Lake Erie loading to the Niagara River. The mean annual loading was developed from the product of the mean annual discharge in each year and the long term average nutrient concentrations from the Lake Erie outlet. The time history of total phosphorus input from Lake Erie for this loading condition is presented in Figure III-1.

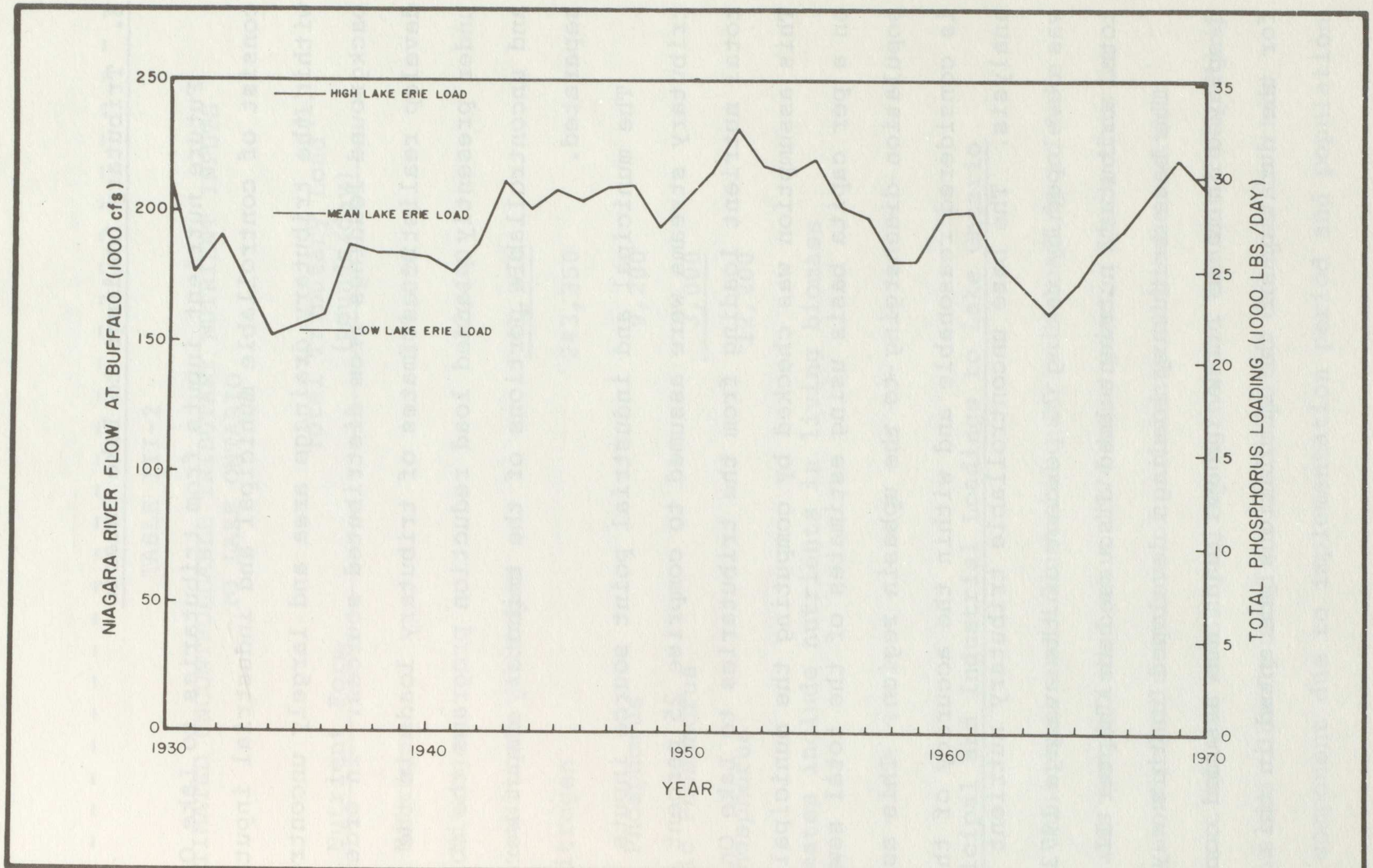

FIGURE III-1
YEAR TO YEAR VARIATION OF
LAKE ERIE PHOSPHORUS LOADING TO THE NIAGARA RIVER

B. Tributary Loadings to Lake Ontario

Future nutrient inputs from tributaries to Lake Ontario consist of controllable municipal and industrial inputs within the tributary drainage area and largely uncontrollable background loadings from distributed sources. In order to develop realistic estimates of tributary loads in the future under presently planned load reduction programs the controllable and uncontrollable portions of the tributary input were separated.

The municipal and industrial point source inputs to tributary streams were assumed to comprise 25 percent of the total nutrient loading from the tributaries to Lake Ontario. This assumption was checked by computing the municipal load on a per capita basis using estimates of the total sewered population discharging to the upbasin region. This assumption is considered reasonable and within the accuracy of the analysis. The base uncontrollable tributary nutrient load was developed by taking 75 percent of the average 1973-1974 total tributary nutrient load discussed in Chapter II.

The base tributary loadings developed in this way are displayed in Table III-2. These loads are assumed constant for the duration of the simulations presented in this study.

TABLE III-2

ESTIMATED UNCONTROLLABLE TRIBUTARY NUTRIENT INPUTS TO LAKE ONTARIO

Nutrient Form	Total Tributary Load[1] (pounds/day)
Organic Nitrogen	169,000
Ammonia Nitrogen	32,400
Nitrite - Nitrate Nitrogen	41,950
Total Nitrogen	243,350
Organic Phosphorus	9,200
Inorganic Phosphorus	3,000
Total Phosphorus	12,200

[1] Estimates include nutrients in living biomass forms

C. Municipal and Industrial Loadings to Lake Ontario

The municipal and industrial nutrient loading to Lake Ontario was established at a 1974 base year. Since this is the only controlable source of nutrients addressed within the context of the Water Quality Agreement the future loading scenarios are closely tied to anticipated changes in this loading component due to implementation period and population growth within the basin. Future nitrogen and phosphorus inputs to Lake Ontario from the combined municipal and industrial discharges will be considered separately.

1) Future Trends in Phosphorus Inputs

The present (1974) total phosphorus loading to Lake Ontario from municipal and industrial sources is estimated to be 22,420 pounds/day. This load consists of 17,620 pounds/day from direct municipal discharges (including Buffalo), 4,100 pounds/day (estimated) from municipal and industrial discharges to tributary streams and rivers, and 700 pounds/day from industrial sources discharging direct to the Lake. This loading is to be reduced to 16,300 pounds/day to satisfy the load reduction requirements laid out in the Water Quality Agreement as described below.

The allowable municipal and industrial loading under the Water Quality Agreement was developed by subtracting the W.Q.A. Lake Erie load and the uncontrollable tributary load from the total allowable phosphorus load. The total allowable municipal and industrial load was then distributed between the organic and inorganic forms according to ratios developed from data presented by Casey and Salbach[2]. The resulting W.Q.A. phosphorus loads are presented in Table III-3.

TABLE III-3

W.Q.A. PHOSPHORUS LOADS TO LAKE ONTARIO IN LBS/DAY

	Organic Phosphorus	Inorganic Phosphorus	Total Phosphorus
Lake Erie to Niagara R. (includes biomass phosphorus)	22,620	3,680	26,300
Tributaries	9,200	3,000	12,200
Municipal and Industrial	6,230	10,070	16,300
Total	38,050	16,750	54,800

The allowable municipal and industrial load in the Lake Ontario basin (including loadings to the Niagara River) is 16,300 pounds/day. The organic and inorganic portions of that loading are shown to be 6,230 pounds/day and 10,070 pounds/day respectively. These load reductions are reasonable to achieve using presently available phosphorus removal technology. The corresponding average effluent concentration is approximately 2.2 mg P/l at 1974 population levels and 1.3 mg P/l at the estimated 2015 population (assuming a population growth rate of 1.3% annually).

The implementation period over which this load reduction is achieved is taken as 10 or 20 years to facilitate a comparison of long term W.Q.A. implementation with short term reductions presented in an earlier study[1]. In this regard a straight line reduction from the 1974 phosphorus load of 21,720 pounds/day (municipal and industrial) to the W.Q.A. loads is assumed for both implementation periods. At the end of the implementation period the loading is maintained at the W.Q.A. level for the entire simulation period. A more detailed illustration of these future loads is contained in the load summaries at the end of this chapter.

2) Future Trends In Nitrogen Inputs

The present study does not consider any planned reduction in future nitrogen loads. Therefore, the nitrogen loadings from municipal and inudstrial sources are increased in accordance with population growth trends for the Lake Ontario Basin. The Great Lakes Basin Commission Framework Study[3] indicates a projected growth rate in the basins major metropolitan areas of 0.9 to 1.5% per year through 2010. On this basis, an average growth rate of 1.3% was employed in developing basin wide population growth. The increase in future nitrogen loadings was similarily assumed to grow at 1.3% per year. The nitrogen forms are assumed to remain at a constant ratio relative to the total nitrogen load. Table III-4 presents a summary of projected nitrogen loadings from municipal and industrial sources.

TABLE III-4

PROJECTED NITROGEN LOADINGS FROM MUNICIPAL AND INDUSTRIAL SOURCES [1]

Year	Organic Nitrogen	Ammonia Nitrogen	Nitrite/ Nitrate Nitrogen	Total Nitrogen
0 (1974)	57,280	187,000	10,060	254,340
10	65,300	213,180	11,470	289,950
20	74,470	243,100	13,080	330,650
30	84,780	276,760	14,890	376,430
40	96,240	314,160	16,900	427,300

(1) Assumes future nitrogen loads increase at 1.3%/year

D. Atmospheric and Sediment Release Phosphorus Loads

Phosphorus loadings from atmospheric and sediment sources are discussed by Casey and Salbach [2]. These loadings are presented in Chapter II.

Certain simulations presented in this study include atmospheric and sediment sources of phosphorus to establish an upper bound on phosphorus loadings to Lake Ontario. These simulations utilizes the loadings presented in Table II-8, assuming them to be invariant in time. There are technical questions with regard to the availability of phosphorus from atmospheric sources for phytoplankton growth, but this issue is not addressed in the present study.

E. Summary of Loading Scenarios

A graphical representation of loading scenarios to Lake Ontario is contained in Figure III-2. The figure represents load scenarios in a 40 year time span and includes loads for a 10 and 20 year implementation period for W.Q.A. load reductions.

It is note worthy that the municipal and industrial load established by the Water Quality Agreement, 16,300 pounds/day represents an average effluent phosphorus concentration of about 2.2 mg P/l. The agreement stipulates in part that:

> 2. Effluent Requirements. The phosphorus concentrations on effluent from municipal waste treatment plants discharging in excess of one million gallons per day, and from smaller plants as required by regulatory agencies, shall not exceed a daily average of one milligram per liter into Lake Erie, Lake Ontario and the International Section of the St. Lawrence River.
>
> 3. Industrial Discharges. Waste treatment or control requirements for all industrial plants discharging wastes into the Great Lakes System shall be designed to achieve maximum practicable reduction of phosphorus discharges to Lake Erie, Lake Ontario and the International Section of the St. Lawrence River.

Hence the W.Q.A. municipal and industrial mass load appears to be greater than the load dictated by effluent requirements. Even if the allowable 16,300 pound/day load is extrapolated to 2015 populations, the average effluent requirement is approximately 1.3 mg P/l. Therefore, there is some "slack"

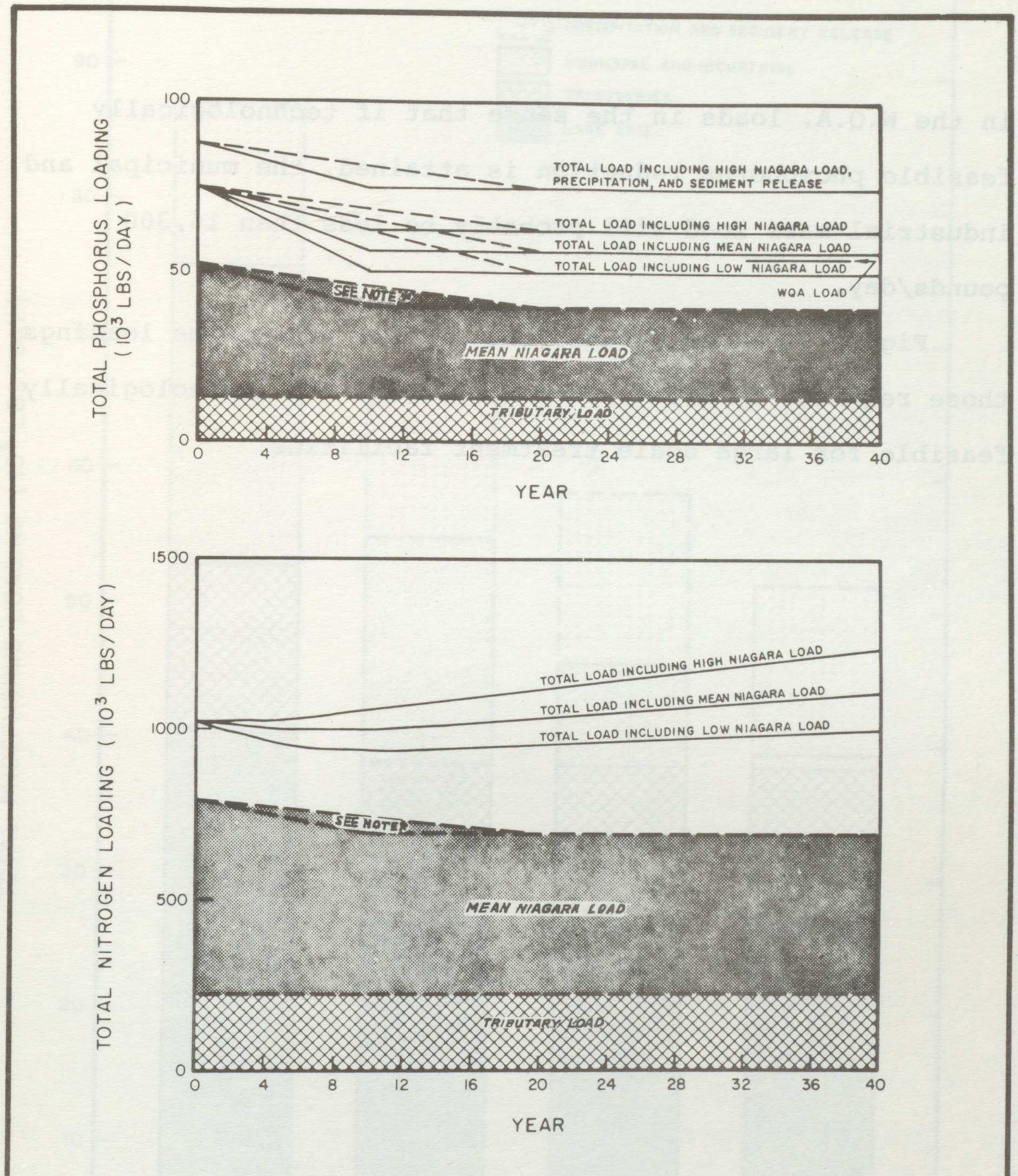

FIGURE III-2

NUTRIENT LOADING CONDITIONS TO LAKE ONTARIO in the W.Q.A. loads in the sense that if technologically feasible phosphorus reduction is attained, the municipal and industrial mass load will probably be less than 16,300 pounds/day.

Figure III-3 summarizes the present phosphorus loadings, those required by W.Q.A., and those that are technologically feasible for large scale treatment facilities.

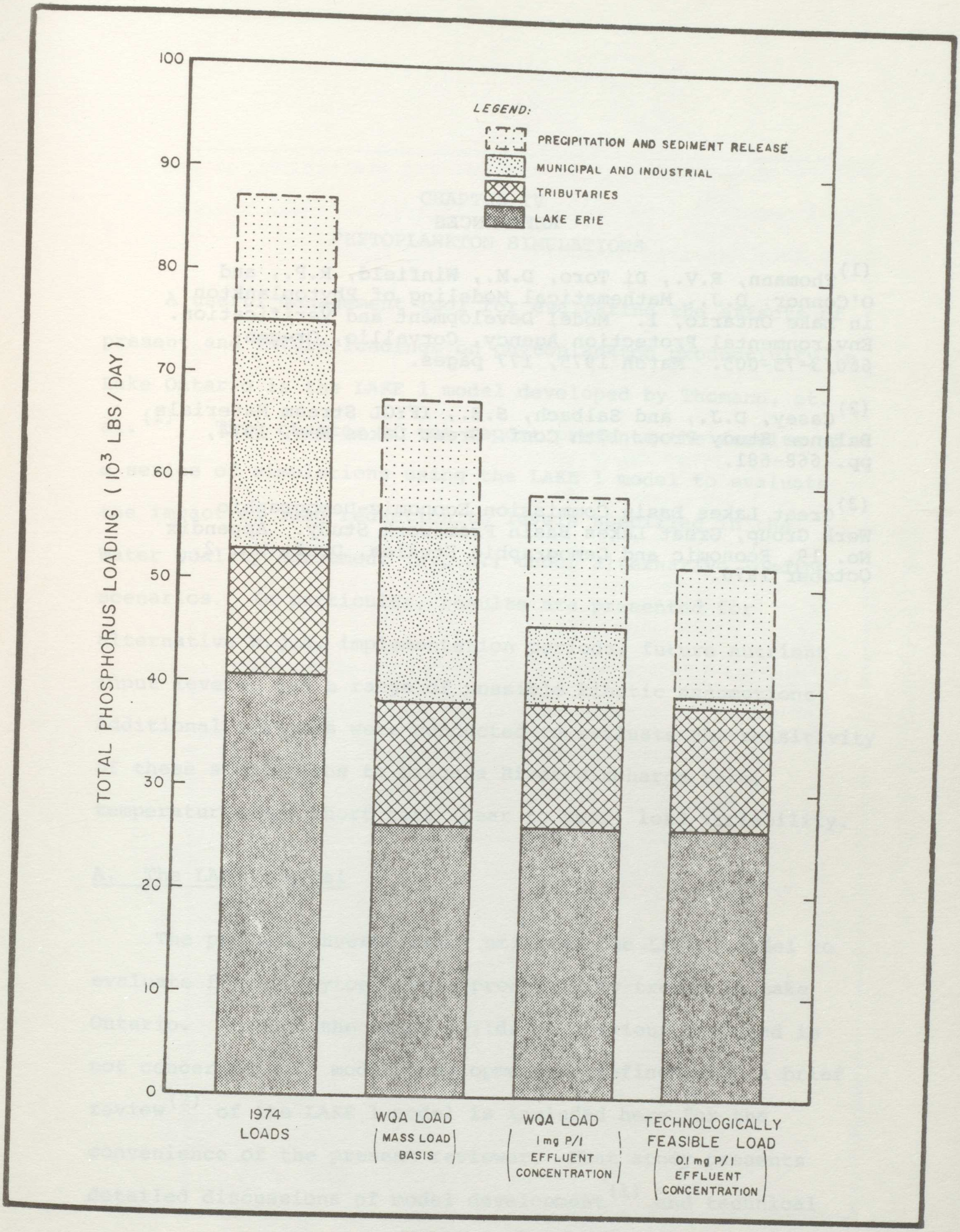

FIGURE III-3

SUMMARY OF PHOSPHORUS LOADINGS TO LAKE ONTARIO

REFERENCES

[1] Thomann, R.V., Di Toro, D.M., Winfield, R.P., and O'Connor, D.J., Mathematical Modeling of Phytoplankton in Lake Ontario, 1. Model Development and Verification. Environmental Protection Agency, Corvallio, Oregon, 660/3-75-005. March 1975, 177 pages.

[2] Casey, D.J., and Salbach, S.E., IFYGL Stream Materials Balance Study Proc. 17th Conf. Great Lakes Res. 1974, pp. 668-681.

[3] Great Lakes Basin Commission Economic-Demographic Work Group, Great Lakes Basin Framework Study. Appendix No. 19, Economic and Demographic Studies, Draft No. 2, October 1970.

CHAPTER IV
PHYTOPLANKTON SIMULATIONS

A useful management tool for evaluating the effects of present and future loadings on phytoplankton productivity in Lake Ontario is the LAKE 1 model developed by Thomann, et. al.[1]. This chapter of the report presents the results of a series of simulations using the LAKE 1 model to evaluate the impact of load reduction to levels specified in the Water Quality Agreement (W.Q.A.) under alternative loading scenarios. In particular, results are presented for alternative W.Q.A. implementation periods, future nutrient input levels, and a range of possible kinetic assumptions. Additional analyses were conducted to evaluate the sensitivity of these simulations to Niagara River discharge rate, temperature, and short term (year to year) load variability.

A. The LAKE 1 Model

The present investigation utilizes the LAKE 1 model to evaluate future phytoplankton productivity trends in Lake Ontario. As such the study builds on previous work and is not concerned with model development or refinement. A brief review[2] of the LAKE 1 model is included here for the convenience of the present reviewer. That study presents detailed discussions of model development[1] and technical considerations relevant to the use and limitations of the LAKE 1 model[2]. The reader is referred to these studies for a more detailed description of the model.

LAKE 1 MODEL REVIEW

Fig. 1 shows the geometry of the Lake 1 model. The principal features included in the model are:

a) a two layer system with a sediment layer, the mixing and stratification being accomplished by vertical exchange

b) phytoplankton settling

c) external environmental inputs of nutrients

d) external environmental inputs of solar radiation, water temperature and other system parameters.

The system's diagram showing the interaction of the key variables is given in Fig. 2. Ten dependent variables are included and incorporate the major features of the interactions of phytoplankton, zooplankton and nutrients. Table 1 gives the basic physical data used and complete details are given in (1).

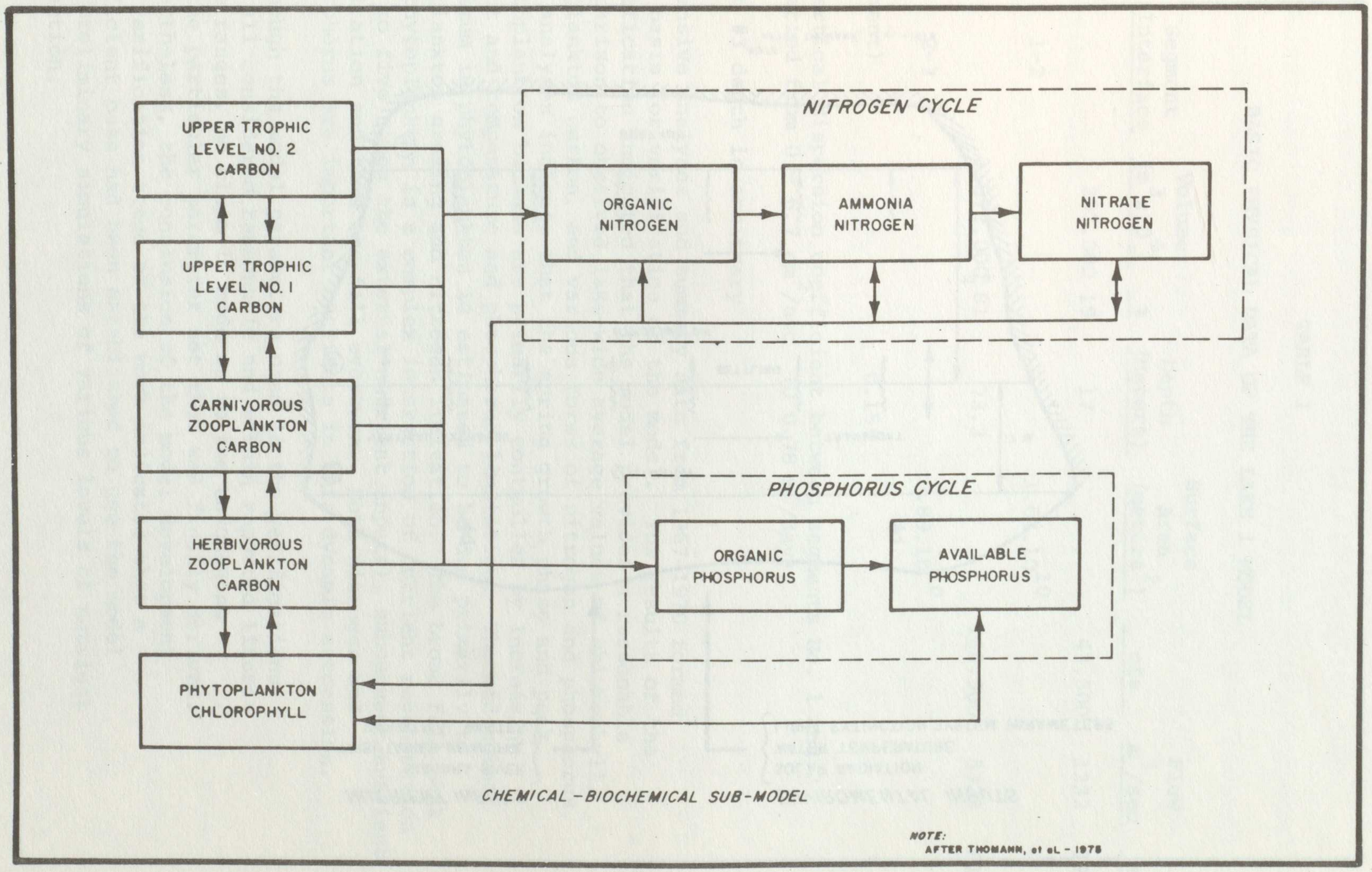

FIG. 1—SYSTEM DIAGRAM - LAKE 1 MODEL

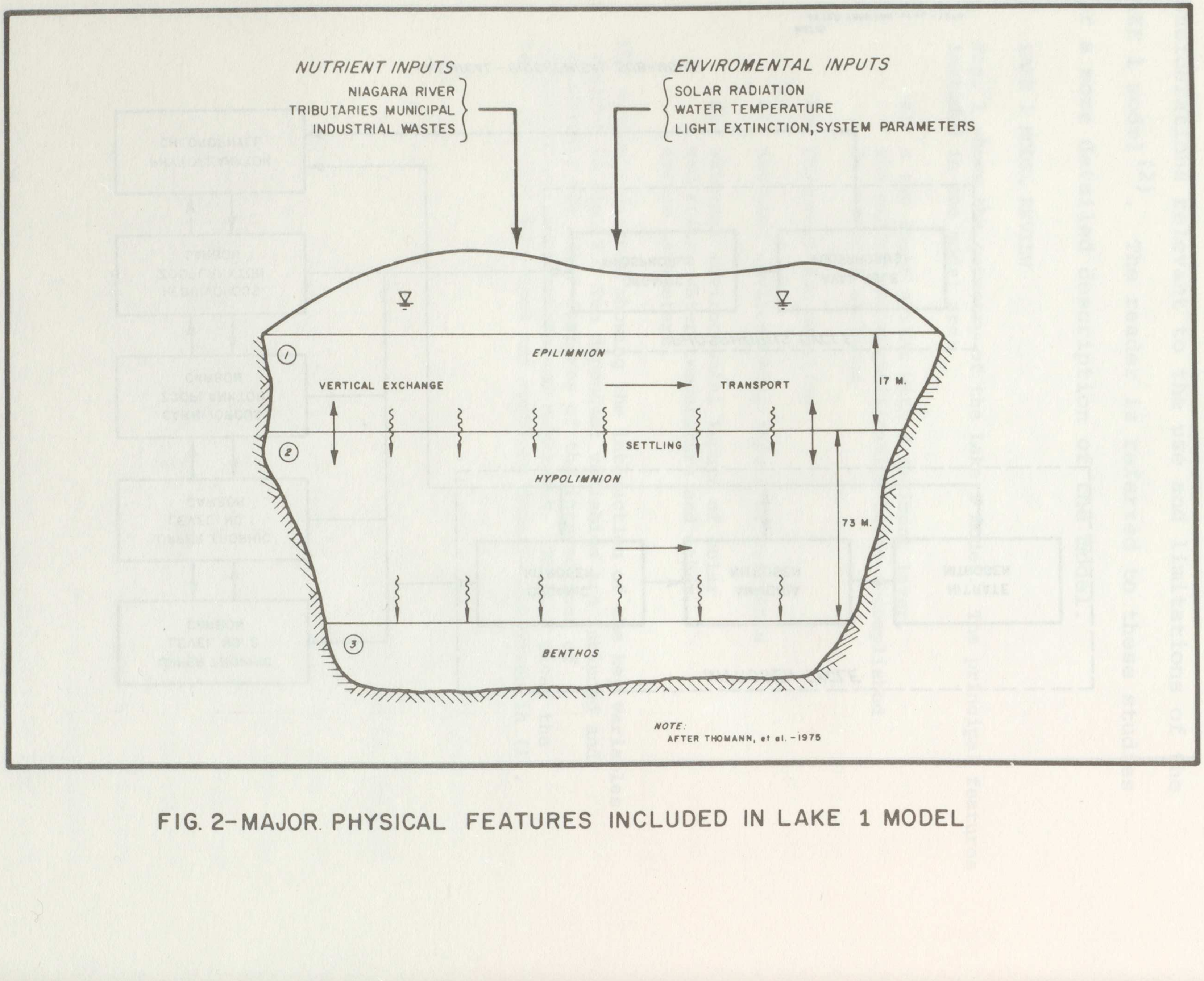

FIG. 2-MAJOR PHYSICAL FEATURES INCLUDED IN LAKE 1 MODEL

TABLE 1

BASIC PHYSICAL DATA OF THE LAKE 1 MODEL

Segment Number	Segment Interface	Volume ($m^3 x10^6$)	%	Depth (Meters)	Surface Area ($meters^2$)	Flow cfs	Flow m^3/sec	%
1		297,000	19	17		43,500	1232	19
	1-2				$1.64.10^{10}$			
2		1,373,000	81	73.3		188,500	5323	81
	2-3				$0.89.10^{10}$			
3(sediment)		-		0.15*				

Note: Vertical dispersion coefficient between segments No. 1 and 2 varied from 0 - 6.7 cm^2/sec (0 0.78 m^2/day)

* Segment #3 depth is arbitrary

Extensive analyses and summary data from 1967-1970 formed the basis for verification of the model. The results of the verification indicated that the model provides a reasonable comparison to observed lake-wide average values of chlorophyll, zooplankton carbon, and various forms of nitrogen and phosphorus. The analyses indicate that the spring growth phase and peak phytoplankton biomass are primarily controlled by increasing light and temperature and phosphorus limitation. The mid-summer minimum in phytoplankton is estimated to be due primarily to zooplankton grazing and nitrogen limitation. The broad fall peak in phytoplankton is a complex interaction of nutrient regeneration (up to five times the external nutrient inputs), subsequent nutrient limitation and then the fall overturn. Both nitrogen and phosphorus are important nutrients in this dynamic succession.

Although the model parameters used in the verifications are all considered reasonable and within reported literature ranges, no claim is made as to the uniqueness of the particular parameter set that was finally derived. Nevertheless, the conclusion of the model development and verification stage of the work indicated that a sufficient base had been established to use the model for preliminary simulations of various levels of nutrient reduction.

The earlier work also included some computations of the Lake 1 Model response under different load inputs, but assumed that all load reduction would be instantaneous, a quite unrealistic situation. In this study, therefore, a more realistic schedule of load reductions over 10 and 20 year periods was assumed, and associated phytoplankton responses were computed.

B. Kinetic Assumptions[1]

Results of phytoplankton simulations utilizing a reasonable set of nutrient-phytoplankton-zooplankton kinetic interactions, as well as sensitivity analyses on the model which consider pertebations of the organic nutrient settling rates and the consequent effect on lakewide phytoplankton growth are contained in reference 2. The present study utilizes three sets of kinetic assumptions to establish a range of lakewide phytoplankton concentrations under what are termed "reasonable", "optimistic" and "pessemistic" assumptions with regard to nutrient settling and other losses in the Lake.

The "reasonable" kinetic assumptions are those which were developed during the verification of the Lake 1 model. A more detailed review of these kinetics is found in reference 1. This set of kinetics includes a non-living organic nutrient settling rate of 0.001/day. No percipitation of inorganic phosphorus is considered under this assumption.

The second kinetic structure is directed toward evaluating phytoplankton growth under conditions that minimize the nutrients available to the phytoplankton; hence the name "optimistic" kinetics. The "optimistic" kinetic assumption was developed such that the net available nutrients in the Lake are in equilibrium with the present peak chlorophyll levels under present loads. In this case, both inorganic phosphorus and non-living organic nutrient forms (organic phosphorus and organic nitrogen) are removed from the system at a rate of 0.001/day. Inorganic phosphorus removal might take the form of phosphate complex percipitation, while organic nutrient decay is a first order settling process.

Finally, a worst case situation is evaluated. This is a kinetic assumption that considers the inorganic and non-living organic nutrients to be conservative (i.e., no decay). Under this assumption the sole removal mechanisms of nutrients from Lake Ontario are the St. Lawrence River outflow and phytoplankton settling. This is termed the "pessimistic" kinetic assumption.

In aggregate these three kinetic assumptions permit the analyst to place upper and lower limits on phytoplankton concentrations developed using the lake 1 Model. In addition, they provide the management decision making process with additional input that answers questions such as: what is the best or worst conditions that might occur as a reslut of a given load reduction program?

C. Results of Phytoplankton Simulations

A total of 34 Lake 1 simulations were completed during the course of this study. A tabular summary of these simulations is provided in Table IV-1. The basis for establishing loading scenarios for each simulation is described in Chapter III. The three kinetic assumptions are outlined in the previous section of this chapter. The simulation results are discussed relative to the phosphorus load reduction and its effect of phytoplankton growth. This is considered the principal controllable factor in the alternative loading scenarios. In any event, nitrogen is generally not the limiting nutrient to peak seasonal phytoplankton biomass[2].

The result of load reductions to W.Q.A. loading levels under a "reasonable" kinetic assumption is displayed in Figure IV-1. The figure presents the annual lakewide peak phytoplankton concentration for a 40 year simulation period. The presently observed phytoplankton concentration and nutrient concentrations are utilized as initial conditions in these simulations. The solid and dashed lines represent responses for a 10 and 20 year implementation period of W.Q.A. load reductions, respectively.

The results show that the equilibrium peak phytoplankton concentration is a function of the final equilibrium phosphorus loading rate to Lake Ontario, and that the trend is toward

TABLE IV-1

SUMMARY OF LAKE 1 SIMULATIONS

Simulation	Kinetic Assumption	Implementation Period (Years)	Load Scenario	Estimated Phosphorus Load at W.Q.A. Implementation
1	Reasonable	10	Mean Niagara Loads	56,500
2			Low Niagara Loads	50,200
3			High Niagara Loads	62,900
4			High Niagara, Atmospheric and sediment loads	75,640
5		20	Mean Niagara Loads	56,500
6			Low Niagara Loads	50,200
7			High Niagara Loads	62,900
8			High Niagara, Atmospheric and sediment loads	75,640
9	Optimistic	10	Mean Niagara Loads	56,500
10			Low Niagara Loads	50,200
11			High Niagara Loads	62,900
12			High Niagara, Atmospheric and sediment	75,640
13		20	Mean Niagara Loads	56,500
14			Low Niagara Loads	50,200
15			High Niagara Loads	62,900
16			High Niagara, Atmospheric and sediment loads	75,640
17	Pessimistic	10	Mean Niagara Loads	56,500
18			Low Niagara Loads	50,200
19			High Niagara Loads	62,900
20			High Niagara, Atmospheric and sediment loads	75,640
21		20	Mean Niagara Loads	56,500
22			Low Niagara Loads	50,200
23			High Niagara Loads	62,900
24			High Niagara, Atmospheric and sediment loads	75,640

TABLE IV-1
(Continued)

SUMMARY OF LAKE 1 SIMULATIONS

Simulation	Kinetic Assumption	Implementation Period (Years)	Load Scenario	Estimated Phosphorus Load at W.Q.A. Implementation
25	Reasonable	10	High Niagara Loads, Low Flows	62,900
26			High Niagara Loads, High Flows	62,900
27			Low Niagara Loads, Low Flows	50,200
28			Low Niagara Loads, High Flows	50,200
29		20	High Niagara Loads, Low Flows	62,900
30			High Niagara Loads, High Flows	62,900
31			Low Niagara Loads, Low Flows	50,200
32			Low Niagara Loads, High Flows	50,200
33	Reasonable	10	Mean Niagara Loads Elevated Temp.	56,500
34	Reasonable	After W.Q.A. Implementation	Variable Niagara Load	50,560-60,460

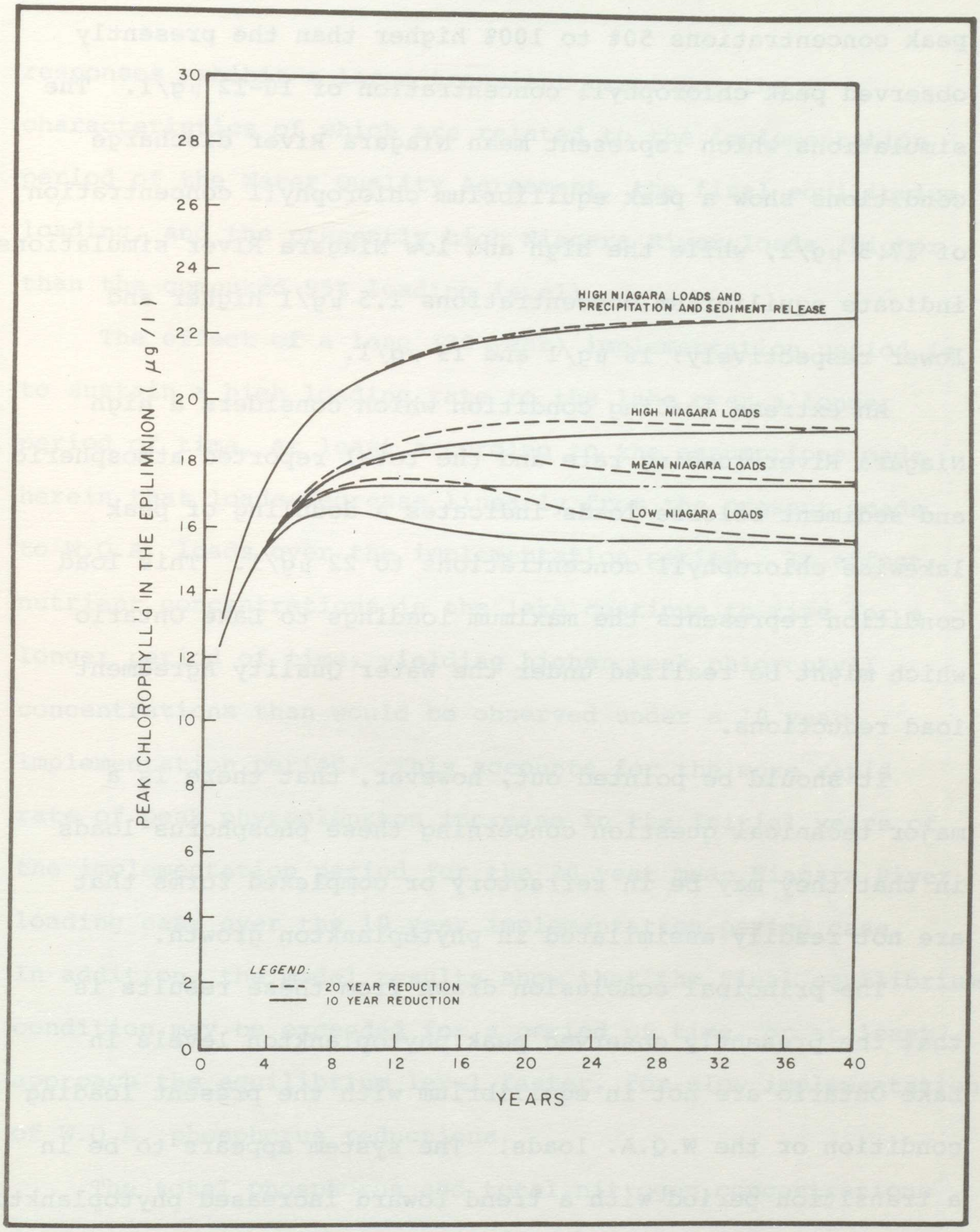

FIGURE IV-1

EFFECT OF W.Q.A. LOAD REDUCTIONS– REASONABLE KINETIC ASSUMPTION peak concentrations 50% to 100% higher than the presently observed peak chlorophyll concentration of 10-12 μg/l. The simulations which represent mean Niagara River discharge conditions show a peak equilibrium chlorophyll concentration of 17.5 μg/l, while the high and low Niagara River simulations indicate equilibrium concentrations 1.5 μg/l higher and lower respectively; 16 μg/l and 19 μg/l.

An extreme loading condition which considers a high Niagara River loading rate and the total reported atmospheric and sediment release loads indicates a doubling of peak lakewide chlorophyll concentrations to 22 μg/l. This load condition represents the maximum loadings to Lake Ontario which might be realized under the Water Quality Agreement load reductions.

It should be pointed out, however, that there is a major technical question concerning these phosphorus loads in that they may be in refractory or complexed forms that are not readily assimilated in phytoplankton growth.

The principal conclusion drawn from these results is that the presently observed peak phytoplankton levels in Lake Ontario are not in equilibrium with the present loading condition or the W.Q.A. loads. The system appears to be in a transition period with a trend toward increased phytoplankton levels over the next 10 to 15 years. The Lake 1 model responses exhibit a large transient response, the characteristics of which are related to the implementation period of the Water Quality Agreement, the final equilibrium loading, and the presently high Niagara River loads (higher than the computed 95% loading level).

The effect of a long (20 year) implementation period is to sustain a high loading rate to the lake over a longer period of time, at least according to the assumptions made herein that loads decrease linearly from the present loads to W.Q.A. loads over the implementation period. In effect, nutrient concentrations in the lake continue to rise for a longer period of time, yielding higher peak chlorophyll concentrations than would be observed under a 10 year implementation period. This accounts for the more rapid rate of peak phytoplankton increase in the initial years of the implementation period for the 20 year mean Niagara River loading case over the 10 year implementation period case. In addition, the model results show that the final equilibrium condition may be exceeded for a period of time, or at least approach the equilibrium level faster, for slow implementation of W.Q.A. phosphorus reductions.

The total phosphorus and total nitrogen concentrations in Lake Ontario which result under the reasonable kinetic assumption and the alternative loading scenarios are presented in Figure IV-2. The Figure represents the lakewide annual

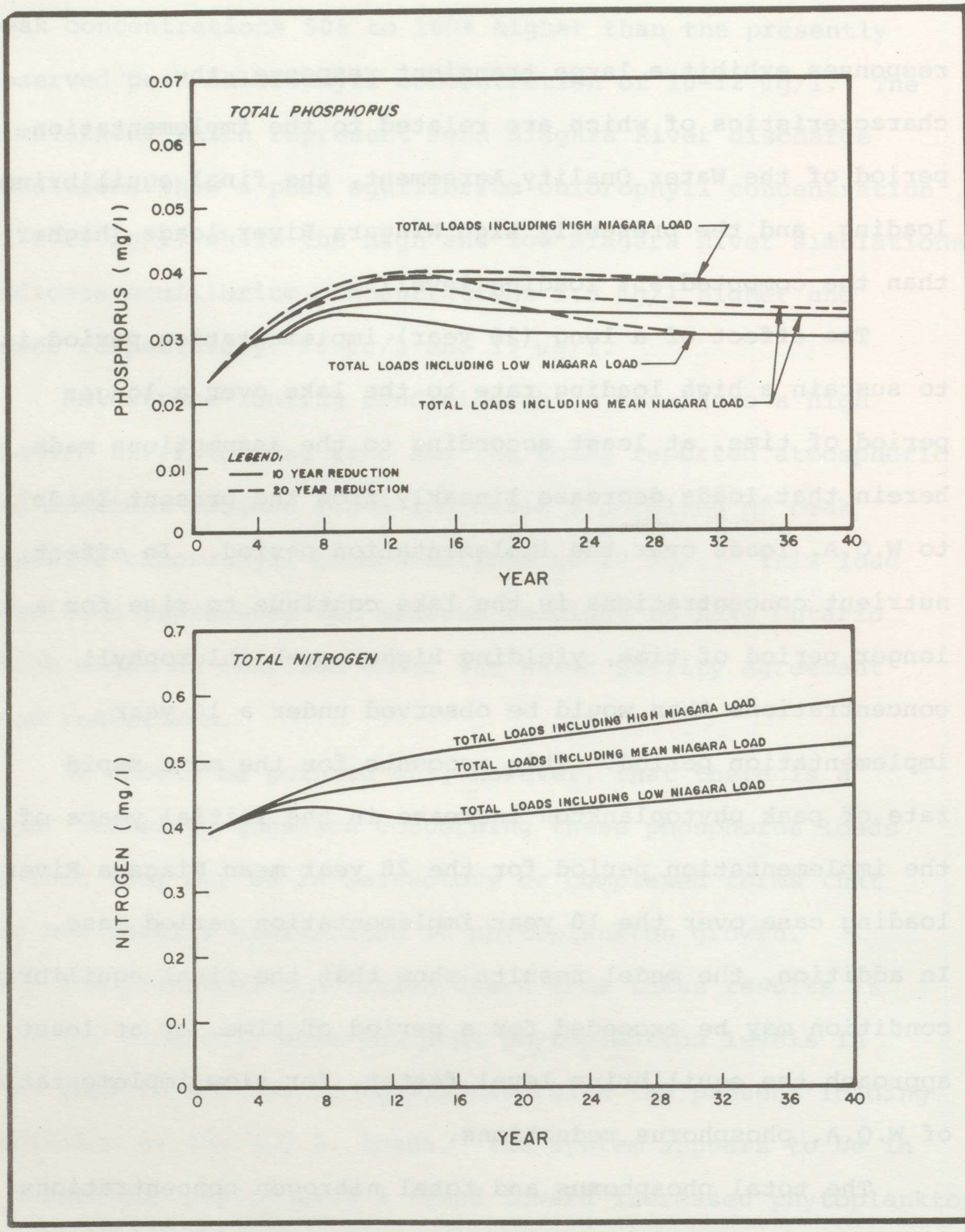

FIGURE IV-2

TOTAL PHOSPHORUS AND TOTAL NITROGEN IN LAKE ONTARIO UNDER REASONABLE KINETIC CONDITIONS average nutrient concentrations for a 40 year simulation period. The figures demonstrate trends toward increased nitrogen and phosphorus concentrations in Lake Ontario even under present load reduction programs.

Similar results are presented for "optimistic" and "pessimistic" kinetic assumptions in Figures IV-3 through IV-6. These simulations represent an analysis of the previous results sensitivity to kinetic assumptions in the Lake 1 Model.

The results using "optimistic" kinetics (the most rapid rate of nutrient loss to the sediments) generally show a decrease in peak phytoplankton concentration from their present level to between 6.5 and 9.0 μg/l depending upon the Niagara River nutrient loading rate. The time required to realize the lower equilibrium concentrations is principally a function of implementation period, and ranges from 11 to 22 years for the 10 and 20 year load reduction programs.

An interesting result is obtained in imposing the atmospheric and sediment release phosphorus loads on top of the W.Q.A. loads in this case. The figure indicates that even under the most optimistic kinetic assumptions there is a loading condition where presently observed peak phytoplankton levels will be unaltered by W.Q.A. load reduction, the transient response in this case is due to the high initial loading rate due to evaluated Niagara River flows during the past 8 years.

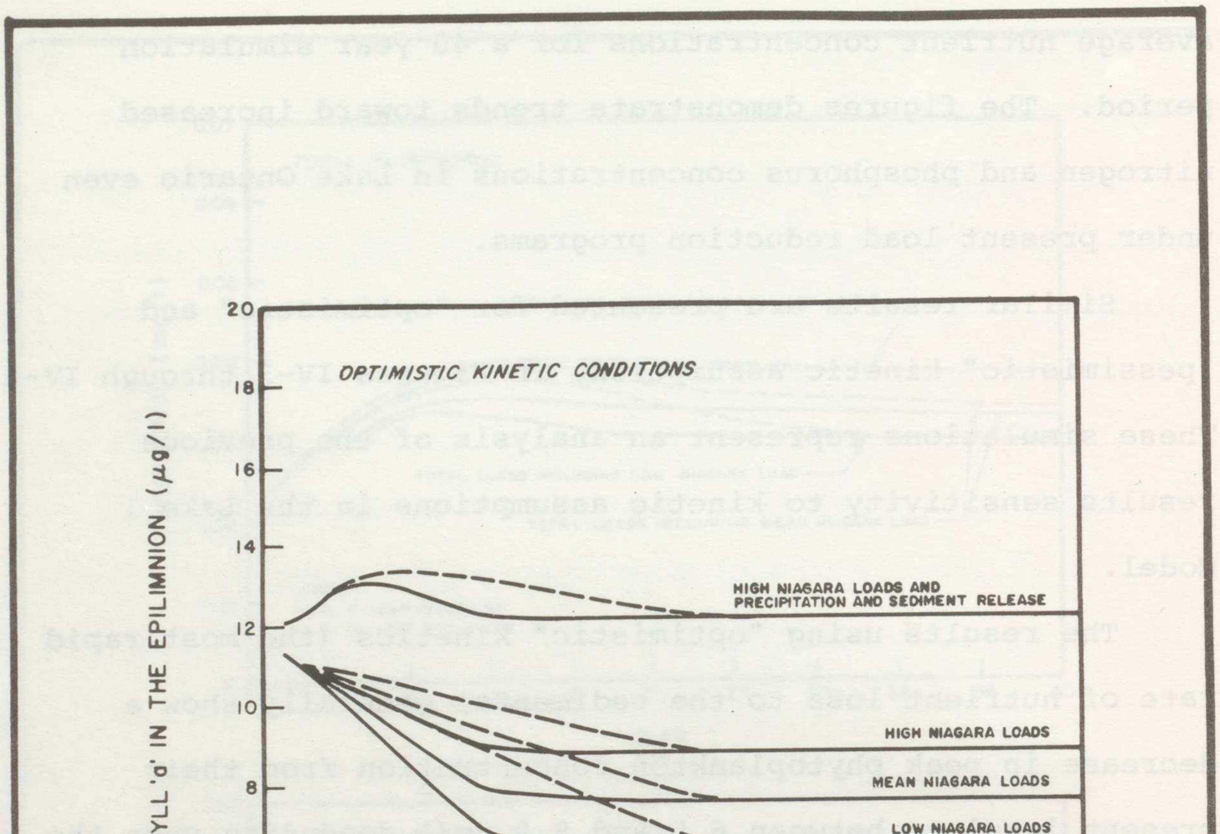

FIGURE IV-3

EFFECT OF W.Q.A. LOAD REDUCTIONS-OPTIMISTIC KINETIC ASSUMPTION

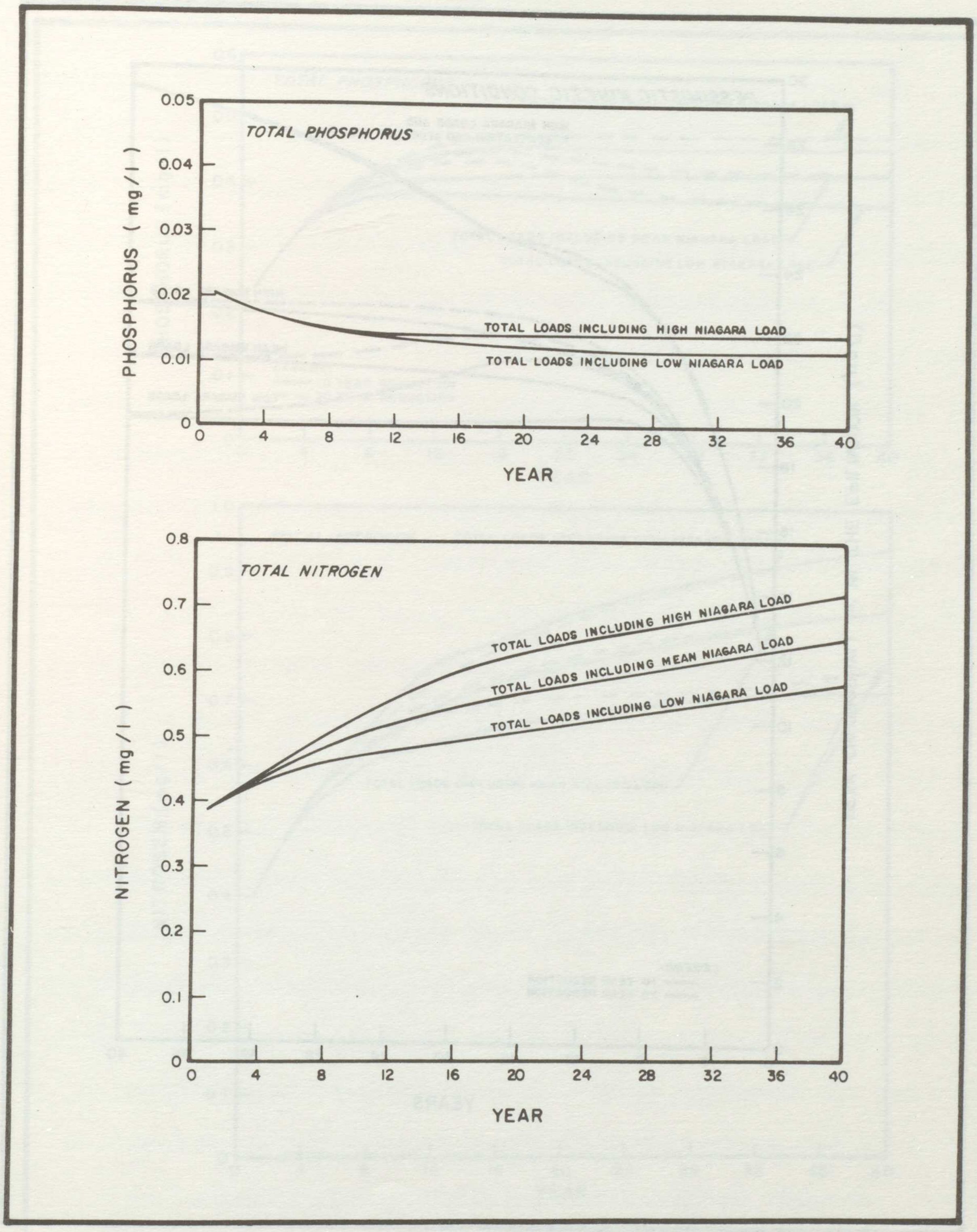

FIGURE IV-4
TOTAL PHOSPHORUS AND TOTAL NITROGEN
IN LAKE ONTARIO UNDER OPTIMISTIC KINETIC CONDITIONS

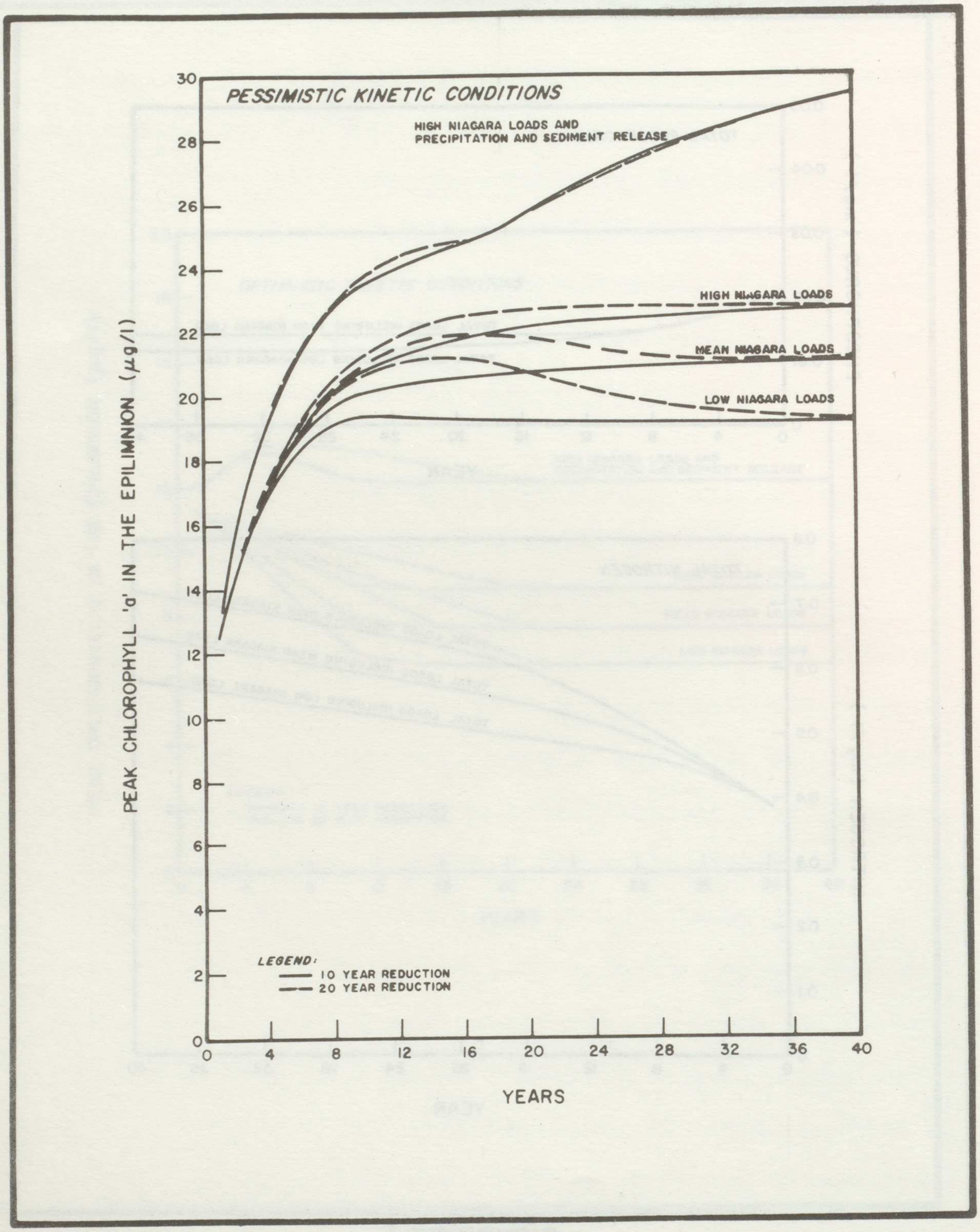

FIGURE IV-5

EFFECT OF W.Q.A. LOAD REDUCTION

PESSIMISTIC KINETIC ASSUMPTIONS

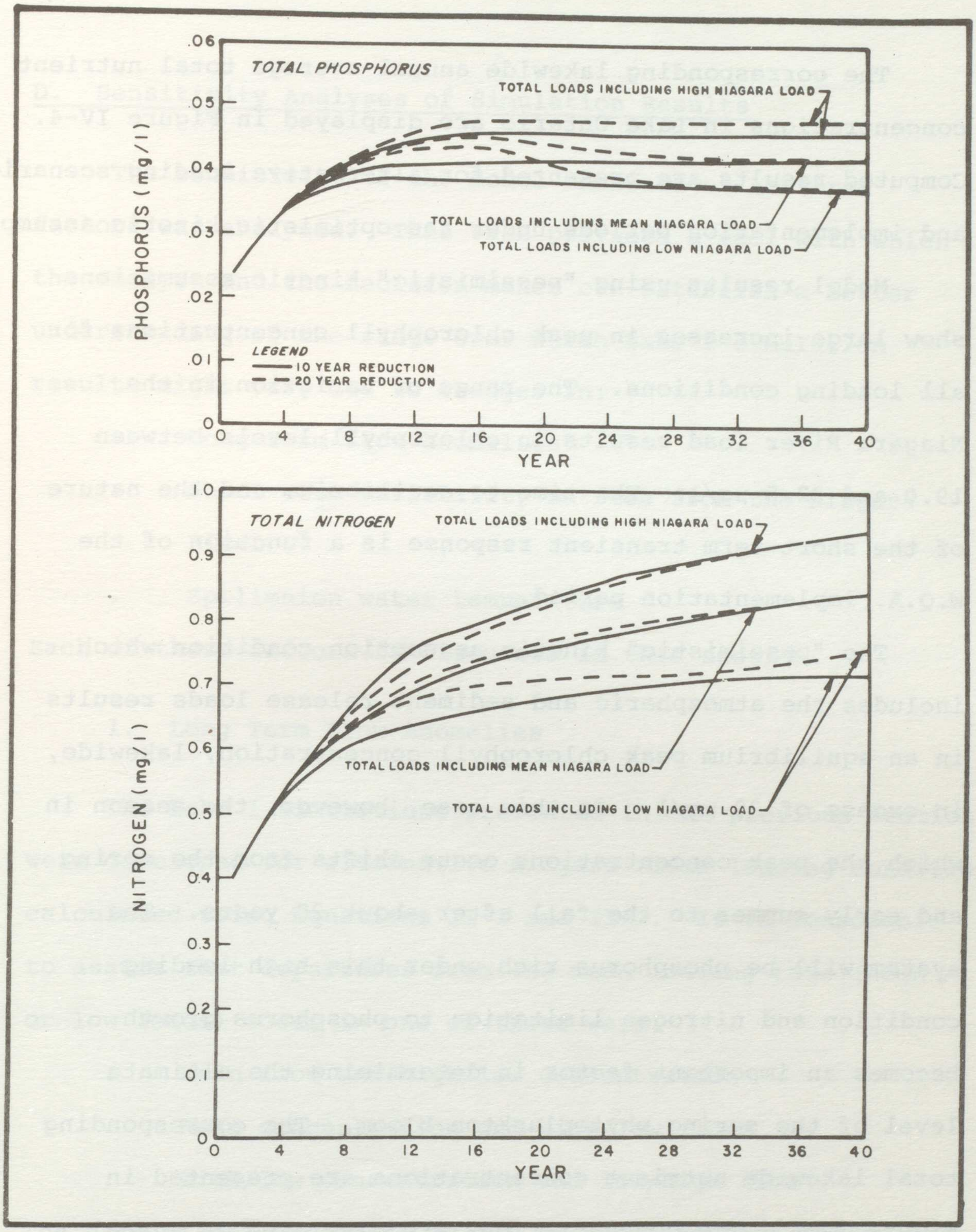

FIGURE IV-6
TOTAL PHOSPHORUS AND TOTAL NITROGEN
IN LAKE ONTARIO UNDER PESSIMISTIC KINETIC CONDITIONS

The corresponding lakewide annual average total nutrient concentrations in Lake Ontario are displayed in Figure IV-4. Computed results are presented for alternative loading scenarios and implementation periods under the optimistic kinetic assumption.

Model results using "pessimistic" kinetic assumptions show large increases in peak chlorophyll concentrations for all loading conditions. The range of variation in the Niagara River load results in chlorophyll levels between 19.0 and 22.5 μg/l. The time to equilibrium and the nature of the short term transient response is a function of the W.Q.A. implementation period.

The "pessimistic" kinetic assumption condition which includes the atmospheric and sediment release loads results in an equilibrium peak chlorophyll concentration, lakewide, in excess of 30 μg/l. In this case, however, the season in which the peak concentrations occur shifts from the spring and early summer to the fall after about 20 years. The system will be phosphorus rich under this high loading condition and nitrogen limitation to phosphorus growth becomes an important factor in determining the ultimate level of the spring phytoplankton bloom. The corresponding total lakewide nutrient concentrations are presented in Figure IV-6. The concentrations are displayed as annual average concentrations.

D. Sensitivity Analyses of Simulation Results

The sensitivity of the model simulations to three factors was analysed. This task provides a tool with which the analyst and the decision maker can establish a better understanding of the range over which Lake 1 simulation results might vary due to changes in:

- Long term flow anomalies
- Short term variability in flow from the Niagara River
- Epilimnion water temperature

Each of these factors is discussed in this section.

1. Long Term Flow Anomalies

The Lake 1 simulations presented in the previous section were developed for alternative Niagara River loading conditions calculated using Equations II-1 and II-2. It is reasonable to assume that departures from the mean loading rate (high or low loads) occur in one of three ways.

- Mean flow and high/low concentration
- Mean concentration and high/low flow
- High/low concentration and low/high flow

The simulations presented in the previous section assume the first condition; that is that in the long term the Niagara River flow approximates the mean flow condition.

The model was tested at other long term flow conditions. These were the high (95%) flow of 233,000 cfs and the low (5%) flow of 171,000 cfs. The results are presented in Figures IV-7 and IV-8 for "reasonable" kinetic assumptions, 10 and 20 year implementation periods, and alternative Niagara River nutrient loading levels.

Figure IV-7 presents the results for high Niagara River flows. The figure shows increases in peak chlorophyll levels of 0.5 to 2.0 μg/l above those for mean Niagara River flows depending upon the loading level. For a condition of low Niagara River flow the peak phytoplankton concentrations decrease 1.0 to 3.0 μg/l depending upon the Niagara River load (Figure IV-8).

By comparing these results with those presented in Figure IV-1, one concludes that long term anomalies in Niagara River discharge can contribute to between 3.0 and 4.0 μg/l variation in chlorophyll concentrations at W.Q.A. loads. This variability is shown to be small for high or low flow conditions that persist for only 5 to 10 years, and increases as the flow anomaly persists for periods up to 40 years. The comparison also indicates that the shorter implementation period is more sensitive to short term flow variability than the 20 year implementation period.

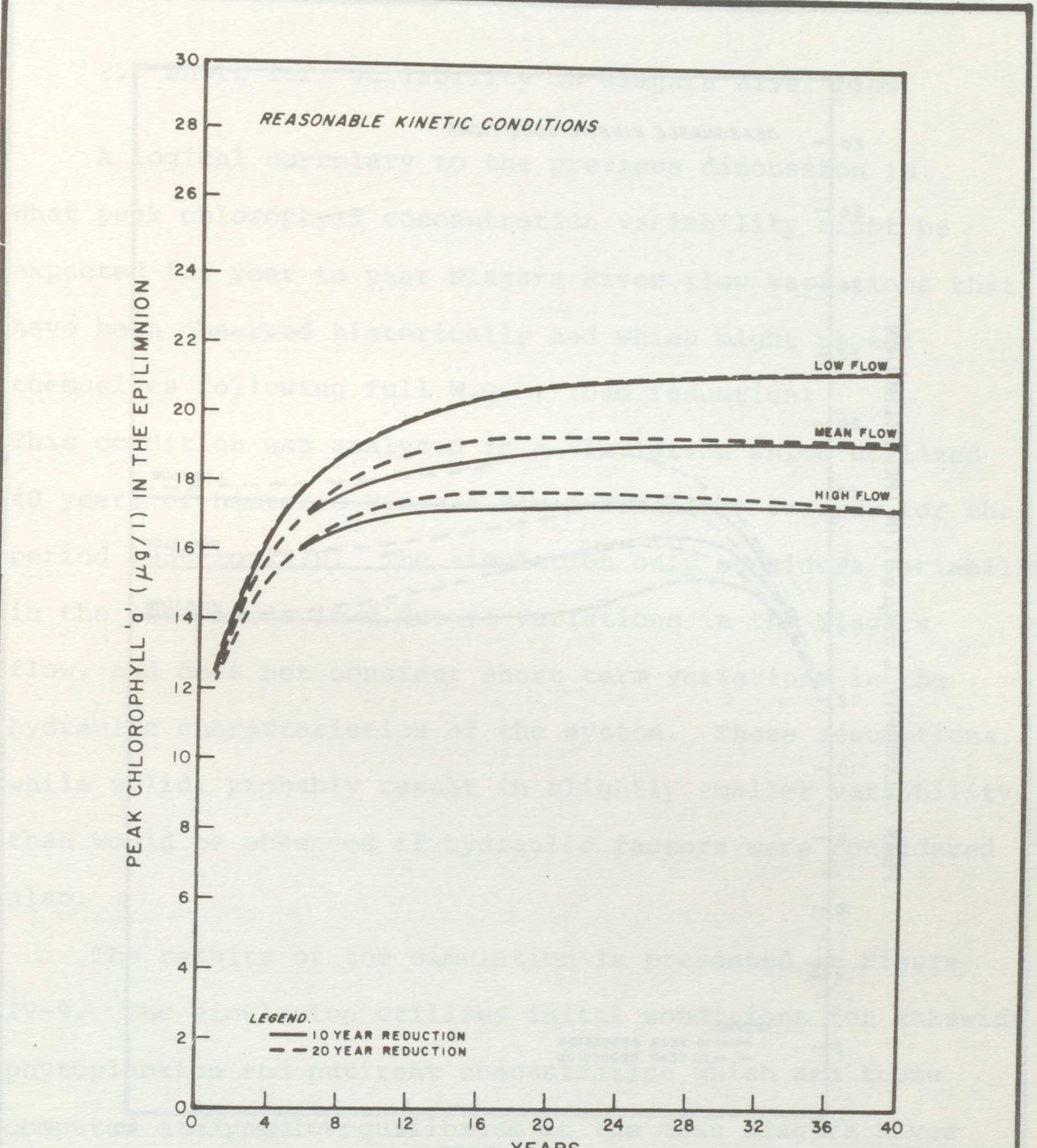

FIGURE IV-7

PHYTOPLANKTON RESPONSES UNDER VARIOUS FLOW CONDITIONS
HIGH NIAGARA LOADS

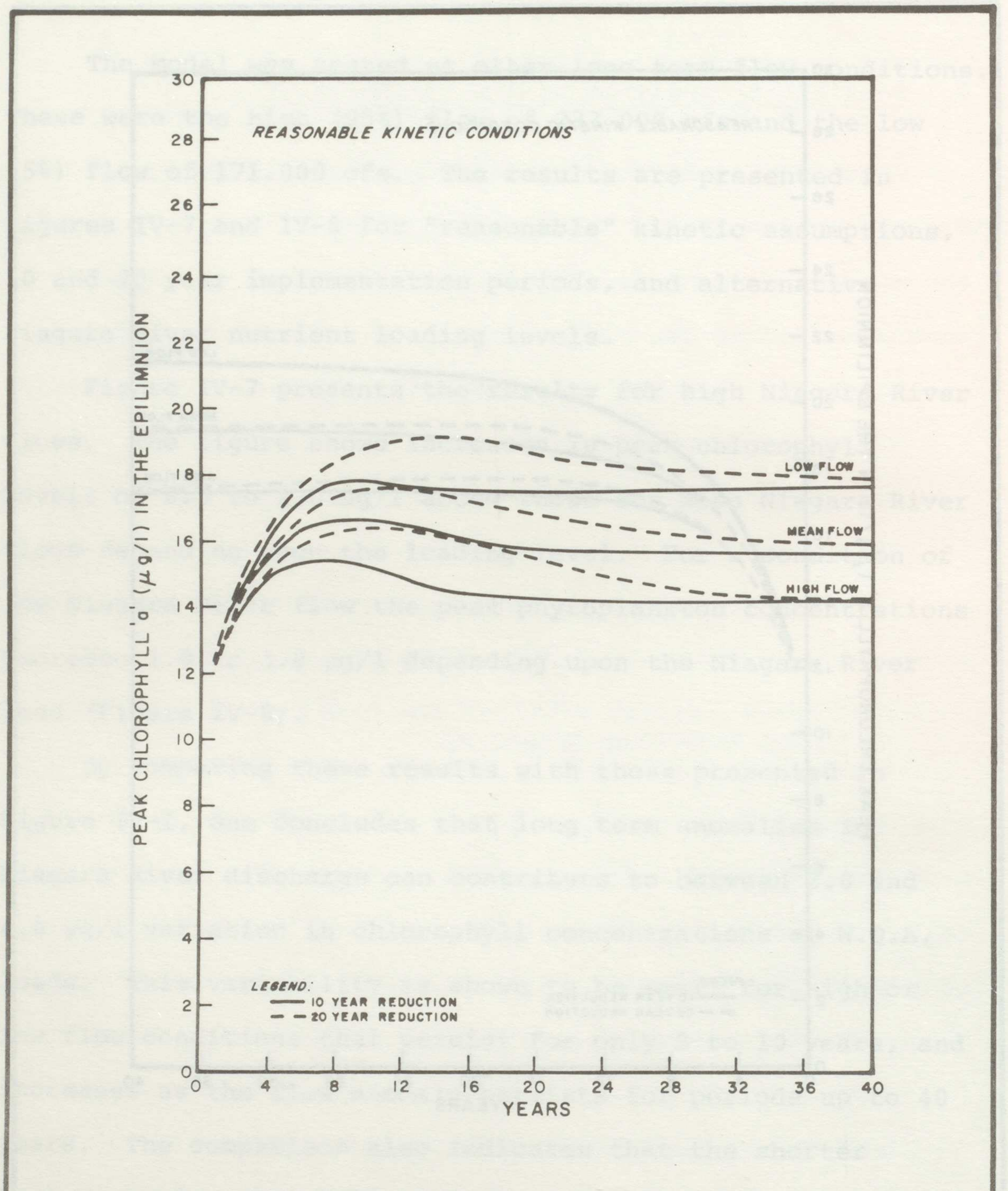

FIGURE IV-8

PHYTOPLANKTON RESPONSES UNDER VARIOUS FLOW CONDITIONS
LOW NIAGARA LOADS

2. Short Term Variability in Niagara River Flow

A logical correlary to the previous discussion is: What peak chlorophyll concentration variability might be expected for year to year Niagara River flow variations that have been observed historically and which might repeat themselves following full W.Q.A. load reduction? This condition was analyzed in a simulation which utilized 40 years of historic Niagara River discharge records for the period 1930 to 1970. The simulation only considers variability in the phosphorus load due to variations in the Niagara flow, and does not consider short term variations in the hydraulic characteristics of the system. These assumptions, while valid, probably result in slightly smaller variability than would be observed if hydraulic factors were considered also.

The results of the simulation is presented in Figure IV-9. The simulation utilizes inital conditions for lakewide phytoplankton and nutirent concentration which are those computed at dynamic equilibrium in the mean Niagara River load-reasonable kinetic assumption simulation (Figure IV-1). The display indicates that short term variability in annual nutrient loads from the Niagara River contributes to small variations in peak phytoplankton biomass, generally less than ±1 μg/l.

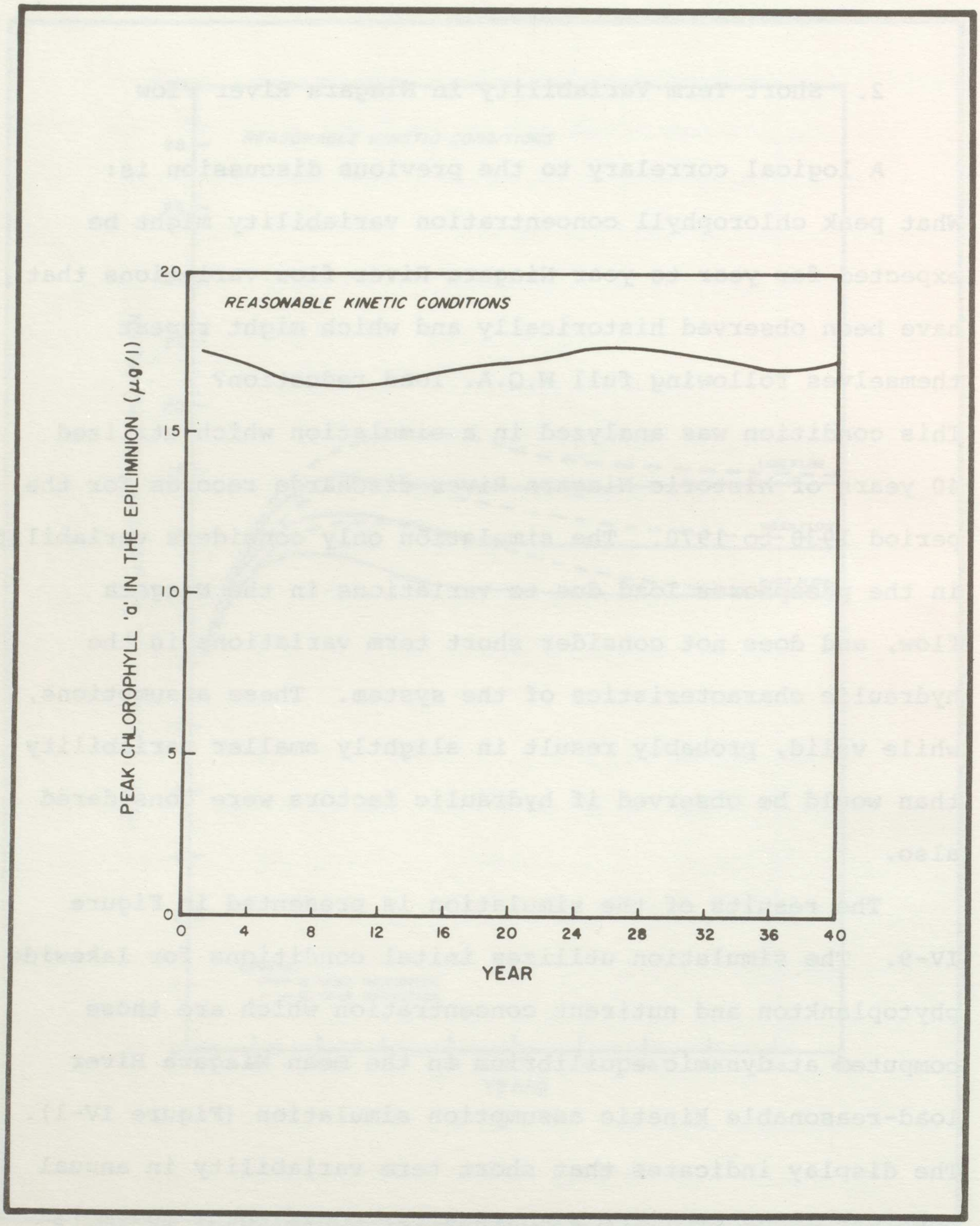

FIGURE IV - 9
TRANSIENT RESPONSE OF CHLOROPHYLL 'a'
DUE TO YEAR TO YEAR PHOSPHORUS LOADING VARIATION

3. Temperature Effects

Water temperatures in Lake Ontario during the IFYGL period appear to be slightly higher than the historical data (1967 to 1970) indicate. Athough for some months water temperature appears to be somewhat lower. It is of interest to assess the impact of increasing water temperature on phytoplankton biomass levels in Lake Ontario, particularly in light of increasing population density and the impact that changing water use pattern might have on water temperatures. The model cannot, however, simulate species shifts that might occur in such cases. A simulation using the Lake 1 Model was developed for this purpose. A comparison between the mean annual epilimnion temperature and the 1972 temperatures is presented in Figure IV-10. The results of the simulation are displayed in Figure IV-11.

E. Summary of Simulation Results

The simulation results presented in the previous sections reflect long term trends in phytoplankton biomass levels due to planned phosphorus load reductions in Lake Ontario. While the results are not intended to be predictions of future conditions they do provide insights into the behavior of the system under alternative loading scenarios which incorporate key elements of the load reduction program

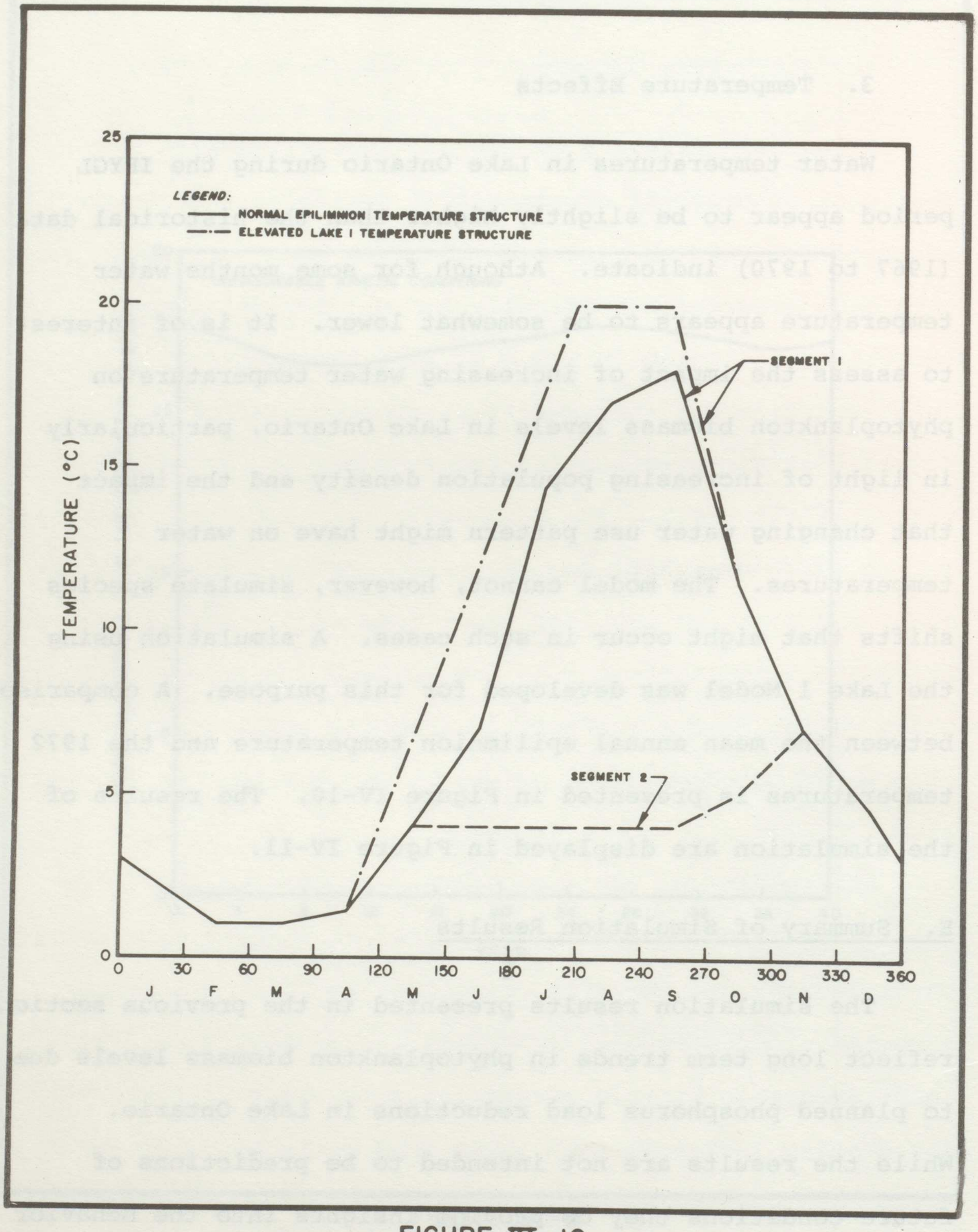

FIGURE IV-10
TEMPORAL VARIATION OF WATER TEMPERATURE

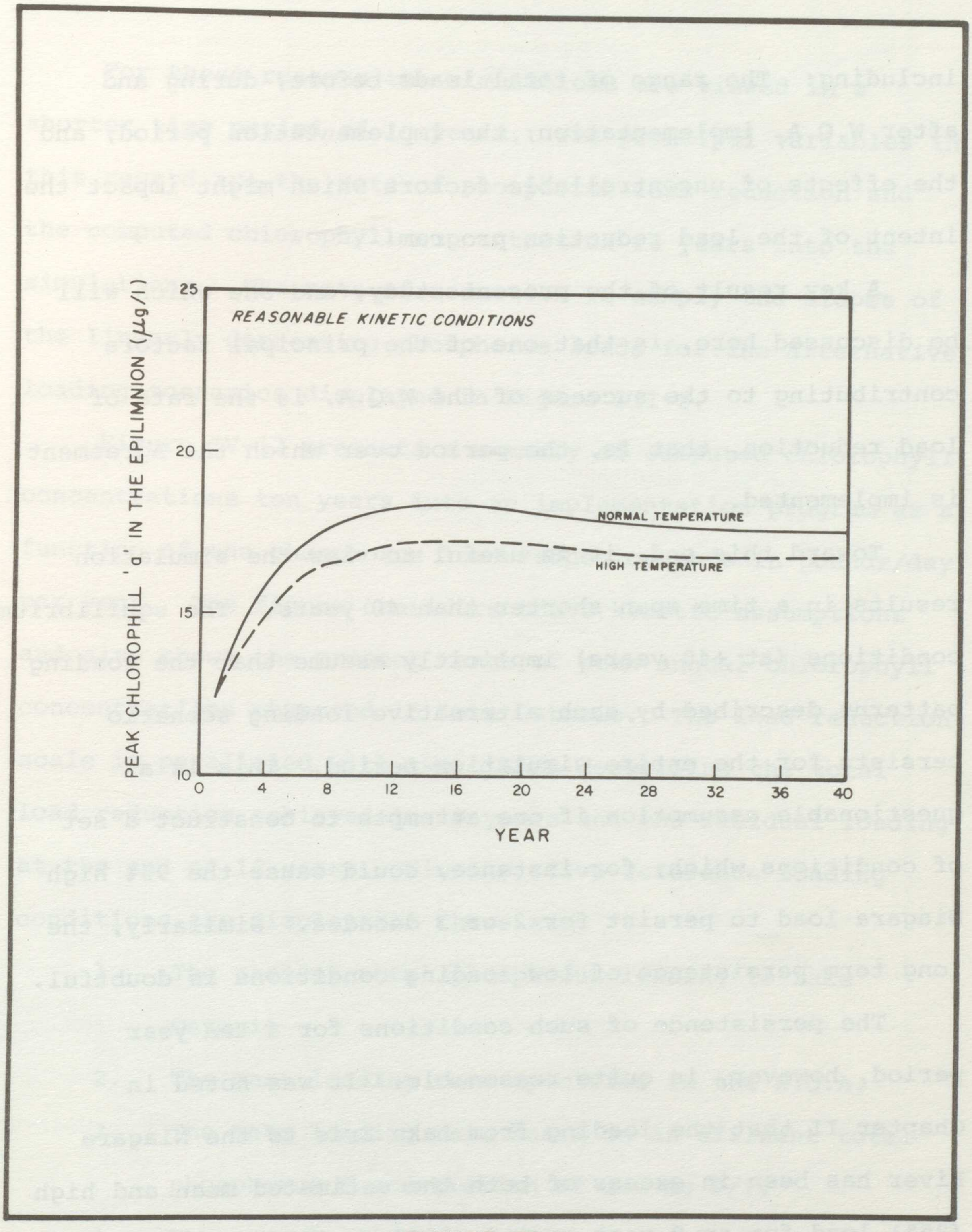

FIGURE IV-II

EFFECT OF LAKE TEMPERATURE ON PHYTOPLANKTON RESPONSES including: The range of total loads before, during and after W.Q.A. implementation; the implementation period; and the effects of uncontrollable factors which might impact the intent of the load reduction program.

A key result of the present study, and one which will be discussed here, is that one of the principal factors contributing to the success of the W.Q.A. is the rate of load reduction, that is, the period over which the Agreement is implemented.

Toward this end, it is useful to view the simulation results in a time span shorter than 40 years. The equilibrium conditions (at +40 years) implicitly assume that the loading patterns described by each alternative loading scenario persists for the entire simulation period. This is a questionable assumption if one attempts to construct a set of conditions which, for instance, could cause the 95% high Niagara load to persist for 2 or 3 decades. Similarly, the long term persistence of low loading conditions is doubtful.

The persistence of such conditions for a ten year period, however, is quite reasonable. It was noted in Chapter II that the loading from Lake Erie to the Niagara River has been in excess of both the estimated mean and high (95%) load for an 8 year period (1967 to 1974).

For these reasons the simulations are viewed in a shorter time period of 10 years. The principal variables in this regard are the rate of phosphorus load reduction and the computed chlorophyll concentration 10 years into the simulations. The rate of reduction is simply the slopes of the linearly decreasing phosphorus loads for the alternative loading scenarios displayed in Figure III-2.

Figure IV-12 presents a summary of computed chlorophyll concentrations ten years into an implementation program as a function of the phosphorus load reduction rate in pounds/day per year. The figure considers the 3 kinetic assumptions and also shows the present range of peak annual chlorophyll concentrations observed in Lake Ontario. The load reduction scale is paralleled with two others describing the total load reduction achieved in 10 years and the residual loading at the end of 10 years. Finally, five reference loading conditions are displayed. These are:

1. The present total phosphorus loading to Lake Ontario
2. The mass loading rate specified in the W.Q.A.
3. The mass loading rate based on an effluent total phosphorus concentration of 1.0 mg P/l.
4. The mass loading rate which is technologically feasible (0.1 mg P/l).
5. Lake Ontario "pastoral" conditions[(2)].

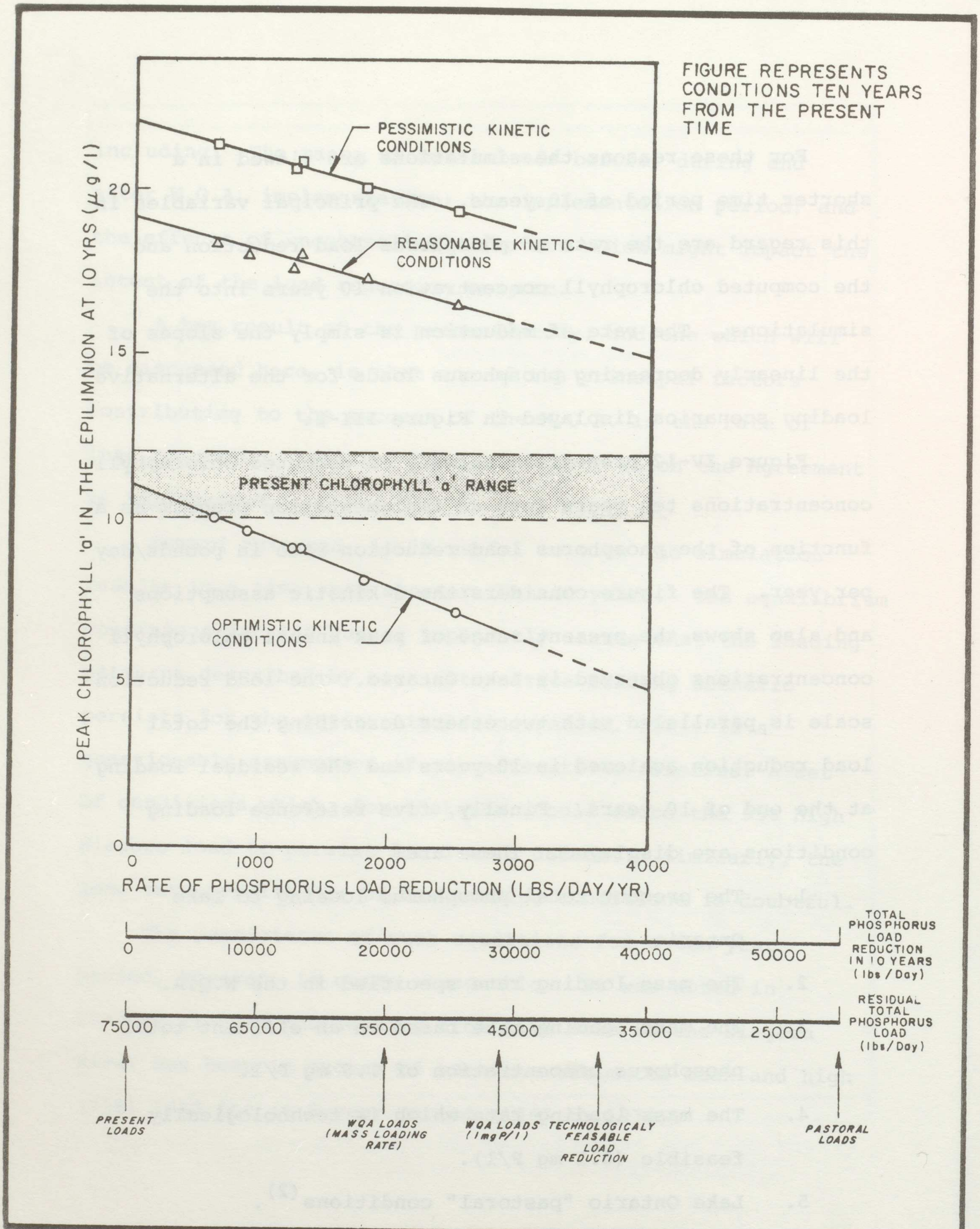

FIGURE IV-12
EFFECT OF PHOSPHORUS LOAD REDUCTION RATE

Figure IV-12 shows that there is some uncertainty that present peak chlorophyll levels will be maintained under the W.Q.A. after a 10 year period. One would have to assume that "optimistic" kinetic conditions prevailed which as indicated in other work[2] may not be the case. If one uses the range between "optimistic" and reasonable kinetics as a guideline, the results in Figure IV-12 indicate that substantial reductions must be accomplished over the next 10 year period to maintain present conditions. It can also be noted that the technologically feasible level of 0.1 mg P/l in the effluent does provide a greater degree of assurance that the present biomass level will be maintained. Thus, the rate of implementation appears to critically impact the degree to which the intended goals of the Water Quality Agreement are realized in term of phytoplankton biomass in Lake Ontario. It appears that a load reduction rate of 2,000 to 3,000 pound/day of phosphorus per year for a ten year period is a sound objective if phytoplankton biomass in the Lake is to be maintained at its present level.

REFERENCES

1. Thomann, R.V., DiToro, D.M., Winfield, R.P., and O'Connor, D.J., Mathematical Modeling of Phytoplankton in Lake Ontario, 1. Model Development and Verification, Environmental Protection Agency, Corvallis, Oregon, 660/3-75-005, March 1975, 177 pages.

2. Thomann, R.V., DiToro, D.M., Winfield, R.P., and O'Connor, D.J., Mathematical Modeling of Phytoplankton in Lake Ontario, 2. Simulations Using Lake I Model, Environmental Protection Agency, Grosse Ice, Michigan, Grant No. R-800610, April 1975.