

**PHOSPHORUS MANAGEMENT
FOR THE GREAT LAKES**

**FINAL REPORT OF THE
PHOSPHORUS MANAGEMENT STRATEGIES TASK
FORCE**

**TO THE INTERNATIONAL JOINT COMMISSION'S GREAT
LAKES WATER QUALITY BOARD AND GREAT LAKES SCIENCE
ADVISORY BOARD**

**JULY, 1980
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INTERNATIONAL JOINT COMMISSION
GREAT LAKES SCIENCE ADVISORY AND WATER QUALITY BOARDS
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International Joint Commission
Great Lakes Science Advisory Board
Great Lakes Water Quality Board

Gentlemen:

Transmitted herewith is the final report of the Phosphorus Management Strategies Task Force. This report is submitted in fulfilment of the requirements specified in the Terms of Reference provided to the task force by the Boards.

As requested by the Commission in its letter of September 13, 1979 to the Secretary of the Science Advisory Board, the report is being submitted to both Boards and the Commission in a form suitable for public release by the Commission if it so desires.

The task force members are pleased to have had this opportunity to contribute to the important task of enhancing water quality in the Great Lakes. With the submission of this report, the task force considers its assignment to be completed. However, we would be pleased to provide any clarification of the findings or further explanation of the basis for any of the recommendations contained in the report which the Commission or its Boards may request.

Respectfully submitted,

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Phosphorus Management Strategies Task Force

PREFACE

This report presents the findings of the Phosphorus Management Strategies Task Force. The task force was appointed in the spring of 1978 by the Great Lakes Science Advisory Board (at that time the Great Lakes Research Advisory Board) with instructions to investigate alternative strategies for managing phosphorus inputs to the Great Lakes. Subsequently, the task force membership was expanded to become a joint task force reporting to both the Science Advisory Board and the Water Quality Board of the International Joint Commission.

The Terms of Reference and membership of the task force are given in Appendices 1 and 2.

As part of its efforts to obtain the latest information, the task force arranged a conference on "Phosphorus Management Strategies for the Great Lakes" sponsored by the International Joint Commission and Cornell University. Presentations at the conference were made by invited speakers recognized as experts on topics dealing with point and nonpoint phosphorus inputs to the Great Lakes, phosphorus availability, modeling approaches, central objectives, and technical, economic, and institutional aspects of management strategies.

The proceedings of the conference together with various reports of the International Joint Commission and other sources have been of great value to the task force in its deliberations. The major documents used by the task force include:

1. Proceedings of the IJC/Cornell University Conference on "Phosphorus Management Strategies for the Great Lakes" held in Rochester, N.Y., April 1979.
2. Report of Task Group III - A Technical Group to Review Phosphorus Loadings Fifth Year Review of Canada - United States Great Lakes Water Quality Agreement, February 1978.
3. Report on Differences in the Great Lakes Phosphorus Load Estimates - Report to Pollution from Land Use Activities Reference Group, February 1979.
4. Review of Models - prepared by the Modelling Group of the Phosphorus Management Strategies Task Force, July 1980.

The statements and views presented in this report are those of the task force members and do not necessarily reflect the views or policies of the Great Lakes Water Quality Board, the Great Lakes Science Advisory Board, nor the International Joint Commission.

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ABBREVIATIONS AND SYMBOLS

cu m	-	cubic metres
d	-	day
gpd/sq ft	-	gallons per day per square foot
ha	-	hectare
kg	-	kilogram
lb	-	pounds
m	-	metres
MGD	-	millions of gallons (U.S.) per day
mg/L	-	milligrams per litre
µg/L	-	micro grams per litre
t/yr	-	metric tons per year

1.0 INTRODUCTION

In 1970, the International Joint Commission reported to the Governments of Canada and the United States' that:

- *"Lake Erie, particularly its Western Basin, is in an advanced state of eutrophication and accelerated eutrophication is occurring in Lake Ontario. The accelerated eutrophication of these waters is due to the presence of nutrients which have been and are being added to these waters. The resultant biological productivity is proportional to the annual rate of input of these nutrients. Of the nutrients involved, phosphorus is the only one that is both growth-limiting in the lakes and controllable effectively by man with present technology.*
- *The major source of phosphorus is municipal sewage. In the United States 70 percent of the phosphorus in sewage originates from detergents, most of the remainder from human excreta. In Canada approximately 50 percent originates from each sewage source. Apart from municipal sewage, the other significant sources of phosphorus are agricultural runoff and some industrial wastes.*
- *The input of phosphorus can be reduced by widespread improvement in the treatment in existing plants of municipal and industrial wastes containing phosphorus. An over-all programme to achieve this is essential if eutrophication is to be halted.*
- *Because of the practical difficulties in implementing the municipal programme contemplated in the preceding conclusion within the reasonable future, it is essential that both countries reduce the phosphorus content of detergents to the maximum practicable extent at the earliest possible time.*
- *The inputs to the waters of the basin of phosphorus, nitrogen and other nutrients from agricultural operations are difficult to control but methods must be found to diminish them."*

and recommended that:

"The Governments of Canada and the United States enter into agreement on an integrated programme of phosphorus control to include:

- (a) *the immediate reduction to a minimum practicable level of the phosphorus content of detergents and the total quantities of phosphorus-based detergents discharged into the Great Lakes System with the aim of complete replacement of all phosphorus in detergents with environmentally less harmful materials by December 31, 1972;*
- (b) *further reduction, as a matter of urgency, of the remaining phosphorus in municipal and industrial waste effluents discharging to Lake Erie, Lake Ontario and their tributaries and to the International Section of the St. Lawrence River, with a view to achieving at least an 80 percent reduction by 1975 and thereafter additional reduction to the maximum extent possible by economically feasible processes;*
- (c) *the reduction of phosphorus discharged to these waters from agricultural activities."*

On April 15, 1972 a Great Lakes Water Quality Agreement² was signed by Canada and the United States wherein they agreed to implement the following programs and other measures to control the inputs of phosphorus:

1. *Programs.* *Programs shall be developed and implemented to reduce inputs of phosphorus to the Great Lakes System. These programs shall include:*
 - (a) *Construction and operation of waste treatment facilities to remove phosphorus from municipal sewage;*
 - (b) *Regulatory measures to require industrial dischargers to remove phosphorus from wastes to be discharged into the Great Lakes System:*
 - (c) *Regulatory and advisory measures to control inputs of phosphorus through reduction of waste discharges attributable to animal husbandry operations.*

In addition, programs may include regulations limiting or eliminating phosphorus from detergents sold for use within the basin of the Great Lakes System.

2. *Effluent Requirements.* *The phosphorus concentrations in 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 litre 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.
4. *Reductions for Lower Lakes.* These programs are designed to attain reductions in gross inputs of phosphorus to Lake Erie and Lake Ontario of the quantities indicated in the following tables for the years indicated."

The responsibility for monitoring progress in implementing these programs and assessing their impact on Great Lakes water quality was assigned to the International Joint Commission. Based on the reports of its principal advisor under the Agreement, the Great Lakes Water Quality Board, the IJC has reported annually to the Governments with recommendations for changes in the programs or their implementation.

In 1978, a report to the IJC by the International Reference Group on Pollution of the Great Lakes from Land Use Activities³ proposed programs to control phosphorus inputs from nonpoint sources and suggested additional controls for point sources. Also in 1978, the Governments reviewed progress under the 1972 Agreement, and signed a new Agreement⁴ in which they tentatively agreed to new target loads and suggested further programs as follows:

1. *"The purpose of the following programs is to minimize eutrophication problems and to prevent degradation with regard to phosphorus in the boundary waters of the Great Lakes System. The goals of phosphorus control are:*
 - (a) *Restoration of year-round aerobic conditions in the bottom waters of the Central Basin of Lake Erie;*
 - (b) *Substantial reduction in the present levels of algal biomass to a level below that of a nuisance condition in Lake Erie;*
 - (c) *Reduction in present levels of algal biomass to below that of a nuisance condition in Lake Ontario including the International Section of the St. Lawrence River;*

- (d) *Maintenance of the oligotrophic state and relative algal biomass of Lakes Superior and Huron;*
 - (e) *Substantial elimination of algal nuisance growths in Lake Michigan to restore it to an oligotrophic state; and*
 - (f) *The elimination of algal nuisance in bays and in other areas wherever they occur.*
2. *The following programs shall be developed and implemented to reduce input of phosphorus to the Great Lakes:*
- (a) *Construction and operation of municipal waste treatment facilities in all plants discharging more than one million gallons per day to achieve, where necessary to meet the loading allocations to be developed pursuant to paragraph 3 below, or to meet local conditions, whichever are more stringent, effluent concentrations of 1.0 milligram per litre total phosphorus maximum for plants in the basins of Lakes Superior, Michigan, and Huron, and of 0.5 milligram per litre total phosphorus maximum for plants in the basins of Lakes Ontario and Erie.*
 - (b) *Regulation of phosphorus introduction from industrial discharges to the maximum practicable extent.*
 - (c) *Reduction to the maximum extent practicable of phosphorus introduced from diffuse sources into Lakes Superior, Michigan, and Huron; and reduction by 30 percent of phosphorus introduced from diffuse sources into Lakes Ontario and Erie, where necessary to meet the loading allocations to be developed pursuant to paragraph 3 below, or to meet local conditions, whichever are more stringent.*
 - (d) *Reduction of phosphorus in household detergents to 0.5 percent by weight where necessary to meet the loading allocations to be developed pursuant to paragraph 3 below, or to meet local conditions, whichever are more stringent.*
 - (e) *Maintenance of a viable research program to seek maximum efficiency and effectiveness in the control of phosphorus introductions into the Great Lakes.*
3. *The following table establishes phosphorus loads for the base year (1976) and future phosphorus loads. The Parties, in cooperation with the State and Provincial Governments, shall within eighteen months after the date of entry into force of this*

Agreement confirm the future phosphorus loads, and based on these establish load allocations and compliance schedules, taking into account the recommendations of the International Joint Commission arising from the Pollution from Land Use Activities Reference. Until such loading allocations and compliance schedules are established, the Parties agree to maintain the programs and other measures specified in Annex 2 of the Great Lakes Water Quality Agreement of 1972.

Basin	1976 Phosphorus Load in Metric Tonnes Per Year	Future Phosphorus Load in Metric Tonnes Per Year
Lake Michigan	6700	5600*
Main Lake Huron	3000	2800*
Georgian Bay	630	600*
North Channel	550	520*
Saginaw Bay	870	440**
Lake Erie	20000	11000**
Lake Ontario	11000	7000**

* These loadings would result if all municipal plants over one million gallons per day achieved an effluent of 1 milligram per litre of phosphorus.

** These loadings are required to meet the goals stated in paragraph 1 above."

Several questions were raised with respect to the validity of the mode's used to establish the proposed target loads, differences in reported estimates of phosphorus inputs, and the effectiveness and relative costs of available technologies to further reduce phosphorus inputs. The Phosphorus Management Strategies Task Force was established by the IJC's Science Advisory Board to review the available data and other information in an attempt to provide answers to these scientific and technical questions. The task force was subsequently expanded in membership and became a joint task force of both the Science Advisory Board and the Water Quality Board and its terms of reference (Appendix 1) expanded to include development of recommendations for alternative phosphorus management strategies for the Great Lakes.

In the remainder of this chapter, the task force provides some perspectives on the ecology of the Great Lakes and the relationship between phosphorus and eutrophication. In subsequent chapters, the task force reviews the phosphorus target loads proposed in the 1978 Great Lakes Water Quality Agreement, discusses the estimates of phosphorus inputs to the lakes, evaluates the mathematical models used to establish target loads, reviews available technologies to reduce both point and nonpoint source inputs, recommends a staged phosphorus management strategy, and identifies additional information needed to further refine the proposed strategy.

1.1 ECOLOGICAL PERSPECTIVES

The Great Lakes represent a continuously changing, dynamic system. Geologically the St. Lawrence drainage system is relatively young. Insufficient time has elapsed for the evolution of many endemic species and the species that occur in the Great Lakes are the ones that could adapt to these large bodies of water. Several marine forms occurred in the pro-glacial lakes and some of these "glacial relicts" remained in the early Great Lakes as the glaciers retreated. Today some Great Lakes' species have close marine affinities while others have gained access to the lakes from other drainage systems. In the past 200 years man has assisted the establishment of additional species through direct introductions of carp, brown trout, rainbow trout, smelt, and salmon or by providing access to the Great Lakes through canals, such as the Erie and New York Barge canals, for the sea lamprey, white perch, and alewife. Each of the new species has resulted in some stress on the system and as a consequence the biota of the St. Lawrence Great Lakes has been changing and evolving long before recent concerns for pollution and eutrophication.

The case for major environmental change rests on data from water intakes and a few early surveys of the lakes. The historical record shows long term increases in total dissolved solids, chloride, sulfate, and combined sodium and potassium in all the Great Lakes except Superior, and increases in calcium in Lakes Erie and Ontario.⁵ These observations are based on data for open lake conditions from in-lake surveys or from water intakes which had been demonstrated to take

in open lake waters.⁶ Data are available for some other substances such as nitrates and iron, but in general the early methods are in doubt and such variability exists in the data that no trend can be established. The exceptions are nitrogen data from Milwaukee, which show a long term decrease in nitrate as the organic fraction (albuminoid nitrogen) increased; presumably the consequence of increased biological uptake of the inorganic fraction.⁵ Some data for western Lake Erie appeared to be reliable and showed increases in nitrogen and phosphorus, although the exact extent of the increase remains in doubt.⁷ The free ammonia content of Lake Ontario water at the Toronto intake doubled between 1923 and 1961.⁸

The dissolved oxygen content of most of the Great Lakes waters is near saturation at all depths. The exceptions are in Lake Erie, Green Bay of Lake Michigan, Saginaw Bay of Lake Huron, and in other small bays and/or harbors. Oxygen depletion in Lake Erie, in the central and occasionally western basins, has become more extensive over the years and indicates a substantially changed environment since the 1930's. This gradual depletion of oxygen has resulted in major changes in the nature and abundance of the biota. Extensive surveys of the bottom waters of the central basin have shown that about 70 percent of the bottom waters develop a pronounced oxygen deficiency each year.

Well documented changes have occurred in the species composition and abundance of benthic communities in western Lake Erie⁹ and southern Green Bay¹⁰ where organisms associated with clean water conditions have been replaced by more pollution tolerant forms. For example, the formerly abundant mayfly, *Hexagenia*, disappeared from these environments as well as from Saginaw Bay, Lake Huron. The opossum shrimp, *Mysis relicta*, which is closely associated with the benthic environment, as well as the plankton, has declined from its former abundance and wide distribution in Lake Erie so that it is now captured infrequently only in the eastern basin.

Fish populations have undergone and are continuing to undergo changes throughout the Great Lakes. Many choice, formerly abundant, commercial species such as lake trout, blue pike, whitefish, sauger, and lake herring have drastically declined in abundance or disappeared from their

former habitats in the lakes. Other species, such as the sea lamprey, alewife, smelt, and salmon, which have found their way into the lakes or been introduced, have prospered.

Changes in plankton have been observed in Lakes Erie, Michigan, and Ontario. Plankton data from the Cleveland,¹¹ Chicago¹² and Toronto⁸ water intakes show long term increases in plankton abundances for Lakes Erie, Michigan, and Ontario, although some studies suggested that the increases at Chicago may reflect local conditions.^{12, 13} The trends seen in the lakes have shown a shift in the diatom populations towards the dominance of species favored by nutrient rich conditions. In Lake Erie a major increase occurred in the abundance of blue-green algae.

Extensive growths of the attached alga, *Cladophora*, have been a problem in Lakes Erie and Ontario since the early 1930's and *Cladophora* is now a major problem along much of the Lake Michigan shoreline. In recent years a red alga, *Bangia*, appeared in the lakes and has become abundant in Lakes Erie, Huron and Michigan, especially around harbors. The significance of this new alga has not been established.

In terms of developing strategies to deal with eutrophication, i.e. increased nutrient loading, it is important to identify those changes which are good indices of eutrophication and those which are not, or may be due to other perturbations of the environment. Increases in nutrient concentrations and decreases in dissolved-oxygen content are accepted indices of eutrophication.¹³ The increases in dissolved solids, or in certain ions such as chloride, have been observed in other lakes undergoing eutrophication, such as Lake Zurich¹⁴ and it has been assumed that increases in the major ions probably reflect what has happened to the nutrients. Nevertheless, the increases in major ions may be more appropriately called environmental changes, which might not indicate eutrophication.

Some of the changes in the biota of the Great Lakes have considerable significance as indices of eutrophication, especially the increases in abundance and changes in the composition of plankton. Extensive growths of *Cladophora* are known to occur in other lakes undergoing

eutrophication.¹⁵ A dramatic decline and even disappearance of salmonid fishes has occurred in a number of lakes.¹⁶ It is likely that environmental changes including those defined as eutrophication have affected fish stocks. Nevertheless, it is unlikely that we will be able to attribute any changes in fish stocks directly to eutrophication, since we must also consider the effect of other stresses such as the successful establishment of populations of various exotic species and their impact on native species: over exploitation by commercial and recreational fisheries, predation by the sea lamprey, physical changes in important habitats for spawning, and the introduction of toxic substances into the aquatic environment. Some changes in the benthic communities may be due to eutrophication where increased organic production has led to changes in the organic content of the sedimentary environment and the dissolved oxygen content of the overlying waters. Some changes in the benthic communities in lake sediments, especially in dominant midge species, are well documented and have been useful for indicating eutrophication.¹⁷ The disappearance of the mayfly, *Hexagenia*, from the bottom of Lake Erie has been associated with decreasing oxygen levels.⁹ Nevertheless, other changes in the benthos of Lake Erie occurred in a relatively short time, which may indicate stresses other than those of eutrophication. Also, the closely similar changes taking place in Green Bay, Saginaw Bay, and western Lake Erie during the same time period could be due to parallel trends in eutrophication or some other stress. It is important to recognize that major changes in the benthic communities took place during the late 1940's and through the 1950's, a period during which toxic materials such as DDT were first used extensively and entered the environment.

1.2 PHOSPHORUS AS RELATED TO GREAT LAKES EUTROPHICATION

Phosphorus has been shown to be a major nutrient controlling phytoplankton growth in the Great Lakes.²⁴ Experiments with natural phytoplankton assemblages have shown phosphorus to be the growth limiting nutrient and that additions of phosphorus will accelerate the growth of diatoms provided supplies of silica are maintained.^{18,19,20} Increases in phosphorus concentrations in the lakes will create blooms of phytoplankton and increase the standing crop.²¹ This relationship

between phosphorus and phytoplankton growth allows total phosphorus to be used as an indicator of the trophic status of the water.²²

Changes in total phosphorus concentration with time have not been observed in the Upper Great Lakes, both because there is little historical data²³ and because phosphorus concentrations apparently have never been very large. The present accepted average total phosphorus concentration in Lake Michigan is only 8 µg/L.²⁴ Year to year changes in the total phosphorus concentrations for Lake Michigan may be as small as 0.2 µg/L during accelerated eutrophication and would be difficult to detect.¹⁸ In addition, the non-conservative nature of phosphorus and its extensive interaction with biological populations make it very difficult to trace phosphorus concentration changes in the Great Lakes.

The only historical trend for nutrients is the decrease in soluble reactive silica that was observed in data collected at the Chicago Water Filtration Plant.²⁵ These data indicate that silica concentrations decreased over a period of forty years from levels of up to 6.0 mg/L. More recent data indicate a decrease in the over-winter concentrations of silica from 4.0 to 1.4 mg/L between 1955 and 1970.²⁶ This silica depletion is indirectly related to phosphorus enrichment since increased phosphorus will stimulate the growth of diatoms in the presence of silica.²⁷

Within the Great Lakes system, the concentration of phosphorus is variable as shown in the published literature. This variability in concentration can be examined in different perspectives which include chronological, seasonal, and spatial differences.

Chronologically, a conclusive upward or downward trend has not been shown for phosphorus concentrations in the Great Lakes. Little historical data exist prior to the 1960's for trends to be identified that encompass more than about ten years. The published literature makes reference to small trends, but a closer examination of the data generally show too much variability between yearly concentrations to be significant.⁵

Early data in the literature comes primarily from water intakes. Weekly water samples from Lake Michigan at an offshore intake at Oak Creek, Wisconsin showed a possible trend from 1961 to 1968. Average concentrations of $\text{PO}_4^{-3}\text{-P}$ ranged from 10 $\mu\text{g/L}$ in 1961 to 20 $\mu\text{g/L}$ in 1968; however, values of 20 and 30 $\mu\text{g/L}$ were recorded randomly for the interim years 1962 to 1967.²⁸ Indiana Harbor data averages for 1965 through 1968 showed extensive variation concentrations of 36, 23, 96, and 24 $\mu\text{g/L}$ of $\text{PO}_4^{-3}\text{-P}$ respectively over the four years.²⁸ A comprehensive review of available data for total phosphorus in Lake Michigan up to 1974 showed no significant trends towards an increase or decrease in phosphorus in sample sets spanning 2-4 year periods.²⁸

On a shorter time scale and for Lake Ontario, a smaller lake, decreases in the total phosphorus concentrations of approximately 1 $\mu\text{g/L}$ for each year since 1973 have been reported.²⁹ Similarly it has been reported³⁰ that winter averages for the total phosphorus concentrations in Lake Ontario were 2-3 $\mu\text{g/L}$ lower in 1977 than concentrations reported in 1974.³¹ Data from 1967 to 1974 on the Niagara River were interpreted by the International Joint Commission⁴⁴ as showing a significant reduction in the total phosphorus concentrations which was attributed to a reduction in the phosphorus loadings. However, the large variability of these data suggest that no real trend is evident for this time period which spans the pre- and post-phosphate detergent controls.

Data have been presented to demonstrate changes in the phosphorus concentration of offshore samples on a seasonal basis.^{23,33} For Lake Michigan, the trends indicate higher concentrations of total phosphorus in the late fall and winter.³⁴ Physical phenomena such as wind, waves, or increased runoff may cause mixing in nearshore stations and may be causing the peak in phosphorus concentrations in April and May.^{33, 35} Data on fluvial discharges to Lake Michigan show that spring concentrations of total phosphorus at the river mouth were higher than concentrations at the same station in July. The Grand River had a total phosphorus concentration of 160 $\mu\text{g/L}$ at its mouth in April and approximately 100 $\mu\text{g/L}$ in July. In the nearshore region off

the Grand River, total phosphorus concentrations are also higher in the spring.³⁶

Spatially, external inputs of phosphorus via tributaries create high concentrations at the mouths of the rivers but generally show that this increase is quickly dispersed within the first 0.5 km offshore of the river mouths. Data on major fluvial input to Lake Michigan show that open lake concentrations of total phosphorus on the order of 7-8 µg/L are maintained at distances of 13 km offshore of the river mouths.³⁶ In April, the concentration of total phosphorus at the mouth of the St. Joseph River was 125 µg/L but rapidly decreased to less than 10 µg/L 13 km offshore from this river. Similar results were noted for the Kalamazoo River, Grand River, Muskegon River, Pere Marquette River, and the Manitou River.³⁶ The extent of the decrease in phosphorus concentration varied with the original concentrations of total phosphorus at the mouth of the river. Inshore total phosphorus concentrations for the Grand River were 160 µg/L, while inshore concentrations for the Muskegon River were only 50 µg/L at its mouth and decreased rapidly to 15 µg/L at 0.2 km offshore.³⁶

Offshore from all eleven rivers sampled, total phosphorus concentrations were less than 10 µg/L at stations representing the open water region. These values agree closely with other data reported on open lake total phosphorus concentrations of 8 µg/L for samples collected in 1971 and 1972³² and 7 µg/L for samples collected in 1965.³⁵

Nearshore variability appears to be more extensive in Lake Michigan with the total phosphorus concentration of inshore sample ranging from 20 to 200 µg/L off the Kalamazoo River and the St. Joseph River respectively. This variation may be attributable to river discharge since conditions off the Saint Joseph River were greatly influenced by the river plume.³⁶

2.0 DEVELOPMENT OF 1978 GREAT LAKES WATER QUALITY AGREEMENT PHOSPHORUS TARGET LOADS

With the signing of the 1978 Great Lakes Water Quality Agreement,² the United States and Canada reaffirmed their intentions to restore and maintain the chemical, physical, and biological integrity of the Great Lakes basin ecosystem. As part of this Agreement, the Parties established tentative total phosphorus target loads which, in cooperation with the State and Provincial Governments, are to be confirmed within eighteen months of the signing of the Agreement and, if confirmed, be used as the basis for load allocations and compliance schedules for the two countries.

2.1 TOTAL PHOSPHORUS TARGET LOADS

The tentative total phosphorus target loads, presented in Table 2.1, were developed by Task Group III, a binational group of U.S. and Canadian scientists organized as part of the fifth-year review of the 1972 Great Lakes Water Quality Agreement to formulate updated phosphorus loading objectives, or target loads, for the lakes. Details of the development of the target loads are described in the report of Task Group III.³¹ The basic approach used by Task Group III was to establish desirable in-lake water quality conditions and then determine the phosphorus loads which would produce these conditions.

Basin	Target Load (t/yr)
Lake Superior	3,400
Lake Michigan	5,600
Main Lake Huron	2,800
Georgian Bay	500
North Channel	520
Saginaw Bay	440
Lake Erie	11,000
Lake Ontario	7,000

2.2 TOTAL PHOSPHORUS CONCENTRATION OBJECTIVES

While phosphorus is considered a major cause of accelerated eutrophication in the Great Lakes, it is difficult to interpret concentrations of this element directly as a measure of the trophic status of a lake. A more effective interpretation can be obtained by relating the total phosphorus objectives to parameters that more directly measure algal biomass, dissolved oxygen, and water transparency, as has been done by Chapra and Dobson.³⁷

The background to the development of the total phosphorus objectives is fully described in the review of phosphorus control objectives presented at the IJC/Cornell University Conference.³⁸ These objectives, as well as the expected water quality that would result if they are met, are presented in Table 2.2.

Lake Basin	Total Phosphorus (µg/L)	Chlorophyll <u>a</u> (µg/L)	Secchi Depth (m)	Trophic State
Superior	5	1.3	8.0	Oligotrophic
Michigan	7	1.8	6.7	Oligotrophic
Huron	5	1.3	8.0	Oligotrophic
Saginaw Bay	15	3.6	3.9	Mesotrophic
Western Erie	15	3.6	3.9	Mesotrophic
Central Erie	10	2.6	5.3	Oligomesotrophic
Eastern Erie	10	2.6	5.3	Oligomesotrophic
Ontario	10	2.6	5.3	Oligomesotrophic

The basis for the selection of these objectives is found in the 1972 Agreement² as follows:

- (1) stabilization of Lake Superior, Lake Huron and Lake Michigan in their present oligotrophic state.

- (2) Saginaw Bay, Lake Ontario and Western and Eastern Lake Erie waters should be free from nutrients entering the water as a result of human activities in concentrations that create nuisance growth of aquatic weeds and algae.
- (3) Central Lake Erie - "restoration of year-round aerobic conditions in the bottom waters".

2.3 MATHEMATICAL MODELS

To estimate lake responses to changes in phosphorus loads, Task Group III used the various mathematical models developed by Vollenweider,³⁹ Chapra,⁴⁰ Thomann,⁴¹ DiToro⁴² and Bierman.⁴³ The models used ranged from simple, completely mixed systems with settling of phosphorus, to complex mechanistic models which involved dynamic calculations for the major physical, chemical, and biological processes. The simplified models empirically correlated the total phosphorus concentration to the various response parameters noted above.

Task Group III developed the target loads for the Lower Great Lakes by calibrating the models to "existing conditions in each lake" and re-running the models with reduced phosphorus loads in order to estimate the responses of the water bodies.

2.4 DEVELOPMENT OF SPECIFIC TARGET LOADS

- (1) Upper Great Lakes (Lakes Superior, Michigan and Huron, except for Saginaw Bay)
- the phosphorus target loads were a reaffirmation that "present water quality" should be maintained in these lakes. Hence, no mathematical models were needed to derive the loads. Rather, the present total phosphorus concentrations were judged acceptable. And it was assumed that phosphorus load reductions, which would be achieved when all municipal wastewater treatment plants discharging more than 3800 cu m/d (1 MGD) have no more than 1 mg/L total phosphorus in their effluents, would be adequate to maintain these concentrations.

- (2) Saginaw Bay - the mathematical models of Vollenweider,³⁹ DiToro *et al.*,⁴² Chapra,⁴⁰ and Bierman *et al.*⁴³ were used to derive the Saginaw Bay target load. The primary criterion used was taste and odor problems at the Whitestone Point Water Filtration Plant in inner Saginaw Bay (which processes approximately 85 percent of the water drawn from Saginaw Bay for human use). The degree of degradation of the inner bay ecosystem, as well as filter-clogging and taste and odor problems in the Pinconning and Bay City Water Filtration Plants were secondary criteria.

The models indicated that a total phosphorus load of 440 t/yr would correspond to an annual average total phosphorus concentration of approximately 15 µg/L. This load would be expected to reduce the taste and odor problems noted above and should reverse some of the inner bay ecosystem degradation, placing Saginaw Bay in a "transition" state between nutrient-deficient and nutrient-rich conditions.

The phosphorus loading objective recommended by Task Group III for Saginaw Bay was based on the average total phosphorus results for all four models and on the results of the Bierman model for taste and odor interferences to the principal municipal water supply.

- (3) Lake Erie - as with the other lakes, phosphorus and chlorophyll *a* concentrations corresponding to a number of phosphorus loads were calculated for each of the three Lake Erie sub-basins by Task Group III,³¹ using the models of Vollenweider,³⁹ DiToro *et al.*,⁴² and Chapra.⁴⁰ To relate the model results more directly to actual central basin conditions, DiToro *et al.*,⁴² correlated their model output for dissolved oxygen concentrations to the areal extent of anoxic conditions in the central basin. The model indicated that a 90 percent reduction in the anoxic area and elimination of "any substantial amount" of phosphorus being released from the lake bottom sediments could be attained with a phosphorus load of approximately 11,000 t/yr.

- (4) Lake Ontario - the models of Vollenweider,³⁹ Thomann *et al.*⁴¹ and Chapra⁴⁰ were used to derive the Lake Ontario load. The primary criterion was degradation of the lake ecosystem, with the principal indicator parameter being annual average total phosphorus concentration. The average result of the three models indicated that a total phosphorus concentration of 10 µg/L corresponded to a phosphorus load of approximately 7,000 t/yr, which would place Lake Ontario at the "lower threshold for the undesirable consequences of phosphorus enrichment", i.e. at the oligotrophic/mesotrophic boundary.

2.5 SUMMARY

The development of tentative phosphorus loading objectives in the 1978 Water Quality Agreement was the first occasion in which the results of different mathematical models were synthesized and used as a basis for management recommendations. These loading objectives should be considered best estimates based on state-of-the-art research, i.e. the models used in their development should be regarded as planning tools and not predictive techniques as discussed in Chapter 4. In perspective, the models have provided a quantitative framework for organizing and interpreting the existing data.

As described in Chapter 3, an important unresolved research issue is the question of the biological availability of various forms of phosphorus inputs and possible transformations in the lakes. A certain fraction of the biologically unavailable forms of phosphorus becomes available in a given system depending primarily on the relative magnitudes of the net transformation reaction and the net settling flux of unavailable phosphorus to the sediments.

A distinction should be made between resolution of the scientific questions concerning phosphorus bioavailability and the implications of a resolution to these questions in a management context. The Vollenweider and Chapra models considered only total phosphorus and the Thomann, DiToro, and Bierman models included explicit distinctions between biologically available and unavailable phosphorus forms in the external loads as well as in the water column. In spite of uncertainties in describing the dynamics of unavailable phosphorus forms, these latter models

reasonably described the present data for biologically available and unavailable phosphorus concentrations in the lakes.

An evaluation of the models and a discussion of the confidence which can be placed in the target loads predicted by them is presented in Chapter 4. The task force accepts the target loads presented in Table 2.1 as reasonable goals, with the degree of uncertainty discussed in Chapter 4, for achieving water quality objectives, and believes that they provide the basis for developing a phosphorus management strategy for the Great Lakes.

3.0 EVALUATION OF PHOSPHORUS INPUTS TO THE GREAT LAKES

Various estimates of the total phosphorus inputs to the Great Lakes have been made employing state-of-the-art technology and in several instances advancing the understanding of significant processes and phenomena which influence the transport of phosphorus to the lakes. In the context of defining the level of decision making that can be supported by the technology and analysis currently available, this chapter addresses issues that are significant in terms of phosphorus loading estimates used in calibrating eutrophication models and the impact on specific target loads developed with these models and the types of loads to be controlled.

3.1 PRESENT LOAD ESTIMATES

Since 1973, the International Joint Commission's Great Lakes Water Quality Board has been publishing annual estimates of the total phosphorus loads to the Great Lakes. These values are comprised of estimates of the primary sources of phosphorus in terms of point sources from municipal and industrial inputs directly to the lakes, inputs via monitored tributaries, atmospheric loadings and loads transported between lakes via the connecting channels. Since 1976, reporting of the indirect point source dischargers has permitted an estimate to be made of the nonpoint sources.⁴⁴ Inputs from unmonitored areas were also estimated. Phosphorus contributed through shoreline erosion has also been estimated, although this input is not included in the total lake loads because it is believed to be virtually unavailable for utilization by phytoplankton. Regeneration of phosphorus from lake bottom sediments is acknowledged, but it has never been quantified by the Water Quality Board. These annual estimates have been used by the Water Quality Board and the International Joint Commission to assess progress made in controlling phosphorus inputs to the Great Lakes.

The difficulties in accurately measuring and estimating phosphorus inputs from the large number of phosphorus sources in the Great Lakes basin have been recognized. Indeed, the Water

Quality Board's efforts have undergone continual revision and refinement. The high variance associated with the estimates for some of the load estimates is illustrated by a decrease of approximately half of the 1977 interconnecting channel load from Lake Erie to Lake Ontario, an increase of approximately 6000 metric tons in the 1978 Lake Erie estimate (due primarily to a significant increase in the state of Ohio tributary load estimate), and an increase of about 2500 metric tons in the 1978 Lake Superior atmospheric load. This annual compilation of loading data from the various Great Lakes' jurisdictions is the only basin-wide effort to quantify the Great Lakes total phosphorus input on a continuing basis.

Separate estimates of the 1976 total phosphorus loadings to the Great Lakes were also made by Task Group III ³¹ and the IJC's Pollution From Land Activities Reference Group (PLUARG) ³.

There were considerable differences among the Water Quality Board, Task Group III, and PLUARG 1976 phosphorus loading estimates for some of the lakes. The three estimates were compared in considerable detail as part of the PLUARG study. ⁴⁵

To a large degree, the basic data used for the three estimates were supplied by the same jurisdictions responsible for their collection in the Great Lakes basin. The Water Quality Board is the source of most of the municipal and industrial point source phosphorus loading data. The Water Quality Board data are derived principally from data submitted by the various states in the Great Lakes basin and the Province of Ontario. Some modifications of the point source data were made by PLUARG and Task Group III, to reflect what they believed were more accurate estimates of the phosphorus inputs from specific sources, especially to Saginaw Bay and Lake Erie.

The tributary loading data are based principally on information submitted by the states and the Province of Ontario to the Water Quality Board. Additional data for some tributaries were obtained in the PLUARG studies³ and extensive data for some tributaries to Lake Erie were collected in the U.S. Army Corps of Engineers Lake Erie Wastewater Management Study.⁴⁶

The PLUARG atmospheric estimates were based on PLUARG atmospheric studies. The Water Quality Board estimates were based on Canadian studies, generalized to the entire Great Lakes basin, except for Lake Michigan, for which U.S. EPA data, from its extensive, recently completed Lake Michigan study, were used. Task Group III used the atmospheric estimates from the Water Quality Board.

The PLUARG interconnecting channel loads, i.e. upstream lake loads for Lakes Huron and Erie were taken from the Water Quality Board. The PLUARG Lake Ontario estimate was based on Niagara River studies conducted at the river mouth by Environment Canada. The Water Quality Board estimates for Lakes Huron and Erie were taken from the Upper Lakes Reference Group⁴⁷ while the Lake Ontario value was based on a 1974 study on phytoplankton in Lake Ontario, conducted for the Water Quality Board by Hydrosience, Inc.⁴⁸

Detailed discussion of the various sources of data used by each group and the differences in the loading estimates for each lake can be found in the PLUARG report.⁴⁵ The total phosphorus load estimates for all lakes except Lake Erie are within 15 percent of each other. The differences are due principally to the slightly different sources of data.

The Lake Erie load estimates are the most diverse. The Task Group III estimate, based on the Lake Erie Wastewater Management Study of the U.S. Army Corps of Engineers, is highest at about 19,500 t/yr, while the Water Quality Board estimate is lowest at about 15,500 t/yr. The PLUARG estimate of 17,450 t/yr is about midway between the Water Quality Board and Task Group III estimates. The main difference between the PLUARG and Task Group III loads is the higher estimate of the U.S. direct municipal load used by the Task Group. The major difference between the PLUARG and Water Quality Board loads is a lower tributary estimate used by the Water Quality Board.

Based on a complete review of the available information, the task force has made "best estimates" of the 1976 phosphorus loads to the various Great Lakes as shown in Table 3.1.

It should be noted that there is no rigid scientific or statistical basis for these estimates, nor can such a basis be presented without a major effort involving reevaluation of virtually all the raw data submitted to the three groups, a task outside the resources of this task force. However, the task force considers that the "best estimates" of the total phosphorus load for each lake is within plus or minus 15 percent of the actual load for the sources included in the estimates.

A coordinated collection of phosphorus loading data, and a standardized and scientifically sound methodology for calculating phosphorus loads will help to reduce the uncertainty in future estimates.

Lake	Direct Municipal	Direct Industrial	Tributary* Total	Atmosphere	Urban Direct	Upstream Load	Total
Superior	72	103	2,455	1,566	16	-	4,212
Michigan	1,041	38	3,596	1,682	-	-	6,357
Huron	126	38	2,901	1,129	16	657	4,867
Erie	6,292	275	9,960	774	44	1,080	18,425
Ontario	2,093	82	4,047	488	324	4,769	11,803

* consists of indirect point sources and nonpoint sources in tributary basin

It should be noted that more "accurate" loads will not necessarily affect the phosphorus reductions required under the 1978 Great Lakes Water Quality Agreement. For the Upper Lakes (Lakes Superior, Michigan and Huron, excepting Saginaw Bay) the recommended reductions are those which will result from achievement of a 1 mg/L total phosphorus concentration in effluents from municipal wastewater treatment plants discharging in excess of 3800 cu m/d (1 MGD). Therefore, the required phosphorus reductions for these lakes are not dependent upon estimates of the present phosphorus loads.

For Lakes Erie and Ontario and Saginaw Bay, the 1976 phosphorus load estimates were used indirectly in the development of the phosphorus target loads. A "base year" load was derived on the basis of the 1976 load from direct point sources and the atmosphere, and tributary loads based on an "average" hydrologic year. Hence, the 1976 estimate can in part affect the ultimate target load established through the lake modeling exercise. The implications of the present loads as they affect the lake modeling results are discussed below.

3.2 LIMITATIONS AND IMPLICATIONS OF EXISTING LOADING ESTIMATES

The target loads were developed, in part, considering measures of eutrophication and employing one or more water quality models in combination with the measured total phosphorus in the Great Lakes. Four aspects of the total phosphorus load estimates are discussed in the context of this use and the implications on water quality management decisions. The four aspects considered are tributary loads, shoreline erosion, bioavailability of various forms of phosphorus, and assignment of tributary loads to primary sources such as point sources, runoff from agricultural land, stream bank erosion, and urban runoff. The uncertainty in estimated total phosphorus loads as related to analysis of existing data on the loads from point sources, atmospheric sources, and connecting rivers between lakes, has been discussed in Section 3.1. The following is a discussion of additional uncertainties which may influence management decisions.

3.2.1 Tributary Loads

Tributary loads are generally measured at upstream locations which are not significantly influenced by the lake backwater. Portions of the measured tributary loads are associated with particulates. Many streams are characterized by increases in total phosphorus concentrations during the high runoff periods associated with storm events. Data from sampling during runoff events in seven of ten streams monitored on the U.S. side of Lake Erie indicated that phosphorus flux increased with increasing flow.⁴⁹ These streams are sometimes referred to as event response streams. The phosphorus associated with higher flow periods can be a significant percentage of the total annual load. The Corps of Engineers⁴⁹ has developed a technique for event sampling of

tributaries and for estimating the annual total phosphorus flux to Lake Erie using these data and a phosphorus loading model. The total phosphorus load estimate for Lake Erie using the phosphorus model to extrapolate Corps data is 79 percent and 49 percent larger than estimates using historical data for certain U.S. and Canadian tributaries, respectively. These differences are for estimated loads summed over various periods and tributaries. It may be concluded that event sampling of tributary loads can increase significantly the estimated total phosphorus entering a lake from tributaries. The increase in phosphorus loads during high runoff events is primarily associated with particulate phosphorus. The documented effects of event sampling on tributary load estimates were obtained in the Lake Erie basin, which has significant regions with high clay content soils.

Other areas of the Great Lakes, with more sandy soils, would tend to have phosphorus fluxes less sensitive to high flows. Some event data were also available for tributaries to other lakes, however, there is no consistent or comprehensive Great Lakes-wide data base with associated analyses that considers this phenomenon. Tributary loading estimates for lakes other than Lake Erie may be low due to this lack of data. Employing Lake Erie as a guide, the underestimate could range from 10 to 30 percent of tributary loads. Since no additional data have been collected it is not possible to determine if the loads have actually been underestimated for individual lakes nor the magnitude of any underestimate.

The event response phenomena suggests that a problem may exist in terms of transporting tributary loads to the main body of the lakes. The tributary loads are estimated from measurements made in streams above the influence of the backwater of the lake. These are stream segments usually characterized by higher velocities during high flow events. The existence of event response streams suggests that settling and subsequent scour of particulate phosphorus are significant instream processes controlling the magnitude and time of delivery of phosphorus loads from tributaries. The influence of the lake backwater tends to lower stream velocities and this tendency is accentuated by bays, deltas, and in the nearshore region of the lakes. It would appear that the total phosphorus loads from tributaries may be settling in the bays, deltas, and nearshore areas of the lake. This settling would tend to reduce the estimates of total phosphorus loads that impact lake eutrophication processes. The phosphorus which settles can ultimately enter lakewide processes

but the time frame over which this occurs would be long and much of the material may be effectively removed from the system. The mathematical models of eutrophication each contain terms that account for settling of total phosphorus. The values of these settling terms are made to compensate for the processes discussed above.

The target phosphorus loads were established in the context of controlling eutrophication on a lakewide scale and the estimates of phosphorus loads from Tributaries are not completely consistent between lakes.

3.2.2 Shoreline Erosion

The load estimates of total phosphorus all exclude considerations of the contribution of shoreline erosion. This exclusion is based on the observation that this source of phosphorus has a high percentage of unavailable phosphorus. The problem associated with this assumption is that target loads have been developed using mass balance models and estimated total phosphorus loads, in conjunction with measurements of total phosphorus obtained in the lakes, to define model coefficients and parameters. Therefore, from the standpoint of developing target loads, the total phosphorus loading estimates should contain all sources of total phosphorus which could influence in-lake measurements of this substance. Table 3.2 presents estimates of the shoreline erosion contribution of total phosphorus and its relative magnitude compared to the other sources of phosphorus.

The significance of the particulate total phosphorus related to shoreline erosion and to event loads in tributaries would be lessened if the material settles rapidly. There appear to be significant percentages of clay and silt, ranging from 25 to 80 percent in the eroded material from shorelines. Much of the phosphorus in tributary loads transported during storm events is associated with particles of this size range. A large percentage of tributary particulate total phosphorus may be associated with clay size particles. It is probable that some portion of the loads from these sources,

Lake	Shoreline Erosion (total sediment) (t/yr)	Total Phosphorus Shoreline ² Erosion (t/yr)	1976 Total Phosphorus All Other Sources (t/yr)
Superior	11,279,000	3,800 ¹	4,212
Michigan	21,778,000	3,700	6,357
Huron	1,763,000	794	4,867
Erie	11,131,000	10,536 ³	18,425
Ontario	3,206,000	1,280	11,803

- Notes: 1. U.S. load only
2. PLUARG reports on U.S. and Canadian shoreline erosion.³
3. Canadian estimate for short term used (1972-1973) @ 9512 t/yr
- Canadian long term estimates (1953-1973) @ 5912 t/yr.

particularly that associated with the larger particles, settles and does not enter lake-wide processes. Unfortunately, the data base does not exist to determine what percentage of these loads settles.

The analysis employed to obtain the target loads assumes:

1. All of the tributary total phosphorus enters the lake. Some of the particulate phosphorus in these loads is calculated to settle and does not enter lake-wide processes. The dissolved portions of the tributary loads do enter lake-wide processes.
2. All the total phosphorus from shoreline erosion settles very rapidly and does not enter lake-wide processes.

The tendency of these assumptions is to eliminate consideration of the effects of particulate phosphorus from shoreline erosion and to assign benefits to control of particulate phosphorus loads from tributaries. Therefore, the projected benefits attributed to the control of particulate

phosphorus from tributaries and other sources may be overestimated. The significance of this possible overestimation of benefits cannot be determined from the existing information.

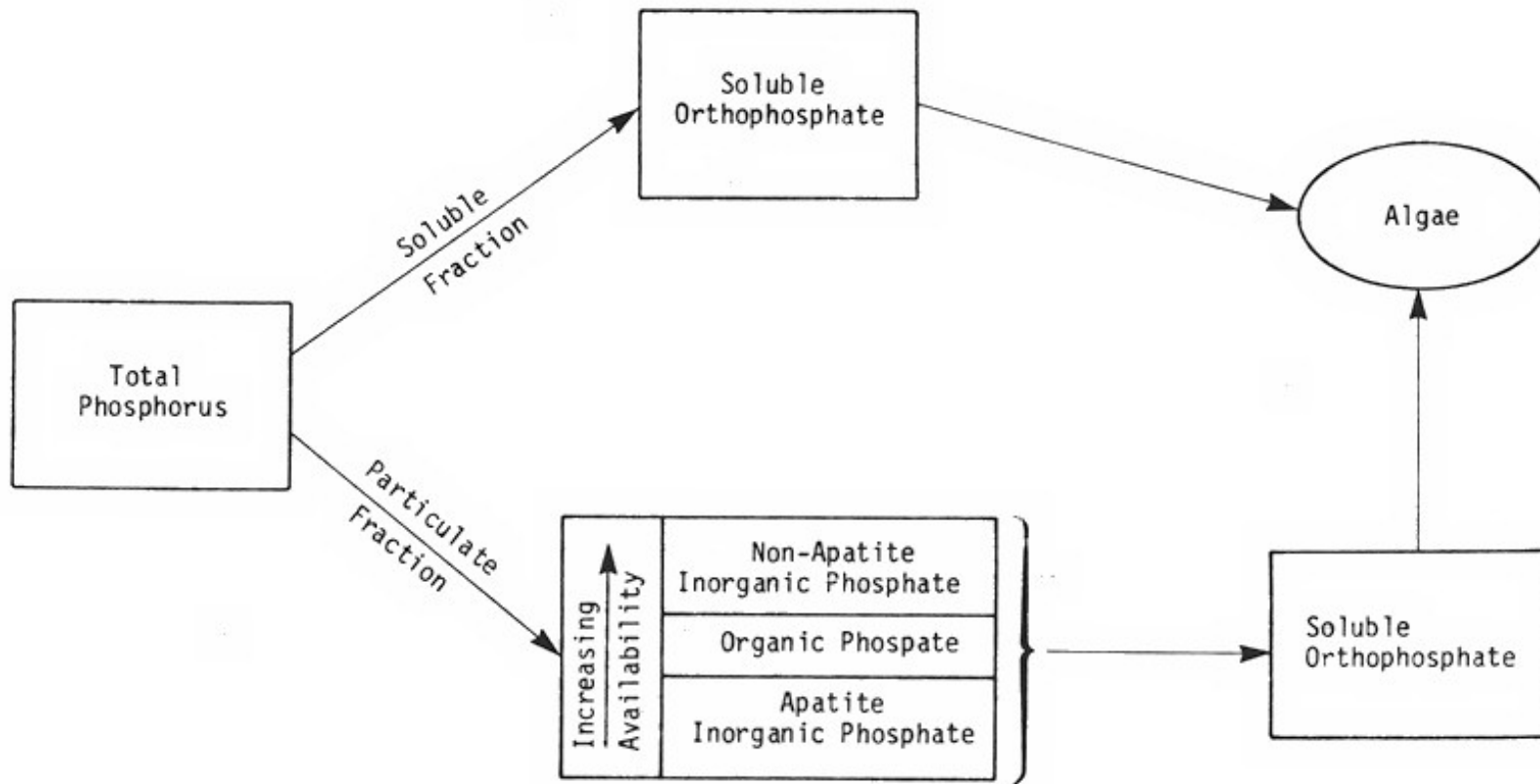
3.2.3 Bioavailability of Phosphorus

Historically, management practices for controlling lake eutrophication have been directed towards total phosphorus. Recent studies have raised questions as to the relevance of this parameter.

Phosphorus in surface waters is made up of soluble and particulate forms. It is widely accepted that, within the soluble fraction, orthophosphate is readily available for algal productivity. The particulate fraction may be chemically defined as non-apatite inorganic phosphorus, apatite inorganic phosphorus, and organic phosphorus. Non-apatite inorganic phosphorus is considered to be the potentially and ultimately available form. Apatite inorganic phosphorus is considered virtually unavailable. A portion of organic phosphorus likely becomes available over time. Questions remain as to the actual utilization of these forms in the aquatic environment. Limited studies are underway to relate these chemically defined forms to the phosphorus used by algae. Figure 3.1 shows a general relationship among these forms of phosphorus and their utilization by algae.

A review of the most recent studies concerned with phosphorus availability have been provided by Lee *et al.*⁵⁰ at the IJC/Cornell University Conference on Phosphorus Management Strategies for Lakes and the Great Lakes Science Advisory Board's Expert Committee on the Engineering and Technological Aspects of Great Lakes Water Quality.⁵¹ Existing evaluations of phosphorus availability have been predicated mainly on chemical extractions which measure available phosphorus as orthophosphate. The results obtained with the chemical methods presently used are relatively comparable. Studies are presently being conducted in an effort to compare chemical and biological methods. Nevertheless, there still remains a paucity of data for making such comparisons. The correlation between algal bioassay data and lake biomass response is still unresolved.

FIGURE 3.1 General Relationships Between Phosphorus Forms And Algae



Note: (This is not a complete nutrient cycling diagram - rather a schematic showing the paths between total phosphorus inputs and algae.)

Chemical analyses of the availability of tributary particulate phosphorus across the basin provides two estimated ranges. PLUARG studies³ using a single chemical method to estimate non-apatite phosphorus found a range of 14 to 40 percent depending upon the tributary sampled. The Lake Erie Wastewater Management Study⁴⁶ using two chemical extractions to estimate non-apatite phosphorus showed a range of 43 to 89 percent in selected Lake Erie tributaries. It remains unclear how either of these procedures used to estimate non-apatite phosphorus relates to the phosphorus actually used by algae.

Soil materials from bluff erosion and wastewater discharge represent the extremes of the availability issue. Williams *et al.*⁵² and Armstrong *et al.*⁵³ both find that bluff materials have biologically available phosphorus in the range of a few percent. The relative biological availability of phosphorus in wastewater is not as clear cut. Recent EPA studies⁵⁴ indicate that the biologically available fraction of phosphorus municipal wastewater to be on the order of 60 to 75 percent. The percentages for a given wastewater remain relatively constant regardless of biological wastewater treatment with supplemental treatment including chemical addition for phosphorus removal. The biological availability of phosphorus question is one requiring further research.

Another factor in defining the availability of phosphorus is the proximity of the phosphorus source to the receiving water. Initial studies by Carlson *et al.*⁵⁵ suggest that streams have a natural ability to reduce the proportion of available phosphorus from upstream sources. While this capability is difficult to measure in large systems, its inclusion in the final equation used to define the impacts of phosphorus from various sources may be of substantial importance.

The foregoing discussion underlines the importance of considering phosphorus availability in formulating management strategies for the Great Lakes. It is unfortunate that the only existing comprehensive data base is total phosphorus. Therefore, although present management strategies must continue to be predicated on consideration of total phosphorus, work should continue to obtain the loading and other aspects of phosphorus availability and their implication for phosphorus management for the Great Lakes.

3.2.4 Primary Sources of Total Phosphorus in Tributaries

In order to assess the feasibility and practicality of managing total phosphorus inputs to the Great Lakes, it is necessary to assign the measured tributary loads to primary sources such as point discharges, runoff from agricultural, urban, and other land uses, and stream bank erosion.

The general procedure employed was to define total tributary loads from measured flows and total phosphorus concentration data. In the PLUARG Study independent estimates of total phosphorus from primary sources on tributaries were developed. The sum of the primary sources of phosphorus on tributaries was compared to the tributary load estimates developed from the river mouth measurements.

In some cases significant adjustments in primary total phosphorus source loads were required. These adjustments could often be related to specific watershed or tributary characteristics. In other cases the agreement between the two calculations was reasonable. This procedure provides some basis for defining primary sources of total phosphorus on tributaries.

There is evidence that total phosphorus discharged by upstream municipal and industrial point sources undergoes transformations and removals from the water column. Phosphorus from these sources is indistinguishable from that associated with other sources at the mouth of the tributary. Phosphorus from treatment plants could be removed in the downstream reaches of tributaries. This removed phosphorus is most probably associated with solid particulates which settle.

The travel time of this particulate phosphorus to the lake is large compared to the average hydraulic travel time of the streamflow and may be in the range of several years. The storm event related increases in tributary phosphorus are probably associated with settling and subsequent scour of particulate phosphorus. This process also can influence phosphorus discharged by point sources on tributaries.

The exercise of calculating the primary sources of phosphorus is an approximation which appears to incorporate some type of long term equilibrium assumption in terms of existing loads. The effectiveness of phosphorus control at point sources on tributaries is subject to some uncertainty. As an illustration of these uncertainties the following questions should be considered:

1. How much of the point source phosphorus discharged to tributaries reaches the open lake and in what time frame?
2. How much of the point source phosphorus from tributaries that reaches the open lake is biologically available and in what time frame?

The same general issues of transport and availability appear to be associated with point and nonpoint sources on tributaries. The significance of questions with regard to point sources increase with increasing distance from the lake and for larger delta or bay systems at the mouth of the tributary.

3.3 FUTURE LOAD ESTIMATES

The task force believes that several changes are necessary to improve the estimates of phosphorus loads. Improvements are required in the estimates from point sources and tributaries and the types of reporting.

3.3.1 Point Sources

Areas in which point source estimates can be improved are to include an estimate for wastewater treatment plant bypasses and combined sewer overflows. A measure of total flow and a flow proportioned sample are needed for each bypass event. Regulatory agencies should require this information to be collected and reported. The estimates of annual treatment plant loads should continue to be based on daily load estimates, i.e. daily flow times the phosphorus concentration in

a daily composited sample.

3.3.2 Tributaries

In order to obtain a reasonable estimate of total loads to the lakes from event response rivers, sampling during high flow events is necessary. Approximately two to three of the largest events must be sampled for a yearly estimate, with 15 to 20 grab samples collected over the hydrograph. An additional 5 to 10 samples should be collected during steady flow periods. This program should yield a loading estimate with an error estimate of 10 to 20 percent.

The above program will result in annual estimates for tributaries which are reliable and estimates which can also be used to detect differences in annual loads. However, this program will likely not be sufficient to detect progress made in control of diffuse sources. Annual variations in the frequency and duration of high flow events as well as basin conditions, such as soil moisture and cover, make any simple evaluation of change in phosphorus loads impossible. If changes in phosphorus loads are to be measured, continuous records of rainfall, streamflow, water quality, soil moisture, and cover will be needed as well as improved methodologies for relating this information. A few watersheds should be selected for such studies.

3.3.3 Reporting of Loads

Total phosphorus loads are needed for two reasons: calibration and validation of lake models and measurement of progress in reducing inputs to the lakes.

For the purpose of lake modeling, an estimate of the total phosphorus load from all sources is needed. Estimates are needed for all point sources, not just those with flows greater than one million gallons per day. An event sampling program for the tributaries as described above is needed as well as estimates of loads from connecting channels and the atmosphere.

Reporting of annual and comparison total lake phosphorus loads is not the best way to measure progress in controlling phosphorus. Rather, only municipal sources with flows greater than 3800 cu m/d (1 MGD) and industrial sources should be reported annually, and compared to specific target loads for these point sources as a measure of progress.

Progress in diffuse source control can best be assessed through monitoring the implementation of conservation measures in the agricultural community and stormwater management controls in the urban areas. Intensive monitoring programs to accurately measure river loadings could be carried out on selected rivers as described above. Implementation of conservation measures can be used as input to models or tools, such as the Universal Soil Loss Equation, to estimate progress based on reductions in potential gross erosion.

3.4 SUMMARY

It appears that the total phosphorus loading estimates developed for the Great Lakes were based on a set of assumptions which were consistent with available data and the degree of understanding of the processes controlling transport of total phosphorus. The various analyses used could be viewed as being at the leading edge of the state-of-the-art. From the standpoint of phosphorus management in the Great Lakes basin these analyses have provided important information and insight. As discussed, there are a number of gaps in our knowledge of loading which should be considered in developing a phosphorus management strategy for the Great Lakes. In general they are associated with the ability to characterize the total load to a lake or lake segment consistent with the methods employed to define target loads; settling of total phosphorus in tributaries, bays, deltas, and near-shore areas; and defining the benefits associated with treatment of point and nonpoint sources on tributaries. The task force has suggested ways to improve the future estimates of phosphorus loads.

The present gaps in fundamental knowledge associated with estimates of total phosphorus loads are not sufficient to require major modifications in the proposed management programs for

control of eutrophication in the Great Lakes. Their existence suggests that the certainty of obtaining benefits from control actions varies with the type and location of the primary source. The most certain benefits are associated with control of point sources discharging directly to the Great Lakes. The certainty of obtaining the anticipated benefits is reduced for controls on point sources discharging to tributaries. The greatest uncertainty of obtaining anticipated benefits is associated with the control of particulates from nonpoint agricultural sources.

4.0 REVIEW AND EVALUATION OF MODELS

As noted in Chapter 2, several mathematical models were used to establish the 1978 Great Lakes Water Quality Agreement tentative phosphorus target loads for Saginaw Bay and the lower Great Lakes. A major part of this task force's charges was to review these models and evaluate their ability to predict the limnological effects of changes in phosphorus loadings and comment on the validity of the target loads.

The task force established a modeling sub-group to review the scientific and technical bases for the models and assess their ability to predict reasonable target loads. Based on the modeling sub-group's detailed review of the models⁵⁶ the task force, in this chapter, provides some general observations on the nature of the modeling process, a brief description and evaluation of the models, and an assessment of the reliability of the target loads.

4.1 PRESENT STATE OF EUTROPHICATION MODELING

Mathematical models have several important functions. One main function is to increase the scientific insight and understanding of real world processes. A second is to provide a quantitative tool for assessing planning and management alternatives. The first function is characterized by the expression of fundamental ideas in mathematical form, leading to equations, graphs, etc., which correlate and synthesize scientific observations and data. The second function is the application of these equations in the evaluation of alternatives for planning design and management purposes.

The analysis by which the Great Lakes target loads were determined represent the present state-of-the-art of modeling the eutrophication process. Over the past few decades a better understanding of the phenomena associated with eutrophication has been achieved and, more importantly quantitative means have been developed for assessing various alternatives for controlling eutrophication, such as reducing phosphorus inputs. However, the approaches are still

very new and, as yet, there is little direct and empirical evidence of their validity in projecting responses of the Great Lakes to reduced nutrient inputs.

Most environmental problems are characterized by components which vary over time, are three-dimensional, and respond in a nonlinear manner, i.e. the effects do not correspond to the environmental disturbances or stresses in a 1:1 manner. Assuming our scientific knowledge of the real situation in systems such as the Great Lakes is complete, at least in principle, an abstraction or "model" of the real system is developed, in which the significant factors are included and irrelevant features are omitted or modified.

After development of the model, whether in equation form or in the form of graphs or plots, it must then be "calibrated" and "validated". The process of calibration involves comparing model predictions with observed or measured data, and is done to insure that the relevant factors in the model have been included and realistically characterized. The validation is usually done by comparison of predicted data with measured or observed data from previous years in the water body being modeled, or by using data from a completely different water body. When such a comparison is satisfactory, the model is said to be validated. What constitutes "satisfactory" depends on the nature of the problem, the structure of the model, the extent of available data, and most important, the purpose of the analysis.

The highest level of validation is achieved when the model predictions identically reproduce the observed real world conditions. This type of validation is, in any practical sense, almost impossible to achieve in environmental modeling because of the time lag involved between the use of a control or remedial measure and the resultant response of a lake, and because of random factors which affect hydrological and meteorological events and nutrient inputs.

Water quality models, in general, should be considered planning and/or management tools rather than precise predictive techniques. As such, they are best used to examine the spectrum of lake responses which may occur as a result of various management alternatives, as well as to

increase our understanding of lake systems. Validation of eutrophication models should be viewed in this context. In many cases, extreme accuracy is not required for management decisions, but rather trends and ranges may be sufficient to answer questions related to the control of eutrophication in the Great Lakes basin.

It is noted that with eutrophication models, especially the more complex ones, the components of the models are outweighed by the number of rate coefficients these components may have, by factors of 2 to 10. That is, a model component or process may have several possible values, all of which are valid under appropriate conditions. Based on the present scientific knowledge of aquatic ecosystems, however, there are usually limited ranges within which the values of these components lie. The validity of the model as a realistic representation of a system as complex as the Great Lakes is based on the internal consistency of these coefficients over a wide variety of environmental conditions.

The nature of the problem, and specifically the time and space scales of the problem, dictate how simple or complex the analysis will be. Given or assuming these scales, a specific question is posed, and the purpose of the analysis should be to answer this question in the simplest, most efficient and realistic manner. The relative complexity of the model is an important factor in its validation -- the more complex, the greater the degree of validation required. The complexity of a model is determined by the number of its components. The models described in the following section cover the spectrum from relatively simple to complex, and each has a particular utility.

4.2 MODELS USED TO DEVELOP TARGET LOADS

The characteristics of the transport (spatial distribution) of nutrients within a given water body are accounted for in various ways --- from the most simplified concept of a completely mixed system to the more complex systems which vary spatially in one or more dimensions. The variations in a water body over time can also be described in several ways -- from the steady-state condition, to the dynamic mode over a diurnal, weekly, seasonal, or annual time scale. As noted above, the necessary degree of complexity of a given model is usually dictated by the nature of the analysis and the answers being sought.

Models may, therefore, be categorized on the basis of the following criteria:

1. Steady-state or dynamic.
2. Completely mixed or spatially variable.
3. Single reactants with simplified kinetics or multiple reactants with complex kinetics.

The models which were applied to the analysis of the eutrophication problem in the Great Lakes have been reviewed by Task Group III.³¹ A summary of this review, with a brief evaluation added by this committee, is presented below.

1. Steady-state, Single Constituent (Vollenweider³⁹)

The Vollenweider model, based on a rational approach, is an empirical correlation between phosphorus load and in-lake concentrations of phosphorus and chlorophyll a, parameterized by depth and hydraulic detention time. In developing the correlations, data were used from sixty temperate-zone lakes which represented a range of conditions from oligotrophic to eutrophic. Conceptually, the model originated from the solutions of a simplified mass balance model of a completely mixed reactor for the equilibrium or steady state condition.

2. Dynamic, Single Constituent (Chapra⁴⁰)

The Chapra model is a simple dynamic mass balance model with phosphorus concentration as the principal variable. Total phosphorus is considered to be a non-conservative substance which is removed by settling to the bed. The model has been applied to the Great Lakes as a coupled dynamic system of basins. Given phosphorus load, volume, and depth, the in-lake phosphorus concentrations are calculated as a function of time, for all of the major Great Lakes basin. An empirical component is included which allows correlations to be made between the calculated total phosphorus concentrations and related parameters such as chlorophyll a and dissolved oxygen concentrations and, in this respect, is similar to the above. This model has been calibrated with Great Lakes data, while the above used data

from many lakes.

3. Dynamic, Multiple Constituents, Single Phytoplankton (Thomann,⁴¹ DiToro⁴²)

The Manhattan College group (Thomann,⁴¹ DiToro⁴²) has developed models for Lake Ontario, the Lake Huron-Saginaw Bay system, and Lake Erie. These are dynamic mass balance analyses which calculate both phosphorus and nitrogen concentrations and the related parameters, chlorophyll *a* concentration, zooplankton concentration, and, for Lake Erie, dissolved oxygen concentration. The phytoplankton growth is a function of phytoplankton concentration and temperature. The same basic conceptual framework has been applied to Lake Ontario and to the Lake Huron-Saginaw Bay system.

4. Dynamic, Multiple Constituents, Multiple Phytoplankton (DiToro,⁴² Bierman,⁴³ Thomann⁴¹)

These models are conceptually similar to the Manhattan models in that a dynamic mass balance is used to directly calculate phosphorus, nitrogen, phytoplankton, and zooplankton concentrations. The phytoplankton biomass is partitioned into 2 classes of diatoms and non-diatoms in the DiToro and Thomann models and applied in Lakes Erie and Ontario. The former also includes sediment nutrient release under anaerobic conditions. The Bierman model incorporates five different functional groups: diatoms, greens, blue-greens (N₂-fixing and non-N₂ fixing), and "others". More detailed mechanisms are also used to describe phosphorus and nitrogen interactions with the phytoplankton. The Bierman model has been applied only to Saginaw Bay.

4.3 ASSESSMENT OF RELIABILITY OF TARGET LOADS ESTABLISHED BY MODELS

As presented in Chapter 2, the models described above were used to determine the effects of changes in phosphorus input loads on the concentration of various water quality constituents.

The models were used to calculate phosphorus input loads to maintain levels of phosphorus and/or chlorophyll and dissolved oxygen which were considered to be indicative of acceptable water quality.

The factors which are considered in assessing the reliability of the target loads computed by the models, may be categorized as follows: (1) differences in loads calculated by various models, (2) reliability of models indicated by the analysis of residuals, and (3) consideration of those elements, which are not explicitly included in the models, but which may have some effect on the target loads. It is evident that with respect to the first two factors, the uncertainty may be quantified to some degree, but only a qualitative assessment may be made concerning the third.

4.3.1 Difference in Target Loads Calculated by Various Models

Assuming that each of the models are of comparable validity for this purpose, a measure of confidence in the target loads established may be derived by comparing the differences in loads computed by the various models.

The models were used to determine the effects of phosphorus input loads on the concentration of selected water quality constituents - principally total phosphorus and chlorophyll. For Lake Erie only, hypolimnion dissolved oxygen was also included. Resulting lake water quality concentrations were calculated for an array of phosphorus loads corresponding to loadings which would result from various levels of control. Target loads were selected as those which would achieve a selected concentration of phosphorus, considered to be an acceptable water quality criterion. The correlation between the phosphorus concentration and the resulting chlorophyll and dissolved oxygen levels were established either empirically or causally.

Comparison of the differences in model calculations showed that, in general, there was agreement among the responses of the four models.⁵⁶ For a given input load, calculated phosphorus concentrations were within a range of about 5 to 25 percent, with an approximate average of about 20 percent. Resulting chlorophyll concentrations for a given load were calculated

within about 35 percent for Lake Ontario, although absolute differences were only 1 or 2 µg/L. For the above, the responses may be interpreted as being comparable. Calculated chlorophyll responses in Lake Erie are a notable exception, in that, while in agreement on phosphorus levels, the models differ radically in the chlorophyll levels predicted.

If, on the other hand, a specific concentration is adopted as a desired level, the difference in input loads calculated by different models to achieve it is greater. For example, loads defined by the models to achieve a specific phosphorus concentration in Lake Ontario differ by about 30 percent; for lower concentrations in Lake Erie, calculated loads differ by more than 50 percent.

4.3.2 Percent Error Between Computed and Observed Values

In the determination of load response relationships, the models were used to project to conditions beyond those for which they were formulated and calibrated. The question regarding the validity of such an extrapolation which immediately arises is: What is the accuracy of such projections? Although no accepted methodology is presently available to answer this question, it is evident that a qualitative and visual comparison of computation and observation is basic to the degree of acceptance of the validity of the model. In general, there was reasonable agreement between the calculated and observed values for each of the models.

A more quantitative measure of the difference between the computed and observed values of the various constituents has been determined by statistical analysis of the residual errors, as described above. The median percent error for Lake Ontario ranged from 26 percent to 41 percent, with an average of 22 percent for all variables. The median percent error for the dissolved oxygen in the Central Basin of Lake Erie is in the range 5 to 15 percent. Allowing for the fact that 50 percent of the sediment oxygen demand was assigned would justify increasing this value, say in the order of 20 percent.

The effect on the target loads may be assessed in an approximate manner by use of the above. Although the calibration error is not equivalent to the prediction error, it may be used to

assign some measure of reliance to the loading. Assuming that the calibration error carries through to comparable error in loading and that there is a linear relation between loading and concentration (both of which assumptions are rather tenuous), the range in target loads would be about 20 or 25 percent.

The percent error in the Lake Ontario model appears to have an annual consistency: the model typically undercalculates the spring bloom, usually overcalculates the summer mix, and occasionally misses the fall bloom. The largest component of the error, however, lies in the spring bloom. Furthermore, a regression analysis of the observed and calculated values indicated that the revised kinetics did, in fact, improve the fit but produce no significant change in the intercept or residual errors as measured by the square of the correlation coefficient.⁵⁶ There appears to be a systematic bias in the model, which undercalculates the chlorophyll for lower concentrations and overcalculates for higher levels. Although it is difficult to relate these statistics to the prediction error of loading, it may be concluded that there is some effect and for present purposes, these observations are offered as a further basis for viewing the target loads within the 25 percent range as indicated above.

While the Lake Erie analysis has a lesser residual error, the assignment of 50 percent of the benthic demand should be an additive factor in the specification of the range of target loads. It is pertinent to note that the projections tend to be on the conservative side in each case.

4.3.3 Issues Not Addressed by the Models

The issues discussed in this section relate to factors which were not included in the models and about which only meager qualitative conclusions can be drawn from the present analysis. The principal unaddressed issues relate to the distinction between the littoral and pelagic zones of the lakes and to the delineation of phytoplankton species, some of which are considered beneficial or desirable and others not. It is believed that these issues are of sufficient fundamental significance and of sufficient practical value to warrant some discussion.

The first issue concerns the littoral and pelagic zones. All of the available models are structured to analyze primarily the pelagic segments of the lakes, or at least, an overall average of lake conditions. None of them directly address water quality conditions in the littoral areas. The practical importance of this issue is evident since the public response is most influenced by the conditions in these areas. Furthermore, these areas are generally characterized by different environmental conditions, with respect to such variables as light, circulation, and nutrient concentrations. It is likely they exhibit different species composition and responses. In general, littoral areas respond more quickly to pollution stresses, but by the same token, will improve more rapidly due to control and reduction of nutrient discharges.

It is recognized that these areas are not as amenable to modeling as are the central zones, primarily because of the hydrodynamic transport within the littoral zone and because of the exchange with the pelagic zone. Both of these features will be unique to each littoral area examined. How these areas respond to nutrient control remains to be seen. One could anticipate that improvements would be more quickly felt with a commensurate public response. It is pertinent to note that present research activities are directed to an analysis of a more finely segmented lake, in which both the littoral and pelagic zones are calculated.

The second issue concerns the differentiation of species. It is a matter of record that seasonal succession of species occurs to some extent, and more important, that long term ecological changes have occurred over the past few decades. A similar phenomenon has been observed in estuaries subjected to increasing discharges of municipal and industrial discharges, as was reported for the Potomac Estuary. The state of the art of eutrophication modeling has not yet developed to the degree which permits adequate definition of this phenomenon.

The models which were used for the target loads for Lake Ontario and Erie incorporated two species, diatoms and "others", in the seasonal analysis. The long term transitions are yet to be addressed in the modeling framework. These issues are raised not to refute the basic validity and utility of the present models, but to offer a perspective from which to view the proposed levels for the target loads.

4.4 SUMMARY

Based on the analysis presented above, it is appropriate to interpret the target loads as a range within a specified percent of the values which are presently proposed. The principle of establishing a range rests on the uncertainties of our ability to reproduce mathematically biological phenomena.

The models were then used to project phosphorus and chlorophyll responses to reduced nutrient inputs. In general, there was agreement between and among the responses of the four models for various projections of phosphorus loading. The differences in the allowable loads predicted by the various models for a given water quality objective had a range of about 25 percent depending on the model selected. In this sense, the target load may be interpreted as having a comparable range. This is predicated on the assumption that the loads used for validating the models were identical. If there were differences, such would be reflected in an increased range of uncertainty in the target loads.

The quantitative specification of the range is based primarily on three factors: (1) the statistical analysis of the residual errors between observed and computed values, (2) the differences in target loads projected by the various models, and (3) the elements which were not included in the models, but which may have an effect on the target loads. Given the evaluation of the models, presented in this report, a range of plus or minus 30 percent is suggested for the target load of 11,000 t/yr for Lake Erie and plus or minus 20 percent for the 7,000 t/yr target load for Lake Ontario.

The concept of interpreting the target loads as a range is one of the bases upon which the task force has developed its proposed phosphorus management strategies. As discussed in subsequent sections, a principal feature of the various strategies is a staged approach. This approach permits assessment of the control achieved in each stage on water quality and, equally important, the opportunity to refine the models to minimize the range and to provide a more reliable basis for establishing future controls.

5.0 COSTS AND TECHNOLOGIES OF PHOSPHORUS CONTROL

A variety of treatment technologies are available to control both point and nonpoint source inputs of total phosphorus. In addition, there are several non-structural options, such as restricting the phosphorus content of detergents and regulating fertilizer application, which can be used to reduce the amounts of phosphorus which could enter the lakes as a result of man's activities. This chapter provides an overview of both the structural and non-structural options and some perspective on the relative costs of implementing different control options.

5.1 PHOSPHORUS MANAGEMENT FOR POINT SOURCES

A major component of the total phosphorus inputs to the lakes is domestic wastewater, of which 20 to 35 percent may be derived from phosphate based detergents. Efforts to reduce the phosphorus content of municipal wastewater discharged in the Great Lakes basin began in the late 1960's and early 1970's. Both phosphate detergent controls and additional treatment at municipal wastewater treatment plants were part of this effort.

Considerable resources have been devoted to the development and application of cost effective technologies for meeting the 1973 and 1975 deadlines for phosphorus control at municipal wastewater treatment plants in the lower Great Lakes basin. Faced with a large number of existing treatment facilities, efforts were concentrated on integrating chemical precipitation into these facilities. Today, chemical precipitation is the most widely used method for reducing the total phosphorus concentration in municipal effluents to below 1 mg/L.

Of the municipal treatment plants in the Great Lakes basin using chemical precipitation for phosphorus removal about half are using aluminum salts and half use iron salts and a few use lime.⁵⁴ Low cost alternative precipitants such as waste pickle liquor and "red mud" have also been studied as have various combinations of chemicals and polymers. As a result, waste pickle liquor now has widespread acceptance where plant processes permit.

In the search for cost effective alternatives capable of producing total phosphorus effluent concentrations in the 0.1 mg/L to 1 mg/L range, other treatment practices, such as land application⁷³ and modification of the activated sludge process to promote luxury biological uptake⁶⁸ of phosphorus have received more critical attention in recent years.

Another alternative in phosphorus management consists of reducing the total phosphorus content in household detergents and substituting it with other builder materials.

5.1.1 Chemical Phosphorus Removal

Chemicals which are used in phosphorus removal include ferrous and ferric chloride and sulphate salts, alum and lime.^{63, 64} They are sometimes used in combination or through separate injection at different points in the treatment process, and have been coupled with polymers to improve clarification.

Alum or ferric salts can be added ahead of primary treatment, into the aeration basin or in the aeration basin effluent channel, provided adequate mixing is available. Ferrous salts, which are available as waste pickle liquor, require conversion to the ferric form before precipitating phosphorus and generally are not effective when added to primary clarifiers. Although pickle liquor is effective when added to the aeration section of activated sludge plants and is low in cost, it has a number of drawbacks. Pickle liquor varies in quality, utilizes oxygen, depresses the pH of wastewater, contributes heavy metals and contains suspended material which can plug chemical pumps and feedlines.

It has been demonstrated that phosphorus removal to 1 mg/L can be consistently achieved through chemical precipitation in conventional and modified activated sludge plants. Increasing chemical dosage in well operated and hydraulically underloaded plants has been reported to attain total phosphorus effluent levels in the range of 0.5 mg/L.⁵⁴ However, in order to achieve effluent phosphorus concentrations below 0.5 mg/L consistently at most activated sludge plants it would be necessary to provide additional final clarifier capacity or effluent filtration, and increase

coagulant dosages and possibly add polymers.

A variety of proven process technologies using lime for phosphorus removal exist. Effluent total phosphorus concentrations as low as 0.05 mg/L have been reported.⁶⁵

The efficiency of phosphorus removal depends on many factors. Three of the most important are the degree of mixing of the chemical with the wastewater, the point of chemical injection, and the ability of the process to remove suspended solids. Significant reductions in the chemical dosages required have been possible through increasing the intensity of mixing at the point of chemical injection and by relocating the point of addition from the raw sewage conduit to the aeration basin or secondary clarifier inlet.⁶¹ Effluent phosphorus levels less than 1 mg/L are consistently achieved with designed clarifier overflow rates of less than 32.6 m/d (800 gpd/sq ft) at peak flow.

Corresponding effluent suspended solids in the range of 15-20 mg/L are obtained. Hydraulic loading problems are most apparent in primary plants where high peak loads reduce phosphorus removal efficiencies. Primary plants meeting the 1 mg/L criteria generally have clarifiers with low overflow rates and are treating a sewage which is compatible with chemical treatment. Polymers are sometimes used to aid in solids capture but, because of their high cost, are considered to be only a temporary solution for offsetting excessive hydraulic loadings.

High levels of total phosphorus removal, through chemical addition, have also been achieved at all types of municipal wastewater treatment lagoons. While lime has not been found to be effective in achieving 1 mg/L when added to either continuously or seasonally discharging lagoons, both alum and ferric chloride are effective.^{66, 67} Continuous chemical addition can produce effluent phosphorus levels in the range of 1 mg/L with effluent BOD and suspended solids at levels of about 30 mg/L. On the other hand, batch treatment of storage lagoon contents can produce an effluent with less than 10 mg/L BOD, 20 mg/L suspended solids and 0.5 mg/L total phosphorus provided the effluent is discharged within 10-12 days after treatment. Capital costs For batch dosage are minimal compared to continuous chemical dosage which requires chemical storage and feed

equipment. Manpower costs are minimal in both cases and chemical dosages are similar to those required for treatment in activated sludge plants.

5.1.2 Biological and Biological/Chemical Processes

Biological removal of phosphorus, without chemical treatment, to levels below 1 mg/L have also been reported in pilot studies.^{68,69} These processes operate on the principle that removal takes place through wastage of phosphorus rich sludge. An anaerobic basin is utilized ahead of the aeration tanks wherein the sludge becomes phosphorus deficient following which, in an aerobic environment, luxury uptake of phosphorus occurs. The sludge must be dewatered rapidly to prevent the release of the phosphorus.

Advantages over conventional chemical precipitation include less sludge, no chemicals, and significantly lower operating costs. However, the biological system may require more careful operational control. Further evaluation is needed to verify process reliability in cold climates. The potentially significant cost advantages of biological phosphorus removal, luxury uptake, merit rapid and diligent assessment of the process reliability for Great Lakes applications.

Recent technology employing a combination of biological and chemical processes has also been successfully demonstrated.⁷⁰ One example is the PhoStrip process⁷¹ which involves phosphorus uptake by microorganisms in an activated sludge aeration basin, with subsequent phosphorus concentration and release in the supernatant of an anaerobic stripper tank. When coupled with lime treatment of the supernatant, the released phosphorus can be successfully precipitated and removed, with the phosphorus deficient sludge being returned to the aeration section.

Advantages of the PhoStrip process over conventional chemical precipitation include lower chemical usage, lower sludge production and, through off-line sludge storage, protection of the activated sludge process against shock loads. Effluent phosphorus levels of less than 1 mg/L are reported at costs which are about 35 percent lower than those reported for conventional chemical precipitation.⁷⁰ It would appear that at plant sizes greater than about 20,000 cu m/d (5 MGD) the

economies of this process become advantageous over conventional technology.⁷²

5.1.3 Land Application for Phosphorus Removal

Land application has been utilized as a method of wastewater treatment and management for many decades. In the nineteenth century, it became relatively common for municipalities to use this process to dispose of their wastes. As urban expansion encroached upon available land and technological interests turned to sewage treatment plants, other approaches replaced many land application systems. There has been a renewed interest in this form of wastewater treatment with over 600 municipalities in the United States currently using land application systems. The majority of these are crop irrigation systems located in western states. In Canada, only a limited number of municipalities treat wastewaters by land application methods. The report on "Land Treatment of Municipal Wastewaters in the Great Lakes basin"⁷³ summarizes the use of land treatment in the Great Lakes basin and the potential of land treatment to remove contaminants entering the Great Lakes and their tributaries.

Land treatment of municipal wastewater involves the use of plants and soil to remove many wastewater constituents. The three principal land treatment processes are known as slow rate, rapid infiltration, and overland flow. In the slow rate process the wastewater to be treated is applied to the land by flooding or spray irrigation. The wastewater is treated as it flows through the soil matrix and a portion of the flow percolates to groundwater. Crop irrigation is an integral part of this system.

In rapid infiltration, the wastewater is applied at a high rate, and most of the applied wastewater percolates through the soil with the treated effluent eventually reaching the groundwater or collecting in under drains. The wastewater is applied to highly permeable soils, such as sands or loamy sands, and crops are not usually used. In overland flow land treatment, wastewater is applied over the upper reaches of sloped terraces and allowed to flow across the vegetated surface to runoff collection ditches. The wastewater is treated by physical, chemical and biological means as it flows through the existing vegetation in a thin film down the relatively

impermeable slope.

Slow rate systems are those most widely used. Table 5.1 summarizes the phosphorus removals that have occurred at land application sites. The differences noted in the characteristics of the renovated wastewater are due to the different reactions that occur with each type of land treatment process.

At most rapid infiltration sites, the groundwater does not reach surface waters in sizable quantities and generally moves through loams and clays before entering a surface stream. Thus, although the groundwater at the rapid infiltration sites may contain higher phosphorus concentrations than at slow rate sites, such groundwater may not be a major source of phosphorus of streams or lakes.

At overland flow sites, the soil is only slightly permeable, and any treatment occurs by reactions at the soil surface. A large portion of the applied wastewater is collected as treated runoff at the bottom of the overland flow slope for either re-application or discharge.

TABLE 5.1 Phosphorus Removal By Land Treatment Systems ⁷⁴			
Type	Range of System Sizes (1,000 cu m/d)	Total Phosphorus Applied Wastewater	Concentration (mg/L) Renovated Wastewater*
Slow rate	0.08 - 213	4.8 - 15.8	0.04 - 0.5
Rapid infiltration	1 - 49	1 - 12.4	0.02 - 5.6
Overland flow	16 - 274	5 - 15	1 - 10
* Analyses of samples of groundwater under the site, groundwater at the site boundary, or runoff from an overland flow system.			

Since the wastewater flow is on the soil surface, wastewater contact with the soil is less than for slow rate and rapid infiltration systems, and phosphorus removal is less with overland flow systems. Chemical addition to the wastewater before application can enhance the phosphorus removal at overland flow sites.

The renovated wastewater from well designed, operated, and managed slow rate or rapid infiltration sites percolates to groundwater rather than discharged to a stream. Where these processes can be used, the phosphorus loading of surface waters such as the Great Lakes is less than would occur with other point source phosphorus control alternatives.

Land treatment systems represent a viable alternative for phosphorus control where site specific conditions, such as soil characteristics, geology, available area, suitable crops, and transmission costs make this process competitive with other wastewater treatment alternatives.

In addition to phosphorus removal, land treatment can have additional benefits such as: (a) reduced sludge production for handling, treatment, and ultimate disposal; (b) recycle of nutrients and organics to the soil-crop system; and (c) removal of toxic and other contaminants. However, some disadvantages may also occur such as: a) accumulation of metals, toxic organic substances, and other contaminants in the soil; and b) possible contamination of groundwater with low molecular weight organic substances.

5.1.4 Costs for Municipal Point Source Controls

Costs of phosphorus removal to achieve effluent levels on the order of 1.0 mg/L through chemical precipitation in primary and secondary plants varies with plant size and distance from the source of chemicals. Total capital and annual operating costs (1975 dollars) for a typical 4,500 cu m/d plant are estimated at \$14,000 and \$1,600 respectively, exclusive of chemical costs.⁶⁴ Similarly, total capital and annual operating costs for a typical 45,000 cu m/d plant are estimated at \$52,000 and \$5,400 respectively. The average chemical cost is given as \$5 per 1,000 cu m of sewage treated, a fact which is meaningful only in the broadest sense of cost comparisons.⁶⁴

No level of municipal point source control alone is likely to achieve the mean target load estimates for Lake Erie. If the mean target load for Lake Erie is met, the target load for Lake Ontario could be met if municipal discharges had an effluent concentration of = 0.15 mg/L total phosphorus.

An effluent requirement of 0.5 mg/L total phosphorus for municipal treatment facilities with flows greater than 3,800 cu m/d (1 MGD) could achieve 24 percent and 34 percent of the load reductions required to achieve the mean target loads for Lakes Erie and Ontario respectively (see also Table 7.1). This level of additional municipal point source control would increase the annual treatment costs for plants in the Lower Great Lakes basins by 92 percent from \$38 million to \$73 million.⁷²

These cost projections are estimated with a computer program based on the uniform application of chemical addition technology for the 1.0 mg/L effluent level plus dual media filtration for the 0.5 mg/L effluent level. The unit costs for these technologies were applied to the size distribution of the existing municipal facilities with known or estimated influent phosphorus levels. The cost of the intermediate technology is based on doubling the clarifier capacity thus reducing the overflow rate from 28.5 to 14.3 m/d (700 to 350 gpd/sq ft), adding 10 percent more chemical and associated sludge disposal costs. It is extremely difficult to make accurate cost projections for phosphorus removal technologies because of the variation in plant performance associated with a given control technology.

This is particularly true with the suggestion to double the clarifier capacity. Because of the economies of scale associated with each technology it is possible to achieve some limited savings in overall costs by applying different technologies to different sizes of plants to achieve the lowest unit costs for a given total load reduction. These potential cost savings are not expected to be dramatic.

If the general applicability and reliability of process modifications utilizing biological luxury uptake of phosphorus are demonstrated, it is possible that phosphorus removal to the 1.0 mg/L

level can be achieved at costs equivalent to those for conventional activated sludge treatment. The availability of an essentially no cost option for reducing the phosphorus content of municipal wastewater discharges to 1.0 mg/L would have a significant impact on the overall phosphorus management strategies.

Land treatment of wastewater, where applicable, can provide excellent phosphorus control 0.1 mg/L. This technology was not included in the cost estimates because reliable cost estimates are highly site specific and sparse.

Emerging technologies for municipal point source control, such as the magnetic separator and adsorption contactor offer the promise of lower phosphorus residuals and reduced land area requirements. Development of these technologies, as well as the attainment of improved reliability and better performance from current technologies, can contribute to the goal of preserving Great Lakes water quality.

5.1.5 Phosphorus Detergent Controls

Phosphorus removal at municipal wastewater treatment facilities was preceded in many areas of the Great Lakes basin by legislation to reduce the phosphorus content of household laundry detergents. In the early to mid-1970's, while institutional mechanisms were developed, most jurisdictions in the United States and Canada implemented detergent phosphorus controls to effect immediate reductions in municipal phosphorus inputs in the Great Lakes.

At the present time Canada limits the phosphate content of laundry detergent to 2.2 percent as phosphorus measured by weight. In the United States, all of the Great Lakes states except Ohio and Pennsylvania have legislative controls limiting the phosphorus content of laundry detergents to 0.5 percent. The existing controls are generally less restrictive or exempt formulations for automatic dishwashers and certain commercial and industrial uses. In those jurisdictions not covered by legislative controls, the soap and detergent industry has reduced the phosphorus content of household laundry detergent from about 11 percent to 5.5 percent thus providing some

reduction in detergent related phosphorus discharges in those areas.

Direct and indirect municipa] phosphorus discharges in the Lake Erie basin in Ohio and Pennsylvania were estimated for 1978⁷⁵ to be 2,441 and 158 t/yr, respectively. In those areas having no controls it is estimated that detergent phosphorus accounts for 20 to 35 percent of the phosphorus in municipal wastewater discharges. The detergent phosphorus contribution to municipal discharges may therefore be estimated for Ohio and Pennsylvania to be 490 to 850 and 30 to 55 t/yr, respectively.

Phosphate, as the major precontrol builder in detergents has three major replacements; nitrilotriacetate (NTA), citrate, and carbonate. NTA is the primary builder substitute used in Canada. There has been some controversy and concern in terms of the health and environmental effects of NTA. The IJC, through the Science Advisory Board, has evaluated studies addressing these concerns and concluded the effects are negligible.^{76,77} Nevertheless, because of these concerns NTA was not used in the United States and carbonates have become the dominant replacement builder. Citrates are not in general use. Recently the U.S. Environmental Protection Agency, after reviewing the available information on the ecological and human health effects of NTA at levels expected to be released to the environment from its use in laundry detergents, has announced that it "sees no reason to take regulatory action against resumed production and use" of NTA.

Studies have been carried out to assess the impact of replacement builders on the phosphorus removal efficiencies of existing treatment systems and the environment. It is generally concluded that there are no adverse long term effects caused by the three major substitute builders on phosphorus removal efficiency or the surface water environment.

Comparative costs associated with detergent phosphorus controls and wastewater treatment are difficult to determine because of the range of variables involved. The Soap and Detergent Association considers costs associated with phosphorus controls to include additional wear on materials and equipment and additional product use including supplemental cleaning aids and fabric softeners used to enhance cleaning efficiency. Hardness of local water supplies is a major variable

impacting these incremental costs.

Proprietary protection precludes an estimate of the direct costs to the industry for reformulation.

Determination of the magnitude and impact of the costs directly related to reformulation is difficult because of the many subjective consumer judgements that must be made. Direct comparison to the incremental cost increases in detergent phosphorus removal at wastewater treatment facilities is difficult because of inadequate accounting and record keeping. Recognizing these shortcomings, the Soap and Detergent Association estimates that the annual cost per family for carbonate detergents is \$13 to \$62 in 1978 dollars. The range is a function of vehicle water hardness, but has a median value of about \$29. Use of NTA and 2.2 percent phosphorus has made the economic impact of detergent reformulations on the Canadian consumers very small. Estimates of the annual cost of removing detergent associated phosphorus to a level of 1.0 mg/L by waste treatment range from \$2 to \$20 per family (1978 dollars) depending upon the assumptions used in the analysis.

Detergent controls that are not in place have accrued benefits for which economic values have not been assigned. Controls provide a measure of treatment for those facilities under 3,800 cu m/d (1 MGD) that have no phosphorus effluent limits, for communities with combined sewer overflows and for unsewered areas. Controls provide some protection from increased phosphorus discharges caused by collection system and treatment plant malfunctions. In addition, a reduction in required treatment provides energy and chemical savings and reduces the volume of sludge requiring ultimate disposal.

It is generally believed that detergent phosphorus controls have helped reduce the rate of eutrophication of the Great Lakes. While there is some question as to the efficacy of this control strategy, it is suggested that extension of controls to uncontrolled areas should have a positive effect on the Great Lakes while municipal wastewater treatment facilities are being brought into compliance with phosphorus reduction requirements.

While there are benefits to detergent phosphorus controls, there are clearly costs. Unfortunately the costs are not well defined so that an accurate cost-benefit analysis is not possible.

5.1.6 Summary

A variety of proven treatment and management options are available to reduce the phosphorus content of municipal wastewaters. The major options are compared in Table 5.2 with respect to effluent quality total phosphorus and relative costs. The most cost-effective option for a given municipality can only be established on a site-specific basis considering such factors as existing facilities, final effluent requirements, location, availability and costs of chemicals, and sludge disposal.

5.2 MANAGEMENT OF NONPOINT SOURCES OF PHOSPHORUS

Interest in nonpoint sources of phosphorus within the Great Lakes basin has been focused through four major programs: the International Reference Group on Great Lakes Pollution from Land Use Activities (PLUARG)³; the United States Federal Water Pollution Control Act Amendments of 1972, PL92-500, particularly Section 108 on "Pollution Control in the Great Lakes" including the U.S. Army Corps of Engineers, Lake Erie Wastewater Management Study⁴⁶ and Section 208 "Areawide Waste Treatment Management"; and in Ontario, river basin studies such as the Thames River Implementation Study.⁷⁸

Each of these programs represent an expenditure of considerable resources on a variety of studies and has resulted in the collection of a substantial data base on the sources of nonpoint pollution. However, what has been lacking in most of the studies with the exception of the PL92-500 Section 108 study on Black Creek in Allen County, Ohio⁷⁹ and the Section 108 Red Clay project on Lake Superior,⁸⁰ has been a rigorous assessment of the effectiveness of nonpoint remedial measures in reducing the movement of phosphorus to the Great Lakes. Work has begun in the Lake Erie Wastewater Management Study to evaluate the effectiveness of conservation tillage practices on phosphorus delivery,⁸¹ but this work is in its early stages and definitive results are not

TABLE 5.2 Municipal Point Source Treatment Options

Process	Effluent Quality Total Phosphorus (mg/L)	Incremental Costs.	Comments
<u>A-S/Chemical</u> Activated Sludge (A-S) <i>plus</i> alum or ferric chloride, ferrous salts or lime <i>plus</i> polymer	 0.6-1.0 0.6-1.0 1.0 -	Capital- \$3,500 per1000 cu m/d capacity. Chemicals - \$5 per1000 cu m treated. O&M - \$80/yr per1000 cu m/d capacity. These waste salts are low cost. Expensive for continuous use.	Peak flow clarifier overflow rate 32.6 m/d (800 gpd/sq ft) essential. Ferric conversion in aeration section. Poor quality can cause problems. Used in primary section only. Limiting pH levels may make it difficult to achieve 1.0 mg/L. Temporary solution to periodic hydraulic overloads.
<u>Physical/Chemical</u> Primary <i>plus</i> alum or ferric chloride, ferrous salts, or lime <i>plus</i> polymer	 1.0 N/A 1.0 -	Similar to A-S/Chemical. N/A Similar to A-S/Chemical. Expensive for continuous use.	Peak flow clarifier overflow rate 32.6 m/d (800 gpd/sq ft) essential. Cannot be used unless converted to ferric salts. Effluent needs pH adjustment. Lime feeding is difficult. Temporary solution to periodic hydraulic overloads.
<u>AWT/Chemical</u> Advanced Waste Treatment (AWT) <i>plus</i> alum or ferric chloride, ferrous salts or lime	 0.3-0.5 N/A 0.3-0.5	 N/A	Using effluent filter and chemical. N/A Using upflow charifier and chemical.
<u>Lagoons/Chemical</u> Aerated or Facultative <i>plus</i> alum or ferric chloride, ferrous salts, or lime	 0.5-1.0 N/A 1-0	 N/A N/A	Continuous chemical feed produces a 1 mg/L effluent. Batch dosage and seasonal discharge gives 0.5 mg/L. N/A Difficult to handle.
<u>Biological</u> Bardenpho A/O Process	 1.0 1.0	Expected to be significantly lower than A-S/Chemical and could be equivalent to conventional A-S alone.	Additional development work required.
<u>Biological/Chemical</u> PhoStrip	0.5	34-37 percent lower than A-S/Chemical.	Lime treatment of waste sludge side stream reduces chemical requirements and sludge production.
<u>Land Application</u> Slow Rate Rapid Infiltration Overland Flow	 0.04-0.5 0.02-6 1.0	Competitive with A-S/ Chemical. " " " N/A	Applicability dependent upon soil conditions, health risks, cost competitiveness and public acceptance. Applicable only where impermeable soils are available.

Note: Care must be taken in comparing costs for various treatment options. Often phosphorus removal can be integrated into existing facilities. Costs of abandoning existing facilities must be considered where this option is proposed.
 N/A - Not Applicable.

yet available. Efforts are also underway in the Thames River basin⁷⁸ to implement remedial measures, but this also is in the early stages of implementation.

All of these studies have concluded that the phosphorus transported to surface waters from nonpoint sources is predominantly carried in association with eroded sediment. This is in contrast to the phosphorus in point source discharges which contains more soluble, readily available forms of phosphorus.

5.2.1 Land Use Activities of Concern

There are a number of procedures available for ranking the relative phosphorus contribution from individual land use activities. The most useful means of assessing contributions of phosphorus, from a remedial measure perspective, is the identification of those land use activities which contribute the highest loading per unit area of land. It is assumed that resources are better invested in treating those areas where the problem is most concentrated. Agricultural and urban land use activities have been identified as the most important contributors of phosphorus.³ Most unit area loads of total phosphorus range from 0.1-9.1 and 0.3 -2.1 kg/ha-yr for agricultural and urban areas, respectively. In comparison, forested areas generally exhibit unit area loads of 0.02-0.67 kg/ha-yr.^{82,83}

Agriculture:

Unit area loads of phosphorus from agricultural areas increase with the proportion of clay in the soil, the degree of slope, and the stream and drainage ditch network density. Maximum sheet erosion is also associated with areas where there has been a high proportion of continuous cultivation of row crops, such as corn and beans. These crops provide the least soil cover during the growing season and are traditionally preceded by fall plowing and extensive seed bed preparation which leaves the soil exposed to erosion during the critical February-April snowmelt and spring runoff period.

In the PLUARG studies^{84,85} it was estimated that rural sources of phosphorus occurred in

the following proportions: cropland - 70 percent; livestock operations - 20 percent; streambank erosion - 5 percent, and unimproved agricultural land - 5 percent.

Urban:

Variations in unit area loads from developed urban areas were found to be primarily a function of the type of conveyance system (separate or combined sewers), population density, occurrence of medium and high density industrial activity, and the area of contiguous urban development. Developing urban areas have been characterized as having the highest unit area loadings of suspended solids due to the often severe soil erosion of exposed soils. Although the range of unit area loads from urban areas was comparable to some agricultural areas, the total area of land in urban uses is only about 5 percent of the total Great Lakes basin area as compared to 35 percent for agricultural uses.

Phosphorus loadings from urban areas must not be looked at in isolation, since the heavy metal loadings from these areas exceed the background levels measured in runoff from agricultural areas. Thus, remedial programs implemented in urban areas could result in reduced metal as well as phosphorus loadings.

5.2.2 Characteristics of Non point Sources-Implications for Management

Despite the rather limited nature of the research completed to date on nonpoint sources, it has become apparent that the approaches to point source control are not suited to the solution of nonpoint problems. A number of factors have been identified which not only affect the kind of remedial measures which can be considered, but also the means by which successful implementation can be achieved. These factors are discussed below.

Temporal Variability

Annual

Great Lakes tributaries serve as the principal conveyance system for transporting

phosphorus from nonpoint sources to the lakes. Monitoring of phosphorus loads carried by most tributaries has, at best, been inadequate and thus our understanding of phosphorus loading variability is suspect. Estimates of tributary phosphorus loads are based on simple arithmetic relationships between measured flow values and concentration data. Measured flows of Great Lakes tributaries generally exhibit a much greater range than the concentration data, and it is likely that wide ranges in flows will describe similar changes in loads.

An assessment of this variability in tributary flows for the 15 year period, 1962-1976 was recently conducted.⁸⁶ Flows in Canadian tributaries to Lake Erie varied ± 38 percent while U.S. tributaries varied ± 49 percent over the same 15 year period. Given this wide ranging natural variability, it will be extremely difficult to justify expenditures on nonpoint remedial programs if measurable short term improvements in tributary phosphorus loadings are expected.

Seasonal

In a number of the studies conducted under PLUARG, a distinct seasonality in the delivery of sediment was identified. In the Maumee River basin, the six months from December to May accounted for 92 percent of the total sediment load delivered to Lake Erie by the river during the period July, 1975 - June, 1977.⁸⁷ Calculations made for the 11 agricultural watersheds studied in Ontario revealed that 75 percent of the total annual suspended sediment load left the watersheds during the months of February through April.⁸⁸

Thus, remedial measures directed towards reducing sediment delivery to the lakes must necessarily provide maximum protection during the late winter and early spring period of the year. For instance, the tradition of fall moldboard ploughing of the basin's heavier soils when used for row crops will have to be reevaluated if beneficial reductions in sediment loadings are to be achieved.

Spatial Variability

Macro Scale

The relative importance of the contribution of individual land use activities varies from lake basin to lake basin. For example, in the Lake Superior basin forested areas contribute 74 percent of the total nonpoint source phosphorus load, while in the Lake Erie basin this land use activity only accounts for 1 percent of the load.³

Therefore, remedial action directed to controlling nonpoint sources of phosphorus will require a different focus in each lake basin and will receive different priorities based on their relative importance and controllability.

Within individual lake basins, marked variations also exist with respect to the relative significance of land areas contributing to the nonpoint problem. Differences in soils, geomorphology, climate, and land use activities result in considerable ranges in nonpoint loadings. The most important factors identified in this regard have been the co-occurrence of areas of fine textured soils being used for row crop agriculture. These areas generate higher loadings of sediment during runoff in relation to their slope, infiltration rates, and susceptibility to sediment suspension and transport.

The implementors of nonpoint remedial measure programs will have to take cognizance of these factors if program resources are not to be dissipated by treating all areas of a given basin to the same level. A program structured on a priority area basis would channel resources into those areas where the greatest and most rapid reductions can be achieved at least cost. Adoption of this approach does raise some concern about the creation of inequities between those basin residents who will need to implement remedial measures first and those who will be involved to a lesser extent and at a later time. Given the perennial problem of limited fiscal resources, adoption of the alternate more equitable approach of requiring uniform compliance would result in a continuation of present priorities and in a smaller loading reduction.

Micro Scale

Although estimates of gross potential soil erosion are useful in determining the impact of erosion on agricultural productivity, their value in assessing impacts on water quality is limited. Of more concern from a water quality perspective is the determination of the sediment delivery ratio, or the proportion of the gross potential erosion which is actually delivered to a stream. This is the fraction which may exert an impact on water quality. Logan has noted that in the Maumee River basin, the annual sediment delivery ratio lies somewhere between 4.2 percent and 14.9 percent.⁸⁷ Soils with the finest textures had the highest delivery ratios and yet exhibit some of the lowest gross erosion rates as estimated by the Universal Soil Loss Equation; a situation which could be overlooked in the design of a remedial measure program if gross erosion rates are the only criterion used to determine problem areas.

The fine particle size clay fractions associated with most soils have a greater surface area and cation exchange capacity, and will remain in suspension longer and thus travel farther than the coarser sand and silt soil fractions. Typically, fine textured soils with high clay contents are more likely to have lower infiltration rates resulting in more surface runoff from areas with such soils. Conventional remedial measures, while effective in controlling gross erosion, may be less efficient in controlling the delivery of the clay size fraction.

When viewed from a management perspective it is important to determine not only what proportion of the gross eroded soil is reaching a watercourse but also the spatial distribution of the source areas. In fact, the sediment delivery ratio is not a constant for a given soil type across the area of a watershed. In studies carried out by Van Vliet *et al.*⁸⁸ in two PLUARG agricultural watersheds, it was revealed that on the average only about 10 percent and 15 percent of the respective watershed areas had the potential for contributing to stream sediment loads during the year. The size of these contributing areas or hydrologically active areas is determined by soil texture, slope, drainage characteristics, and land management. What is now lacking from a management perspective is a method for defining these areas in the field. Once those responsible for implementation can systematically identify these areas on the land, the application of remedial

measures will become more efficient and effective.

Important concerns also remain with respect to determining what proportion of the total suspended solids found in the headwaters of tributaries is actually transported to the lakes. Some of this material may be trapped by dams and other obstructions or the sediment associated nutrients may be used *in situ* by the biological community in the streams.

5.2.3 Remedial Measures

Agencies in both countries will need to redefine their pollution control programs to be more responsive to the management of nonpoint sources. Existing and planned urban stormwater conveyance systems, which have been designed to move runoff away from urban centres as quickly as possible, will need to be redesigned to make them more responsive to reducing urban stormwater pollution. In agricultural areas, many of the remedial measures tested and adopted over time as effective for reducing gross soil erosion have not been adequately evaluated to determine their suitability for reducing the delivery of fine grained sediments to the water course.

For example, in the Corps of Engineer's Lake Erie Wastewater Management Study,⁴⁶ estimates of nonpoint phosphorus loading reductions have only been based on the conclusions of two simulated rainfall plot studies and one field analysis. Similarly, the PLUARG estimates of reductions achievable are subject to a 50 percent margin of error.

Although the exact reductions which can be achieved by these programs under Great Lakes basin conditions are uncertain, significant reductions in agricultural related phosphorus loadings can be achieved. In many cases these reductions may be realized without the implementation of expensive and disruptive remedial measures.

Studies to evaluate the actual effectiveness of remedial measures under Great Lakes basin conditions must be conducted, before commitments to full scale implementation are made. However, considerable progress can be made immediately through the use of technical assistance, education, and pilot demonstration programs.

The remedial measures identified in Tables 5.3 and 5.4 are those which generally show some promise for reducing pollution from agricultural and urban nonpoint sources. It should be noted that when several of these measures are combined in a comprehensive land treatment system, the loading reduction achieved often exceed the sum of the parts. Although costs of remedial measure options are a key consideration, they vary markedly according to type of farming system or urban area, climate, and site physical characteristics, such as soil type, drainage, and slope.

Selected Measures - Agriculture

It has been demonstrated that sediment is the primary vehicle for moving phosphorus from agricultural lands. Therefore, the principal focus of remedial measures has been towards minimizing the disturbance of the soil surface and stabilizing a protective vegetative cover to reduce the potential for soil detachment. Changes to conservation tillage practices have received the most attention. (See Table 5.3).

Selected Measures - Urban

Measures for reducing pollution in urban stormwater have primarily been directed towards control at source, control in the collector system, and storage with treatment.

While implementation of measures to control the quantity of urban runoff are easily accomplished in developing urban areas, important questions remain with respect to how these measures can be effectively implemented in established urban areas.

TABLE 5.3 Remedial Measures For Agricultural Nonpoint Sources

<u>Conservation Tillage</u> - includes no till, disk plant, and chisel plow
No Till - with the exception of a narrow strip penetrated by a fluted coulter (5-8cm) there is no disturbance of the residue cover or the soil profile. Usually seeding, fertilizing and herbicide application are all carried out in one operation.
Reductions in soil loss of up to 90 percent over conventional tillage have been attributed to this technique with no sacrifice in crop yields on some soils and in some areas of the basin. Sediment phosphorus reductions have been reported to fall anywhere between 10-90 percent when evaluated on a watershed basis.
Disk Plant - may consist of one or two passes over the field followed by a planting operation. The system loosens the entire soil surface to a shallow depth (10cm), breaks up crop residue and mixes this with the top surface soil. Reductions in soil loss of between 70-90 percent have been reported on some soils.
Chisel Plow - results in the break up of soil to a depth of 20 cm, but does not result in a turn over of the soil surface layer. Consequently a large portion of crop residue is maintained on the surface. Chisel plowing is normally followed by at least one disking. Sediment loss reductions between 30 and 90 percent have been reported. ^{88,89}
<u>Vegetative Buffer Strips</u> - when maintained adjacent to water courses prove effective in reducing the rate of overland flow and trapping sediment in suspension. A 50 foot wide strip may remove up to 50 percent of sediment load. ⁷⁹ Level of utility is affected by their width, vigour, height of vegetation and slope. In addition to the costs for developing and maintaining these strips, the other long term operating cost is the loss of productive agricultural land.
<u>Contour Cultivation</u> - this technique requires that cultivation be done parallel to the natural contours of the land. Surface runoff which normally flows down the fall line is now diverted laterally, and more gently to the base. Average soil losses can be reduced by 50 percent on moderate slopes (3-7 percent). ⁹⁰
<u>Cross Slope Tillage</u> - as opposed to contour cultivation this approach only requires that cultivation proceed at right angles to direction of slope. Probably more easily adopted than contouring although sediment reductions may only be one half as much. ⁸⁹
<u>Strip Cropping</u> - by alternating strips of close grown crops (hay and grains) with row crops (corn) across the slope, the length of the slope is effectively broken. Increases the absorption of overland flow and reduces its velocity. This technique is also effective in reducing wind erosion. Strip cropping may reduce sediment yields up to 85 percent. It encourages crop rotating by farmers.
<u>Fertilizer Application</u> - poor timing and placement of fertilizer can increase the levels of soluble inorganic phosphorus leaving a watershed. Generally these levels are low, less than 9 percent, however, this form of phosphorus is the most readily available to algae. Incorporation of applied fertilizer into the soil profile at a time when crops can maximize their use of it, will assist in reducing the loss of fertilizer nutrients due to surface runoff.
<u>Subsurface (Tile) Drainage</u> - in many areas where soils are characterized as poorly drained, the construction of subsurface drains can reduce runoff and subsequent soil loss. On these soils, the installation of subsurface drains may also improve crop yields when following conservation tillage practices.
<u>Management of Livestock Manure</u> - although this source is of less importance when total loadings are examined (20 percent of the agricultural nonpoint phosphorus loading in the Great Lakes basin) considerable improvements can be made in existing operations. Factors such as location of feeding operations relative to water courses, the size and design of manure storage facilities, frequency of winter spreading, and distance of spreading from streams and open ditches are some of the many factors which ultimately affect the delivery of manure related phosphorus to streams.

TABLE 5.4 Remedial Measures For Urban Nonpoint Sources

Source Control

Measures for reducing pollution in urban stormwater have primarily been directed towards control at source, control in the collector system and storage with treatment. In most localities water quality problems identified with urban stormwater have only been associated with combined sanitary and storm systems. Stormwater alone has been considered to be of a relative low priority. Control at source may be accomplished using a variety of approaches which include:

Street Sweeping - the efficiency of street sweepers in reducing the total pollutant load is dependent on a number of factors including frequency of sweeping, condition of pavement, type of equipment used (vacuum or mechanical sweepers), frequency of rainfall and public attitudes. Reliable predictions of the effectiveness of these measures are generally not available, however, estimates indicate that removal levels for phosphorus may range from 4 to 44 percent for vacuum sweepers and 5 to 16 percent for brush sweepers depending on the frequency of operation.

Catchment Basin Cleaning - now performed only about once or twice a year. A more regular program combined with street sweeping may improve quality - 25-50 percent.

Urban Runoff Control

A reduction in the quantity and an increase in the runoff period of urban stormwater will also reduce the total loading of pollutants from urban areas. This can be accomplished either through a reduction in the total flow which might ultimately reach a sewer system and/or a redirection of flow overland thereby increasing the time available for natural infiltration before introduction to the artificial conveyance system. Measures available include:

- | | |
|----------------------|---------------------------|
| Roof Top Ponding | Detention/Retention Ponds |
| Temporary Check Dams | Infiltration Basins |
| Drainage Swales | Porous Pavements |

Stormwater Treatment

Measures are available to treat urban stormwater runoff. These options are generally very expensive and would probably only be cost effective where severe local water quality problems were being experienced and where more than one pollutant parameter was of concern. Measures available include:

- | | |
|---------------------------|---|
| Physical-Chemical Systems | Swirl Concentrators |
| Stationary Screens | Horizontal and/or Vertical Shaft Rotary Screens |
| Treatment Lagoons | Air Flotation |
| Trickling Filters | Contact Stabilization |

Urban Construction

The most important source of sediment in urban areas is derived from developing urban lands where yields may be 1000 times greater than on comparable agricultural land. There are a variety of proven measures available for dealing with this problem. What seems to be lacking in a Great Lakes context is the administrative will to implement them.

- | | |
|---------------------------|---|
| Sedimentation Ponds | Matting and Netting for Slope Stabilization |
| Organic Mulch | Temporary Mulch and Seed |
| Chemical Soil Stabilizers | Staged Land Clearing |
| Retaining Walls | Hydro Seeding |

5.2.4 Costs for Nonpoint Source Controls

The costs for agricultural nonpoint source controls to reduce phosphorus loadings range from almost no cost⁴⁶ to a range of from \$15 to \$58 annually per watershed hectare.⁸⁴ The types of measures which should be implemented are very site-specific and very little data, are available to determine their cost-effectiveness over the long term. As discussed previously, this is a major information need identified by the task force. Demonstration projects need to be carried out.

5.2.5 Summary

Agricultural and urban land use activities have been identified as the most important nonpoint sources of phosphorus. Unlike the inputs from point sources, nonpoint loadings are characterized by considerable temporal and spatial variability. Major changes in annual loading rates result from natural fluctuations in the hydrologic cycle and considerable variation within a single year can be attributed to the importance of the spring runoff period.

Viewed from a spatial perspective, there are major differences in the relative importance of nonpoint sources to the total nutrient budget of individual lakes. Within individual lake drainage basins there are areas which contribute a disproportionate share of the total nonpoint source load.

These inherent characteristics of nonpoint sources will have to be considered in the design of an effective management program. Nonpoint source management plans are also hampered by a lack of knowledge about the effectiveness of remedial measures in reducing loadings and the importance of the question of relative biological availability of phosphorus from point and nonpoint sources.

Given the complexity of the nonpoint problem, the following represent some of the important considerations which must be taken into account in the design of a nonpoint management program:

- (1) Those areas which account for the delivery of the greatest proportion of nutrients must be systematically identified, in order to make the application of remedial measures more efficient and effective.
- (2) Remedial measures must be effective in reducing the delivery of the fine-grained soil particles, especially during the critical late-winter early-spring runoff period.
- (3) Implementation of remedial measures must proceed on a priority area basis treating those areas where the largest and most rapid reductions can be achieved at least cost.

5.3 OTHER CONSIDERATIONS

The implementation of measures to reduce the phosphorus inputs to the Great Lakes has several ancillary benefits and detriments which, although not quantifiable at this time, can be described qualitatively.

Chemical addition for phosphorus removal at existing primary and secondary municipal wastewater treatment plants will reduce the suspended solids and BOD and is likely to reduce the amounts of toxic organic substances and heavy metals in their effluents. The nutrient content of sludges produced at these plants will be increased. However, the amounts of sludge to be treated and disposed of will also increase significantly. In addition, the possible increased content of heavy metals and toxic organic substances in these sludges may require a restriction in application rates for land disposal and limit other disposal options. Including requirements for phosphorus removal at municipal wastewater treatment plants introduces more complex technology which requires higher operator skills.

Because of the biochemical, physical, and chemical removal mechanisms associated with soil systems, many constituents are removed by land treatment. Removal of toxic and hazardous constituents is a relatively new pollution control interest, and there are few data to define the

removals that occur at land treatment sites. However, the limited available data indicate that land treatment systems can reduce contaminants such as pesticides, herbicides, cadmium, zinc, and 2,4-D concentrations in the applied wastewater to essentially background groundwater concentrations.

In addition to the phosphorus and other contaminants removal benefits, land treatment has further environmental benefits such as: reduced sludge production for treatment and ultimate disposal, and recycle of nutrients and organics to the soil-crop system. Potential disadvantages, which include the possible accumulation of contaminants such as heavy metal, toxic organic compounds, and pathogenic organisms in soil systems, must also be recognized. The magnitude of this remains to be quantified.

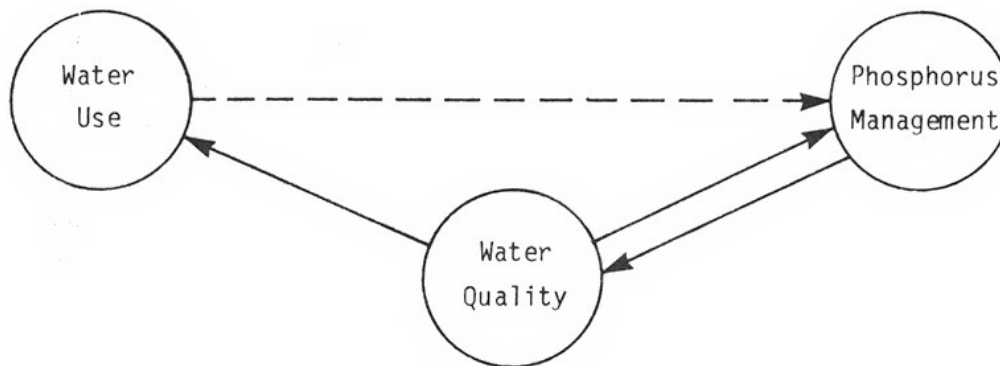
6.0 STRATEGIES FOR ASSESSING THE SOCIAL AND ECONOMIC IMPACTS

In the preceding chapters of this report the task force has identified both a range of phosphorus target loadings for the lakes and the remedial measure options which can be implemented to achieve further phosphorus loading reductions.

In considering the strategies to be used, consideration must be given to the system linking phosphorus management, water quality, and water use as shown in Figure 6.1. It is clear from our examination that the linkages between phosphorus management and resulting water quality remain uncertain.

To the extent possible, this task force has attempted to quantify the range of variability that exists thus reducing this level of uncertainty. Additional effort will be required to further refine these estimates.

FIGURE 6.1 Phosphorus Management Linkages



In the context of phosphorus management the task force has also identified an important gap in our understanding of the linkage which exists between Great Lakes water quality and the use of this resource. To date, only minimal attention has been directed towards developing an understanding in this important area.

The task force has not had sufficient time nor resources to provide an assessment of the consequences that changes in water quality hold for the use of the water resource. Therefore, it

is of critical importance that governments not only continue their present commitments to improve the knowledge of the linkages between phosphorus management and resultant water quality but also to undertake new programs directed towards assessing the implications which changes in water quality hold for users of this resource.

Given this situation the task force in this section proposes a conceptual framework outlining the commitments required over the long term to properly assess the social and economic consequences of managing the Great Lakes. Once this knowledge is established governments will have a more reasonable basis for developing policy and for determining whether the consequences, including both positive and negative impacts, warrant the commitment of additional expenditures for phosphorus removal.

6.1 BACKGROUND

The determination of desired water quality objectives in the lakes has largely been the purview of limnologists. Thus, these objectives--the desirability of restoring year round aerobic conditions in the bottom waters of the Central Basin of Lake Erie and reducing nuisance growths of algae, weeds, and slimes that are or may become injurious to any beneficial water use--have been expressed without full consideration of balancing their benefits and costs. Moreover, past decisions to spend billions of dollars to reduce phosphorus inputs have been taken without the benefit of quantification of the impacts or consequences these actions hold for society in general and in particular, the users of the resource (such as commercial fishermen, tourists, and those depending on the lakes for a potable water supply).

However, today, most of us are aware of the scarcity of resources available to apply to the solution of water quality problems.

Part of the reason for the existence of this situation was the extent of public attention commanded by environmental issues in the early seventies. This focus of interest encouraged political initiatives to deal with situations which had purportedly reached crisis proportions.⁹¹

Today, although environmental problems are still of concern to society,^{92,93,94} economic issues have become preeminent. Without a clear articulation of the benefits and costs of further programs aimed at management of the Great Lakes, little support will be forthcoming.

In the United States a report by the Comptroller General⁹⁵ reviewing water quality management planning concluded that, to "accomplish the legislative goals of clean water requires the development of sound water quality management plans. The plans should consider the general public's perception of significant water quality problems and understanding of what the water quality management effort is trying to accomplish".

Since the signing of the first Great Lakes Water Quality Agreement in 1972, there have been a number of isolated and relatively unrelated attempts to determine the public's goals for the Great Lakes and their assessment of the need for and the direction of further programs.^{92,96,97}

Unfortunately, these efforts have fallen short of providing politicians and managers alike with a clear enunciation of the expected social and economic consequences of taking further action to manage the Lakes.

6.2 BASIS FOR THE FRAMEWORK

The conceptual framework presented in this chapter describes an approach for taking action in the face of these economic and social uncertainties while, at the same time, generating the necessary information to resolve these uncertainties.

The framework recognizes that there are four pieces of information needed before intelligent policy decisions can be made. These are:

1. A knowledge of the "state-of-the-world", not only as it is but as it would be as a result of any policy changes.
2. A clear idea of the desired objectives of the policy.

3. An understanding of the status of existing policy that may conflict with or support policy objectives.
4. An understanding of the likely social cost of making a mistake--that is, choosing the wrong policy.

Certainly the tools of limnology, hydrology, etc. are crucial to the first piece of information. It is questionable, however, whether these scientific disciplines or any other discipline such as economics and political science can, by itself, shed much light on the other three pieces. Unfortunately, there has been a tendency to ask the physical scientist to do too much. The scientist has been asked, for example, to specify "target loads" as if these targets have a totally "scientific" basis. He or she may be able to relate the likely physical conditions of the lakes to loadings, but there is no purely scientific way of determining what physical conditions would be in the best interests of society.

On the other hand, the political scientist can assist in providing information on the second and third piece of information and the economist, knowledgeable in the tools of cost-benefit analysis, can help with the fourth. However, conducting political, economic, cost-benefit, and policy analyses are impossible without the technical information provided by the physical and biological scientists. Yet this information, while necessary, is not sufficient. Item four, especially, requires information on social and political preferences that cannot be generated solely by analytical methods.

In short, a policy framework that recognizes the four elements of intelligent policy decision needs a balanced mix of information from the physical scientist, the social scientist, and the general public.

6.3 CURRENT STATUS OF POLICY-RELEVANT INFORMATION

The following is a brief summary of what is known regarding the four pieces of information relevant to the issue of phosphorus management in the Great Lakes.

1. Knowledge of the State-of-the-World

Since most of this report covers this first area, a summary will not be presented. It is probably safe to conclude that while much is known about the physical relationship between phosphorus loading and the quality of the Lakes, the knowledge is not sufficiently precise to justify strategies requiring attainment of precisely defined targets.

2. Clear Idea of Objectives

While the current quality objectives appear unambiguous, improvement may still be needed. For example, while there is a desire to reduce "nuisance" growths of algae, "nuisance" has not been precisely defined. Fairly high concentrations of algae may not be perceived as a nuisance to fishermen if the nutrients serve to increase certain fish yields. Similarly, the goal of maintaining "aerobic" bottom conditions may have to be replaced with a more specific dissolved oxygen goal. Attaining aerobic conditions, with very low dissolved oxygen, may not be considered worth the trouble if certain fish species cannot be supported.

3. Understanding of Status of Current Policy

The issue here is not what is or is not mandated by current treaties and laws, but rather by the status of implementation of these treaties and laws. Knowledge of what treatment technology is in place as the result of these laws is poor, especially in the United States. Even less is known about the implications for phosphorus loadings that will result from the soon to be revised Best Available Technology and industrial pretreatment regulations. Although these new regulations are primarily targeted towards toxic chemicals, the recommended technologies may have profound effects on both industrial and municipal phosphorus discharges.

It is difficult to determine the extent to which implementation of the existing U.S. legislation, for example the 1977 Clean Water Act, the Resource Conservation and Recovery Act, and the past legislation embodied in the 1972 Water Pollution Control Act Amendments, will

contribute to attainment of the currently stated phosphorus target loads. New policy incentives may or may not be required.

4. Social Cost of Policy Error

To ascertain the likely social costs of making a policy error requires an analysis of the costs, benefits, distributional implications, and implementation possibilities of various policy alternatives--including the alternative of doing nothing. Current knowledge of these areas seems rather weak. While the unit costs of certain municipal and agricultural phosphorus treatment technologies have been estimated (see Chapter 5), total incremental policy costs, which account for the current status of in-place treatment technology, have not been estimated. There appear to have been no efforts to provide quantitative estimates of benefits or of cost and benefit distributions among individuals, households, or geographical regions. Analyses of implementation strategies appear nonexistent.

As a result, while agricultural strategies appear to be least-cost approaches to currently stated targets, it is unclear whether such strategies can be realistically implemented. In addition, the equity of placing the burden on agricultural populations rather than on more urban populations has not been assessed.

It does appear that, at current phosphorus loading levels, the eutrophication of the Great Lakes has stabilized and the process may even be reversible. This situation is fortunate for it permits the cautious approach embodied in the conceptual framework. If necessary, more radical policies can be applied at a later date without the delay leading to serious consequences.

6.4 SPECIFIC STRATEGIES

The above conceptual framework and the current state of knowledge suggest the following three specific actions:

1. Urge the implementation of current laws and treaty agreements and reassess the situation after a period of one year.
2. Assemble data, when available, from existing sources, or develop new data covering the following benefit categories:

Municipal Water Supplies (Potable Water)

The Great Lakes serve as an important source of drinking water for the majority of basin residents (35 million people). To what extent have water quality conditions related to phosphorus additions resulted in increasing costs both capital and operating at water treatment plants? From the consumer's perspective can periodic taste and odor problems be linked to phosphorus related water quality conditions? Do public perceptions of differences in the trophic character of individual lakes result in the adoption of more costly water supply options, e.g. London and Kitchener/Waterloo?

Industrial Water Supply (Direct Users)

Many industries in the Great Lakes basin utilize technologies which require large quantities of water for both consumptive and nonconsumptive uses. Do industrial users of Great Lakes water realize economic penalties due to differences in the trophic condition of water supplies? Does water quality act as an important locational factor? Do industries which have nonconsumptive uses of water, e.g. cooling water face additional costs for pretreatment in some areas as opposed to others?

Hydro Electric Power Generation

In an increasingly energy power world, conversion of Great Lakes water power to electricity, about 50 billion kilowatt-hours each year, makes an important contribution to the region's energy budget. Have additional costs been incurred either by alterations to standard plant design or through changes in operational procedures to accommodate changing water quality conditions resulting from increasing phosphorus loadings?

Property Values

Decaying aquatic vegetation washed up on Great Lakes shorelines has often been identified as one of the most obvious liabilities associated with eutrophic waters. Has the occurrence of this phenomenon affected shoreline property values? Have areas which have not experienced similar problems exhibited parallel or divergent pricing trends? To what extent are the locational preferences of buyers affected by real or perceived notions of water quality?

Tourism & Recreation

Ontario earnings from tourism and recreation account for \$9.34 billion or 11 percent of the Gross National Product. Have patterns and intensity of tourism and recreation activity been affected by the changing trophic character of the Great Lakes?

Swimming

Swimming is one of the most popular recreation activities based on an analysis of user day participation levels. Are those involved in direct water contact recreation activities affected in their pursuit of these activities by changes in trophic conditions? What are the costs of keeping beaches clean of decaying aquatic vegetation? Have there been changes in the focus of marina operations to areas with higher quality water?

Sport Fishing

The expression coarse and undesirable is often used to describe the fish species normally found in eutrophic waters. To what extent has the change from so called high quality stocks to the coarser varieties affected the sport fishery? Is the quantity of catch as important or more important than the quality?

Recent stocking of anadromous fish has resulted in a new focus for the sport fishery. Do trophic conditions affect the survival of these fish?

Aesthetics

Shoreline vistas and sparkling waters are credited with holding important intrinsic

values for visitors to the lakes. To what extent do eutrophic conditions detract from these values? Have there been measurable differences in the number of visitors to shoreline recreation sites in areas subjected to eutrophic conditions as opposed to those which have not? Is the recent upsurge in development of new shoreline recreation facilities linked with changing trophic conditions?

Waterfowl Habitat

Important populations of waterfowl inhabit Great Lakes coastal regions. They also serve as an important flyway for migrating waterfowl. What are the effects of eutrophication on waterfowl habitat and migration patterns? What is the effect on waterfowl hunting and its supporting infrastructure?

Commercial Fishing

Over the last 50 years there has been a marked change in the composition of the commercial fish catch, (from lake trout and blue pickerel to perch). Has the Great Lakes commercial fishery been damaged by changing trophic conditions? Is it possible to isolate the impact of trophic conditions from other problems which affect the fishery, such as the introduction of toxic contaminants and overfishing?

3. Establish a variety of mechanisms to obtain information on social benefits and costs associated with changing trophic conditions in the Great Lakes. A number of these mechanisms are presented below:
 - a) Establish an Advisory Committee comprised of members of the public to provide an input to detailed program design at the earliest stage.

Since many of the parameters being examined in the study directly involve the measurement of public values through one way and two way communication, it will be a definite advantage to involve the public in providing study direction. This is important for two reasons: first, it avoids possible criticism that public values were not fairly or adequately assessed and second, innovative and constructive insights can often be offered by those not

burdened with preconceptions and doctrinaire lines of reasoning. Establish clearly defined objectives for this committee within the overall study framework and provide sufficient fiscal resources.

- b) Institute a coordination mechanism between Canada and the United States to ensure development of a comprehensive study design.

The Great Lakes represent a major shared resource between Canada and the United States. Solutions to whole lake problems must be considered in a comprehensive fashion by both countries; therefore, impacts must be assessed from a comparable data base. This will avoid later problems when efforts are made to assess the relative consequences for each country of different phosphorus management strategies.

- c) Develop a social profile of the Great Lakes basin to identify:
 - the various publics to be involved;
 - the level of knowledge and beliefs about the subject matter;
 - the leadership and organizations; and
 - the media coverage and effectiveness.

Completion of this first step will help to avoid later problems of having overlooked segments of the population who have a useful contribution to make. The information gathered will also facilitate communication with the various publics identified.

- d) Undertake a program of public information involving:
 - development of fact sheets on remedial measure options and water quality impacts;
 - media presentations;
 - public meetings; and
 - audio visual information.

The conduct of an information program will ensure that those publics involved are

informed about the issues and thus able to make a more constructive input. Public meetings can serve the dual purpose of identifying individuals who are interested in participating in a more intensive program of public consultation as well as facilitating the collection of concerns from a wider audience.

- e) Assess the attitudes and perceptions of Great Lakes residents through social surveys and informant interviewing.

Through the uses of some of these techniques, those who are unable/or unwilling to become involved in a more public discussion of issues will have an opportunity to contribute.

Information collected in surveys will contribute to the process of understanding broad based public attitudes and perceptions. Sound water planning and management must consider how people perceive the lakes and what aspects of this resource they are concerned about. Users and nonusers alike must be considered.

- f) Provide for more in depth involvement of the public.
 - establish a public consultation program on a regional basis with representation from elected officials (all three levels of government), industrial interests affected by changing water quality, other interest groups, e.g. anglers clubs, cottager associations, educators, commercial fisherman...
 - use "nominal group", and other public participation techniques as means of determining the benefits from identified management approaches.
 - provide objectives, time frame, and ensure technical support where required.

Use of this approach provides an opportunity for an intensive interaction with those most actively involved in activities which may be affected by changes in water quality. Through the use of techniques such as the nominal group, there is a real opportunity to

determine overall public perceptions and to describe regional variations.

- g) Survey the status of in-place treatment technology for municipal, industrial, and agricultural facilities.

Information of this sort is essential for ascertaining the true incremental costs of alternative strategies.

- h) Undertake one or two case studies.

Probably one of the more manageable ways of assessing the social and economic implications of eutrophication will be to begin with a study covering a more restricted area than that of the entire Great Lakes basin. Along both of the Canadian and American shorelines there are a number of embayments which would be suitable. These embayments are already eutrophic due to high nutrient loadings and restricted circulation with whole lake waters.

A study of the social and economic issues of concern to residents and visitors alike could be readily compared to those found in areas immediately adjacent which are not located on eutrophic waters. In Canada, the Bay of Quinte, and to a lesser extent Burlington Bay in Lake Ontario are areas where problems associated with eutrophic conditions already exist. In the United States, Saginaw Bay in Lake Huron and Green Bay in Lake Michigan provide parallel opportunities.

It is believed that these steps will provide a sensible approach given the present state of information and the needs for future information. In addition, this approach will provide a more balanced response to the four basic information needs identified in the conceptual framework.

In the preceding chapters, the task force has provided a discussion of phosphorus target loads, phosphorus inputs, models used to develop targets, and techniques and costs of phosphorus control. On the basis of this information, the task force is proposing a staged approach to further phosphorus management for the Great Lakes. In addition, the task force has concluded that, in order to establish policy that will be effective over the long term, it will be necessary to carry out a program to obtain information that can be used to properly assess the social and economic consequences of managing phosphorus inputs to the Great Lakes.

Chapter 6, entitled "Strategies for Assessing the Social and Economic Impacts of Great Lakes Phosphorus Management", provides a conceptual framework outlining the commitments required to initiate a program which should be undertaken immediately to provide the knowledge base needed to develop and implement policy in parallel with the staged approach to phosphorus management given in the following discussion.

7.1. BASIC PREMISES

The phosphorus management strategy and recommendations that follow, are based on the evaluations and observations made by various members and subcommittees of the task force. These evaluations and observations have provided the framework within which the following basic premises have been identified.

- The findings of the task force with respect to present phosphorus loads to each of the Great Lakes, eutrophication control objective and target loads, and estimated further reduction in phosphorus loads which may be required to meet the target loads, are summarized in Table 7.1.
- The tentative total phosphorus target loads proposed in the 1978 Great Lakes Water Quality Agreement represent the best scientific opinion as to reasonable goals for achieving water quality objectives and provide the basis for developing a phosphorus management strategy for the Great Lakes.

TABLE 7.1 Phosphorus Control Program For The Great Lakes

Lake	1976 Total Phosphorus Input Load (t/yr)	Eutrophication Control Objectives		Estimated Total Phosphorus Loading After Full Implementation of Present Programs* (t/yr)	Additional Reductions In Total Phosphorus Loadings Which May Be Required (t/yr)	
		Objectives	Total Phosphorus Target Load (t/yr)		Best Estimate	Range
Superior	4200	Nondegradation	3400	3400	-	-
Michigan	6400	Nondegradation	5600	5600	-	-
Huron	4900	Nondegradation	4400	4400	-	-
Erie	18400	Improved quality	11000	14700	3700	0 to 9,400
Ontario	11800	Improved quality	7000	9600	2600	200 to 5,400

* Present programs include restrictions on the phosphorus content of detergents and a requirement that all point source discharges of greater than 3,800 cu m/d (1 MGD) contain not more than 1.0 mg/L of total phosphorus.

t/yr - metric tons per year

A measure of uncertainty has been identified with respect to both the target loads and the estimates of the input loads.

Based primarily on an assessment of the models used to develop the target loads, the task force estimates that the target loads for Lake Erie and Lake Ontario have a range of plus or minus 30 percent and 20 percent, respectively.

After reviewing the data and assumptions used in developing present estimates of total phosphorus inputs to the lakes during 1976, the task force considers these estimates to be within plus or minus 15 percent of the actual load for the sources included.

It is recognized that tributary phosphorus inputs are also characterized by significant annual variations due to weather and hydrology. This annual variation can be as large as the reductions expected from implementation of major control programs in the tributary watersheds.

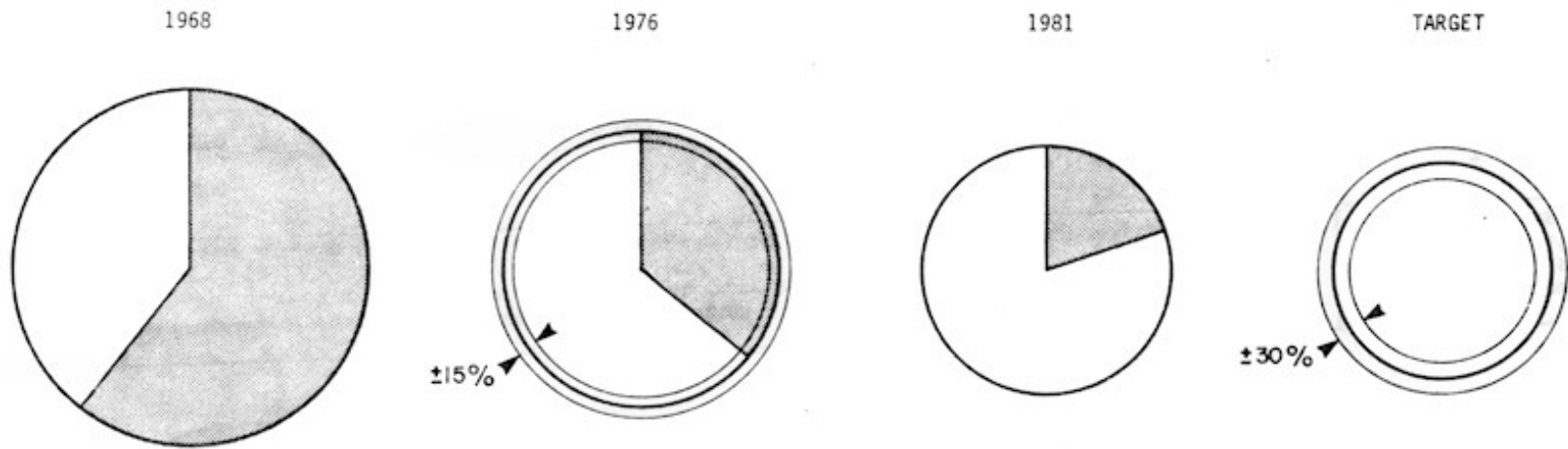
The task force recognizes the fact that only further study of the factors leading to these uncertainties will allow a tightening of these ranges. This conclusion gives direction to further work. But more importantly, the load ranges give direction for strategy development.

- Lakes Erie and Ontario have undergone major changes in water quality and biota associated with eutrophication. The task force believes that it is highly probable that programs and remedial measures in addition to those specified in the 1972 Great Lakes Water Quality Agreement will be required to reduce phosphorus inputs. The best estimate of the additional load reduction which may be required in order to meet the target load of 11,000 t/yr for Lake Erie is 3,700 t/yr and to meet the target of 7,000 t/yr for Lake Ontario a reduction of 2,600 t/yr may be required.

The estimates of past, present, and future input phosphorus loads and their relationship to the target loads proposed by Task Group III, are illustrated in Figure 7.1 for Lake Erie and in Figure 7.2 for Lake Ontario. The degree of uncertainty in both the inputs and target loads determined by the task force are also shown in Figures 7.1 and 7.2. Recognizing the uncertainty in both the targets and the input loads, future load reductions which may be required for Lake Erie vary from zero to 9,400 t/yr and for Lake Ontario from 200 to 5,400 t/yr.

- The open waters of Lakes Superior, Michigan, and Huron are considered to be oligotrophic and control of anthropogenic inputs of phosphorus to these lakes, as recommended in the 1978 Great Lakes Water Quality Agreement, is based on a concept of nondegradation or maintenance of the present high quality waters in these lakes. The target loads shown in Table 7.1 should be met with full implementation of the recommended control programs. However, specific portions of the upper lakes, such as Saginaw Bay, Green Bay and portions of Georgian Bay, are presently degraded and additional reductions in phosphorus inputs to these areas may be required.
- The present phosphorus and chlorophyll objectives, developed by the Science Advisory Board's Committee on the Scientific Basis for Water Quality Criteria and used by Task Group III as the basis for establishing the target loads, represent the best scientific opinion of experts. However, these objectives should be properly viewed as guidelines and may change as our understanding and knowledge increases.
- The final specification of phosphorus and chlorophyll objectives can not be fully ascertained without a better understanding of the social benefits to be derived from a reduction in eutrophication.

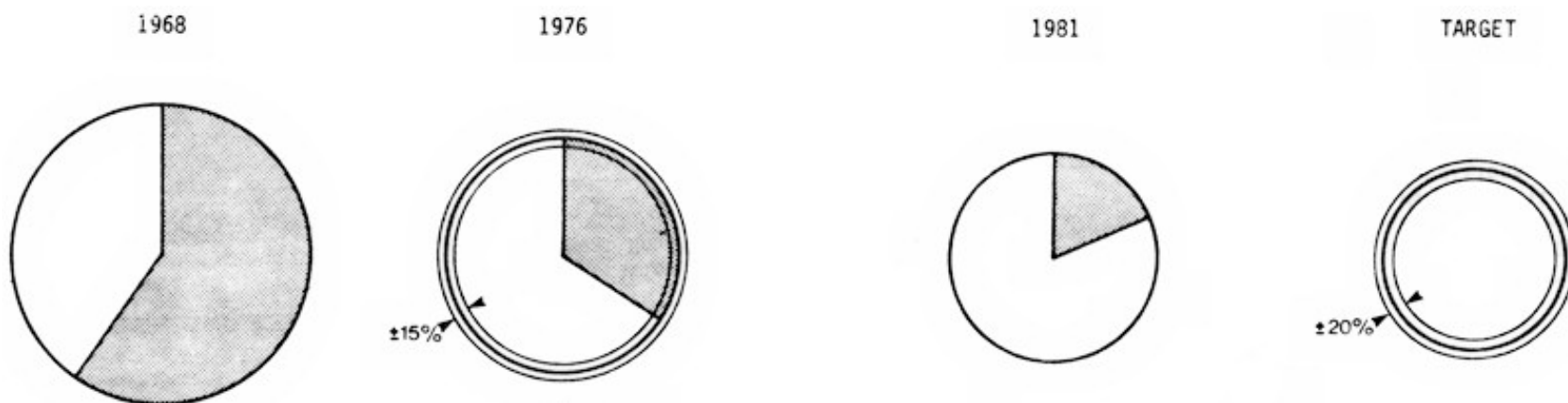
FIGURE 7.1 Estimated Total Phosphorus To Lake Erie



PHOSPHORUS CONTROL PROGRAMS STATUS	No Programs	Partial Implementation of 1972 Agreement Programs	Full Implementation of 1972 Agreement Programs	Target Load To Achieve Desired Water Quality Conditions
TOTAL LOAD (t/yr)	30,000	18,400	14,700	11,000
MUNICIPAL LOAD (t/yr)	18,200	6,600	2,900	

Note: Area of circles is proportional to total phosphorus load and hatched area is proportional to municipal point source load.

FIGURE 7.2 Estimated Total Phosphorus To Lake Ontario



PHOSPHORUS CONTROL PROGRAMS STATUS	No Programs	Partial Implementation of 1972 Agreement Programs	Full Implementation of 1972 Agreement Programs	Target Load To Achieve Desired Water Quality Conditions
TOTAL LOAD (t/yr)	19,400	11,800	9,600	7,000
MUNICIPAL LOAD (t/yr)	11,600	4,000	11,800	

Note: Area of circles is proportional to total phosphorus load and hatched area is proportional to municipal point source load.

- Control of eutrophication of the Great Lakes has been of major concern because of the deleterious changes in quality and biota. Nevertheless, it is important to recognize that other stresses, e.g. introduction of exotic species, overfishing, and toxic substances may have contributed to these changes. The relative importance of these stresses has not been determined, but it is possible that a strategy which addresses the eutrophication issue can contribute to resolving the toxic substances problem.
- The models, which were used to calculate the target loads, have been structured to analyze conditions in the pelagic zone of a lake or the lake as a whole, but do not specifically address the littoral zone. This area, to which the public is more sensitive and of which they are more aware, may respond in a different manner.
- Given the present state of knowledge, phosphorus management strategies must be based on control of total phosphorus. However, the question of biologically available versus the nonavailable phosphorus is an important concern and programs must be developed to permit formulating management strategies based on control of bioavailable forms of phosphorus.
- Chemical precipitation technology for phosphorus removal to 1.0 mg/L is being practised at many municipal wastewater treatment plants in the Great Lakes basin. As well, proven technologies exist which can reduce the total phosphorus concentration of municipal waste waters to 0.3 mg/L and less. The cost of phosphorus removal for achieving these levels varies considerably. This is attributed to situations which allow for add-on processes to existing plants on one hand in contrast to situations which require the design of a new plant.

7.2 STAGED APPROACH

In view of the above premises, the task force concludes that it is highly probable that programs in addition to those specified in the 1972 Agreement will be required to further reduce

both point and nonpoint source phosphorus inputs to the Great Lakes. However, given the nature of the variations and the degree of the uncertainties identified in these premises, the task force proposes that a phosphorus management strategy be developed as a continuing process encompassing a staged approach which includes implementation programs, study programs, evaluation of studies, and decision making.

A staged approach will permit the phosphorus management strategy to minimize the effect of these variations and uncertainties and be sufficiently flexible to incorporate modifications as the management strategy is implemented.

The approach accepts the target loads as guidelines for planning purposes. Target loads and control programs can be refined and developed in a sequential, interdependent, and evolving fashion, i.e. implement, measure and evaluate, and plan. Analysis of the benefits gained and the knowledge derived as the strategy is implemented will provide the basis for making interim decisions.

The task force's recommendations for the proposed strategy are presented in terms of: management of point sources, management of nonpoint sources, and major informational needs to more precisely define an appropriate strategy.

7.3 MANAGEMENT OF POINT SOURCES

A major component of any strategy for phosphorus management is a program to control municipal wastewater point source inputs. Recommendations for implementing such a program are presented below:

RECOMMENDATION NO. 1

All municipal wastewater treatment plants discharging in excess of 3,800 cu m/d (1 MGD) in the Great Lakes basin should be designed and operated so that the total phosphorus concentrations in their effluents will not exceed a maximum of 1.0 mg/L. This objective should be pursued and accomplished as quickly as possible.

Full implementation of this program will achieve the target loads for the Upper Great Lakes and reduce the 1976 estimated total phosphorus loads to Lakes Erie from 18,400 t/yr to 14,700 t/yr and for Lake Ontario from 11,800 t/yr to 9,600 t/yr. Population increases will result in somewhat higher loads even with provision of adequate wastewater treatment.

In the lower Great Lakes basin, adequate wastewater treatment facilities generally exist, or are under construction. However, there is still a great deal of noncompliance with the phosphorus objective. This can largely be attributed to the inadequate operation and maintenance of existing facilities. Programs of financial and technical support to municipalities may be required to ensure full achievement of the 1.0 mg/L total phosphorus control objective.

The fundamental problem faced in the development of the strategy was to gain insights into the extent, urgency, and timing of remedial measures. The fact is that both Lakes Erie and Ontario do not presently meet the Agreement water quality objectives. The partial implementation of the program of phosphorus removal at municipal sewage treatment plants has led to an apparent improvement in water quality and further improvement is expected with full implementation of the program. The task force therefore urges the governments, as a matter of high priority, to fully implement phosphorus removal to 1.0 mg/L at all municipal sources with flows greater than 3,800 cu m/d (1 MGD).

The next problem is to define what additional controls should be implemented, in what time frame, recognizing the fact that the extremes of the ranges for the estimates of the target and input loads for Lake Erie overlap (Figure 7.1) and nearly overlap for Lake Ontario (Figure 7.2). Should governments await the results of the presently agreed to phosphorus control program, recognizing that phosphorus sources will continue to increase as populations expand, or implement additional measures leading to further phosphorus control?

After full achievement of the present programs, the best estimate of the expected total phosphorus load to Lake Erie, is 14,700 t/yr. The present estimate of the target load required to achieve the water quality objectives is 11,000 t/yr. This leaves a difference of 3,700 t/yr to be

removed by additional phosphorus control programs. PLUARG³ and LEWIS⁴⁶ estimate that nonpoint source controls in the Lake Erie basin could remove from 1,800 to 5,000 t/yr. In the absence of definitive cost performance relationships for nonpoint source controls the task force judges that 2,000 t/yr could be removed at costs which are economically competitive with additional point source controls. Therefore, additional point source controls may be needed to remove the remaining 1,700 t/yr (3,700 t/yr - 2,000 t/yr). This would mean that municipal treatment facilities larger than 3,800 cu m/d would need to reduce their effluent phosphorus concentrations to about 0.3 mg/L.

The best estimate of the expected load to Lake Ontario, after full implementation of present programs, is 9,600 t/yr. The present estimate for the target load is 7,000 t/yr. This leaves an estimated 2,600 t/yr which may have to be removed to meet water quality objectives. PLUARG estimates the limited nonpoint source control opportunities in the Lake Ontario basin to be 200 t/yr. PLUARG also estimates that the load to Lake Ontario will be reduced by 1,200 t/yr when the target load of 11,000 t/yr for Lake Erie is achieved. This leaves 1,200 t/yr which may have to be controlled by additional treatment of municipal point sources indicating an effluent phosphorus requirement of about 0.3 mg/L.

Elimination of all municipal point discharges would reduce the phosphorus loads to Lake Erie by 2,800 t/yr and to Lake Ontario by 1,800 t/yr. These reductions alone are not sufficient to meet projected target loads.

The above facts clearly indicate that a combination of point and nonpoint source controls will be required in both the Lake Erie and Lake Ontario basins in order to meet the projected target loads. All approaches which can reduce the phosphorus loads to the Great Lakes should be considered for each sub-basin and each locality. There undoubtedly will be different sets of cost-effective approaches that are desirable in different parts of the Great Lakes basin.

Given a requirement for further removal of phosphorus from point sources, a program is recommended which includes evaluation and study, additional treatment at existing municipal wastewater treatment facilities, and consideration of new and innovative technologies including land

application. This program is summarized in Figure 7.3 and detailed in the six following recommendations:

RECOMMENDATION NO. 2

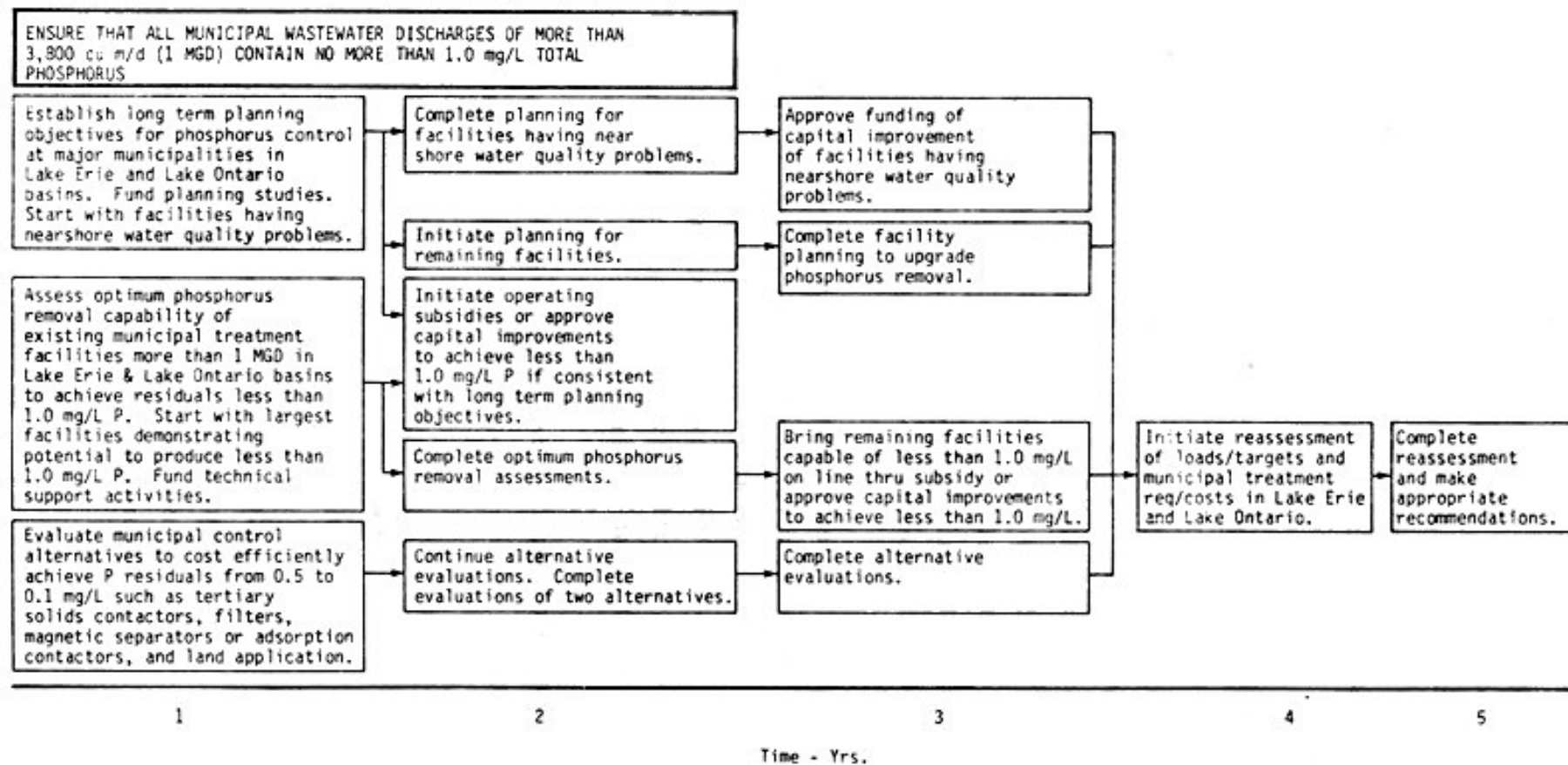
Governments should immediately evaluate the ability of municipal wastewater treatment facilities in the lower Great Lakes basin, currently required to meet an effluent limit of 1.0 mg/L total phosphorus, to be operated so as to produce effluent concentrations below 1.0 mg/L. Those plants identified which can achieve levels less than 1.0 mg/L should be operated to achieve these levels as soon as possible.

Effluent phosphorus concentrations less than 1.0 mg/L could be achieved at many existing plants by optimization of such operations as chemical dosing, pH control, and flow control. The major goals of the proposed study are: a) identification of existing facilities where improvement is possible, b) identification of means of funding and other issues of implementation, and c) operation of the facilities at the lower levels.

Two alternatives are suggested to provide municipalities with an economic incentive to defray the increased operating costs that this recommendation could involve:

- (1) Approve construction of new facilities to achieve the established optimum phosphorus removal for the type of treatment proposed at the same time ensuring that the new facilities are consistent with long term planning objectives to achieve phosphorus levels of 0.3 mg/L or less. This is basically capitalization of the increased operating costs.

FIGURE 7.3 Recommended Municipal Point Source Control Program



- (2) Senior levels of government could provide municipalities in the lower Great Lakes basin with an operating subsidy for every kilogram of phosphorus removed below the 1.0 mg/L requirement during the next five years. A similar subsidy could also be used to provide the same incentive to the nonpoint source control program implementors. This would encourage further reductions in phosphorus inputs at costs equivalent to the costs of current programs.

RECOMMENDATION NO. 3

It is recommended that all planning for future municipal point source discharges in the lower Great Lakes basin should, for planning purposes, consider future requirements for total phosphorus removal to concentrations on the order of 0.1 to 0.5 mg/L.

Future discharge objectives from municipal facilities should be developed employing mass loading allocations. Mass loading allocations are recommended to encourage the consideration of a variety of managerial and other structural approaches to reduce phosphorus inputs. These approaches may include:

- *industrial pre-treatment requirements for phosphorus*
- *detergent phosphorus controls*
- *effluent fees*
- *user fees dependent on phosphorus inputs*
- *other treatment options such as land application*
- *combinations of the above*

The planning should include detailed consideration of costs, effectiveness, and possible implementation difficulties.

Facility plans to meet the long term objectives should be prepared. Capital improvements which are inconsistent with these plans should not be approved. These plans should consider the decentralizing of new capacity investments to preclude land area restrictions for contemplated tertiary facilities at existing sites as well as provide opportunities to use land treatment for new capacity wherever possible and cost-effective.

As soon as practical, within the next 5 years, upgrade municipal control facilities in the Lake Erie and Lake Ontario basins larger than 3,800 cu m/d (1 MGD) which are capable of achieving total phosphorus effluent concentrations of less than 1.0 mg/L where justified on the basis of nearshore or receiving stream water quality considerations.

RECOMMENDATION NO. 4

It is recommended that existing laws and regulations to control the phosphorus content of detergents in the Great Lakes basin be retained and that controls be extended immediately to include Pennsylvania and, in particular, Ohio. It is further recommended that an independent study of direct and indirect costs, benefits and disbenefits associated with detergent phosphorus controls be carried out.

Phosphorus detergent controls were initiated in the early to mid 1970's as a method of removing phosphorus from wastewater while municipal wastewater phosphorus treatment facilities were built.

The earliest controls were effective in reducing wastewater phosphorus concentrations. Decreases of 50 percent and more were achieved. Voluntary reductions by the detergent industry in areas where legislated controls have not been imposed, have reduced the proportion of detergent phosphorus present in municipal wastewater to 20 to 35 percent.

Immediate reduction in phosphorus loads to the Great Lakes may still be realized with an extension of detergent controls to jurisdictions which have no such controls and whose waste

treatment programs are not in compliance. In particular, controls in Ohio at the 2.2 or 0.5 percent as phosphorus have the potential for reducing municipal phosphorus discharges by 170 and 730 t/yr respectively. Similar reductions for Pennsylvania would range from 30 to 50 t/yr. The impact of the Pennsylvania input is small but the discharge of detergent phosphorus from Ohio facilities is substantial. Prior to Ohio coming into treatment compliance, immediate benefit will be realized by implementing detergent controls.

Continuation of existing detergent phosphorus controls are essential as they provide a measure of phosphorus control for:

- communities with discharges of less than 3,800 cu m/d (1 MGD) without phosphorus removal,
- communities with combined sewer overflows,
- households which are unsewered,
- collection systems and treatment plants which malfunction, and
- for treatment plants with phosphorus removal, they reduce the degree of treatment required, energy and chemical consumption, and sludge production.

Existing detergent controls apparently involve consumer costs. The detergent industry suggests these costs are large compared with the incremental costs of phosphorus removal at the wastewater treatment facilities. A need exists to verify these costs and investigate alternative control measures that may be used to reduce detergent phosphorus inputs to the Great Lakes. The future efficacy of such controls must be verified by appropriate studies that address economic and social costs, benefits and detriments, and alternative control strategies. The results of these studies should be used to provide an update or modification of the task force's recommendations that existing detergent control programs in the Great lakes basin should be retained with Ohio and Pennsylvania implementing similar controls.

RECOMMENDATION NO. 5

It is recommended that the governments initiate a technology development and demonstration program for alternative and innovative treatment technologies which reliably and cost effectively achieve various effluent total phosphorus residuals down to 0.1 mg/L. It is further recommended that governments develop and evaluate, by field studies, alternative municipal control technologies to reliably and cost-effectively achieve reduced effluent residuals of phosphorus which can be used for both new facilities and to upgrade existing facilities.

Research and development efforts which focus on new or innovative technologies should be continued and expanded in both the United States and Canada. These technologies should be implemented when they are found to be cost-effective. Recent information indicates that new technology used in Sweden is capable of achieving less than 0.3 mg/L total phosphorus at costs equivalent to current technology. Site specific evaluations of feasible and cost effective technologies which could be implemented at major point sources (over 38,000 cu m/d) should be carried out.

RECOMMENDATION NO. 6

It is recommended that where cost-effective, land application of wastewaters be utilized.

Increasing numbers of studies have shown that land application can be a cost-effective technology for the treatment of municipal and industrial wastes. This technology has been used primarily for the treatment of wastes from small communities but also can be considered for larger communities. If all plants with flows less than 38,000 cu m/d (10 MGD) were converted to land application, the total phosphorus load discharged by municipal sources in the Lake Erie basin would be decreased by 700 t/yr, and in the Lake Ontario basin by 500 t/yr.

Site selection and design guidelines recently have become available in both the United States and Canada to help communities, consulting engineers, and public officials identify the cost-effectiveness of land application in a site-specific situation. In evaluating land application as a means to achieve very low phosphorus inputs to surface waters, full consideration should be given to the possible adverse impacts of soil and groundwater contamination.

RECOMMENDATION NO. 7

It is recommended that studies be initiated to quantify the reductions in toxic and hazardous substances that occur concurrent with phosphorus removal.

An ancillary benefit of phosphorus removal by chemical precipitation or land application is likely to be a reduction in the amount of toxic and hazardous substances (heavy metals and trace organics) discharged to the Great Lakes. The magnitude of such reductions is unknown. Concurrent studies should evaluate this ancillary benefit as well as its possible impact on sludge disposal/utilization strategies.

7.4 MANAGEMENT OF NONPOINT SOURCES

Nonpoint source controls for urban and agricultural areas, particularly erosion control on farm lands which are intensely cropped and have medium to fine-grained soils, may be required to provide at least a part of the projected additional load reductions needed for Lake Erie and possibly Lake Ontario.

RECOMMENDATION NO. 8

It is recommended that the nonpoint source component of comprehensive phosphorus management plans developed for each country include the implementation of:

- *a basin wide public information and education program; and where appropriate, those low cost measures which can result in a reduction in*

nonpoint loadings based on a common sense approach to problem solving (PLUARG's proposed Level 1 measures);

and the development of:

- a modelling capability for predicting phosphorus reduction for critical areas within the basin; and*
- demonstration watershed studies within these critical problem areas to evaluate the cost effectiveness of a variety of remedial measures, identify any problems associated with their implementation, and provide examples of implementation as incentives for other farm operator.*

Implementation and Evaluation:

Both PLUARG and the Lake Erie Wastewater Management Study have identified nonpoint source control measures which can be implemented cost-effectively. The greatest benefit from nonpoint source controls is likely to be achieved in the areas draining into the western and central basins of Lake Erie.

The effectiveness of a nonpoint management program will be predicated on the extent to which the related issues of remedial measures and the institutional arrangements required for their implementation are brought together. Without a clear understanding of how each influences the other, little substantive progress will be made towards reducing nonpoint sources of phosphorus.

Important questions remain with respect to remedial measures. What measures are optimal for use under varying soil, climate, and land management systems and what phosphorus load reductions can be expected given the wide range of variables which will ultimately affect these measures?

The implementation of a nonpoint source remedial measure program is complex. Which measures should be used, where should they be implemented to achieve maximum reductions for the money spent, how can farmers and municipalities be encouraged not only to adopt but also implement these measures over the long term, and finally how can the changes in loadings which ultimately occur be accurately assessed?

Answers to these questions cannot be developed separately but must be approached holistically. This situation is in marked contrast to the situation which preceded the implementation of the point source phosphorus control program in 1972. At that time the institutional means of achieving rapid implementation were in place. However, there was considerable uncertainty concerning which remedial measures were the most appropriate.

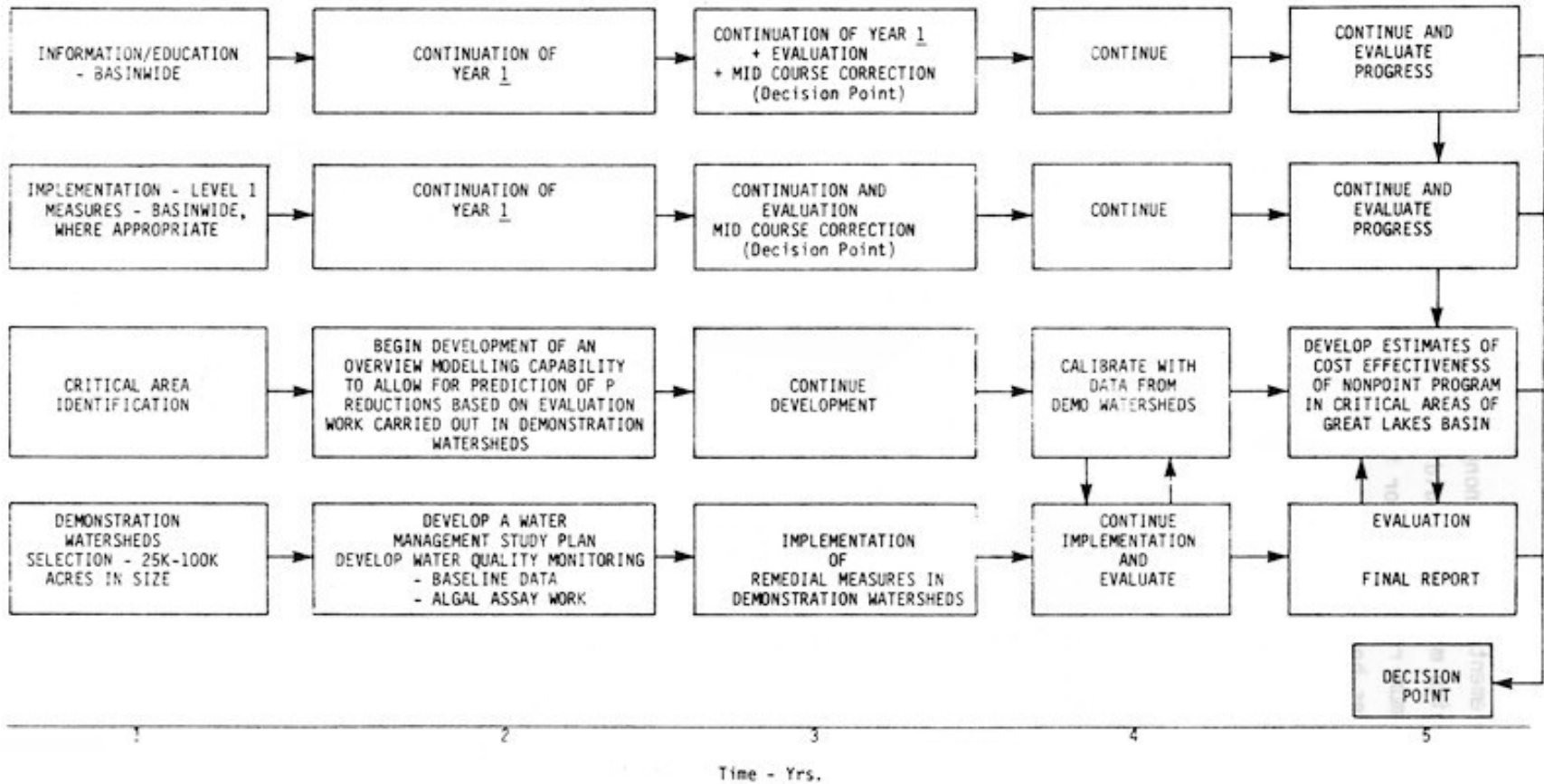
To resolve these issues, Canada required the adoption of small pilot-scale studies. Regarding nonpoint pollution control, the unknowns are greater and the control which existing institutions can exert over implementation will be much less. Thus, there is even a greater need for a similar incremental approach before widespread adoption of an extensive nonpoint source control program.

The principal actions which should be undertaken to achieve the necessary implementation and evaluation of the nonpoint programs are discussed below and are illustrated in Figure 7.4.

7.4.1 Information/Education

Concern about nonpoint sources of phosphorus in the Great Lakes began in the early 1970's and this concern was largely restricted to those persons studying the lakes. Since the completion of a number of studies which addressed the nonpoint problem, concern over nonpoint sources has been growing. General public awareness of the problem, however, still remains at a low point. The PLUARG agricultural surveys conducted in Canada and the United States underlined this fact.

FIGURE 7.4 Framework For A Nonpoint Source Management Program



A fundamental requirement of any program directed towards encouraging individuals or institutions to adopt a program or measure is to develop an awareness of the problem and its solution. Governments must be committed to beginning this first step in a comprehensive and dedicated manner if widespread adoption and implementation are to be achieved.

As a first priority this program should be directed towards those who are responsible for developing nonpoint source management programs. Once this task is accomplished the program should be widened to encompass the general public.

Reliance on information programs to accomplish implementation will not be sufficient. Education program involving components of demonstration and technical assistance will also be required if widespread voluntary adoption of improved management practices is to be accomplished.

Throughout the conduct of the information and education programs, there must be an ongoing evaluation of their effectiveness in developing a high level of awareness and commitment to the implementation of remedial measures. This evaluation process must be continued through the period of more widespread implementation in order to regularly assess the level of achievement and the changing attitudes of those implementing the programs to allow for necessary modifications in program delivery.

7.4.2 Level 1 Remedial Measures

Level 1 remedial measures³ are low cost or no cost measures which should be implemented where appropriate across the basin. They are based on utilizing sound management practices or good land stewardship in rural areas and programs for pollutant reduction at source in urban areas. Until a more thorough analysis of the specific problem areas and alternative remedial measures is undertaken, the implementation of these measures should remain on a voluntary basis. Both PLUARG and the LEWMS have indicated, however, that these measures are the most cost-effective next step in a phosphorus management strategy. PLUARG estimates a 900 t/yr reduction in urban

and rural diffuse sources will result from implementation of these practices. LEWMS estimated that a reduction of 1,800 to 5,000 t/yr would result in the Lake Erie basin if reduced tillage were adopted on those soils where appropriate, and assuming full implementation, that net farm income would remain the same or increase. A reasonable expectation within the next 10 years is that a 2,000 t/yr reduction in nonpoint source phosphorus load is achievable.

7.4.3 Critical Area Identification

Not all land areas contribute equally to the nonpoint source phosphorus load to surface waters. As well, the lakes vary widely in their respective trophic conditions. Given this situation it is vital that these areas where degraded water quality and higher unit loadings of pollutants occur be identified.

A number of studies (PLUARG,³ LEWMS^{4,6}) have identified areas where problems are most acute. Before implementation takes place it is important that further definition of these areas take place to ensure the effective delivery of remedial measures. Areas with highly erodible soils, intensive farming practices, steep slopes and frequent storm events exhibit high rates of soil loss and, therefore, are defined as critical areas for the control of phosphorus inputs to the Great Lakes.

PLUARG, in its basinwide approach to holistic problems, defined the first general level of critical area identification. The Lake Erie Wastewater Management Study focussed on a single lake. It then identified a watershed in Ohio, Honey Creek, to provide a more detailed second-level evaluation of critical areas within a major basin. This level of planning is still too large to prioritize critical sub-basins for implementation of best management practices. A third level of detailed sub-basin planning is needed to identify critical areas of a manageable size in order to demonstrate specific practices appropriate to reduce the total phosphorus inputs from agricultural land.

Some areawide water quality management plans have identified critical areas at this level of detail. These areas are prime candidates for demonstration projects such as those recently funded under the Rural Clean Water Program and Model Implementation Program. Further

guidance on the effectiveness of urban housekeeping measures in reducing phosphorus, metals and toxics should be forthcoming from the U.S. National Urban Runoff Program.

Since it will be difficult to accurately assess the effects of Level 1 programs on tributary loads due to variations in the hydrologic cycle, trend monitoring using biological indicators and chemical measurement will be necessary to indicate the overall direction of load reductions. Further evidence of progress can be gathered by measuring the adoption rate of these practices. Surveys should be made in the first year to establish baseline data and in the third and fifth years to measure the rate of adoption.

7.4.4 Demonstration Watersheds

Within the critical problem areas it is especially important that a number of demonstration watersheds, representative of those land use and land form characteristics which contribute to the problem, be established. As with the previously noted Treatability Studies Program, this would give decision makers the necessary flexibility to evaluate a variety of approaches with ample time for review. The demonstration watershed program will provide an insight into the problems associated with implementation and an evaluation of the relative costs and effectiveness of a variety of remedial measures in reducing the loss of both total and available forms of phosphorus. These studies will also be useful in demonstrating to farmers and urban dwellers in other areas the benefits to be derived from implementation of remedial measures.

Within each demonstration watershed there will be requirements to enlist the full cooperation of farmers and local government agencies and to underwrite the full costs of implementation of remedial measures. This support will be required for a period of at least three years to ensure that sufficient monitoring is carried out to adequately assess the effectiveness of remedial measures. Each watershed study will also require the development of a watershed management study plan. These plans will identify the phosphorus sources within the watershed and the measures which will be used to treat these sources for the least cost. It is probable that not all sources within a watershed will be treated. It is also probable that within several demonstration

basins the same kinds of sources will not be treated uniformly. For example, in one watershed management of livestock manure may be more effective than a sediment control program in reducing the loss of phosphorus.

7.5 INFORMATION NEEDS

Throughout this report many information needs have been identified which need to be filled so that future phosphorus management strategies can be defined more precisely. There is a need to improve the estimates of phosphorus loads, develop new phosphorus control technologies for both point and nonpoint sources, and demonstrate the cost effectiveness of new as well as existing technologies.

In addition, there are two informational needs which require special attention in order to reduce major uncertainties in the direction and extent of implementation for future phosphorus control programs. These are the questions of the bioavailability of various forms of phosphorus (Section 3.2.3) and the ability of models to predict in-lake effects in response to reduction in phosphorus inputs (see Chapter 4).

RECOMMENDATION NO. 9

It is recommended that a permanent organization be established within the institutions under the Great Lakes Water Quality Agreement to serve the phosphorus management needs of the Great Lakes. This organization would be charged with the task of reducing uncertainties regarding:

- *Target loads*
- *Bioavailability*
- *Social benefits and costs of control measures*
- *The appropriateness of institutional approaches*
- *The structure of analytical models as well as the development of appropriate data bases to facilitate attainment of the above objectives.*

The ability of this task force to fulfill its responsibilities has been hampered by its inability to conduct its own research. Thus, it was forced to adopt secondary sources of information and had little opportunity to resolve conflicts between these sources.

In particular, the task force had to rely on models with structures that were inadequate to resolve crucial issues regarding the relation between phosphorus loadings and the water quality in specific regions of the lakes. Clearly new model structures will have to be developed if, for example, the focus shifts to nearshore areas of the lakes rather than the lake as a whole.

Similarly, resolution of the choice between limiting phosphorus in detergents and reducing the phosphorus loads at the municipal treatment plant could not be resolved since independent information on the social costs of detergent limitations could not be developed.

A well-funded research and analysis effort, within the framework of the proposed organization and one which would be directly responsive to the needs of policy-makers, is required to provide the information needed for the management strategy to move from one stage to the next.

An appropriate step in this direction would be the formation of a committee to evaluate more fully the differences between the loading models and lake responses. One of the important and most immediate tasks of this committee would be to perform computations on all models for the purpose of synthesizing the various approaches and reconciling differences as they arise. Such an analysis would provide a more quantitative basis for resolving the uncertainties of the present state of the analysis.

A second, but equally significant task, would be the formation of a comprehensive and uniform scientific and engineering report on the models and more importantly, on the most recent developments of these models. Since the establishment of the target loads, further advances have been made in the understanding of the phenomena and in the refinement of the models. The implications of these developments should be evaluated with respect to the target loads.

Finally, the committee would establish the procedures for continuous review and analyses of current research to be incorporated in the comprehensive report at regular intervals. These reports, analyses and procedures would be specifically oriented to serve the needs of the IJC and its advisory Boards. Such a repository of information would be invaluable to the decision makers.

7.6 SUMMARY

It is anticipated that the next major decision point in the phosphorus management program for the Great Lakes will occur in about 5 years. At that time, assuming the recommended implementation, evaluation, and information gathering are carried out, it will be possible to determine, with more certainty, the magnitude of further reductions of phosphorus inputs which may be required. In addition, decisions can be made with a greater degree of confidence as to what sources should be controlled with an assurance that the costs associated with the implementation of additional controls are commensurate with expected benefits.

At the present time, the degree of uncertainty which is still attached to major elements of the phosphorus question suggest that existing programs should be more fully implemented and evaluated before commitments are made to major programs to further reduce input loads of phosphorus on a whole lake basis. However, the basic premise that phosphorus loadings to the Great Lakes must be reduced in order to control eutrophication is still valid and the uncertainty associated with the magnitude of further reductions required and best means of achieving them, should not be construed as a lack of support for the basic program.

Although the need for further phosphorus controls is evident, clear directions on the extent, timing, and type of additional controls needed are not apparent. The effectiveness of nonpoint source controls, phosphorus bioavailability, and the cost of these remedial measures can only be quantified in a very incomplete fashion with the information available to the task force and their applicability is likely very site specific. It is for these reasons that the task force is not prepared to recommend across-the-board additional remedial measures at this time. Instead, it recommends to governments that additional phosphorus removal should be implemented, as a matter of priority,

for those lake portions and nearshore areas which clearly exhibit severe eutrophication problems such as Saginaw Bay in Lake Huron, the western basin of Lake Erie, and the Bay of Quinte in Lake Ontario.

The extent to which further reductions are made in the point and nonpoint sources of phosphorus responsible for these eutrophication problems should be governed by technical feasibility, cost-effectiveness, and social acceptability. These factors are likely to be very site specific and will require demonstration studies. Such studies should be carried out as soon as possible, completed and implemented soon thereafter.

Despite the indications that additional reductions will be required to meet present target loads it is recommended that the impact of the reductions effected by achieving the 1.0 mg/L total phosphorus objective on the water quality of the two lower lakes be monitored and evaluated particularly in the littoral areas with emphasis on chlorophyll. Recommendations for the implementation of additional major, lake-wide, phosphorus control programs should be contingent upon identification that these observed in-lake responses are consistent in magnitude and direction with desired goals.

The task force's recommendations for the immediate phase of a phosphorus management strategy are:

- that a program including information/education, technology development, demonstration watersheds, and model evaluations, be undertaken as soon as possible in order to provide the knowledge base needed to develop and implement policy in parallel with a staged approach to phosphorus management;

- that, as quickly as possible, all municipal wastewater treatment plants discharging in excess of 3,800 cu m/d (1 MGD) in the Great Lakes basin be designed and operated so that the total phosphorus concentrations in their effluents will not exceed a maximum of 1.0 mg/L;
- that governments immediately evaluate the ability of municipal wastewater treatment facilities in the lower Great Lakes basin, currently required to meet an effluent limit of 1.0 mg/L total phosphorus, to be operated to achieve effluent concentrations below 1.0 mg/L and those which can be so operated should begin as soon as possible;
- that for planning purposes, all future municipal point source discharges to the lower Great Lakes basin should consider requirements for total phosphorus removals to concentrations on the order of 0.1 to 0.5 mg/L;
- that future discharge objectives for municipal facilities should be developed employing mass loading allocations in order to encourage the consideration of a variety of managerial and other structural approaches to reduce phosphorus inputs. These approaches may include:
 - industrial pre-treatment requirements for phosphorus
 - detergent phosphorus controls
 - effluent fees
 - user fees dependent on phosphorus inputs
 - other treatment options such as land application
 - combinations of the above.

The planning should include detailed consideration of costs, effectiveness, and possible implementation difficulties;

- that existing laws and regulations to control the phosphorus content of detergents in the Great Lakes basin be retained and that controls be extended immediately to include Pennsylvania and, in particular, Ohio;
- that an independent study be conducted on the direct and indirect costs, benefits and disbenefits associated with detergent phosphorus controls;
- that the governments initiate a technology development and demonstration program to develop and evaluate, by field studies, alternative and innovative municipal wastewater treatment technologies which can reliably and cost-effectively achieve various effluent total phosphorus residuals down to 0.1 mg/L which can be used for both new facilities and to upgrade existing facilities;
- that where cost-effective, land application of wastewaters be utilized;
- that studies be initiated to quantify the reductions in toxic and hazardous substances that occur concurrent with phosphorus removal;
- that the nonpoint source component of comprehensive management plans developed for each country include the implementation of:
 - a basin-wide public information and education program; and
 - where appropriate, those low cost measures which can
 - result in a reduction in nonpoint loadings based on a common sense approach to problem solving;

and the development of:

- a modelling capability for predicting phosphorus reductions for critical areas within the basin; and
- demonstration watershed studies within these critical problem areas to evaluate the cost-effectiveness of a variety of remedial measures, identify any problems associated with their implementation, and provide examples of implementation as incentives for other farm operators;
- that a permanent organization be established to serve the phosphorus management needs of the Great Lakes. This organization would be charged with the task of reducing uncertainties regarding:
 - target loads
 - bioavailability of various forms of phosphorus
 - social benefits and costs of control measures
 - the appropriateness of institutional approaches
 - the structure of analytical models as well as the development of appropriate data bases to facilitate attainment of the above objectives.

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APPENDIX 1
TERMS OF REFERENCE FOR
PHOSPHORUS MANAGEMENT STRATEGIES TASK FORCE

I. Introduction

Several actions have been taken by some jurisdictions in the Great Lakes Basin to reduce phosphorus inputs, as for example, phosphate bans in household detergents and effluent limitations for phosphorus from sewage treatment plants. Experts recognize that multiple controls on phosphorus are needed to achieve the desirable water quality conditions and that present controls may not be optimum. Particularly, the findings of PLUARG need to be woven into the over all control strategy, and as yet, a clear assessment of the trade-offs between alternative control strategies has not been laid out so that decision-makers can be assured that all effective avenues are being used and optimized. For such reasons, a task force needs to examine the question outlined above for the use of the jurisdictions within the Great Lakes basin.

II. Terms of Reference

1. Review and evaluate the adequacy of existing data, factors affecting phosphorus loads, analyses and technologies pertinent to the development of alternative phosphorus management strategies: Items of concern to include: the assumptions and rationale underlying the phosphorus loads recommended in the 1978 Water Quality Agreement between Canada and the United States on Great Lakes Water Quality, dated November 22, 1978; the availability and practicability of technology and the costs for control of point and nonpoint sources; the reduction of phosphorus content in detergents and associated costs; consideration of the biological availability of phosphorus in the assessment of alternative phosphorus management strategies; and the applicability of systems approaches for determining control strategies.

2. Evaluate and test alternative phosphorus management strategies specifically as they impact on: a) ecology; b) waste treatment; c) sludge disposal; d) energy considerations; and e) economics.
3. To incorporate, as time allows, the findings of the associated task forces and committees on health effects, environmental impacts, societal aspects, and nutrient objectives.
4. Identify specific subject areas where additional information is needed.

III. Membership

The Task Force should consist of representatives of industry, government and universities with uni- or multi-expertise to address the three preceding items.

The representatives would, for example, have expertise on: ecological effects due to various phosphorus loadings; nonpoint source control technology, substitutes; phosphorus regulatory processes; etc.

IV. Liaison

The Task Force should contact and work closely with other current IJC Task Forces and Reference Groups which are examining other facets of the phosphorus issue in relation to the Great Lakes. These would include, for example, the Task Force on Health Effects of Non-NTA Detergent Builders Nutrient Objectives Work Group, the Pollution from Land Use Activities Reference Group and Task Group III of the Five Year Review of the Water Quality Agreement. The findings of these groups should be utilized, wherever appropriate, in the development of the Task Force's Final Report.

V. Timing

The Task Force should provide an interim report in the summer of 1979, and its final report by January 1980.

APPENDIX 2
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