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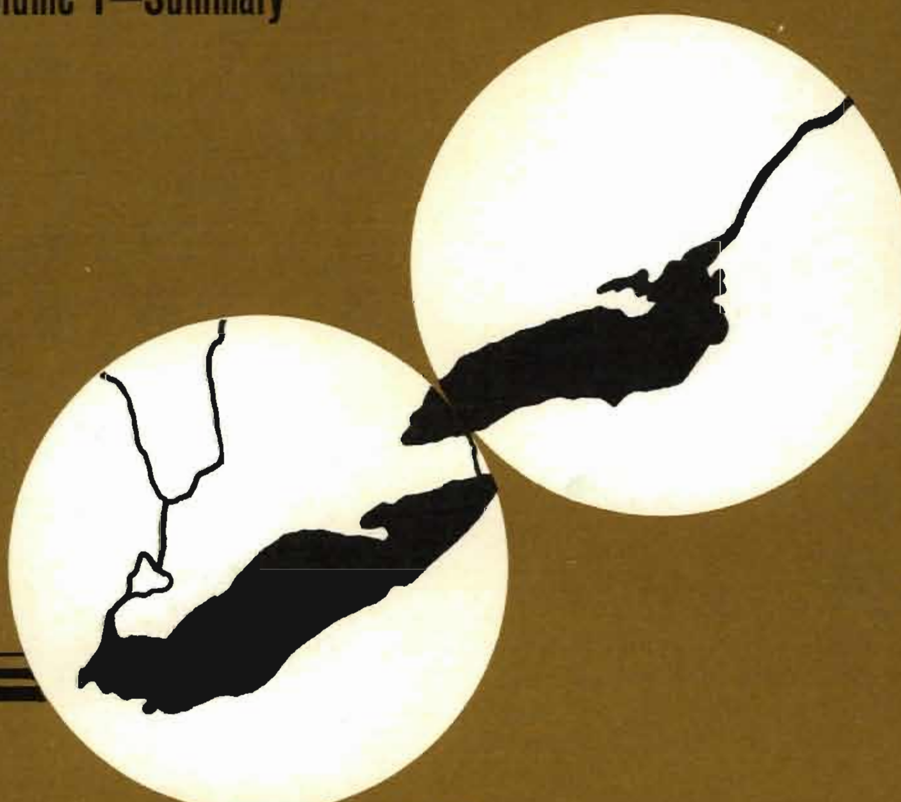
report to the INTERNATIONAL JOINT COMMISSION on the

POLLUTION OF LAKE ERIE, LAKE ONTARIO AND THE INTERNATIONAL SECTION OF THE ST. LAWRENCE RIVER

Volume 1—Summary



BY THE
INTERNATIONAL LAKE ERIE WATER POLLUTION BOARD,
AND THE
INTERNATIONAL LAKE ONTARIO—ST. LAWRENCE RIVER
WATER POLLUTION BOARD.

1969

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POLLUTION OF LAKE ERIE, LAKE ONTARIO AND THE INTERNATIONAL SECTION OF THE ST. LAWRENCE RIVER

BY THE
INTERNATIONAL LAKE ERIE WATER POLLUTION BOARD
AND THE
INTERNATIONAL LAKE ONTARIO - ST. LAWRENCE RIVER
WATER POLLUTION BOARD
1969

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C O N T E N T S

Volume 1

Summary Report

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International Lake Erie Water Pollution Board
International Lake Ontario - St. Lawrence River Water Pollution Board

September 2, 1969.

International Joint Commission,
United States and Canada.

Gentlemen:

In accordance with the International Joint Commission's directive, dated August 23, 1965, the Water Pollution Boards have conducted investigations to determine the extent and nature of pollution in the waters of Lake Erie, Lake Ontario and the international section of the St. Lawrence River.

Herewith transmitted is the report of the Boards in three volumes. Volume 1 summarizes the pertinent data contained in Volumes 2 and 3 and states the Boards' findings and recommendations. Volume 2 (Lake Erie) and Volume 3 (Lake Ontario - St. Lawrence River) provide detailed technical information on the quality of waters under reference, and develop the basis on which the recommendations in Volume 1 are made.

Data on which the report is based cover the period from 1963 through 1967, but further source information has been added in order to include significant observations.

It is worthy of mention that international relationships have been of a high order throughout this joint Canadian - United States study. At the personal level, friendships have developed and mutual understanding and respect have grown among the many individuals of our two countries who participated. At the official level, there has been full cooperation of the several provincial, state and federal agencies which carried out the coordinated programs involved in the undertaking. The mutual regard and desire to proceed in concert give promise of effective cooperation in the joint international action that will be required for the abatement and control of pollution of the Great Lakes.

The members of the Boards and the state, provincial and federal agencies from which they have been drawn appreciate the opportunity to be of assistance to the Commission.

Respectfully submitted,

H.W. Poston,
Chairman,
U.S. Section.

Ernest A. Watkinson, M.D.,
Chairman,
Canadian Section.

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Mr. J.F. Hendrickson	International Affairs Officer, Federal Water Pollution Control Administration, Department of the Interior, Washington, D.C.
Mr. W.A. Lyon	Director, Bureau of Sanitary Engineering, Commonwealth of Pennsylvania, Department of Health, Harrisburg, Pennsylvania.
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Mr. P.M. Higgins	Public Health Engineering Division, Department of National Health and Welfare, Ottawa, Ontario.
Dr. W.M. Sprules	Director, International Fisheries Branch, Department of Fisheries and Forestry, Ottawa, Ontario.
Mr. F.A. Voege	Assistant General Manager, Ontario Water Resources Commission, Toronto, Ontario.

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Mr. R.J. Van Derwerker	Sanitary Engineer Director, Public Health Service, Department of Health, Education and Welfare, New York, New York.

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Mr. D.S. Caverly	General Manager, Ontario Water Resources Commission, Toronto, Ontario.
Mr. P.M. Higgins	Public Health Engineering Division, Department of National Health and Welfare, Ottawa, Ontario.
Dr. W.M. Sprules	Director, International Fisheries Branch, Department of Fisheries and Forestry, Ottawa, Ontario.
Mr. F.A. Voege	Assistant General Manager, Ontario Water Resources Commission, Toronto, Ontario.

FORMER BOARD MEMBERS

Canada

Mr. W.R. Edmonds* 1964-1965	Department of National Health and Welfare
Mr. W.K. Sharpe 1964-1968	Department of National Health and Welfare

United States

Mr. L.F. Warrick 1964-1965	Department of Health, Education and Welfare
Mr. S.C. Martin 1964-1967	Department of Health, Education and Welfare

Mr. G.A. Hall 1964-1968	State of Ohio
Dr. M.H. Thompson 1964-1967	State of New York
Mr. K.S. Krause 1965-1966	Department of the Interior
Mr. E.J. Anderson 1966-1967	Department of the Interior
Dr. A. Hirsch 1967-1968	Department of the Interior
Mr. L.F. Oeming 1968-1969	Michigan Water Resources Commission

*William R. Edmonds (deceased December 7, 1968)

Mr. W.R. Edmonds served on the Technical Advisory Boards investigating pollution on the International Boundary Waters (1946-1949) and also was the first Canadian Chairman of the Lake Erie Water Pollution Board and the Lake Ontario-St. Lawrence River Water Pollution Board.

He continued his association with the current studies as a technical consultant to the present Chairman of the Canadian Section as well as contributing and assisting in the development of this report.

INTRODUCTION

The first comprehensive report on pollution of boundary waters was issued by the International Joint Commission in 1918[1] following investigations from 1913 to 1916. The section of that report dealing with water pollution problems in the Great Lakes area, though concerning itself primarily with the Connecting Channels (St. Clair River, Lake St. Clair, Detroit River, and Niagara River) did examine the quality of waters in both the western and eastern ends of Lake Erie and Lake Ontario, and in the international section of the St. Lawrence River. Subsequently, in its 1950 report[2], the Commission re-examined the problem of pollution in these waters based on studies undertaken from 1946 to 1948.

Pollution problems have changed materially over the period of study from 1913 to the present. The 1913 investigations were almost solely concerned with bacterial pollution from domestic sewage, a reflection of the few municipal sewage treatment plants then in existence. Industrial pollutants were not discharged in sufficient quantities to seriously affect water uses. The investigations showed that the open waters of Lakes Erie and Ontario were essentially free of bacterial pollution except for the western basin of Lake Erie near the mouth of the Detroit River and Lake Ontario near the mouth of the Niagara River. Bacterial pollution on a localized scale in nearshore waters did, however, constitute a direct threat to municipal water supplies.

The report of 1950 indicated that many of the municipalities identified in the earlier report had constructed sewage treatment works and water filtration plants to ensure safe water supplies. However, the extension of sewer services and the installation of treatment plants for domestic wastes had not kept up with growth in the area. The economic, industrial and agricultural expansion which took place from 1913 to 1946 resulted in major increases of sewage discharges and new wastes. Industrial pollution which was not considered to be a problem in 1913 was recognized as a growing problem in 1948.

Control programs to combat the bacterial pollution reported in the 1918 study and to provide the treatment recommended in the 1950 report were not adequate to keep pace with the problems arising from continued urban and industrial expansion in the lower lakes basins. Changes in manufacturing processes and commodity use had caused new and widespread pollution problems, while bacterial pollution continued in evidence despite the fact that many of the major sources were controlled. The urban and industrial complexes in the lower

[1] Final report of the International Joint Commission on the Pollution of Boundary Waters Reference, August, 1918.

[2] Report of the International Joint Commission on the Pollution of Boundary Waters, October, 1950.

lakes basins were developed without adequate knowledge of the effects of multiple releases of wastes to water. Further, many resource materials were discharged into the lakes because ignorance existed of ways and means to convert these materials to economic benefit. In other cases materials recovery systems were either inadequate or poorly operated.

On October 7, 1964, the Governments of the United States and Canada informed the International Joint Commission that they had reason to believe the waters of Lake Erie, Lake Ontario, and the international section of the St. Lawrence River were being polluted by sewage and industrial wastes, and accordingly had "agreed upon a joint reference of the matter" to the Commission pursuant to the provisions of Article IX of the Boundary Waters Treaty of 1909.

The Commission was requested to inquire into and report to the two governments as soon as practicable upon the following questions:

1. are the waters of Lake Erie, Lake Ontario, and the international section of the St. Lawrence River being polluted on either side of the boundary to an extent which is causing or is likely to cause injury to health or property on the other side of the boundary?

2. if the foregoing question is answered in the affirmative, to what extent, by what causes, and in what localities is such pollution taking place?

3. if the Commission should find that pollution of the character just referred to is taking place, what remedial measures would, in its judgment, be most practicable from the economic, sanitary and other points of view, and what would be the probable cost thereof?

In order to make the necessary investigations and studies to form the basis for its report to the Governments of the United States and Canada, the Commission established two Advisory Boards:

1. The International Lake Erie Water Pollution Board, and

2. The International Lake Ontario and St. Lawrence River Water Pollution Board.

Representatives from the Federal Governments of the two countries, and from the States of New York, Pennsylvania, Ohio, Michigan, and the Province of Ontario were appointed to these Boards.

While the two lakes, Erie and Ontario, are the smallest of the five Great Lakes, over half the population of the Great Lakes region live and work in these two basins. Thus Lake Erie and Lake Ontario have been subjected over the years to great use pressures, and have received large quantities of industrial and municipal wastes. It seems appropriate, therefore, that the first major international investigation of the Great Lakes pollution problems should be directed at these two lakes.

When the United States and Canada became signatories to the Boundary Waters Treaty, they did so in recognition of the value of protecting the boundary and transboundary waters and established an order of precedence for water use. These were (1) domestic and sanitary, (2) navigation, and (3) power and irrigation. The uses of these waters for industry, recreation, and fish and wildlife purposes were not cited in the Treaty. However, they have played an increasingly important part in the development of the lakes and are recognized as uses which are entitled to full consideration along with those specifically named in the Treaty.

PROGRAM OF INVESTIGATIONS

In 1960, the Congress of the United States appropriated funds to launch a comprehensive pollution study of the Great Lakes, specifically providing for the Secretary of the Department of Health, Education and Welfare "to conduct research and technical development work, and make studies, with respect to the quality of the waters of the Great Lakes,....."[1]. Actual studies of Lake Erie were initiated in 1963 and of Lake Ontario and the international section of the St. Lawrence River in 1964. Subsequently, through reorganization, these studies were continued by the Department of the Interior and have been used in the preparation of this report.

In Canada studies of the lower Great Lakes for this report began in 1964 after water pollution became a matter of reference to the International Joint Commission by the two governments. The Department of National Health and Welfare, the Department of Energy, Mines and Resources, the Fisheries Research Board of Canada, and the Ontario Water Resources Commission, all initiated programs to develop data on which to base recommendations for the necessary remedial actions on the two lakes.

[1]Federal Water Pollution Control Act, 1956, as amended (33 U.S.C. 466 *et seq.*).

Of considerable importance in the development of this report has been a cooperative and well-coordinated program of investigations and special studies by personnel from federal, state and provincial agencies. Other sources of pertinent data have been examined and incorporated in this report for the evaluation of long term changes.

INTERIM REPORTS

Since the work of the Advisory Boards was initiated, semi-annual reports have been submitted to the Commission to apprise it of the Boards' progress.

In September of 1965, the Boards submitted an interim report to the Commission. In that report the Boards recognized significant pollution in Lake Erie and the rapid development of similar conditions in Lake Ontario and the international section of the St. Lawrence River. The report recommended the development of a comprehensive program to locate sources of pollution; to bring these sources under control or to eliminate them; to develop and adopt uniform regulations at federal, state and provincial levels concerning discharge of wastes from pleasure craft and vessels; to encourage and support research and related activites; and to establish data centres on both sides of the border to facilitate the exchange of data. In December 1965, the International Joint Commission summarized the Boards' findings and issued its own "Interim Report" to the Governments of Canada and the United States.

A second interim report was prepared by the Advisory Boards and submitted to the Commission in June, 1968. This report reiterated the conclusions stated in the 1965 report and noted the achievements in pollution abatement since that time. A number of other pollution reports commissioned by federal, state and provincial agencies participating in this study have been tabled with the Advisory Boards. These have been thoroughly reviewed and recognized in the planning of surveys, preparation of data or as source documents.

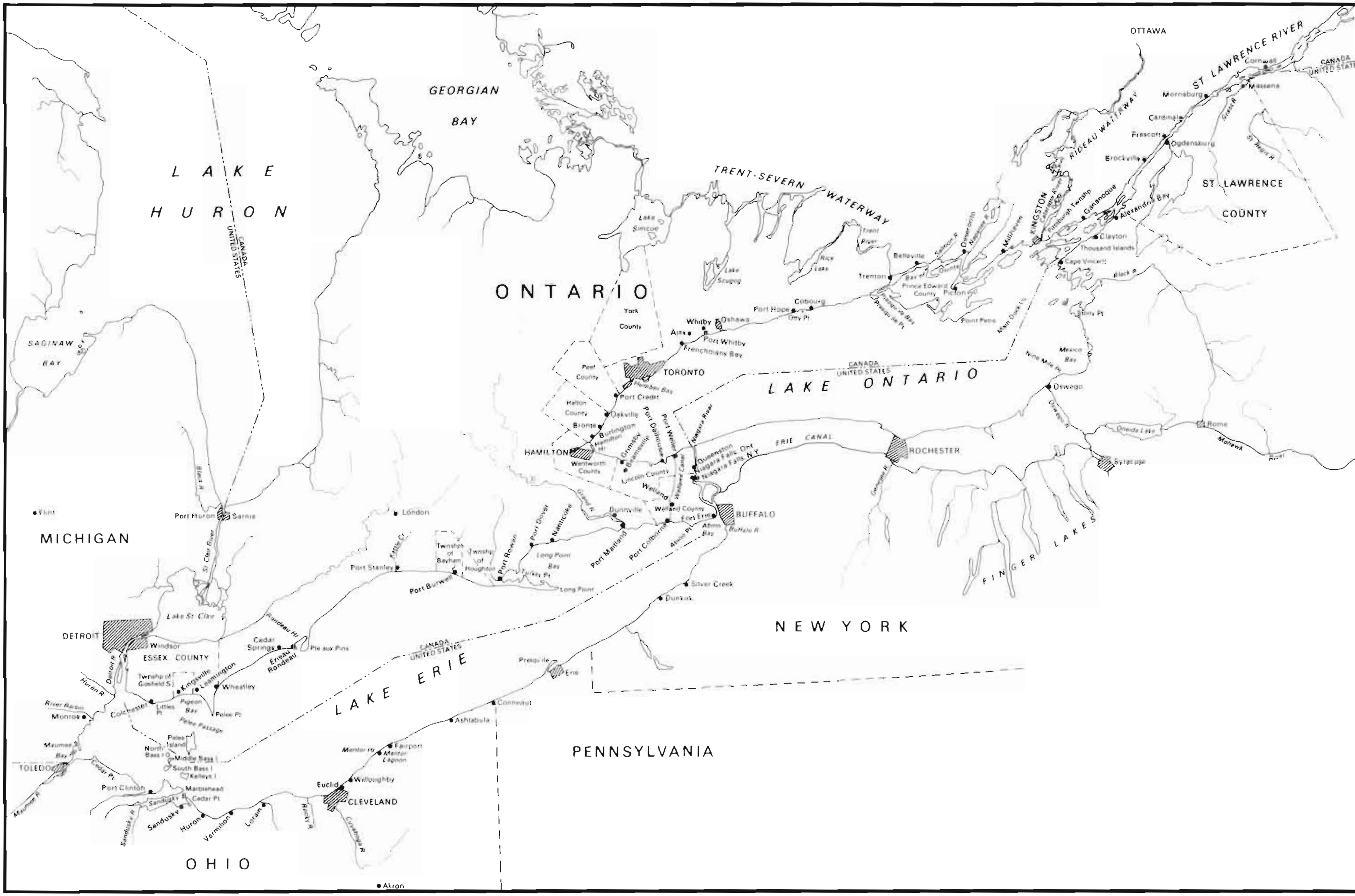
PRESENT REPORTS

This report has been prepared in three volumes. In Volume 1 the Boards have endeavoured to summarize the findings and to identify the critical problems of pollution, and pollution control measures which are of immediate concern to both countries as well as those long range problems which must be brought under continuing review and study. Volume 2 contains the scientific and engineering data and findings which have been used to determine the sources and levels of pollution in Lake Erie, as well as recommendations for the necessary remedial measures. Volume 3 contains similar information for

Lake Ontario and the international section of the St. Lawrence River.

EXISTING POLLUTION CONTROL PROGRAMS

The Boards fully recognize the ongoing pollution abatement programs of the bordering states and the Province of Ontario. The recommendations of this report reinforce these existing programs, and are not intended to replace earlier completion dates or more stringent water quality criteria where such exist.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GEORGIAN BAY
SAGINAW BAY
ONTARIO
MICHIGAN
LAKE ONTARIO
LAKE ERIE
NEW YORK
PENNSYLVANIA
OHIO
OTTAWA
ST LAWRENCE RIVER
RIDEAU WATERWAY
TRENT-SEVERN WATERWAY
ST LAWRENCE COUNTY
FINGER LAKES
ERIE CANAL
CANADA
UNITED STATES
Lake Simcoe
Lake Scugog
Rice Lake
Trent River
York County
Peel County
Halton County
Wentworth County
Lincoln County
Welland County
Essex County
Prince Edward County
TORONTO
HAMILTON
BUFFALO
ROCHESTER
DETROIT
CLEVELAND
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Bronte
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Grimsby
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Vermilion
Lorain
Euclid
Willoughby
Fairport
Mentor Hr
Ashtabula
Conneaut
Erie
Presqu'ile
Dunkirk
Silver Creek
Akron
Oneida Lake
Mohawk River
Black R
Detroit R
Huron R
Maumee R
Sandusky R
Cuyahoga R
Grand R
Oswego R
Genesee R

1. SUMMARY OF FINDINGS AND RECOMMENDATIONS

1.1 SUMMARY OF FINDINGS

Transboundary Pollution

The Advisory Boards conclude, on the basis of data and other information developed by the United States and Canada over the last six years, that Lake Erie, Lake Ontario and the international section of the St. Lawrence River are being polluted on both sides of the boundary (United States-Canada) to an extent that is causing and is likely to cause injury to health and property on the other side of the boundary.

The Advisory Boards have concluded from flow studies conducted by United States and Canadian agencies, that there is substantial mixing of waters in the lakes to the extent that concentration levels of polluting materials are remarkably uniform throughout extensive areas of each lake. Thus, there appears to be no doubt that all major sources of pollution to the lakes have contributed directly, or indirectly, to their generally degraded condition.

To support this finding the following evidence is provided:

1. nutrients, especially phosphorus, have been and are being added to the waters of reference in such quantities that Lake Erie, particularly the western basin, is in an advanced state of eutrophication. Similarly, accelerated eutrophication is occurring in Lake Ontario with the effects being carried into the St. Lawrence River.

2. the eutrophic conditions described above have caused excessive algal growths which interfere with water uses, including water supplies, aquatic life, aesthetics, industrial uses, recreation and shoreline properties.

3. commercial fisheries statistics while showing relatively stable catches over the last forty years in terms of weight indicate that dramatic changes in the fish populations have occurred. The contribution to the annual catch made by once abundant and valuable species has decreased while that of less valuable species has increased. This important change, at least in part, is attributable to the effects of pollutants.

4. disposal of dredged materials, floating refuse, and suspended materials also cause pollution problems in the lakes.

5. bacterial contamination occurs in local areas, mostly along the United States shores of Lake Erie and the Canadian shores of Lake Ontario.

6. additional pollutants that are of immediate concern in the referenced waters are organic contaminants, spills of oil and other hazardous substances, radioactive materials, viral contamination and thermal pollution.

Extent

The Advisory Boards conclude that serious pollution problems exist throughout the waters of reference including many beach areas and the shoreline.

To support this finding the following evidence is provided:

1. pollutants entering the boundary waters are first identified as point sources with local effects.

2. dispersion soon diminishes the local effects but over the years pollutants have continued to reach the lakes in very large quantities so that the general quality of the lake waters has deteriorated significantly.

3. serious pollution problems are occurring in local waters and harbours. Complexes of urban and industrial development have been created without adequate knowledge of the effects of multiple releases of wastes to the lakes.

4. the large increase in population and industrial activity anticipated in the lower lakes basin over the next twenty years may necessitate restrictions on some developments to protect the resources of the lakes. These restrictions could be avoided if adequate provision is made to restore and maintain water quality.

Causes and Localities

The Advisory Boards conclude that the major sources of pollution to the referenced waters are municipalities and industries. Municipal wastes comprise the principal source of phosphorus to the lower lakes. Municipal and industrial wastes also contribute dissolved and suspended solids, oxygen-consuming materials, toxic substances and pathogens.

The following specific sources of pollution are identified:

1. the major contribution of many polluting materials to Lake Erie arises from the Detroit River, which receives very large quantities of pollutants from the heavily industrialized Detroit metropolitan area, and partially treated sewage from the City of Windsor, Ontario.

2. the Maumee River at the western end of the lake, and the Cuyahoga River at Cleveland discharge significant amounts of pollution to Lake Erie.

3. the Niagara River is the greatest contributor of pollutants to Lake Ontario. Already in a nutrient-enriched state from Lake Erie, the Niagara River receives additional waste materials from the heavily industrialized Buffalo and Niagara Falls areas on the United States shore. Finally, the city of Niagara Falls, New York, discharges poorly treated wastes to the river.

4. Rochester and Toronto contribute major amounts of nutrients to Lake Ontario.

5. waste discharges from private and commercial vessels are sources of pollution to both lakes.

6. disposal of dredged materials is a significant source of pollution in some areas.

7. nutrient runoff from agricultural lands is considered to be a source of pollution but there is limited reliable information at the present time on the magnitude of this contribution.

8. oil and gas well drilling in the lakes must be recognized as a potential source of pollution. Because of a number of generally favourable conditions surrounding the extensive well drilling activity in the Canadian portion of Lake Erie, (uncomplicated geological conditions, effective regulations and good operational practices) no serious problems have arisen.

Finally, there are two general conclusions to which the Advisory Boards can readily find unanimous agreement. First, that the lower lakes (Erie and Ontario) and the international section of the St. Lawrence River are seriously polluted from waste sources in Canada and the United States to the detriment of both countries; and second, that vigorous and effective remedial programs must be carried out promptly and on a continuing basis, to reverse the deteriorating conditions of the lakes.

1.2 RECOMMENDATIONS

The Boards recommend:

1. that the Commission adopt the Water Quality Objectives as set forth in this report for Lake Erie, Lake Ontario and the international section of the St. Lawrence River and further that new water quality objectives be developed for the Connecting Channels to replace objectives adopted by the Commission in 1951 from the Report on Pollution of Boundary Waters (1950).

2. that a program of phosphorus[1] control be implemented in the drainage basins of Lakes Erie and Ontario to reduce the adverse effects on water quality and water use resulting from excessive biological growth. The required reduction be achieved by:

(a) immediate reduction to minimum practical levels of the phosphorus content of detergents and the amounts of phosphate-based detergents used; complete replacement of phosphorus compounds in detergents with environmentally less harmful substitutes as soon as possible, but not later than 1972.

(b) implementing programs for the reduction of phosphorus from municipal and industrial waste effluents discharging directly to Lake Erie and Lake Ontario, and for the necessary treatment of waste effluents discharging to the tributaries where the influence of these on the lakes is significant.

Facilities for the control of discharges directly to Lake Erie and the Detroit River should be provided no later than 1972 and for their tributaries, including Lake St. Clair and the St. Clair River, no later than 1975. Similarly, facilities for the control of discharges directly to Lake Ontario and the Niagara River should be provided no later than 1975 and for their tributaries no later than 1978.

In the initial stage of this program, these facilities are to provide by the above dates not less than an 80 percent reduction of the phosphorus from municipal and industrial waste loads discharged to the Lake Erie and Ontario basins from the Province of Ontario and the States of New York, Pennsylvania, Ohio, Indiana and Michigan. It is anticipated that by 1986,

[1]The term phosphorus in this report refers to phosphorus as a constituent of various organic and inorganic complexes and compounds, not to elemental phosphorus as a chemical substance. Concentrations and loads are given in terms of the element phosphorus to assure uniformity of expression.

reductions of 95 percent or more will be required for Lake Erie.

(c) the development of programs for the control of phosphorus from agricultural activities. State and provincial water pollution control agencies should encourage and assist agricultural agencies in the development of such programs as soon as possible, but not later than 1972.

(d) regulation of any new uses or significant changes in the addition of phosphorus to the drainage basins that would result in appreciable additions to the lakes.

3. that state and provincial agencies accelerate their pollution control programs where necessary to meet the objectives recommended in this report.

4. that federal, provincial, state and local agencies, authorities and commissions review their existing laws and regulations relating to the reporting and control of spills and disposal of oil and toxic or deleterious substances, including transportation of these materials, and strengthen programs, laws and regulations where necessary. Such programs, laws and regulations are required to prevent discharges of these substances to waterways and to improve the capability for control and clean up in the event of spills.

5. that an international contingency plan be formulated to deal with pollution incidents (a discharge of oil or other hazardous substance of such magnitude or significance as to require immediate response to contain, clean up or dispose of the material to prevent conditions threatening public health, welfare, safety and damage to property).

6. that the Province of Ontario and the States of New York, Pennsylvania, Ohio and Michigan develop compatible policies and regulations by 1970 with reference to the prevention of pollution from oil and gas exploration and production in the referenced waters.

7. that federal, provincial and state laws be reviewed and revised where necessary to provide legislation for water quality management authorities to prevent or abate pollution where a number of waste sources in more than one jurisdiction collectively cause pollution or deteriorate water quality.

8. that adequate water quality surveillance and monitoring activities be maintained in the referenced waters including inputs from tributaries to allow for assessment of and

adjustments to programs of enforcement, management, planning and research.

9. that compatible legislation for the control of water pollution from all classes of boats and vessels be considered by the various governments and implemented by 1970. Further, that the various governments consider the possible need to regulate commercial bulk transport of hazardous materials.

10. that dredged material containing objectionable quantities of pollutants be disposed of in a manner to protect the quality of the referenced waters; control of disposal operations be put into effect by 1972 or earlier and that unconfined open lake dumping of such material be prohibited.

11. that federal, provincial, state and local agencies review existing or potential pollution problems associated with solid waste disposal practices and existing laws and regulations relating to solid wastes to provide effective methods for the prevention of water pollution.

12. that compatible and coordinated programs designed to effectively control pollution from herbicides and pesticides be implemented by 1972 and that substitutes be found for persistent toxic chemicals and their use encouraged.

13. that viral research be intensified so as to determine the significance of viruses in water, the epidemiologic relationship of the various types and amounts of viruses in waters used for recreation and human consumption, and morbidity caused by exposure to viruses.

14. that municipal and industrial waste collection and treatment systems be operated and maintained to avoid bypassing of untreated wastes and to attain as a minimum standard the approved design and degree of treatment at all times.

15. that municipalities carry out policies of separating combined storm and sanitary sewage collection systems in newly developed areas; in areas with existing combined sewer systems, separation of the storm and sanitary systems be undertaken or control measures be instituted to prevent pollution from combined sewer overflows, and further that all municipalities submit for approval plans for abating pollution from combined sewers by 1972.

16. that power companies, private interests and authorities planning thermal power plants on Lake Erie and Lake Ontario be required to submit plans to pollution control agencies to ensure that site selection and design are such as to eliminate or minimize adverse effects on the receiving waters of thermal

inputs and radioactive materials and that the effects of large thermal inputs to these lakes be evaluated by power authorities, private interests and water pollution control agencies.

17. that the federal, provincial and state governments give high priority to the support of research essential for the continuing improved management of water resources.

18. that federal, state and provincial agencies begin or accelerate programs to control riverbank and shore erosion.

19. that an appropriate Board be appointed on a continuing basis for the coordination of joint international programs in water pollution control of the Great Lakes. This coordination is to include:

(a) water quality objectives and plans for their attainment.

(b) recommendations for legislation affecting these waters.

(c) a water quality management model for the Great Lakes.

(d) development of plans and programs to prevent spills of polluting materials and to handle the contingencies arising from spills should they occur.

(e) monitoring and surveillance.

(f) research.

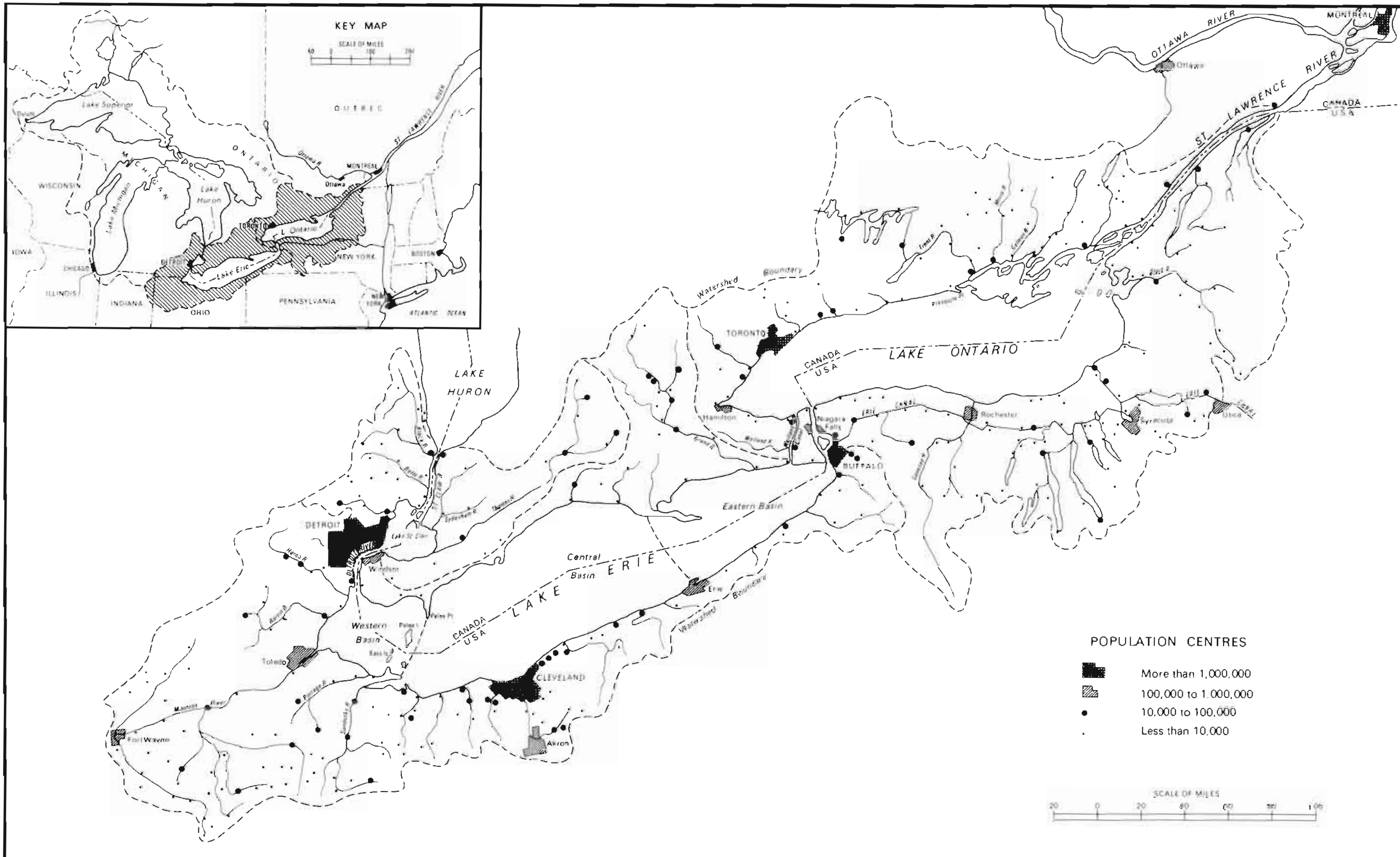


Fig. 2. 1. 1 Lake Erie and Lake Ontario drainage basins.

2. DESCRIPTION OF STUDY AREA

2.1 PHYSICAL FEATURES

Lakes Erie and Ontario occupy the terminal portion of the system of Great Lakes drained by the St. Lawrence River. They are the smallest of the Great Lakes and for that reason are more sensitive and responsive to changes induced by human activities. This is particularly true of Lake Erie which has a mean depth of only 58 ft (18 m).

The two lakes drain a total of 59,000 square miles of watershed area, excluding the watershed of the upper lakes. This area extends into four bordering states and covers a large portion of southern Ontario. The Lake Ontario drainage basin is almost equally divided between the United States and Canada, whereas 70 percent of the Lake Erie basin lies wholly within the United States (Fig. 2.1.1).

The climate of the region is continental in character, with localized influences due to the lakes themselves. Prevailing winds in the winter are from the northwest and southwest sectors, whereas summer winds predominate from the south to the northeast sectors. Average annual precipitation is in the range of 29 to 32 inches. The leeward shores of the lakes receive the highest precipitation, mostly as snowfall during winter.

The mean discharge rates used in this report are 178,000 cubic feet per second (cfs) for the Detroit River at the entrance to Lake Erie; 202,000 cfs for the Welland Canal and Niagara River; and 232,000 cfs for the St. Lawrence River at the outlet of Lake Ontario. Variations in water level are more pronounced in Lake Erie than in Lake Ontario due to the shallow depth and the fact that water levels of Lake Erie are not regulated.

Both lake basins are erosional in origin, the shape and orientation having been controlled by the nature of the underlying bedrock. The island chains of western Lake Erie are formed of erosion-resistant dolomite formations, while the remainder of the Lake Erie basin is a composite of two depressions located in areas of weak shale and siltstone bedrock. The bedrock is mantled with thick unconsolidated glacial and late-glacial deposits, particularly in the eastern and central basins. The Lake Ontario basin is situated along an outcrop band of soft shale bedrock, with underlying sedimentary rock strata of shale, limestone, dolomite and sandstone. The strata lap to the north to a complex of older igneous and metamorphic rocks known as the Canadian Shield.

Following the last ice retreat the whole area has undergone uplift resulting in the formation of dramatic shore bluffs in Lake Erie which are being eroded by wave action.

2.2 POPULATION

The whole of the Great Lakes basin supported fewer than 300,000 persons early in the nineteenth century. In 1966, 30 million people lived on the shores of or near the Great Lakes, equivalent to about one in every three Canadians and one in eight Americans, a one hundredfold increase in population in 150 years. In 1966, in the Lake Erie basin the population was 10.4 million persons on the United States and 1.4 million on the Canadian side. In the Lake Ontario basin the populations in 1966 were 2.3 and 3.8 million on the United States and Canadian sides, respectively.

In the Great Lakes basin there are essentially four major zones of urbanization, Cleveland-Akron-Lorain, Windsor-Detroit-Flint, Toronto-Hamilton-Buffalo, and Chicago-Milwaukee. The first two of these exert a direct influence on the waters of Lake Erie, and the third on Lake Ontario.

In the Lake Ontario basin population is concentrated in an arc extending from the western end of the lake from Niagara to just east of Oshawa, including the major urban areas of Hamilton and Toronto. Other population pressures are expected in the Rochester metropolitan area and the Oswego, Syracuse metropolitan areas on the southern shore of the lake. It is predicted that within the next 50 years a megalopolis will extend from Milwaukee on the west shore of Lake Michigan to Montreal supporting a population of some 50 million people (MacNish and Lawhead, 1968).

Even within as short a time span as 20 years a definite trend toward urbanization is clearly evident in the basins with accelerated growths taking place in many of the principal cities. It can be anticipated further that urban localities will account for the major portion of the projected increases in population and industry.

The problems of water supply and waste disposal with such central developments have already reached major proportions in some of the tributary basins. Future developments must be planned within broad basin concepts where a limitation in growth of population and industry might have to be recognized as a basic principle of water management policy.

2.3 NATURAL RESOURCES

Much of the total Great Lakes basin economy has developed in the Lake Erie and Lake Ontario basins because of the abundance of ores and minerals nearby. The proximity of these raw materials, low cost water transportation, minerals, petroleum, natural gas and timber has led to the centralization of many of the base metal and primary industries in both countries. It is estimated that in 1964 industry alone contributed about 18 billion dollars to the economy of the Lake Erie basin and about 7 billion dollars to that of the Lake Ontario basin. Industry ranks as the major economic base for both regions, but mining is an important aspect in Ontario since it contributes to a wide range of products. The farmland areas bordering the two lakes have had a significant effect on the economic development in the two basins.

The Lake Ontario basin contains large tracts of forested lands in the Precambrian areas bordering the lake. These regions are well-suited to recreation-oriented sports and are being developed by private and government interests. Lands have also been set aside on the lakes and channels for public parklands and recreation areas.

2.4 WATER USES

The water uses required to support the populations and industries in the basins are numerous. Those depending upon or affecting water quality are domestic and industrial water supplies, cooling waters, domestic and industrial waste water disposal, navigation, power development, agriculture, irrigation, fisheries and recreation.

Withdrawals of water for municipal use are heavy and indicative of the relative use pressures on the lakes by the two countries. United States municipalities withdraw some 634 million gallons per day (U.S. mgd) from Lake Erie while Canadian withdrawals amount to 20 mgd (Imp). In the Lake Ontario basin Canadian use is the heaviest with withdrawal of 349 mgd (Imp) versus 83 mgd (U.S.) in the United States.

Hydroelectric power authorities utilize the lake system for the power potential of the outlet rivers. The hydroelectric development of the lower lakes and rivers is approaching its potential capacity and is now being supplemented with major developments in thermal and nuclear power generating plants. These facilities and industry withdraw 13,000 mgd (U.S.) of water from both lakes, most of which is subsequently returned to the lakes.

Utilization of the lakes as a waterway dates back to the days of the early explorers and fur traders. Since then the waterway has been improved with navigation facilities, channels, locks and harbours making it one of the most sophisticated water transportation systems in the world. Traffic and tonnages have increased steadily since the seaway opened in 1959; tonnages have more than doubled in the Welland Canal and in the St. Lawrence Canal system over the period 1959 to 1966.

The increase in water-borne commerce may pose further threats to other water uses by the discharge of ship wastes and the potential danger of cargo and material spills from collisions or accidents.

PLATE I WATER USES IN LOWER LAKES

Summer Exodus to
Toronto Island

Swimming
in Lake Ontario

A Cool Drink

Commercial Waterway

3. WATER QUALITY PROBLEMS

3.1 ACCELERATING ENRICHMENT

3.1.1 Nature of the Problem

In recent years a great number of accounts have been published referring to Lake Erie as a dead or dying lake. Such articles have often led to a good deal of misinterpretation and misunderstanding. For this reason, it is necessary to consider the nature of the problem.

Suspended algae in open water (phytoplankton) and rooted plants and attached algae on the bottom in shallow areas constitute the plant life of lakes. These plants, directly or indirectly, serve as the source of food for all of the animals that make up the complex communities of life in lakes. Many factors control the biological productivity of lakes; however, since plant growth depends on the supply of essential nutrients, lakes well supplied with nutrients tend to be the most productive. Indeed, this relationship provides a recognized basis for lake classification.

According to the trophic system of lake classification, lakes are generally classified as *oligotrophic*, *mesotrophic* or *eutrophic*, depending on their degree of plant nutrient enrichment and biological productivity. Oligotrophic lakes are poorly supplied with plant nutrients and support little plant growth. As a result biological production is generally low, their waters are clear and the deeper waters are well supplied with oxygen throughout the year. Eutrophic lakes are rich in plant nutrients and support a heavy growth of plants. As a result, biological production is generally high, the waters are turbid because of the dense growth of phytoplankton, and the deeper waters during periods of restricted circulation become deficient in oxygen as a result of the decomposition of great quantities of organic material produced. Lakes intermediate between oligotrophic and eutrophic, that is, with a moderate supply of nutrients, moderate plant abundance and biological production, are known as *mesotrophic* lakes.

If the supply of nutrients to an extremely oligotrophic lake is progressively increased, the lake will become more mesotrophic in character; with further continuing enrichment it will eventually become eutrophic and finally extremely eutrophic. This whole process of progressively becoming more eutrophic is known as *eutrophication*. Thus, eutrophication refers to the whole complex of changes which accompany continuing enrichment by plant nutrients. These include progressive increases in the growth of algae and other plants, general increases in biological productivity, successive changes in the kinds of plants and animals living in the lake, oxygen depletion in deep water during periods of restricted circulation, and decreasing depth as a result of accumulating organic sediments. The three general lake types (oligotrophic, mesotrophic and eutrophic) are merely relative in that they indicate the general degree of eutrophy in a spectrum ranging from oligotrophy to eutrophy.

Sewage, some industrial wastes and surface runoff from heavily fertilized farmlands contain significant concentrations of essential plant nutrients which enrich lake waters. With increased urbanization, industrialization, intensified agricultural practices and use of phosphate-based detergents in recent decades, there has been an ever increasing number of examples of such enrichment and rapid eutrophication of lakes in many parts of the world. Lakes of all types and sizes have been affected. In some cases even very oligotrophic lakes have become eutrophic in a matter of a few decades. The end result of excessive enrichment is always the same: production of dense nuisance growths of algae and aquatic weeds that generally degrade water quality and render the lake useless for many purposes. Heavy enrichment particularly favours the growth of certain algae that produce unpleasant side effects. *Cladophora*, an attached alga growing on rocky shores often accumulates on beaches when disrupted by wave action. Blue-green algae can also accumulate at the shore as a result of wind action causing unsightly, odourous scums.

The similarity of the eutrophication resulting from man's activities as described above to natural eutrophication is often overemphasized. The natural enrichment and eutrophication of lakes are generally so slow that they can only be measured on a geological time scale. For example, most lakes in north temperate regions were created by glacial action six to twelve thousand years ago; yet many of these lakes are still in an oligotrophic condition. The extent of enrichment and eutrophication which has occurred in many of the world's lakes in the past few decades would require thousands of years under natural conditions. Indeed, such enrichment might never be possible naturally. It is unfortunate and misleading, that the drastic eutrophication in lakes affected by man is so often referred to as a mere acceleration of a natural phenomenon. This analogy often gives the impression that eutrophication is irreversible. That this is not true has been demonstrated in a number of cases where man's wastes have been diverted away from lakes and they have subsequently recovered to a less eutrophic condition.

Sewage effluents, certain industrial wastes and the runoff from agricultural land are all extremely rich in a number of plant nutrients. Of these nutrients, compounds of phosphorus and nitrogen are generally considered to be the most significant and their key role in eutrophication has long been recognized. Experience in many lakes has shown that of these two, phosphorus is most often the controlling nutrient. Although many other nutrients and growth promoting substances are common in sewage effluents and other wastes, there is no evidence from the present state of knowledge for attributing a principal role to any of these substances in the eutrophication process. On the other hand, they may play a role in determining the composition of the biological community or the type of algal water bloom.

The nature of the enrichment problem in Lakes Erie and Ontario is clearly the fertilizing effect of added nutrients in causing eutrophication. The nature of the problem is not that the lakes are dead; on the contrary, it is the abundance of life.

3.1.2 The Present State of Eutrophication

Table 3.1.1 gives the best available assessment of the current trophic state (oligotrophic-mesotrophic-eutrophic) of Lakes Ontario and Erie using a number of physical, chemical and biological criteria.

Based on the criteria examined in Table 3.1.1, it is concluded that Lake Ontario is presently in a stage of eutrophication between oligotrophic and mesotrophic. Lake Erie in its present condition is rather eutrophic, although it has some mesotrophic characteristics. It is obvious that the three interconnected basins (Fig. 2.1.1) of Lake Erie differ in their degree of eutrophy. The western basin is clearly eutrophic. The central basin is moderately eutrophic and the eastern basin is mesotrophic with some oligotrophic characteristics.

The differences in degree of eutrophy shown by Lakes Ontario and Erie and the three basins of Lake Erie should be expected for a number of reasons. First, other things being equal, the shallower a lake is the more predisposed it is towards eutrophy. With a given supply of plant nutrients per unit of lake surface area, the shallower the lake the higher the concentration of nutrients in the lake water and the greater the fertilizing effect on plant growth. In this regard, Lake Erie (mean depth 18 metres) is more prone to eutrophy than Lake Ontario (mean depth 84 metres). Similarly, the western basin of Lake Erie (mean depth 6.9 metres) is more disposed to eutrophy than the central basin (mean depth 18.5 metres) or the eastern basin (mean depth 24.4 metres). Another obvious cause for the differences among the basins of Lake Erie is the location of nutrient inputs. More than half of the total phosphorus and total nitrogen inputs to Lake Erie enter directly into the western basin. Considering the rapid uptake of nutrients and their deposition in the lake sediments, and the gross movement of water through Lake Erie from west to east, there is little doubt that the western basin serves in some degree as a nutrient trap for the central basin. The central basin acts similarly for the eastern basin, just as Lake Erie as a whole serves as a nutrient trap for Lake Ontario and Lake Ontario for the St. Lawrence River. Of the total input of phosphorus entering Lake Erie only 16 percent leaves the lake through the outlet; and of the total nitrogen entering Lake Erie only 44 percent leaves the lake.

The inshore waters of Lake Erie and Lake Ontario are more eutrophic than offshore waters. This is a reflection of the shallower depths involved and the fact that most nutrient inputs, both natural and man-derived, enter along the shores. The geographical proximity of these highly eutrophic problem areas to known centres of nutrient pollution is perhaps the best evidence that the activities of man are creating the problem.

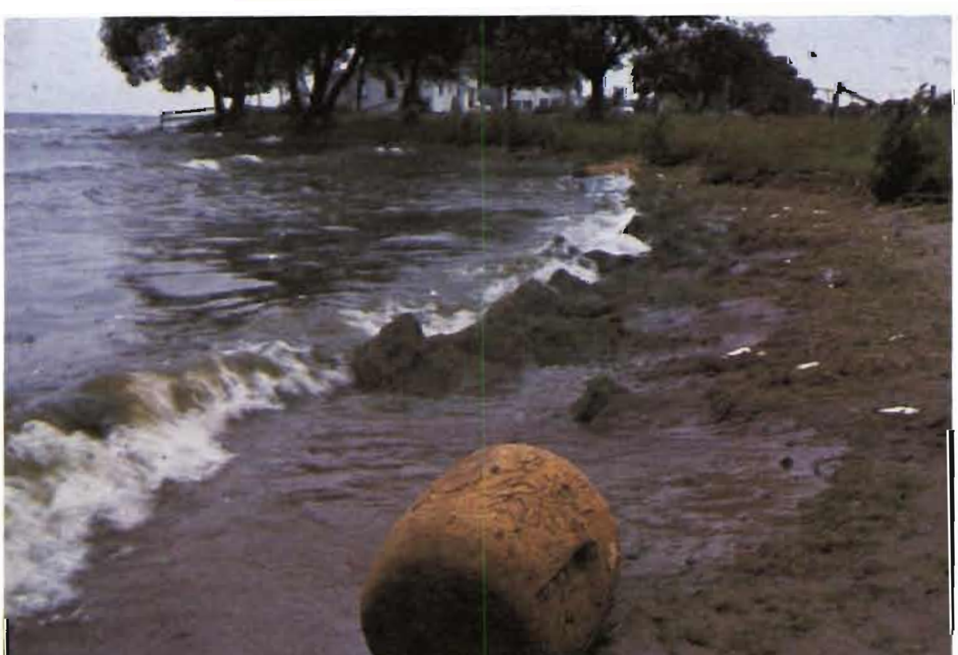
3.1.3 Recent Changes and Water Quality Problems

There is a serious deficiency of statistically valid limnological data on Lakes Erie and Ontario from earlier years. What little historical information does exist is primarily for the western basin of Lake Erie. Nonetheless, evidences of recent rapid eutrophication have been documented in a number of publications: Beeton (1961 and 1965), Davis (1964), Schenk and Thompson (1965).

The best evidence of recent dramatic changes in Lakes Erie and Ontario is the long history on certain chemical data examined by Beeton (1965). These data are presented in Fig. 3.1.1. Although variability of the data prevents the determination of the fine details of the trends in concentration, the curves show that marked increases have occurred since 1910. The increases have been greatest for chloride and sulphate, both of which are conspicuous in domestic and industrial wastes. The chemicals in Fig. 3.1.1 of course are not growth-limiting plant nutrients. With reference to total phosphorus concentrations, data over a shorter period of time from the western basin of Lake Erie show increases from 14 μg/l in 1942 to 33 μg/l in 1958, 36 μg/l in 1959 and 40 μg/l in 1967/68. These figures indicate an even greater increase in phosphorus than shown by any of the chemicals in Fig. 3.1.1. Similar dramatic increases in phosphorus have been observed in other lakes in various parts of the world and correspond well with the widely increasing use of phosphate-rich detergents since the 1940's (Vollenweider, 1968).

PLATE II **CLADOPHORA PROBLEMS**

Beaches littered with decaying algae lower property values. North shore Lake Erie, east of Welland Canal entrance.



Attached algae, East end of Lake Ontario, Wolfe Island Ferry Dock.

Table 3.1.1 Best overall estimates of current trophic states in the open waters of the three basins of Lake Erie and in the open waters of Lake Ontario. It must be recognized that the range from oligotrophy (O), mesotrophy (M), and eutrophy (E) is continuous.

Category	Lake Erie			Lake Ontario
	western basin	central basin	eastern basin	
Physico-chemical:				
Morphometry	E	M-E	O-M	O
Transparency	E	M	M	M
Nutrient concentrations	E	M	M	M
Nutrient loading		E*		M
O_2 in hypolimnion	**	M-E	O	O
Biological:				
Phytoplankton	E	M	M	O-M
Zooplankton	E	M	M	O-M
Bottom fauna	E	M-E	O-M	O-M
Fish production		E*		O
Overall assessment:	E	M-E	O-M	O-M

*For the lake as a whole.

**The western basin of Lake Erie is normally unstratified in summer.

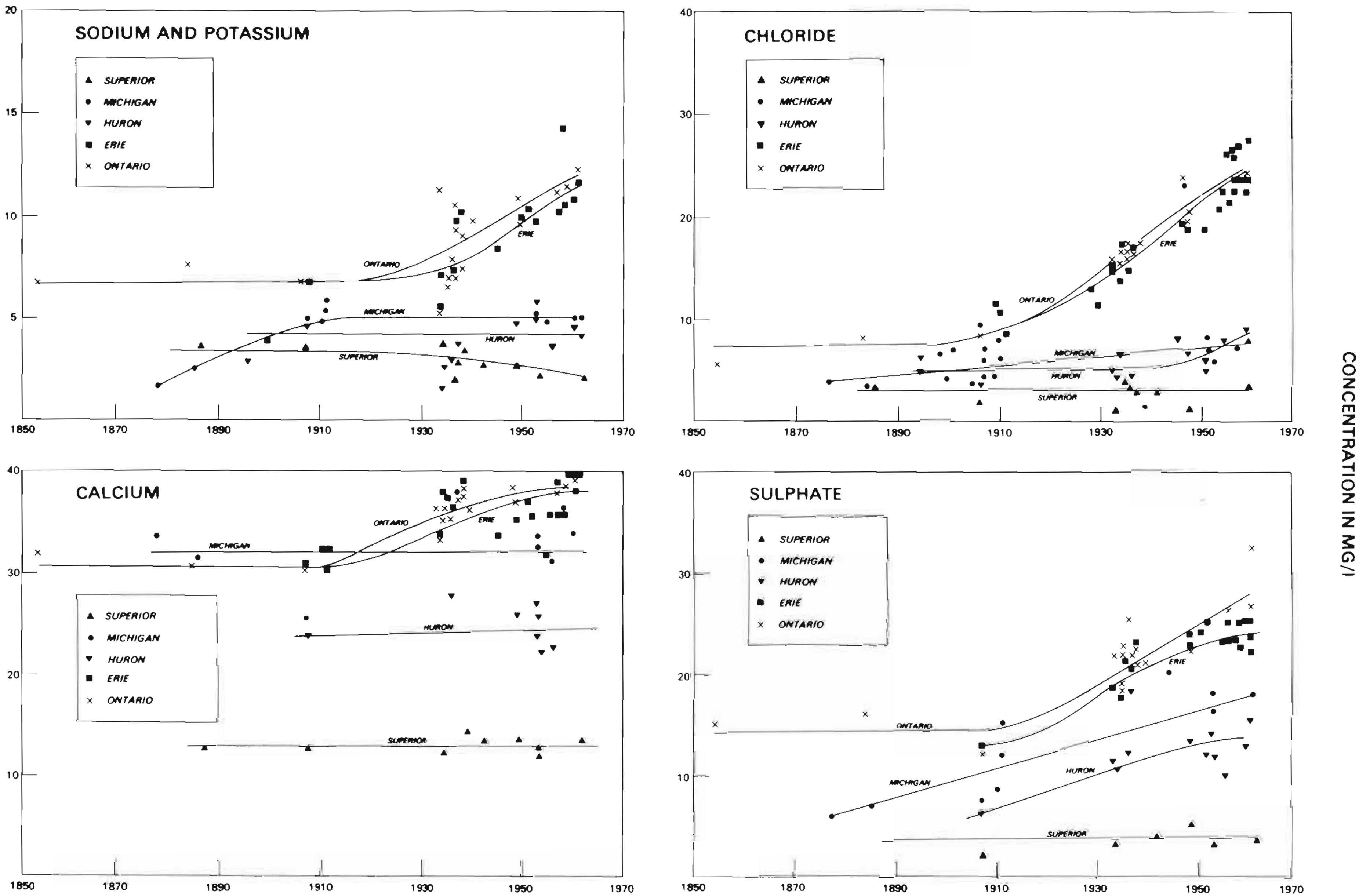


Fig. 3. 1. 1 Changes in the chemical characteristics of Great Lakes waters (after Beeton, 1965).

PLATE III WATER QUALITY PROBLEMS

Sailboat
avoids polluted waters
of Genesee River,
Rochester, N.Y.

Algal scum at
Oak Orchard Creek outlet
to Lake Ontario.

Poor handling of solid wastes,
near Cleveland, Ohio.

There has been a recent rapid eutrophication of Lake Erie's western basin. Studies carried out between 1928 and 1957 showed that the phytoplankton was dominated by species of diatoms. More recent work indicates an increasing representation of flagellates, blue-green and green algae during the summer and fall. Nuisance growths of *Cladophora* have been reported for many years in the island area of the western basin. The extent of these nuisance growths has increased substantially in recent years. Marked changes in the abundance and species of zooplankton have occurred since 1939 in the western basin. Great modifications of the bottom fauna in the western basin, the island area and the western part of the central basin have also occurred over the period from 1930 to 1961. The caddis fly larvae and mayfly nymphs formerly extremely abundant in these areas have all but disappeared. Concurrently, there have been tremendous increases in the types of bottom organisms typical of eutrophic waters (a tenfold increase in the abundance of sludge-worms, and a fourfold increase in the abundance of midge larvae). Also, these eutrophic forms have extended their range of distribution into the adjacent parts of the central basin.

Evidence of recent changes in the central and eastern basins of Lake Erie is more limited. However, in the Cleveland area Davis (1964) has shown that average algal abundance increased from 100-200 cells per ml in 1927/30, to 1200 cells per ml in 1944/48, and to 1300-2400 cells per ml in 1960/64. The generic composition of the phytoplankton also changed during this time to forms more typical of eutrophic waters. In recent years there have also been increases in the frequency and extent of blue-green algal blooms and in nuisance growths of *Cladophora* and rooted aquatic plants in both the central and eastern basins of Lake Erie. Although there are no data adequate to assess the degree of increase in nutrient levels in the eastern and central basins during the past 50 years, the increased algal growth itself reflects the likely trend. The general pattern of nutrient increase has probably been similar to that shown for the western basin of Lake Erie. Low dissolved oxygen concentrations during late summer were detected in limited areas of the bottom waters in the central basin as early as 1929. Recent observations indicate that such oxygen depletions have become more severe, widespread and prolonged.

Commercial fishing records give reliable evidence that marked changes in the fish populations of Lake Erie have occurred during the past 40 years. These changes are the result of a number of factors, overfishing, pollution, sea lamprey predation, and invasion by such introduced species as the smelt and the alewife. However, some of the changes that have occurred, particularly the drastic decline of both lake herring and whitefish, are typical of the changes in fish populations which accompany eutrophication. The low levels of oxygen found in the cold hypolimnetic waters of the central basin during the late summer are well below those regarded as minimum for healthy maintenance of fish populations. The declines of lake herring, whitefish, and blue-pike, all of which require low water temperatures may well be associated with increasing oxygen depletion in the deep waters of the central and eastern basins. Lake herring, whitefish, walleye, blue-pike and sauger spawn over rocky or gravel shoals. It is suspected that the decline of these species may be related to increasing algal growth or accumulation of organic deposits on spawning grounds. In spite of all the changes in commercial fish catches in Lake Erie over the past 40 years the total catch from the lake has remained at about the same level. The major change has been in the kinds of fish, with less valuable forms now predominating.

Adequate historical data are not available to assess the extent to which the trophic status of Lake Ontario as a whole has been modified by human activity; however, localized changes are evident. Schenk and Thompson (1965) have shown that average phytoplankton populations doubled in concentration at the Toronto Island Filtration Plant during the period from 1923 to 1954, with associated increases in nutrients as well. A most obvious change in recent times has been the general increased nuisance growth of *Cladophora* and rooted plants in many inshore areas.

Striking changes in the fish fauna of Lake Ontario have also occurred in the past three decades. There have been drastic declines in the abundance of the more valuable and desirable salmonid and coregonid species typical of oligotrophic lakes. Except in some localized areas (Bay of Quinte) there has been no excessive oxygen depletion in the deep cool waters as in Lake Erie. On the other hand, excessive growths of *Cladophora* on some spawning grounds are believed to have had an adverse effect.

In summary, the water quality problems which have developed as a result of biological changes in Lakes Erie and Ontario in recent years are as follows:

1. in some areas the increasing growths of algae have led to a deterioration in the quality of the domestic water supply as a result of taste and odour problems. Algae have also caused problems in water treatment plants by clogging of filters, thereby increasing the costs of water treatment.

2. nuisance growths of rooted aquatic plants such as *Cladophora* and blooms of blue-green algae have impaired the aesthetic qualities of water and interferred with recreational activities. Such growths have also been a problem in the fouling of commercial fish nets. When these luxuriant plant growths are blown ashore they litter beaches in many areas with masses of decaying matter which cause obnoxious odours and generally foul the beaches and desirable shoreline property.

3. dramatic changes in the fish populations have occurred. Once abundant and valuable species have been replaced by species of less value both to the commercial and the sport fishery. Although other causes are involved (overfishing, lamprey predation and invasion by new species) nutrient pollution is at least in part responsible.

4. in Lakes Ontario and Erie during the months of June to August, many beaches are littered with the dead remains of alewife, smelt, perch, white bass and gizzard shad. In recent years the alewife has become increasingly prominent among the dead forms. Fish mortalities of the magnitude observed in Lake Michigan in 1967 (which cost the City of Chicago nearly a quarter of a million dollars just to clean its beaches) have not occurred in Lake Erie or Lake Ontario; however, alewife mortalities still constitute a serious problem.

Although many of the present water quality problems are localized, there can be no question that the entire lakes are being affected. Unless some action is taken to curb this rapid eutrophication, there will be an ever increasing deterioration of water quality.

3.2 ACCUMULATING SOLIDS

3.2.1 Sediments

The probable major sources of the post-glacial mud accumulations in the lakes are erosion of soils in the drainage area, shoreline recession and reworking of shallow lake bottom deposits. Although studies are now underway, sufficient information is not yet available to accurately assess rates of sediment accumulation, or the rates of exchange of organic matter, phosphorus and nitrogen between the sediments and the lake waters.

PLATE IV OIL PROBLEMS

Oil covered shoreline,
Burlington Bay,
Hamilton, Ontario.

Ducks,
covered with oil
and helpless,
freeze into the
ice and die
from exposure.

Typical slick
from spill of
heavy oil
to confined area.

Glacial deposits are widely exposed on the lake beds adjacent to the shore. These are generally lake clays and clay tills characterized by a stiff to hard consistency, and a lack of organic matter. Approximately 58 percent of the lake bottom in Lake Erie is covered with a grey silty clay or clay mud deposit. The mud occurs as a continuous offshore deposit within each sub-basin.

The highly polluted state of bottom sediments in the western basin of Lake Erie is indicated by the spread, and increase in population density of sludge worms in this area (Section 3.1.3). Examination of the total organic content of bottom muds in Lake Ontario has revealed that up to 6 percent occurs along the axis of the central part of Lake Ontario in the Kingston basin area and in the muds of the western basin extending out as a tongue from the mouth of the Niagara River.

In most areas, oxidizing conditions prevail within the top centimetre of sediment. This mud surface is usually capped by a thin oxidized microzone, believed to be enriched ferric hydroxide and ferric phosphate. It forms a chemical barrier that keeps phosphate ions in the reduced sedimentary layer below from going into solution, and also assimilates material falling to the bottom. However, at times of oxygen depletion of the bottom water, the microzone is destroyed. This results in a release of phosphate and ferrous ions to the overlying waters.

Though the clay deposits, so widely distributed in Lake Erie and Lake Ontario, may be an asset so far as their sorptive capacity for phosphate is concerned, they are affecting spawning areas of desirable fish forms and degrading sand and gravel deposits in Lake Erie and Lake Ontario. Some of the gravel deposits are commercially valuable and have been mined in both lakes. Continuous encroachment on these areas by muds may well render a natural resource less valuable. Even if it was not necessary to limit shore erosion to protect lake front properties, it would be necessary to prevent the further deterioration of spawning areas and sand and gravel deposits in the lakes.

3.2.2 Disposal of Dredging Spoils

Dredging is another means by which muds and pollutants are introduced and redistributed in the lakes from heavily silted and polluted tributaries and harbour areas.

The maintenance of adequate navigation depths requires routine dredging of both commercial and recreational harbours and ship channels. The materials dredged from harbours at river mouths are composed mainly of eroded soils with varying amounts of municipal and industrial wastes. Some of these sediments contain large amounts of pollutants such as oil, toxic materials, metals, nutrients, and oxygen-consuming substances. On the other hand, materials dredged from outer harbour areas may consist of lake sediments moved into the channels by storms and currents. Lake disposal of these materials may not be objectionable from the standpoint of water quality, but may affect other aspects of the water environment such as fish spawning grounds and wildlife feeding areas.

In most harbours it has been customary to dispose of the dredged materials in deep waters a few miles offshore, but pollution from this source may still degrade water quality. The dredging operation itself may also damage water quality through resuspension of pollution-bearing sediments.

Dredging in Lake Erie is fairly extensive occurring periodically in some 22 ports, harbours or river mouths. In 1967 over 6 million cubic yards of material were dredged and dumped into the lake. Dredging in Lake Ontario is less extensive, occurring periodically in various ports, harbours and river mouths.

3.2.3 Floating Materials and Refuse

Floating materials and refuse are nuisances in Lake Erie, Lake Ontario and the international section of the St. Lawrence River. These generally result from the irresponsible dumping of garbage and rubbish by commercial vessels and pleasure craft and by unauthorized disposal from shore properties. Floating garbage and rubbish are not generally present in large enough quantities to cause chemical or biological deterioration of water quality, or to cause a hazard to health. The problem is, nevertheless, a nuisance at water intakes and to shore property owners, swimmers and boaters.

3.2.4 Suspended Materials and Turbidity

Turbidity is a measure of the extent to which suspended matter in water inhibits the penetration of light because of particle scattering and absorption. Increases in turbidity result from material carried into the lakes by rivers, erosion of shore bluffs, wind-induced water turbulence and plankton.

Since the growth of plankton depends upon the availability of light, turbidity is an important physical factor affecting plankton production. High turbidity values are also a measure of the suspended loads in the water. Turbid water frequently occurs near tributaries and along the shore where it reduces the aesthetic quality and endangers spawning beds from deposition and sedimentation. The source and composition of the material are difficult to trace and identify.

Except for the detrimental effects of turbidity on aquatic life and the impaired aesthetics of beaches, the present levels do not seriously affect the water quality of the lakes and the international section of the St. Lawrence River for most uses.

3.2.5 Total Dissolved Solids

Dissolved solids represent the residue left on evaporation of a filtered sample of water. They have increased from approximately 140 mg/l in 1910 to about 185 mg/l in 1967 in both lakes. Present levels of dissolved solids in Lake Erie and Lake Ontario are still well below the maximum allowable concentration of the United States Public Health Service standards for drinking water (United States Public Health Service, 1962). The waters are suitable for irrigation but may need treatment for some industrial uses.

Though these increases in themselves do not pose any immediate danger to the use of the waters, they do indicate the changes which have occurred through man's use of the Great Lakes and their Connecting Channels as receiving waters for wastes.

3.3 BACTERIAL CONTAMINATION

The abundance of coliform bacteria has long been used to evaluate water quality in relation to public health. This group of organisms includes three important biotypes: *Enterobacter*, and *Citrobacter* which are usually found on plants and grains, in the soil and to a small extent in human and animal feces; and *Escherichia*, which originates in the intestinal tract of man and animals. Although coliforms are not normally regarded as pathogenic, the presence of members of this group in a water serves as an indication of the potential presence of the scarcer, and much more difficult to isolate, pathogenic organisms of the digestive tract, such as those causing typhoid fever, dysentry and cholera. Standards for water quality are based to a large extent on coliform concentrations.

Data collected from the 1963-1964 and 1966-1967 Lake Erie studies indicate that coliform concentrations in the main body of Lake Erie are low (mostly less than 5 coliforms per 100 ml). However, several inshore areas do have bacterial pollution problems. These areas are immediately adjacent to major population centres and at the mouths of the large tributaries entering Lake Erie (Toledo and Cleveland, Ohio, Erie, Pennsylvania, Port Maitland, Ontario, and the Detroit, Maumee, Cuyahoga and Grand Rivers).

All bacterial pollution appears to be localized. The collected 1963-64 and 1966-67 data do not indicate transboundary pollution with the exception of the Detroit River, where a transboundary effect has been noted.

The majority of Lake Erie water samples collected more than two miles offshore had median coliform densities of less than 1 coliform per 100 ml or at the most, 10 coliforms per 100 ml. The lowest densities occurred in deep water samples. Preliminary winter data though sparse, were comparable to those obtained during the summer.

The highest counts for the majority of bacteriological parameters studied in 1966-67 were observed in the western basin. Studies were of necessity confined to waters navigable by deep draught vessels. Studies of the shallower waters of the western basin in 1963-64 indicated that the highest lakewide coliform levels occurred in the vicinity of the major tributaries. High counts were observed consistently at all depths in these areas.

In the central basin the majority of sampling stations had median coliform densities of 5 or less per 100 ml. Though the Cuyahoga River contributed greatly to the pollution of the Cleveland area, the 1963-64 and 1966-67 data indicate that bacterial pollution from this source does not penetrate deeply into the lake but instead follows the shoreline in an easterly direction.

Data collected in the eastern basin during the 1966-67 study indicate that this is the least polluted basin in Lake Erie, with the exception of the harbours at Port Maitland, Ontario, and Erie, Pennsylvania (beaches at Presque Isle are not affected).

Although the offshore waters of Lake Erie can be classified bacteriologically as good, there are very serious problems of bacterial pollution in nearshore waters. There is a direct hazard to health, particularly near the large metropolitan centres of Detroit, Toledo, Cleveland and Buffalo. Raw sewage, discharged directly to the lake, much of it from combined sewers, is the major source.

Approximately one-third of the United States shoreline is either continuously or intermittently fouled with bacterial contamination, in particular Michigan beaches near the mouth of the Detroit River and those near Cleveland. In general, Canadian shore waters are much more acceptable than United States shore waters. Bacterial contamination, however, is evident on the Canadian side of the Detroit River and can be traced for 10 miles to the east along the north shore of Lake

Erie. Shoreline bacterial contamination has not affected waters for public water supply, since most intakes are located well out from shore away from points of waste input.

In Lake Ontario the bacterial quality of offshore waters is excellent, but degradation occurs along the shoreline and in harbour areas. High bacterial densities show a close correlation with heavily populated areas. Tributaries in most instances introduce fairly high quantities of bacterially polluted water into the lake. The tributary waters mix and dissipate their pollutional load in the lakes and except for inshore and harbour areas in close proximity to the tributary mouths, the water quality of the inshore areas remains good.

The Niagara River is one of the major contributors of bacterial pollution to Lake Ontario. The highest coliform, fecal coliform and fecal streptococcus median densities recorded in 1967 were at stations in the Niagara River area.

Data obtained from a survey of the southern shore indicate that the lake readily assimilates tributary waters and except for a few inshore stations east of Rochester, New York, there is only minimal pollution with the majority of stations recording median coliform counts of less than 5 coliforms per 100 ml. The study of Canadian inshore waters has revealed that the majority of tributaries west of Oshawa were discharging polluted waters into Lake Ontario with recorded median coliform densities in excess of 2,400 coliforms per 100 ml. However, median coliform counts one mile from shore were less than 100 and two miles from shore were less than 10 coliforms per 100 ml.

Local bacterial pollution problems are common near populated areas and have resulted in the closure of bathing beaches, particularly in the vicinities of Toronto and Rochester. The coliform-polluted areas, however, are limited to waters well within two miles from shore.

Bacterial pollution in the international section of the St. Lawrence River is local in nature and there is no evidence of transboundary movement of such contamination. In general, shoreline bacterial contaminations in Lake Ontario and the international section of the St. Lawrence River have not affected waters for public water supply, since intakes have been constructed away from points of waste inputs.

3.4 OIL SPILLS AND DISASTERS

The risks of contamination by oil and other hazardous substances are as numerous and varied as the uses of the materials and the means of transportation. These involve almost any form of manufacture, production, storage and transportation networks encompassing terminal and dockside facilities, tank farms, loading facilities, freighters, pipelines, tank cars and trucks.

Apart from major oil spills, severe cases of local pollution have occurred as the result of mishaps in transferring petroleum products between ship and shore, discharging ballast from vessels, cleaning oil tanks and from the negligent discharge of oily bilge wastes. These accidents occur at the rate of several a month during the shipping season on the Great Lakes. Some 30 sunken ships in the two lakes also pose a threat of oil pollution.

Other potential hazards in the lower lakes arise from oil and gas drilling on submerged lands in Lake Erie where such operations hold a potential risk for blowouts of wells, indiscriminate dumping of oil-based drilling muds, cuttings, and losses of oil or gas in production, storage, and transportation. Pipelines from offshore platforms to storage facilities are subject to rupture by storms and the dragging of ships' anchors. It should be noted, however, that gas well drilling and production operations have been carried out successfully in the Canadian waters of Lake Erie for more than 50 years without a serious pollution incident.

Although highway and rail accidents involving hazardous materials and oils tend to be discounted as local incidents, accidents have occurred which endangered local water supplies and tributaries in both countries.

Other sources of oil pollution are waste oil from gasoline filling stations, accidental spillage during industrial transfer and storage, leaks from pipelines and related systems. The United States Army, Corps of Engineers, has estimated that 40 percent of all oil pollution enforcement cases with which it is involved are from other than vessels. In addition, disasters or spills involving other substances are possible and should be anticipated in contingency plans.

Although the likelihood of a major oil spill on the lakes is fairly remote, the risk is real and continuing. The loss of 1000 tons of bunker fuel or similar petroleum product would be enough to pollute extensive areas of the lake and many miles of shoreline. The immediate consequences of such a disaster would be the damages to water supplies, bathing beaches and other recreational facilities as well as the destruction of large numbers of waterfowl. The effects of oil pollution on the littoral ecology are largely unknown but experience elsewhere indicates that some of the methods used to remove or disperse the oil are more harmful than the oil itself.

The Torrey Canyon incident of March, 1967, and the recent Santa Barbara events have served to emphasize that effective programs for mitigation of damages from spills should be established. Quick action is required in such situations and preplanning is dictated. Such planning would include prevention, surveillance, notification and cleanup.

3.5 DISSOLVED OXYGEN DEPLETION

Low dissolved oxygen (DO) concentrations were detected in limited areas of the bottom waters of the central basin of Lake Erie as early as 1929. Oxygen depletion in these waters was reported in 1959, 1960 and 1964 (Beeton, 1963; Anderson and Rodgers, 1964; United States Public Health Service, 1965). These have become more widespread and have had significant effects on the biological community, playing a role in the shift to less desirable fish species.

Oxygen data on Lake Ontario have been collected only in recent years. In general, this lake is able to maintain adequate oxygen levels because of its large reserve of dissolved oxygen present in the deep water. The dissolved oxygen concentrations also reflect the relatively low amounts of oxygen-consuming substances contributed to Lake Ontario.

3.6 DEVELOPING PROBLEMS

3.6.1 Organic Contaminants

Organic contaminants include the persistent or biochemically resistant compounds which occur in industrial and domestic wastes, insecticides, herbicides and other agricultural chemicals. In view of their persistence and toxic nature, even in low concentrations, they pose a continuing threat to receiving waters and the aquatic environment.

Many of these substances resist conventional water and waste treatment processes and their effects have already been experienced in public water supplies and in the food processing industry. The problem presents itself in many other forms as well: new product formulations, organic and inorganic complexing and lack of suitable detection techniques. As a result it is difficult to present quantitative data and to assess any major changes in the concentrations of these persistent substances in the lakes. Studies to date show that lake values are well below the standards of 200 μg/l of carbon chloroform extract (CCE) set by the United States Public Health Service and the Ontario Water Resources Commission. However, concentrations of 250-660 μg CCE, far exceeding the acceptable limits, have been found in the Cuyahoga River, off Cleveland, Ohio, and have been higher than desirable near Metropolitan Toronto, Ontario.

Pesticides are specific forms of organic contaminants which deserve particular attention. Herbicides and insecticides may reach potable water supplies from aerial spraying, runoff from agricultural areas, percolation through the soil to underground supplies and waste discharges by producers and from canneries whose wastes contain residues of pesticides. The amounts likely to be present in water supplies will thus be dependent upon existing circumstances. High concentrations might be present in surface waters because of aerial spraying, discharges into streams from producing plants, accidents and misuse such as the emptying of surplus insecticides, or spray tanks rinse waters. Incidents of this nature have resulted in fish mortalities. Because of their persistence and accumulative nature, lower concentrations have affected fish fertility. Furthermore, heavy concentrations might also contribute characteristic odours, since most of the herbicides and insecticides are highly odourous.

The United States Public Health Service and the Department of the Interior have carried out studies on pesticide levels in the waters of the Great Lakes basin since 1958. Pesticides were observed to be present in the St. Clair River as early as 1960 and in the eastern end of Lake Erie in 1958. Pesticides are being detected more frequently in water samples taken from the lower lakes although concentrations do not appear to be increasing. Pesticides have been observed in the Lake Ontario basin since 1962 when the United States Public Health Service established a station on the St. Lawrence River at Massena, New York. While dieldrin, endrin and DDT or its derivatives were observed in 1962, only DDT has been observed at this station with any consistency since that time.

Recent studies of pesticide residues in the internal organs of fish in Lakes Erie and Ontario, indicated that levels were generally low. The Great Lakes Fisheries Commission has warned, however, that pesticide levels in certain important Lake Michigan fish are already affecting reproduction and pose a serious threat to the rehabilitation of the fishery resources of that lake. Though DDT levels in fish from the lower lakes are not as high as Lake Michigan fish, the persistency of these chemicals makes their consideration a matter of serious concern not only for the fishery resource but also for human health. This has recently been demonstrated by the seizure of 34,000 pounds of Lake Michigan Coho salmon in 1969 by the United States Food and Drug Administration (USFDA). The DDT residue in these fish ranged from 13 to 19 parts per million, about twice the allowable (USFDA) limit for red meat.

Further research is urgently needed on these synthetic pesticides and organic contaminants, their effect on plants and animals, and their ultimate impact on man. Enough is known, however, to demonstrate the need for closer control over pesticide usage. A permit and accountability system is in use in Ontario which will yield information on the kinds, amounts, and places of pesticide application throughout the entire watershed areas. Such a system coupled with programs of environmental monitoring would permit an assessment of the total organic contaminant use and the persistence of the chemicals involved.

3.6.2 Radioactivity

Monitoring programs for the measurement of radioactivity in the Great Lakes have been undertaken by government agencies in Canada and the United States for the past several years.

Initially, the naturally occurring radionuclides found on the earth's surface were the main causes of concern. However, with the advent of nuclear weapons testing and the increased applications of nuclear energy and nuclides in atomic reactors, medicine, industry and other areas of research, the problem has assumed greater importance in recent years. In the case of Lakes Erie and Ontario the main source of radioactivity is from fallout following nuclear weapons testing.

Fallout radionuclides can enter bodies of water directly through precipitation and dry fallout, or through runoff and leaching of the soil. The greatest percentage of fallout occurs with rains after atmospheric nuclear weapons testing. In the late 1950's fallout levels as high as 35 picocuries per litre (pCi/l) occurred in Lake Ontario. In the early 1960's a moratorium on atmospheric testing resulted in a lowering of total beta activity to 10 pCi/l. Subsequent testing in 1962 produced an increase in radioactivity to 26 pCi/l. Fallout from the more recent tests has not been appreciable in water samples in the Great Lakes region as evidenced by gross beta activity levels of less than 10 pCi/l.

Radioactive wastes from nuclear reactors, waste processing plants, industrial, medical and research uses, are either discharged directly to the lakes or through municipal sewers. On entering the water, the radionuclides are diluted and distributed by vertical and horizontal mixing. The dilution effect is greatest in large lakes, hence relatively low levels of radioactivity are found in such bodies of water. Furthermore, the amount of radioactivity that can be discharged to surface waters by nuclear reactors or other operations is carefully controlled by government regulations, thus ensuring that the radioactivity is maintained at levels within prescribed standards.

The Ontario Hydro Douglas Point nuclear reactor on Lake Huron has been continuously monitored for radioactivity since 1963 by the Ontario Department of Health and the Radiation Protection Division of the federal Department of National Health and Welfare. Samples of water, fish and beach sands have been analyzed for gross alpha and beta activities from strontium-90 and cesium-137. No anomalous results have been obtained which could be attributed to lack of adequate controls or to the operation of the nuclear reactor.

Lake Erie and its tributaries were studied by the United States Public Health Service from 1963 to 1965 to determine the gross beta and alpha radioactivity levels in water, bottom sediments and plankton samples (Risley and Abbott, 1966). In general, the results indicated that the radioactivity of the water was low and well within the accepted standards for drinking water. Beta activity for dissolved solids of the lake and the sampled tributaries averaged 7.9 and 14.3 pCi/l, respectively. In both cases the alpha activity averaged less than 1 pCi/l.

Lake Ontario has received special attention over the past few years. In addition to fallout radionuclides, it receives wastes from the uranium refinery at Port Hope, Ontario, and from medical, university and research facilities. Also, a nuclear generating station, which is scheduled to be operational in the early 1970's, is being built at Pickering, 20 miles northeast of Toronto. Pre-operational monitoring of this area began in early 1969.

Observations have shown that the concentrations of strontium-90 and cesium-137 in the Toronto drinking water are the lowest of all lake derived sources studied in a national drinking water monitoring program of the Department of National Health and Welfare. Average values over a four-year period for the Toronto supply were 1.02 pCi/l for strontium-90 and 0.17 pCi/l cesium-137 compared with the national average of 2.20 pCi/l and 0.25 pCi/l, respectively.

It should be noted that all values observed in Lakes Erie and Ontario are well below maximum permissible concentrations recommended by the International Commission for Radiological Protection (ICRP) and are within the allowable limits of the United States Public Health Service drinking water standards (United States Public Health Service, 1962).

3.6.3 Thermal Effects

Industrial and thermal power requirements for cooling waters represent one of the most significant uses of water in the basins. Demands will continue to increase as a function of economic development and power consumption. Power requirements are based on an expected doubling of capacity every ten years and most of this production is expected to be met by fossil- or nuclear-fueled generating stations.

A typical thermal power plant converts heat to electric energy, wasting large quantities of heat in the process. For example in a 2000 megawatt plant, heat is rejected at a rate of 2.5 to 3 million British thermal units (BTU) per second. The heat rejection differs with the type of plant. Nuclear-fueled plants reject 50 percent more heat than fossil-fueled plants of similar electrical capacity.

It has been projected in the United States that if all future plants were nuclear-fueled the total heat rejected by the year 2000 would increase by twelvefold but if all future plants were fossil-fueled the heat increase would be sevenfold. However, improvements in nuclear reactor design are expected to reduce heat losses to the point where heat rejection will be equivalent to today's fossil-fueled units.

Localized effects of thermal pollution in confined areas or along the shoreline can stimulate algal growth and cause oxygen depletion. The quantities of waste heat may be such that the survival and productivity of lake species are endangered by high temperatures and altered seasonal characteristics. Uncontrolled thermal inputs could have more serious and direct effects on the quality of water for drinking, recreation and industrial uses including cooling.

Artificially heated waste waters need not necessarily be considered as a waste product without value. Multiple uses are possible and should be encouraged through the development of satellite industries, communities, recreation facilities or the siting of such operations where the waste heat could free or prevent the formation of winter ice in shipping channels, locks or harbours.

Thermal pollution is not yet a major problem. Whether it becomes a problem or a benefit is still to be determined. Governments, municipalities, water and power authorities can determine this outcome before additional thermal plants are planned and put into operation.

3.6.4 Viruses

Although viruses require the presence of living, susceptible cells in order to grow and multiply, available evidence indicates that they survive outside these cells for considerable periods of time (Gilcreas and Kelly, 1955; Rhodes *et al*, 1960; Malherbe and Coetzee, 1965; Joyce and Weiser, 1967). Water must therefore be considered as a possible vector in the transmission of viral diseases. Viruses of human, animal and plant origin could reach potable water supplies by means of urban and rural runoff or via direct discharge. The latter could occur by allowing animals direct access to the body of water, by discharge from pleasure or commercial watercraft, or from municipal and domestic sewage treatment plants. The viruses which would be expected to be present in the largest numbers would therefore be those found in the intestinal tract of man and animals. The viruses which have been most intensively studied in connection with water supplies are those of the enteric group (Poliomyelitis, Echo, Coxsackie viruses, etc.), which are pathogenic to humans. However, some viruses of animal origin may be capable of causing infection in man, but the significance of these and plant viruses in water is largely unknown.

There is a large volume of evidence to indicate that many of the treatments afforded sewage are not adequate with respect to viruses; viable viruses have been isolated in effluents from sewage plants employing tertiary treatment, and they are not inactivated in lagoons or septic tanks. As has been noted elsewhere, some sewage enters the lakes untreated and most probably would contain viruses.

The number of viable viruses present at any given point in the lower lakes would be dependent on several factors, such as proximity to large urban areas, bathing beaches, agricultural areas and so on. Winds and currents would tend to disperse and dilute any concentrated discharge and play a part in reducing viruses to a non-infective level. Where, however, there is the possibility of survival of even low numbers of viruses, such as in the nearshore waters where pollution is greatest, there should be cause for concern. This is especially critical, since it is these very regions that are used for recreation and water supplies.

The actual time of survival of viruses depends upon the degree of pollution and apparently is greatest in slightly or moderately polluted water. Such conditions of pollution prevail in many areas of both Lake Erie and Lake Ontario.

Since viruses are very different from bacteria, the indicators used as an index of bacterial pollution (the coliform count) may not be applicable to viral pollution. There is as yet no suitable agent available which can be used as an indicator of the presence of human or other viruses. As a result of the absence of an indicator organism, and since large scale investigations are hampered by the lack of an adequate isolation method which can be applied to waters where only small numbers of viruses would be expected to occur, there are no data available regarding the presence of viruses in the Great Lakes.

Table 4.1.1 Direct inputs of phosphorus from municipal, industrial and major tributary sources 1966-67 (short tons per year).

Lake Erie

Direct municipal US	Direct municipal Canada	Direct industrial US	Direct industrial Canada	Detroit River	Maumee River	Cuyahoga River	Other tributaries US and Canada	Totals
2,710	30	Nil	20	17,600	2,690	2,600	4,450	30,100

Lake Ontario

Direct municipal US	Direct municipal Canada	Direct industrial US	Direct industrial Canada	Niagara River	Oswego River	Genesee River	Twelve Mile Creek	Other tributaries	Totals
950	2,010	Nil	180	7,700	620	310	590	1,320	13,680

4. SOURCES, CHARACTER AND DISPOSITION OF WASTE INPUTS[1]

Continuous discharges of treated, untreated and partially treated waste waters enter Lakes Erie and Ontario and the international section of the St. Lawrence River from municipalities and industries situated along their shores. The inflowing streams carry debris, eroded soil, components of municipal and industrial wastes and land drainage waters from sources within the tributary basins. When considered as point sources of material inputs, the tributaries especially the Detroit and Niagara Rivers contribute by far the greatest portion of the waste loads. Sources of intermittent or uncontrolled pollution include vessels, dredging materials, spills of oil or other hazardous materials, sediments, oil and gas well drilling and combined sewer systems. Natural sources of materials input to the lakes are the sediments from eroded shorelines and the atmosphere.

In this report a direct input is one delivered directly to the lake rather than through a tributary. Tributary inputs include contributions from all upstream sources. A summary of the inputs of phosphorus from direct municipal, industrial and tributary sources contributing to the eutrophication problems in the lakes is given in Table 4.1.1. Of the total phosphorus input to the two lake systems, 67 percent is derived from municipal sewage with an additional 8 percent from industrial wastes. The bulk of this material is discharged into tributary waters, rather than directly to the lakes themselves.

4.1 MUNICIPALITIES

Constituents in municipal wastes which may contribute significantly to local or lake-wide pollution problems include dissolved and suspended solids, oxygen-consuming wastes, toxic materials, pathogenic bacteria and nutrients. Raw or partially treated sewage continues to be discharged to Lake Erie from the villages of Port Burwell, Port Stanley and Port Rowan in Ontario. On Lake Ontario, the village of Wellington, Ontario, and the city of Oswego, New York, both discharge inadequately treated sewage to the lake. Five municipalities - Cape Vincent, Clayton, Alexandria Bay and Morristown in New York and Prescott, Ontario, discharge inadequately treated sewage to the St. Lawrence River.

The municipalities discharging wastes directly to the lakes contribute about 10 percent (2,740 tons per year) of the total phosphorus loading to Lake Erie and 22 percent (2,960 tons per year) of the total introduced directly to Lake Ontario (Table 4.1.1). The percentage of the total direct municipal loadings of phosphorus, nitrogen, BOD_5 (biological

[1]See Appendices 1.1 to 1.11 for locations and sources of Canadian and United States waste loads.

oxygen demand with a 5 day incubation period) and chlorides contributed by each state and by Ontario are shown in Table 4.1.2 for the lakes and the St. Lawrence River. There are no Michigan municipalities discharging directly to Lake Erie. Estimates of the phosphorus contributed from tributaries by municipalities were 55 percent (16,000 tons per year) of the total discharged to Lake Erie and 32 percent or 4,500 tons per year for Lake Ontario. Large metropolitan areas from which wastes are discharged to tributaries near their mouths include Detroit, Windsor, Toledo and part of Cleveland. The cities of Buffalo and Niagara Falls, New York, discharge to the Niagara River.

Combined sewer systems at Toledo, Cleveland, Erie, Rochester, St. Catharines, Hamilton, Toronto, Kingston and Cornwall overflow to the lakes and the international section of the St. Lawrence River during periods of surface runoff or because local sewage flows may exceed the capacity of the sewage collection or treatment systems. These discharges contain high concentrations of bacteria, BOD_5, suspended solids, chlorides and nutrients.

4.2 INDUSTRIES

The main sources of industrial wastes discharged directly to the lakes are located on the United States side of Lake Erie (23 of 27 sources) and on the Canadian side of Lake Ontario (44 of 45 sources). Eight of the eleven major industrial sources discharging directly to the St. Lawrence River are located along the Ontario shoreline. Waste waters originate from a variety of industries including steel making, oil refining, automobile manufacturing, aluminium fabricating, food processing, chemical, paper and rubber plants. Wastes discharged in large quantities include oil, suspended and dissolved solids, and oxygen-consuming materials. While industrial wastes usually have an adverse effect on the immediate lake waters, persistent waste constituents such as chlorides and other dissolved solids contribute to the increasing impairment of the overall quality of the lakes.

The industrial sources within the lower lakes basin contribute 10 percent of the phosphorus entering the lakes. When taken together municipal and industrial wastes accounted in 1967 for about 75 percent (29,000 tons per year) of the total amount of phosphorus discharged to the drainage basin of the lower lakes (21,000 tons per year to Lake Erie and 8,000 tons per year to Lake Ontario). The total direct industrial loadings of phosphorus, nitrogen, dissolved solids and chlorides to each lake and the St. Lawrence River are summarized in Table 4.2.1.

Table 4.1.2 Direct municipal waste discharges.

	Phosphorus (P) %	Nitrogen (N) %	BOD_5 %	Chlorides %
Lake Erie				
Ontario	1	1	2	4
Ohio	85	89	82	85
Pennsylvania	11	8	5	9
New York	3	2	11	2
	100*	100*	100	100*
	(2,740)	(9,410)	(23,700)	(24,280)
Lake Ontario				
Ontario	68	77	46	86
New York	32	23	54	14
	100**	100**	100	100**
	(2,960)	(13,250)	(42,160)	(146,880)
St. Lawrence River				
Ontario	89	94	86	94
New York	11	6	14	6
	100***	100***	100	100***
	(210)	(1,190)	(3,800)	(4,430)

*78% of the phosphorus, 76% of the nitrogen and 75% of the chlorides are contributed by the three municipalities: Cleveland and Euclid, Ohio, and Erie, Pennsylvania.

**94% of the phosphorus, 92% of the nitrogen and 96% of the chlorides are contributed by the four regions: Metro Toronto, Hamilton and St. Catharines, Ontario, and Rochester, New York.

***83% of the phosphorus, 91% of the nitrogen and 92% of the chlorides are contributed by the four municipalities: Kingston, Brockville and Cornwall, Ontario, and Ogdensburg, New York.

Figures in brackets are quantities in short tons per year discharged directly from municipal sources to the lakes and the St. Lawrence River.

Table 4.2.1 Direct industrial waste discharges (short tons per year).

	Total phosphorus (P)	Total nitrogen (N)	Total dissolved solids	Chlorides
Lake Erie	20	200	182,000	15,000
Lake Ontario	180	17,700	328,000	9,000
St. Lawrence River	50	4,500	244,000	42,500

Table 4.3.1 Total phosphorus inputs by major tributaries and sources.

Lake Erie

	Detroit River %	Maumee River %	Cuyahoga River %	Other tributaries U.S. and Canada %	Total %
Municipal	42	5	7	5	59
Industrial	4	1	1	1	7
Other drainage	10	4	2	10	26
Lake Huron	8	-	-	-	8
	64	10	10	16	100
	(17,600)	(2,690)	(2,600)	(4,450)	(27,340)

Lake Ontario

	Niagara River %	Oswego River %	Black River %	Genesee River %	Twelve Mile Ck. %	Other Trib. %	Total %
Municipal and industrial*	24	4.3	1	2	4.6	8.1	44
Other drainage	6	1.6	1	1	1	3.4	14
Lake Erie	42	-	-	-	-	-	42
	72	5.9	2	3	5.6	11.5	100
	(7,700)	(620)	(180)	(310)	(590)	(1,140)	(10,540)

*With the exception of the Niagara River basin, industrial sources of phosphorus contribute a small part of the total load.

Figures in brackets are in units of short tons per year.

4.3 TRIBUTARIES

The major tributaries draining upstream municipal, industrial and agricultural areas convey materials which include debris, sediments, pesticide residues, dissolved solids, nutrients and oxygen-consuming substances into the lakes. These tributary loads often compound local pollution problems at or near the point of discharge to the lake, where they contribute significantly to the nutrient supply, and the lake-wide problems of eutrophication and increased levels of dissolved solids.

Major waste loads are carried to Lake Erie by the Detroit, Maumee, and Cuyahoga Rivers. The Detroit River introduces 83 percent (29,000,000 tons per year) of the dissolved solids, 74 percent (3,300,000 tons per year) of the chlorides, and 58 percent (17,600 tons per year) of the total phosphorus and 65 percent (126,000 tons per year) of the nitrogen from all sources discharging to Lake Erie (Table 4.5.1). The Maumee River is the largest source of suspended solids accounting for more than 40 percent (2,000,000 tons per year) of the total tributary inputs to the lake. The Sandusky and Grand Rivers of Ohio, Cattaraugus Creek and Buffalo River of New York and Grand River in Ontario also carry heavy waste loads into Lake Erie.

Of the total loading on Lake Ontario from all sources, the Niagara River accounts for 55 percent (95,000 tons per year) of the nitrogen, 56 percent (7,700 tons per year) of the total phosphorus and 76 percent (5,200,000 tons per year) of the chlorides (Table 4.5.1). Detailed information on the primary sources of pollution of the river is contained in the "Summary Report on Pollution of the Niagara River" (International Joint Commission, 1967). In Ontario, Twelve Mile Creek, the Welland Canal outlet and the Credit, Humber and Don Rivers all carry significant material loads to Lake Ontario. The Oswego River, Genesee and Black Rivers in New York also carry large loads of nitrogen, phosphorus, chlorides and suspended solids.

A large portion of the phosphorus conveyed by the tributaries to the lakes originates from municipal waste waters with other sources accounting for less significant contributions of nutrient (Table 4.3.1). Nevertheless, the amounts discharged from inland drainage sources other than municipal and industrial wastes account for about 20 percent of the total phosphorus input to the lakes excluding the outflow from Lake Huron. In the Lake Erie basin slightly higher loads are found which probably reflect the intensive agricultural activities in its tributary basins.

4.4 OTHER SOURCES

4.4.1 Boat and Vessel Wastes

Commercial vessels and recreational watercraft are sources of wastes in Lakes Erie and Ontario, and the international section of the St. Lawrence River. Large numbers of commercial tankers, barges, and cargo ships use the St. Lawrence Seaway each year, bringing in foreign trade products to inland markets, and carrying United States and Canadian goods to all parts of the world. Thousands of pleasure craft use the lakes as a prime recreation area.

Approximately four to five thousand commercial vessels use the seaway each year, most of which are equipped with marine toilets. Only a very small percentage provide holding tanks or treatment facilities. In all probability the majority discharge their wastes directly overboard.

The wastes comprise sewage, garbage, bilge and ballast waters, dunnage and bunker oil. The discharge of these substances, accidental or otherwise, causes problems particularly in harbour and docking areas. Only a few of the port facilities on the lower lakes provide collection and treatment of vessel wastes. Discharges of fuel oil may also occur during fueling operations, or during pumping of ballast, either in port or while under way.

Exact numbers of pleasure craft using the lower lakes is unknown but estimates set the figure in excess of 250,000. Most of the larger boats have toilet facilities, but like commercial vessels, relatively few provide holding tanks or treatment devices. The greatest pollution problems occur near the larger centres of population, and more specifically in those marina areas where disposal facilities are not available.

The increase in pleasure boating in recent years has resulted in a growing concern for pollution from this source and has led to the enactment of legislation and regulations requiring waste treatment control on pleasure craft equipped with toilets in Ontario, Michigan and New York. An increasing number of marinas are being fitted with pump-out facilities and a further extension of this program is required.

4.4.2 Disposal of Dredged Materials

Routine maintenance dredging is performed annually at 15 major, and several small harbours and channels in the United States waters of Lake Erie, the lower Detroit River, and the Niagara River, and at 3 major United States harbours in Lake Ontario. The agency responsible for this work, the Corps of Engineers, United States Army, estimates the future annual maintenance dredging to be 6,800,000 cubic yards for Lake Erie and 480,000 cubic yards for Lake Ontario (United States Army, Corps of Engineers, 1969).

In Canada, the Department of Public Works is responsible for maintenance dredging, which is carried out as required at 4 Canadian harbours in Lake Erie and at 8 locations in Lake Ontario. Estimated annual amounts are not available, but in 1968 quantities totaled 297,000 cubic yards in Lake Erie and 577,000 cubic yards in Lake Ontario. Of the latter amount, 450,000 cubic yards were used for land fill.

It has been the general practice at most harbours to dispose of the dredged material in the open waters of the lakes at locations which would not interfere with navigation.

The enlarged and deepened harbour areas act as settling basins and trap much of the sediment originating from land runoff and municipal and industrial waste discharges. Therefore, at many harbours, the sediments contain large quantities of pollutants such as iron, oil and grease, toxic materials, nutrients, and oxygen-consuming substances. It is estimated by the Federal Water Pollution Control Administration that, during the period January 7, 1966 to January 7, 1967, approximately 71,000 short tons of volatile solids, 18,000 tons of oil and grease, 2,000 tons of phosphorus, 2,000 tons of nitrogen, and 60,000 tons of iron were transferred to Lake Erie from Cleveland Harbour by dredging.

The disposal of these waste materials in the lake environment, with which they are not in equilibrium, constitutes a source of pollution. Although there are short term effects which may include increased turbidity, discoloration, oil slicks, oxygen depletion, and toxicity, the primary concern is for the long term effects on the water quality of the lakes.

In recognition of the problem of dredged materials, the Federal Water Pollution Control Administration and the Corps of Engineers have conducted a joint two-year study to find other suitable methods of disposal. Confined disposal areas on shore and in the lake near shore have been found to provide good protection of lake water quality. The United States Army, Corps of Engineers has proposed three plans of varying scope for providing alternative disposal at harbours which contain polluted sediments (United States Army, Corps of Engineers, 1969).

Preliminary results of a recent study by the Ontario Water Resources Commission with the assistance of other provincial and federal agencies indicate the majority of Canadian dredging operations on the Great Lakes shipping channels have been satisfactory. Only in a few cases have pollutants been involved in dredged materials.

4.4.3 Sediments

Decomposition of organic sediments contributes carbon dioxide, ammonia, phosphorus, iron and manganese to the overlying waters and can seriously affect its quality. Constituent exchanges occurring at the mud-water interface are produced by biological activity, physical disturbances and chemical reactions. A better knowledge of these interactions is needed to understand the potential for enrichment of overlying waters by the sediments. The effects of sedimentation on desirable fish populations may also be one of the factors contributing to changes in fish life in the lakes.

Large quantities of sediment enter the lakes from rural and urban land runoff as a result of subdivision and highway construction, shoreline erosion, plowing and other agricultural activities. While the physical damage from sedimentation may be obvious, the chemical effects of sedimentation are more subtle. Phosphate compounds, unlike other constituents of fertilizers, are not easily leached out of soil and tend to cling to soil particles. Nutrients are also incorporated into the bottom sediments through the death and sedimentation of plankton. Under some conditions these nutrients may be recycled into the oxygen-deficient bottom waters of Lake Erie.

4.4.4 Oil and Gas Wells

Natural gas is being produced in substantial quantities from Canadian submerged lands in Lake Erie. While traces of oil have been reported, no commercial exploitation has proven economically feasible. At the end of 1968, 221 wells of 529 drilled were producing natural gas at the rate of 3,700 million cubic feet per year, or 30 percent of the Province of Ontario's total production. During 1968 45 new wells were drilled in Lake Erie of which 16 were producers. Few wells have been drilled in the United States portion of Lake Erie and there has been no production of either oil or gas to date. Some submerged lands offshore from Pennsylvania were leased for drilling in 1969, but exploration is not anticipated until 1970.

The increasing frequencies of oil spills including the recent blowout of a well in the Santa Barbara basin have raised the concern of conservationists and others over potential hazards in Lake Erie. Canadian oil and gas interests have been drilling in Lake Erie since 1913 without significant pollution incidents. The potential exists, however, and strict regulations and close supervision are required to minimize the dangers.

4.4.5 Atmosphere

Precipitation, dustfall and fixation of nitrogen by algae are several of the natural sources of nutrients to the lakes. These are generally in the form of nitrates and ammonia.

Estimates based on the studies of Matheson (1951) suggest that the amount of nitrogen contributed by rain, snow and dustfall to the surface of Lake Erie is about 16,000 tons per year and about 12,000 tons per year to the surface of Lake Ontario. The contribution by nitrogen fixation to the two lakes is considered to be insignificant.

4.5 OVERALL BALANCE OF MATERIALS IN LAKES

Increases of dissolved constituents in Lake Erie from all sources were described by Beeton (1965) (Fig. 3.1.1). Total dissolved solids have increased rapidly since 1910. The chloride level in Lake Erie is about 2.5 times that of Lake Huron and has tripled in the past 50 years.

Comparison is made in Table 4.5.1 of four material constituents - chlorides, total dissolved solids, total nitrogen and total phosphorus - for both Lake Erie and Lake Ontario in relation to the sum of all inputs to the lakes and the quantities observed in the outflows during the study period of 1965 to 1967. Estimates of the difference between the inflow and outflow quantities or the amounts of these constituents retained in the lakes are also given in the Table.

The inputs of chlorides and total dissolved solids to Lake Erie are found to be essentially in balance with the discharge of these materials through the Niagara River and Welland Canal. The lack of balance of the constituents, nitrogen and phosphorus, indicates retention or alteration of these materials within the lake. Whereas the phosphorus retained or stored in the sediments is 84 percent, only about 56 percent of the incoming nitrogen is retained in the lake. In Lake Ontario, 77 percent of the phosphorus and 35 percent of the nitrogen are retained in the lake.

It is noted that the determination of the output of chlorides and dissolved solids from Lake Erie is slightly greater than the total inputs to the lake, whereas the output for Lake Ontario is considerably less than the total inputs to that lake. This suggests that in the case of total phosphorus the percentage retained in the lakes may in fact be similar and not significantly different.

The difference in rates of storage of phosphorus and nitrogen can be explained by the difference in the phosphorus and nitrogen cycles. Only under special circumstances, is stored phosphorus returned from the sediments to the water in significant quantities.

The high percentage of the phosphorus which is deposited in the lakes is important in determining the rate at which the lakes ought to respond to remedial measures. As an example, considering only the volume of Lake Erie and the volume of river discharge into that lake one might presume that it would take only 2.5 years to completely replace the lake water. However, vigorous mixing in the lakes interferes with the orderly replacement of lake water by the inflowing rivers. Because of this process the lakes do not immediately reflect changes in input concentrations. Elementary considerations indicate that the time required to accommodate 90 percent of a change in input of an inert substance would be 6 years for Lake Erie. However, when a substance which is involved in biological productivity, the situation is modified. In the case of phosphorus a substantial proportion is removed from the lake water each year by growing plants and deposited on the lake bottom where it tends to be retained. The importance of this process relative to that of removal of phosphorus through the lake outlet is such that there are strong theoretical reasons to indicate that the lakes will react quickly to a decreased loading and that a 90 percent response can be expected in Lake Erie in a period considerably less than 6 years.

4.6 TRANSBOUNDARY MOVEMENT OF POLLUTANTS

One of the principal questions to be resolved is whether the waters of Lake Erie are being polluted on either side of the international boundary to an extent which is causing or is likely to cause injury to health or property on the other side of the boundary. Technical information included in Volumes 2 and 3, especially on circulation of the lake waters, water chemistry and sources of material inputs, allow some statements to be made concerning transboundary movement of pollutants.

The Detroit River is by far the major source of contaminants to Lake Erie and its western basin (Tables 4.3.1 and 4.5.1), although the western basin also receives major loadings from the Maumee and Raisin Rivers. For the main part, surface and bottom flows in the western basin are dominated

Table 4.5.1 Materials balance for lower lakes 1966-67 (in thousands of short tons per year).

	Chlorides[1]	Total dissolved solids	Total nitrogen	Total phosphorus
Lake Huron output	1,000	23,657	66	2.2
Detroit R. output	3,300	29,000	126	17.6
Lake Erie				
total input	4,500	35,000	194	30.1
total output	5,000	36,000	85	4.7
difference	500	1,000	109	25.4
percent difference or retained	11	3	56	84
Niagara R. output	5,200	38,000	95	7.7
Lake Ontario				
total input	6,900	46,000	173	13.7
total output	6,100	37,000	113	3.1
difference	800	9,000	60	10.6
percent difference or retained	12	20	35	77

[1]The difference between the inputs and outputs of chlorides cannot be interpreted as an indication of the percent retained, but as a measure of the reliability of the determination of the materials balance. The differences of 11 and 12 percent between the total inputs and outputs for chlorides for both lakes provides a good example of this reliability. It is assumed that the determination of the materials balance for total nitrogen and phosphorus is of comparable reliability.

by a major southward thrust of the Detroit River outflow which extends eastwards to the Ohio shore. A gyre which tends to concentrate contaminants from the Maumee and Raisin Rivers along this shore, develops between the Detroit River outflow and the western shore of the basin. Some of the Detroit River inputs become trapped in this gyre. However, in the surface layers, the Detroit River is turned from a southwestward flow to a northwestward current west of the Bass Islands. This water crosses over to the Canadian side and flows out of the western basin through Pelee Channel (Fig. 4.6.1).

It is clear that the Detroit River flow carries polluting materials to both United States and Canadian waters and shorelines. In addition, the evidence suggests that the mean summer flow about Pelee Island is a counterclockwise gyre in the bottom waters, while being mainly clockwise about the island above the thermocline. In either case, inputs originating on the United States side are transported into Canadian waters and vice versa.

In the central basin the predominant surface flow is southward from Pelee Channel along the southern shore of the lake. Easterly flows dominate throughout the rest of the basin. These appear to be counterbalanced by generally westerly flows at intermediate depths in the main body of the lake, but with a continuing easterly flow near the United States shoreline. This implies that tributary and outfall discharges tend to stay along the shore and move eastward parallel to the southern side of the lake.

In the eastern basin the surface flow is mostly easterly towards the Niagara River outlet. However, discharges not caught in the Niagara River outflow can be distributed over the whole basin. At intermediate depths a counterclockwise gyre is evident which exchanges waters across the international boundary from the south shore into the Long Point Bay area.

In general, surface water tends to move toward the south shore and deeper waters towards the north shore. It should be noted that these general patterns are net flows and may not represent the situation at any given time. The currents, and in particular the surface flows, are very responsive to the wind field. Changes in the direction and speed of the wind can cause rapid changes in the currents of the lake, both by direct action on the water surface and by inducing large set-ups and seiches which are accompanied by substantial current speeds at intermediate depths.

The lakewide effects of circulation and mixing processes are also evident from the distribution and concentrations of chemical, biological and bacteriological parameters. The concentrations and distributions of some substances are also subject to seasonal influences, natural decay, complexing and biological uptake. Transboundary movements are evident off the mouth of the Detroit River, where high bacterial counts on one side of the boundary may well have originated on the other side.

The remarkably uniform distribution of conductivity, chlorides and dissolved solids in the central and eastern basins illustrates how effective the mixing and exchange of waters are in the lake. It is only in the eutrophic western basin that concentrations are not uniform.

Transboundary effects are clearly evident at the outlet of the lake where the residual loads carried through the lake enter the Niagara River and become part of the total pollution load of this well-mixed river. There is little doubt that both sides of the river are affected as well as Lake Ontario.

In Lake Ontario there are several dominant features of the net flow which permit some general inferences to be drawn on transboundary movements. In the summer, a large counterclockwise circulation persists in the main lake with westerly flows along the northern shore of the lake and easterly currents along the south side. This pattern suggests that materials originating in the Rochester area are transported northward to the Canadian shore and that materials originating in the heavily populated Canadian western basin are swept along the New York State shoreline (Fig. 4.6.1).

There is also no doubt, from the evidence presented, that in Lake Ontario, material inputs from the Niagara River affect both Canadian and United States waters and shores, depending on the currents at the time. The heavily polluted Niagara River outflow, has been shown to turn mostly along the New York State shore under westerly wind conditions. Under easterly winds, the outflow from the river has a major component directly across the lake, almost to the shore in the Oakville-Port Credit area. It is estimated that the Niagara River accounts for 55 percent of the input of nitrogen, 56 percent of the phosphorus, and 76 percent of the chlorides to the lake.

With winds from north around to southeast, a surface gyre develops in the western basin which tends to trap materials from the Niagara River and the Toronto-Hamilton-St. Catharines region within that basin. With winds from westerly directions, the pollutants in the western basin tend to be dissipated by flows towards the eastern end of the lake along the New York State shore.

In general it is difficult to state that a certain concentration of a pollutant on one side of the lake is due to a particular source on the other side. However, it is clear from the studies on mixing and advection that the material inputs from the Niagara and Detroit Rivers and from both sides of the two lakes have transboundary effects.

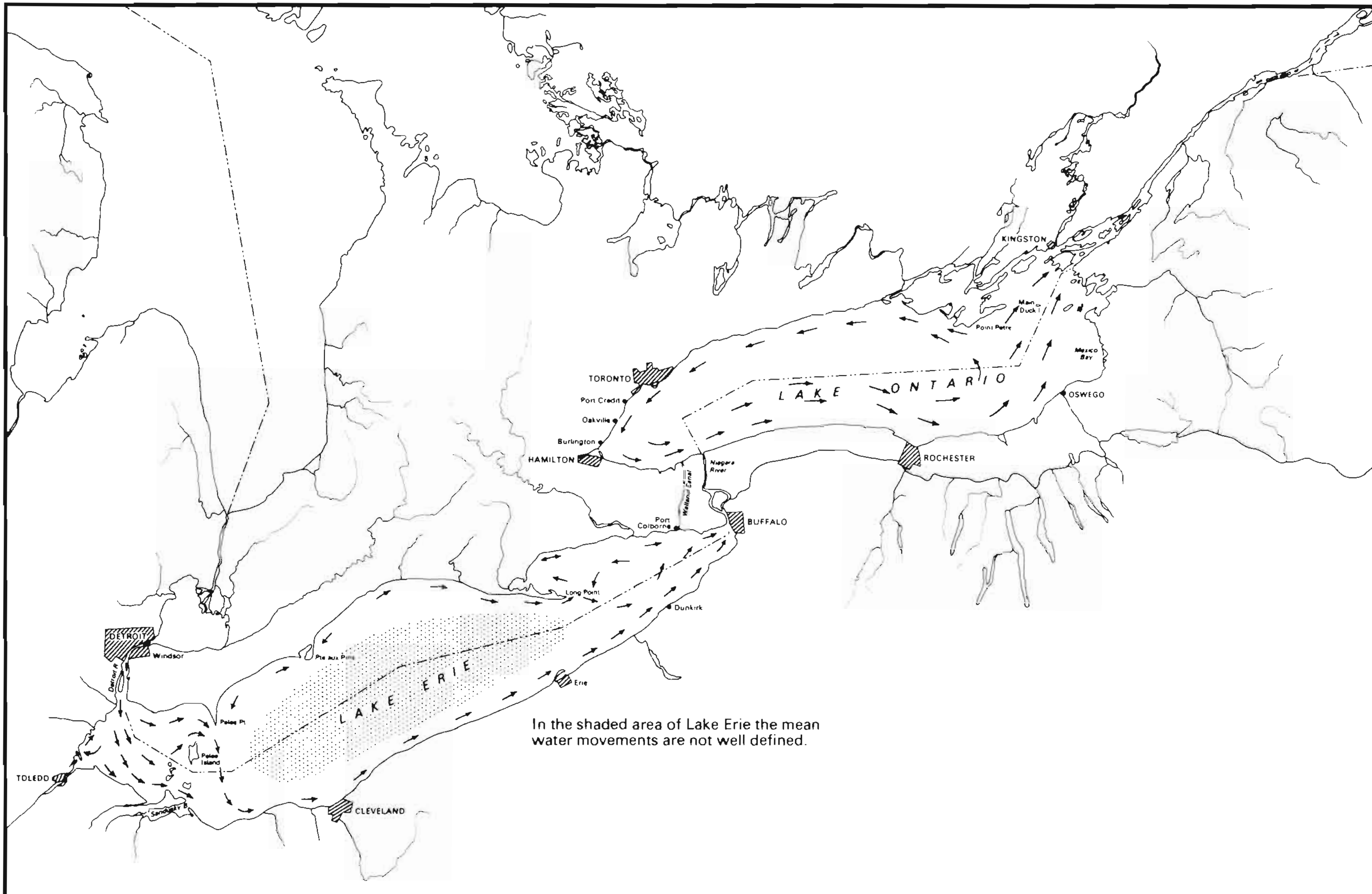


Fig. 4. 6. 1 Mean water movement in Lake Erie and Lake Ontario.

5. WATER QUALITY OBJECTIVES

5.1 ESTABLISHMENT OF WATER QUALITY OBJECTIVES

Although water quality objectives or standards have been established for the waters of Lake Erie, Lake Ontario and the international section of the St. Lawrence River by provincial and state authorities, it is desirable that the International Joint Commission develop objectives for its use in administering the Boundary Waters Treaty.

Water quality objectives should be designed to provide suitable water quality for present and future beneficial use of the waters. Uses which should be considered are:

(a) domestic water supply

(b) propagation of aquatic life and wildlife

(c) recreation and aesthetics (including body contact and pleasure boating)

(d) agriculture (including irrigation and stock watering)

(e) industrial supply (including process and cooling waters, and power generation)

(f) commercial shipping.

Water quality objectives should apply to the receiving waters since it is the quality of the lake waters that is important. Regulation of waste discharges to assure compliance with the objectives will involve the setting of effluent controls and monitoring of waste discharges by the provincial and state pollution control agencies. A review of objectives will also be required to meet the demands and requirements of population, industrial growth and technological changes in industry and waste treatment processes.

5.1.1 General Objectives

These general objectives should apply to all waters at all places and at all times;

(a) free from substances attributable to municipal, industrial or other discharges that will settle to form putrescent or otherwise objectionable sludge deposits, or that will adversely affect aquatic life or waterfowl.

(b) free from floating debris, oil, scum and other floating materials attributable to municipal, industrial or other discharges in amounts sufficient to be unsightly or deleterious.

(c) free from materials attributable to municipal, industrial or other discharges producing colour, odour, or other conditions in such degree as to create a nuisance.

(d) free from substances attributable to municipal, industrial or other discharges in concentrations that are toxic or harmful to human, animal, or aquatic life.

(e) free from nutrients derived from municipal, industrial and agricultural sources in concentrations that create nuisance growths of aquatic weeds and algae.

5.1.2 Specific Objectives

The specific objectives listed below are for evaluation of conditions in the waters of the lower Great Lakes other than areas in proximity to outfalls where mixing zones should be prescribed by pollution control agencies.

The parameters selected are intentionally limited to those believed to be most meaningful in relation to International Joint Commission responsibilities. The recommended objectives are designed to protect international waters for the most restrictive use in each case.

(a) Microbiology (Coliform Group) - The geometric mean of not less than five samples taken over not more than a 30-day period shall not exceed 1,000/100 ml total coliforms, nor 200/100 ml fecal coliforms in local waters.

Water used for body contact recreation activities should be free from bacteria, fungi, or viruses that may produce enteric disorders, or eye, ear, nose, throat and skin infections.

Discussion: Where ingestion is probable, recreational waters can be considered impaired when the above criteria are exceeded. As a general rule, the waters of international significance will be protected and maintained if local water quality conditions meet these microbiological objectives or standards. The International Joint Commission adopted an objective for bacteria in the Boundary Waters (Connecting Channels) in which the coliform median value, MPN (most probable number) was not to exceed 2400/100 ml (International Joint Commission, 1950 and 1951).

(b) Dissolved Oxygen - Not less than 6.0 mg/l at any time in epilimnetic (upper) waters or in concentrations which would not adversely affect cold water species in hypolimnetic (lower) waters.

Discussion: The objective is established to support fish and their associated biota, particularly cold water species.

(c) Total Dissolved Solids - Not more than 200 mg/l.

Discussion: The total dissolved solids concentration is a gross indicator of water quality, and is approaching the 200 mg/l level, which indicates the need for immediate action to reduce inputs of dissolved materials. Dissolved solids become important to domestic and industrial water supplies at about 500 mg/l.

(d) Temperature - No change which would adversely affect beneficial use.

Discussion: It is not considered practicable at this time to establish absolute limits, due to the lack of adequate information on the effects of temperature changes in the referenced waters.

(e) Taste and Odour - Virtually no taste or odour.

Phenols - Not to exceed a monthly average value of 1.0 μg/l. It would be desirable to obtain even lower concentrations.

Discussion: The effectiveness of conventional water treatment in removing odour from public supplies is highly variable depending on the nature of the material causing the odour. Tainting of fish flesh may result from materials not adequately removed by waste treatment processes. It is desirable that odour and taste producing materials be virtually absent. The International Joint Commission adopted an objective for phenols in the Boundary Waters (Connecting Channels) in which the average value was not to exceed 2.0 μg/l. The objective for taste and odour called for a threshold number of 8 or less (International Joint Commission, 1950 and 1951).

(f) pH - No change from present levels.

Discussion: Present levels are considered to be within the desirable range, falling within the objectives for the Boundary Waters (Connecting Channels): "The pH of these waters following dilution is to be not less than 6.7 nor more than 8.5." (International Joint Commission, 1950 and 1951).

(g) Iron - Not to exceed 0.3 mg/l.

Discussion: The objective conforms to the United States Public Health Service drinking water standards (United States Public Health Service, 1962) and the Canadian drinking water standards and objectives (Department of National Health and Welfare, 1969) for protection of public water supplies. This value is the same as the Connecting Channels objective for iron as set forth in the 1950 report.

(h) Phosphorus - Concentrations should be limited to the extent necessary to prevent nuisance growths of algae, weeds and slimes which are or may become injurious to water use.

Discussion: Phosphorus, which under certain conditions stimulates nuisance growths of algae, weeds, and slimes, is considered to be susceptible to control. It has been found that algal blooms can be expected to follow in years when the concentration of inorganic phosphorus and inorganic nitrogen exceed 10 and 300 μg/l, respectively, at the time of spring turnover.

Reduction of phosphorus inputs to the lower lakes is the only method currently available for controlling the rate of eutrophication. It is expected that phosphorus control would result in a return to a condition of mesotrophy for Lake Erie as a whole, and a condition of oligotrophy for Lake Ontario.

(i) Radioactivity - Gross Beta - not to exceed 1000 pCi/l

Radium-226 - not to exceed 3 pCi/l

Strontium-90 - not to exceed 10 pCi/l.

Discussion: Objectives were established to conform to United States Public Health Service drinking water standards, for protection of public water supplies.

5.2 REVISION OF WATER QUALITY OBJECTIVES FOR THE CONNECTING CHANNELS

Since the Connecting Channels have a profound effect on the water quality of the lower lakes it is recommended that the Advisory Boards for the Connecting Channels develop revised water quality objectives for adoption by the International Joint Commission. Their objectives should be compatible with those set out in this report for the lower lakes.

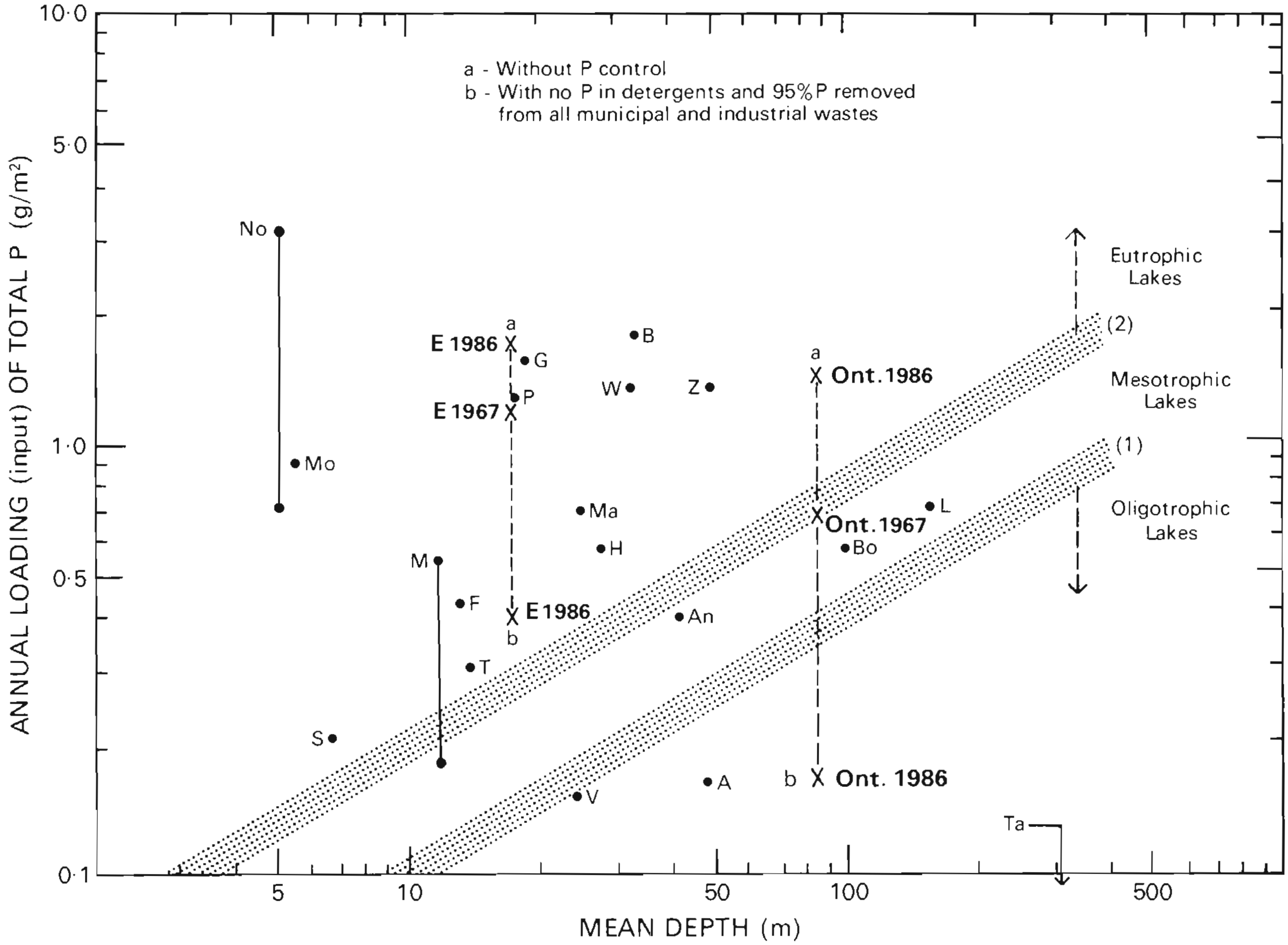


Fig. 6. 1. 2 State of eutrophication for a number of lakes in Europe and North America.

LEGEND

A - Aegerisee (Switzerland)
An - Lake Annecy (France)
B - Baldeggersee (Switzerland)
Bo - Lake Constance (Austria, Germany, Switzerland)
F - Lake Furesø (Denmark)
G - Greifensee (Switzerland)
H - Hallwillersee (Switzerland)
L - Lake Geneva (France, Switzerland)
M - Lake Mendota (U.S.A.)
Mä - Lake Mälaren (Sweden)
Mo - Moses Lake (U.S.A.)
No - Lake Norrviken (Sweden)
P - Pfäffikersee (Switzerland)
S - Lake Sebasticook (U.S.A.)
T - Türlersee (Switzerland)
Ta - Lake Tahoe (U.S.A.)
V - Lake Vänern (Sweden)
W - Lake Washington (U.S.A.)
Z - Zürichsee (Switzerland)
E - Lake Erie
Ont.- Lake Ontario

6. REMEDIAL MEASURES

6.1 RATIONALE FOR PHOSPHORUS REMOVAL

The most serious water pollution problem in the lower Great Lakes, having long term international significance, is the increasing eutrophication of the lakes. This deterioration of water quality, due to the luxuriant growth of algae and other plants and its repercussions on the overall biota of the lakes, is clearly the result of the increasing input of fertilizing nutrients from municipal sources, industrial wastes and land drainage. Although many of the most obvious effects appear localized, each lake is being adversely affected across the international boundary by nutrient enrichment from essentially all sources in both countries. Unless action is taken by Canada and the United States to reduce the nutrient input and fertilization of the lakes, there will be an ever increasing deterioration of water quality.

Complete diversion of municipal and industrial wastes would no doubt be the surest method of eliminating the majority of all nutrients from human-derived sources. This method has been successfully carried out on a number of smaller lakes through the construction of a complete canalized system which carries all wastes away from the lake. Unfortunately, complete diversion from Lakes Erie and Ontario is not economically possible due to the volume of wastes involved and the distances to the sea. With the present state of knowledge and technology, the only feasible approach to the problem in the lower Great Lakes is the removal of specific nutrients from wastes.

Phosphorus and nitrogen are recognized as the most important nutrients responsible for eutrophication. Trace elements and organic growth substances also play a part, however, their roles are inadequately understood as yet. The experience in many lakes indicates that phosphorus is most often the controlling material.

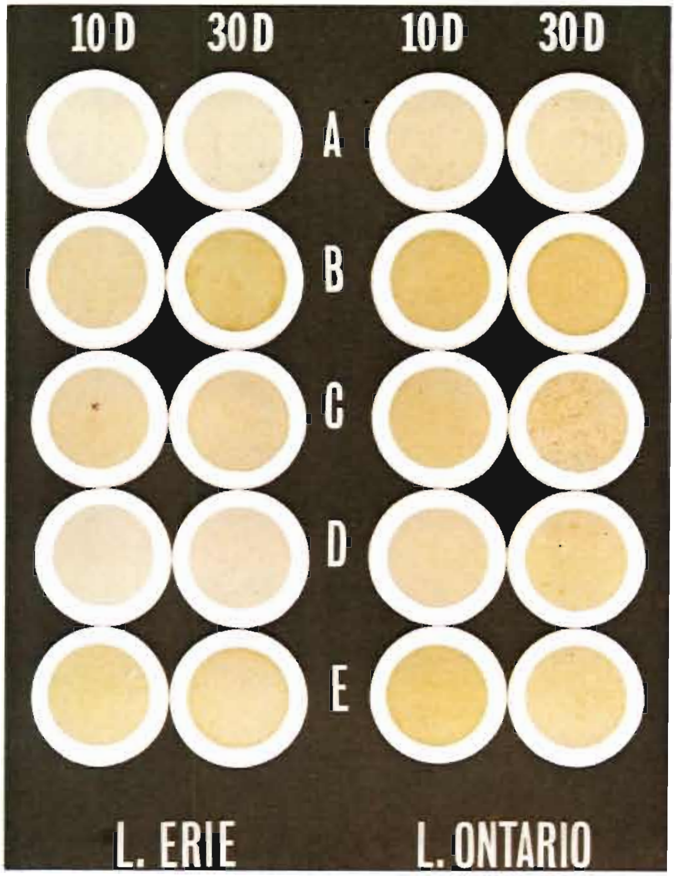
The reasons for proposing phosphorus removal from wastes to combat eutrophication are:

1. that in most natural waters the growth of algae is controlled more by the supply of phosphorus compounds than by the supply of nitrogen compounds. Other nutrients are generally of lesser importance. There is every reason to believe that this is also the case for Lakes Erie and Ontario.

2. that the loading of phosphorus to the lakes can be controlled more effectively than that of nitrogen (70 percent of the total phosphorus contributed to Lake Erie is attributable

PLATE V

EFFECT OF PHOSPHATE REMOVAL ON ALGAL GROWTHS



Filter residues showing algal growths from culture experiments using waters from the eastern basin of Lake Erie and the western basin of Lake Ontario.

The "A" flasks contained lake water alone.

The "B" flasks, lake water plus 2 percent raw sewage.

The "C" flasks, lake water plus 2 percent effluent from a secondary waste treatment plant.

The "D" flasks, lake water plus 2 percent effluent from sewage treated chemically to remove phosphorus (with essentially no removal of nitrogen).

The "E" flasks, the same as the "D" flasks, but with phosphate added to replace that removed.

Note the fertilizing effects of raw sewage (B) and secondary effluent (C); the beneficial effect of treatment for phosphorus removal (D); and the demonstration that phosphorus is the factor involved (E).

to municipal and industrial sources, *versus* 30-40 percent for nitrogen; comparable figures for Lake Ontario are 57 percent of phosphorus and 30 percent of nitrogen).

3. that efficient and relatively inexpensive methods are available for 80-95 percent removal of phosphorus during sewage treatment, whereas comparable elimination of nitrogen compounds is not yet feasible.

4. that nitrogen is contributed more from the uncontrollable sources than phosphorus because:

(a) phosphorus has a higher natural retention in soils than nitrogen.

(b) phosphorus is subject to further losses by natural biological sedimentation processes.

(c) the release of phosphorus from bottom sediments to water is less both in magnitude and in percentage than is the case for nitrogen.

(d) appreciable quantities of readily assimilable nitrogen compounds (nitrates and ammonia) are delivered directly to the lakes in precipitation. The comparable quantities of phosphorus are so low that they have yet to be accurately measured.

(e) during times of nitrate deficiency in surface waters some blue-green algae can utilize N_2 derived from the atmosphere as a source of nitrogen. An equivalent phenomenon does not exist for phosphorus uptake.

The most direct and obvious evidence of the importance of phosphorus in the enrichment of the lower Great Lakes by man's wastes comes from recent culture experiments (Vallentyne, 1969). These are illustrated on Plate 5 which shows the relative amount of algal growth in water taken from the eastern basin of Lake Erie and the western basin of Lake Ontario. All cultures contained the same volume of lake water and were incubated under identical conditions of light, time and temperature. One set of cultures was filtered after 10 days growth, when algal populations were near their maxima. The other set was filtered after 30 days, showing the residues remaining after the growth and decay of the populations. The heavy growths in the "B" and "C" flasks show the strong fertilizing effects of both raw sewage and effluent from a conventional treatment plant. The similarity of the "A" and "D" flasks shows the beneficial effect of chemical treatment for phosphorus removal, virtually returning the lake water to its original condition in respect to algal growth. The pronounced growths in the "E" flasks show that phosphorus was indeed the factor involved.

Consideration of phosphorus removal as a remedial measure for controlling eutrophication has two fundamental requirements. First, reliable estimates of the total input (loading) of phosphorus and the input from the various sources are required in order to estimate the extent of reduction that can be achieved (at the present time, it is assumed that only municipal and industrial wastes are amenable to direct control). Estimates of nutrient input from all sources have been a substantial part of the work in the preparation of this report. Tables 6.1.1, for Lake Erie, and 6.1.2, for Lake Ontario, give the inputs of total phosphorus from the various sources for the present time (1967) and the projected inputs for 1986 if no remedial measures are undertaken. These projections allow for anticipated population and industrial growth in the Great Lakes region. The tables also give the projected total loading in 1986, if by then all phosphorus is eliminated from detergents and 95 percent of the phosphorus is removed from all municipal and industrial wastes.

The second requirement is for a basis of evaluating the probable effect on the lake if a program of phosphorus reduction were carried out. The recent work of Vollenweider (1968) on the role of phosphorus and nitrogen in the eutrophication of lakes provides the only basis for making this evaluation. Vollenweider made a comparison of all the world's lakes where reliable information was available on both phosphorus loading and the degree of eutrophication. The 20 lakes for which such information was available varied in area and depth. In order to compare these lakes of different area and volume, the loadings were expressed as the amount of phosphorus delivered to a unit surface area in a unit time (grams of total phosphorus per square metre of lake surface per year). Predicted effects were then evaluated as a function of the mean depth of the lakes.

Fig. 6.1.2 shows Vollenweider's evaluation of the effect of phosphorus loading and the degree of eutrophication. The two lines enclose the range of mesotrophic conditions. This area was defined on the basis of knowledge of the trophic conditions of various lakes involved. Three of the lakes - Leman, Bodensee (Constance) and Annecy - are definitely mesotrophic, while Lake Mendota was still rather mesotrophic in the early 1940's (the lower point). Lakes Sebasticook and Turler are slightly eutrophic, Vanern and Aegerisee are oligotrophic. The upward slope of the two lines enclosing the range of mesotrophy, is in good agreement with the accepted fact that the deeper the lake and the greater its volume, the greater is its capacity to absorb a given nutrient load.

This evaluation of the role of phosphorus in eutrophication is based on empirical rather than theoretical relationships. As such, it provides a solid basis for comparison which is free from assumptions. However, as Vollenweider points out, mean depth is the only parameter considered here in relation to phosphorus loading, and other factors (flushing time, geographical location, etc.) must be considered. Also, the added effects of other nutrient substances and growth factors may be involved. For this reason, he emphasizes that the actual boundaries denoting the mesotrophic range as shown in Fig. 6.1.2 might be different for other lakes.

The relative position of points for some of the lakes in Fig. 6.1.2 strongly indicates that their mesotrophic boundaries must indeed be considerably different. For example, the relative distance above line (2) would indicate Lake Washington was more eutrophic than either Zurichsee or Lake Mendota. In fact, Lake Washington is considerably less eutrophic than either of these lakes.

In this regard it is interesting to note the relative position of the points describing the 1967 situations in Lakes Erie and Ontario. In Fig. 6.1.2, the upper X (1986) gives the projected loading in 1986 without any phosphorus control, and the lower X gives the projected 1986 loading if all phosphorus is eliminated from detergents and 95 percent of the phosphorus from all municipal and industrial wastes is removed. At the present time it is estimated that 50 to 70 percent of the total input of phosphorus from all municipal and industrial wastes into the lower Great Lakes comes from detergents. It is projected that this will become about 70 percent by 1986 if no controls are carried out.

Fig. 6.1.2 suggests that Lake Ontario is presently mesotrophic, in the upper range nearer to eutrophy. However, based on the various criteria examined earlier (Table 3.1.1), Lake Ontario actually seems to be much more oligotrophic than this: in a stage between oligotrophic and mesotrophic. If this is true, then elimination of phosphorus from detergents plus 95 percent removal of phosphates would return Lake Ontario to an oligotrophic range (Fig. 6.1.2). It seems very probable that this would indeed be the case.

Lake Erie is indicated as being rather highly eutrophic in 1967 from its position in Fig. 6.1.2 Also, it is suggested that it would still be well within the eutrophic range after elimination of phosphorus from detergents plus 95 percent removal of controllable phosphorus in 1986. As was

Table 6.1.1 Lake Erie: Annual input of total phosphorus (short tons per year).

Source	1967			Projected for 1986 without control measures		
Lake Huron	2,240			2,600		
	U.S.	Canada	Total	U.S.	Canada	Total
Detroit River						
Municipal	10,750	760	11,510	15,000	1,050	16,050
Industrial	350	630	980	1,000	1,580	2,580
Land Drainage	1,490	1,380	2,870	1,600	1,500	3,100
Sub-Total	17,600			24,330		
Point Sources						
Municipal	2,710	30	2,740	4,000	50	4,050
Industrial	Nil	20	20		50	50
Sub-Total	2,760			4,100		
Other Major Tributaries						
Municipal	4,360	480	4,840	8,000	1,050	9,050
Industrial	560	470	1,030	1,000	1,180	2,180
Land Drainage	3,320	550	3,870	4,000	950	4,950
Sub-Total	9,740			16,180		
Total-Municipal & Industrial	21,120			33,960*		
Total-Other Sources	8,980			10,650		
TOTAL	30,100 (1.06 $g/m^2.yr$)			44,610 (1.57 $g/m^2.yr$)		
TOTAL - If by 1986 all phosphorus is eliminated from detergents and 95% removed from all municipal and industrial sources				11,160 (0.39 $g/m^2.yr$)		

* It is estimated that 70% of this will be from detergents.

Table 6.1.2 Lake Ontario: Annual input of total phosphorus (short tons per year).

Source	1967			Projected for 1968 without control measures		
Lake Erie						
Niagara River	4,500			6,700*		
	U.S.	Canada	Total	U.S.	Canada	Total
Niagara River						
Municipal	2,000	330	2,330	5,860	400	
Industrial	150	80	230		210	6,470
Land Drainage	50	50	100		50	50
Unaccounted	540			600		
Sub-Total	7,700			13,820		
Point Sources						
Municipal	950	2,010	2,960	1,740	5,700	7,440
Industrial	Nil	180	180	20	460	480
	3,140			7,920		
Other Major Tributaries						
Municipal) Industrial)	920	1,200	2,120	2,500	2,000	4,500
Land Drainage	470	250	720	510	270	780
Sub-Total	2,840			5,280		
Total-Municipal & Industrial	7,820			18,890**		
Total-Other Sources	5,860			8,130		
TOTAL	13,680 (0.65 $g/m^2.yr$)			27,020 (1.29 $g/m^2.yr$)		
TOTAL - If by 1986 all phosphorus is eliminated from detergents and 95% removed from all municipal and industrial sources (including controls on Lake Erie).				3,400 (0.17 $g/m^2.yr$)		

*Increased in proportion to projected 1986 loading to Lake Erie.
**It is estimated that 70% of this will be from detergents.

found for Lake Ontario, the earlier examination of various criteria indicated that Lake Erie is considerably less eutrophic than Fig. 6.1.2 suggests. It thus seems more probable that the recommended phosphorus removal might well bring Lake Erie back down into the mesotrophic range. This assessment of Lake Erie is for the lake as a whole; regardless of phosphorus control, the western basin will continue to be more eutrophic than the central and eastern basins.

Although Lake Erie has obviously undergone rapid eutrophication in recent years, it must be emphasized that it was not an oligotrophic lake before these recent changes. This can be inferred from the rather shallow depth, the rich soil and sedimentary rock drainage area, and the early history of a highly productive fishery. Even prior to recent changes, Lake Erie was probably a mesotrophic lake and any control measures applied will not alter its trophic condition below mesotrophy.

The conditions in the international section of the St. Lawrence River are largely dependent on the quality of water flowing out of Lake Ontario. Implementation of phosphorus control in the Lake Ontario basin would be sufficient to improve water quality in the St. Lawrence River. However, no increases should be allowed in the phosphorus loads discharged directly into the St. Lawrence River. Indeed some of these sources may need control to eliminate local nuisance conditions downstream from their points of entry.

In this consideration for phosphorus control, only detergents, municipal and industrial wastes have been considered as amenable to control. Further reductions in phosphorus input could be achieved with implementation of techniques to reduce the inputs from land drainage. There seems little doubt that a considerable input comes from agricultural lands. For example, it is estimated that more than 89,000 short tons of total phosphorus were contained in fertilizers applied to lands in the Lake Erie basin in 1966. If only 2 percent of this reached the waters of Lake Erie it would represent a substantial input. Control of such sources should be implemented as soon as possible. Implementation of this program in the Lake Erie basin would further reduce the input to Lake Ontario.

A good deal of concern is expressed about the regeneration of nutrients from sediments of enriched lakes after the nutrient supply from controllable sources is cut off. Once a lake has become productive enough so that oxygen is exhausted from deep water during summer, chemical changes at the mud-water interface cause a release of nutrients into the water from the surface sediments. This has been estimated as 8 percent of the total phosphorus load for one small eutrophic lake (Vollenweider, 1968). Large lakes are believed to be proportionately less affected than small lakes, but Lake Erie, which already shows considerable oxygen depletion in the hypolimnion, is approaching this dangerous point in eutrophication. Prevention of this state would serve to delay the regeneration of another source of nutrient enrichment.

The recovery time for a lake to revert to a less eutrophic condition after reduction of nutrient input is very difficult to assess. It depends on how far the total nutrient load is reduced and the extent to which the remaining load is diluted. This in turn depends on the volume of water, area, thermal stratification and circulation, renewal of the lake volume, recycling of nutrients within the lake, and sediment-water exchange processes. The exchange between water and bottom sediments is primarily at the surface layer, at least in deeper waters. If the external input of nutrients to the lake is drastically reduced, it will decrease the nutrient content of the surface sediments, and the amount of regeneration of nutrients from the muds.

If all phosphorus were removed from detergents and 95 percent removed from municipal and industrial wastes by 1986, the total phosphorus loading to Lake Erie in 1986 would be only 37 percent of what it was in 1967. Although there are no data on the total loading to Lake Erie in earlier years, there is evidence that mean phosphorus levels in the western basin increased about threefold from 1942 to 1967. With the not unreasonable assumption that this reflects the proportional change in phosphorus loading, it suggests that the conditions in Lake Erie might eventually be restored to those of the early 1940's. The same phosphorus control in the Lake Ontario basin would reduce the loading in 1986 to about 25 percent of the 1967 values. There are no historical data on either phosphorus or the phosphorus content for Lake Ontario. However, similar control would appear to be sufficient to eventually restore Lake Ontario to a condition well into the range of oligotrophy.

The evaluation of the probable effects of phosphorus removal is the best assessment that can be made with our present knowledge. Perhaps the most difficult question to answer is whether or not eutrophication can be controlled by the reduction of phosphorus alone. All evidence suggests that it can. Phosphorus removal is the only economically feasible solution at the present time, and it is the logical place to start in a series of accessory remedial measures that may ultimately be necessary if population and technological growth in the Great Lakes basin continue without limit. Thus, it is not claimed that phosphorus removal will control all the problems of the future; only that it is the best known remedial measure at present and one that must be accepted as the basis for all future controls. Treatment for removal of nitrogen compounds may have to be instituted in the future.

Encouragement can be taken from the fact that phosphorus removal as a remedial measure is now being undertaken at the very eutrophic Swiss lake, Zurichsee, where 55 percent of the phosphorus loading comes from controllable sources (Fig. 6.1.2). Phosphorus removal is also being undertaken in Sweden. If phosphorus is as important as believed, then the results of the recent sewage diversion from Lake Washington (Fig. 6.1.2) are also most encouraging (about 50 percent of the phosphorus loading came from sewage). Lake Washington has already shown dramatic recovery to a much less eutrophic condition since the diversion was completed little more than one year ago.

It is obvious that a very high degree of phosphorus removal will be necessary by 1986, particularly in Lake Erie. We have examined here the projected effects of elimination of all phosphorus from detergents and 95 percent removal from all municipal and industrial wastes by 1986. Although this high degree of phosphorus control is not presently feasible, it is expected that it will be necessary by 1986.

6.2 MUNICIPAL AND INDUSTRIAL WASTE TREATMENT

Remedial measures are required to reduce the fertilization and resulting adverse effects on water quality from nuisance biological growths by implementing phosphorus removal or control at waste water sources and other locations.

These measures are outlined under Recommendations (Section 1.2). They include immediate reduction and eventual replacement of phosphorus in detergents and implementation of programs for the reduction of phosphorus in municipal and industrial waste effluents. The municipal and industrial pollution control effort should be guided by the limits set out in the basis of recommendations for control of phosphorus inputs to the lower lakes and their connecting rivers.

As previously indicated, a very high degree of phosphorus removal will be required in Lake Erie to arrest the rate of eutrophication and improve lake water quality. For this reason, all feasible approaches to the phosphorus removal problem must be implemented. The question may be raised as to why it is necessary to remove phosphorus both from detergents and at sewage treatment plants.

The first concerns timing. Partial replacement of phosphates in detergents is now possible with no reduction in cleansing power. Also if urgency is attached to finding an environmentally harmless substitute for full replacement of phosphates, it might be possible to find an answer within a few years. As seen from the dates recommended in Section 1.2 for sewage plant nutrient removal, it will be economically and physically impractical to have full facilities completed for Lake Erie and its tributaries before 1975 and for Lake Ontario before 1978. If the technology for detergent phosphate removal can be quickly developed, an almost immediate elimination of a substantial proportion of the phosphorus loading to Lake Erie and Lake Ontario could be achieved to prevent further deterioration of these lakes while sewage treatment facilities are being built.

Secondly, the requirement of phosphorus removal would in many cases impose undue financial burdens on small municipalities, individual homes and industries in the drainage basins. In such cases treatment facilities cannot be economically provided, other than by reduction of the phosphorus contributed by detergents. An added benefit from a program of phosphate removal from detergents would be a significant reduction in the rate of fertilization and eutrophication of inland lakes and rivers in the drainage basin of the Great Lakes, improving their quality for recreational, domestic and other uses.

Thirdly it is estimated that treatment costs for phosphate removal at sewage treatment plants would be reduced by a half to two-thirds by removal of phosphates from detergents. At the present time 70 percent of the phosphorus in municipal sewage in the United States and 50 percent in Canada arises from phosphate-based detergents, the overall basin average lying close to that of the United States. The current average content of phosphorus in sewage is about 10 mg/l, of which 7 mg/l originates from detergents. If phosphates were replaced in detergents, removal of 80 percent of the remaining phosphorus at the sewage treatment plant would then reduce the concentration to 0.6 mg/l. To achieve the same effluent concentration without replacement of phosphates in detergents would require more than 95 percent removal at the sewage treatment plant with two to three times the overall cost, largely due to the additional chemicals needed and solid wastes produced. Since solution of the combined sewer overflow problem will take a number of years to accomplish, an early reduction in phosphorus inputs to the lakes from this source could be achieved by detergent reformulation.

The two remedial measures should be thought of as complementary since detergents and human wastes are the principal sources of phosphorus to the lakes. For these reasons both measures should be instituted as recommended.

Water pollution control should be treated like any other public utility, the purpose of which is to serve the public with the best and most efficient service. Greater attention should be given to providing standby equipment capable of preventing water pollution during periods of breakdown or inadequate performance. The need exists for municipalities to extend the policy of separating combined storm and sanitary sewage collection systems in newly developed areas to include the correction of existing combined sewer systems. In existing combined sewered areas, where separation is not economically feasible, municipalities should provide for control of pollution resulting from overflows of these systems.

There are several municipal locations where basic sewage service is still lacking and sewage treatment needed. Nutrient removal will probably become a universal requirement throughout the Great Lakes basin as the density of urban development increases. Priorities should be established to attack initially the major sources of the problem. The cost estimates given in Chapter 7 are based on correcting the outstanding problems in the lower Great Lakes basin and providing for growth and improvements over the period to 1986.

The principal industries contributing direct discharges of wastes to the lakes are listed in Appendices 1.1 to 1.8. In a number of cases their waste recovery and/or treatment programs are inadequate to protect the quality of lake waters. Accelerated industrial remedial programs are required to control oxygen-consuming materials, organic substances, acids, alkalis, iron, phenols, oils and toxic substances.

6.3 CONTROL OF POLLUTION FROM LAND DRAINAGE

Measures are required to reduce the amount of phosphorus lost from the lands of the drainage basins of the lower Great Lakes. This will require improved control of animal waste disposal, soil and riverbank erosion by those responsible for livestock and land management. Water pollution control agencies should ensure that appropriate action is taken to reduce the input of phosphorus from these sources by encouraging government agricultural and other agencies to develop and implement plans directed toward this objective. These measures should include improved practices of soil fertilization, land tilling and conservation activities. A system of inventory and improved techniques for the application of toxic pesticides and herbicides to field crops should be developed at the earliest opportunity. Substitutes should be found for persistent toxic chemicals and their use encouraged.

6.4 OIL AND INDUSTRIAL MATERIAL SPILLS

An international program is required to cope with oil, industrial or toxic spills on the Great Lakes whether such incidents are considered as catastrophes, or less spectacular events. The essential elements of the program must recognize prevention, surveillance, notification, and cleanup.

Contingency plans, which are essentially procedural arrangements for the notification and cleanup of spilled pollutants, have been developed in the United States for the Great Lakes basins by the Federal Water Pollution Control Administration. These plans are extensive and have been developed to the point that a significant response capability is now available. Development of similar plans has been initiated in Canada, and as details are worked out coordination of the international aspects of such plans should be provided by the International Joint Commission.

Water quality objectives and their enforcement are the most effective methods of preventing pollution of a continuing nature. Pollution prevention programs should include a requirement by governments to have all those who handle, process, transport and dispose of materials which may cause water pollution, examine existing facilities, procedures, personnel training and operations to prevent spills and other pollution incidents.

Immediate reporting is essential in the case of a sudden pollution incident. A proper surveillance and reporting system is necessary to effectively organize countermeasures and minimize pollution damages. Existing legislation should also be reviewed at all levels of government to ensure that in the event of danger of pollution from a recurring or non-recurring source, the authority exists for undertaking adequate measures to abate pollution either by the parties concerned, or the appropriate governments if the parties fail to do so.

The first step in any effective cleanup program on the Great Lakes should be to develop an international contingency plan. Such planning must recognize the problems at all levels: local, regional, state, provincial, national and international. The plan must also involve those agencies which have the technical and scientific personnel trained and located to handle the problems. This may require the integration of resources, manpower, materials, equipment and technology in both countries.

The contingency plan and prevention measures although directed primarily to oil spills and disasters should also encompass the handling, storage and transfer of hazardous substances whether by ship, rail or road. Cargo tonnages now transported on the Great Lakes are expected to increase substantially by the turn of the century. It is not unreasonable to expect that a part of the increase might include oil. Therefore, consideration should be given now by the appropriate regulatory agencies to the increased potential of pollution from this source.

6.5 OTHER SOURCES

6.5.1 Vessel Wastes

Compatible rules and regulations governing all types of waste discharges from vessels and boats are required. Local, provincial, state and federal governments concerned with water pollution control and the licensing and registering of all commercial and recreational vessels should develop these rules and regulations to be effective no later than 1970. The agreements should not preclude interim measures that might be promulgated and made effective by any local, state or provincial governments prior to 1970.

The rules and regulations should include all forms of pollutants which might be discharged from any type of vessel or boat using the international waters between the United States and Canada. Of particular concern are discharges of sewage, ballast, bilge water, waste oils, garbage, litter and related solids.

6.5.2 Thermal Wastes

Plans and programs for the location and operation of thermal power plants, including conventional and nuclear-fueled generating stations on the Great Lakes should recognize both the potential benefits and adverse effects of waste heat.

6.5.3 Radioactivity

Radioactive wastes, discharged directly to the lakes or their tributaries from nuclear reactors, waste processing plants, industrial, medical and research centres, are presently monitored by federal, state and provincial authorities. Such wastes should continue to be controlled and monitored.

A lake surveillance program should be implemented for observance of total levels of radioactivity. The need for contingency plans must be recognized in advance of a serious accident or undesirable radioactive levels in the lakes.

6.5.4 Dredging

The disposal of dredged material containing objectionable quantities of pollutants should be undertaken in such a manner that the materials will not damage the quality of waters and wildlife feeding areas in Lakes Erie and Ontario.

6.5.5 Solid Wastes

Solid wastes, some of which contain garbage, metals, oil and other deleterious substances, should be disposed of in areas or containments where there can be no adverse effects on water quality. Shore improvements and other construction operations which utilize refuse or other deleterious materials or wastes should not be permitted, unless authorization has been granted by the appropriate authorities.

6.6 SURVEILLANCE AND MONITORING

Water quality surveillance and monitoring of lake waters, tributary streams and waste sources are carried out for three basic reasons:

1. enforcement - to determine degree of compliance of pollution sources with the water quality objectives or standards;

2. management - to develop comprehensive water quality management programs for the drainage basins and assess the progress made in pollution abatement following their implementation;

3. research and prediction of water quality trends - to determine long term trends in water quality for planning, research, and development of water quality prediction models.

Surveillance and monitoring for these purposes, require detailed sampling programs in nearshore areas and tributary basins to assess the direct impact of waste sources and to develop comprehensive water quality management plans for the drainage system. Lakewide sampling and observational programs are required in the lakes for research investigations and the prediction of long term water quality trends. The survey programs should be developed internationally, using common standards of observations and sampling techniques. Water quality surveillance and monitoring of lake waters, tributaries and waste sources should be expanded to allow continuation of and adjustment to the programs for enforcement, management, planning and research. As the necessary corrective programs are established, provision should be made for a continuing review of the effectiveness of the programs and their adjustment in the light of the expanded information available through continued monitoring.

An early warning system must be provided at all sites where the potential exists for major spills of oil, radioactive contamination, or other hazardous material. Strict surveillance of pesticide use should be initiated along with continuous monitoring of pesticide concentrations in the aquatic environment, and procedures be established to account for distribution and application of pesticides.

6.7 FURTHER STUDIES

Federal, provincial and state governments should develop, encourage and support research leading to more effective water quality management policies for the future. There are a number of problems requiring further research attention. Many of these are noted in various sections of this report, and the more important ones summarized here.

Because of the very large financial implications (Section 6.8) increased engineering development efforts on alternative means for reducing pollution overflows from combined storm and sanitary sewer systems should receive considerable support. Less expensive nutrient removal and waste treatment processes resulting from research projects would also yield large benefits. Research to find environmentally harmless replacements for phosphates in detergents is urgently needed.

Environmental problems require the application of our present knowledge in environmental technology as well as the information and results obtained from continuing research investigations. Among the problems needing the most urgent attention are those concerned with (a) the nutrient requirements for algal growth and determination of whether and how micro-nutrients may limit growth, (b) sediment-water interchanges of polluting substances, (c) pesticide movement through the food chain and its effect on various life forms, (d) more refined estimates of lake chemical budgets including an assessment of the extent of man-made and natural sources, (e) better understanding of circulation of lake waters and diffusion of pollutants, (f) development of reliable remote reading or automatic recording instruments for monitoring chemical, biological and physical parameters in the lakes, (g) effects of increased heat inputs on the energy balance and the ecological balance of nearshores areas, (h) viral epidemiology.

Some of these studies will contribute to the development of water quality prediction models. Such models can be used to develop more efficient surveillance systems, to anticipate water pollution control needs, and permit rational planning for water pollution control. To be complete, water quality prediction models must incorporate socio-economic studies including industrial, demographic and water use projections. Information must also be acquired on public perception of pollution problems and on their willingness to pay for pollution abatement.

6.8 SUMMARY OF COSTS

The cost of waste management measures to correct outstanding problems and provide for the rapid development expected in the lower lakes drainage basin in the next two decades is presented in this section. Capital costs for municipal and industrial waste treatment are based on projected populations and anticipated industrial development as foreseen until 1986. Allowance is made for the existing backlog of needed works and equipment replacements, however, provision is not made for sewer extensions, land acquisition, or the costs of financing. The estimates provide for the implementation of phosphorus removal in accordance with the program contained in the recommendations of this report. A summary of the municipal and industrial costs for waste treatment, in 1968 dollars, is given in Table 6.8.1 for each lake and river system.

The cost of constructing municipal waste treatment plants, including facilities for nutrient control, to meet the needs in 1986 is estimated at $(Can.) 185 million and $(U.S.) 895 million for the drainage basins in Canada and the United States, respectively. These totals include $(Can.) 37 million and $(U.S.) 335 million to meet today's sewage treatment needs in both countries and allow $(Can.) 108 million and $(U.S.) 295 million for upgrading of services, increases in population growth, and replacement of facilities to satisfy the water quality objectives. Costs of maintenance and operation will continue to increase from year to year as improved facilities are provided.

The capital costs for phosphorus removal amount to $(Can.) 40 million and $(U.S.) 265 million for municipal and industrial waste treatment. While these costs represent the initial capital investment, there may be opportunities for cost reduction depending on the design of the basic treatment plant.

Using the example of alum coagulation and settling in conjunction with activated sludge treatment for phosphorus removal, operating costs in the range of 3-5 cents per 1,000 gallons of sewage treated may be expected[1]. These costs include debt retirement, operation and maintenance and will vary with the type of sewage treatment, plant capacity and other local

[1]Estimates of cost are based on current cost of chemicals (liquid alum) at Cinncinati, Ohio, and on adding the chemicals between the primary sedimentation tank and the aeration chamber in an activated sludge plant. Treatment costs would vary with the size of plant, type of treatment, locality and availability of chemicals.

Table 6.8.1 Estimated capital costs for waste treatment and nutrient removal in thousands of dollars*.

Drainage system	Existing backlog	Municipal future growth	Phosphorus removal	Industrial	Total
		CANADA			
Detroit - St. Clair	7,000	14,700	4,300	5,600	31,600
Lake Erie	2,500	13,900	5,800	1,609	23,800
Niagara River	750	4,500	1,200	1,500	7,950
Lake Ontario	26,000	65,000	26,200	14,600	131,800
St. Lawrence River	650	10,300	2,100	3,400	16,450
TOTALS	36,900	108,400	39,600	26,700	211,600
		UNITED STATES			
Detroit - St. Clair	48,000	40,000	62,000	100,000	250,000
Lake Erie	65,000	90,000	125,000	185,000	465,000
Niagara River	96,000	72,000	32,000	36,000	236,000
Lake Ontario	118,000	89,000	43,000	134,000	384,000
St. Lawrence River	8,000	4,000	3,000	23,000	38,000
TOTALS	335,000	295,000	265,000	478,000	1,373,000

*1968 dollars

factors. As the cost of chemicals becomes a major part of the total cost for phosphorus removal for larger capacity treatment plants, means of reducing these costs should be pursued.

For ease of comparison, costs have been estimated on current sewage flow rates using the initial objective of 80 percent overall reduction in the phosphorus discharged from municipal and industrial sources in the lower lakes basin in each state and province. Also recognized is the present impracticality of phosphorus reduction for smaller communities with populations of 10,000 persons or less and the desirability therefore, of obtaining 90-95 percent removal in the larger installations. The costs are given in Table 6.8.2 for both the conditions where detergent phosphorus is present (10 mg/l) and absent (3 mg/l) in sewage.

The comparative advantage in chemical cost savings for the case with detergents removed from sewage is clearly apparent. For Lake Erie and the Detroit-St. Clair River system the initial objective would be met by reduction of the 10 mg/l level in the sewage of the larger centres by 95 percent at a total annual cost for chemicals of $(Can.) 1.2 million dollars and $(U.S.) 17.6 million dollars respectively for both countries. However, the same objective could be met with costs of $(Can.) 260,000 and $(U.S.) 5.3 million with a phosphorus level of 3 mg/l in sewage and only an 80 percent removal requirement for the larger communities. An annual saving in costs of chemical treatment at sewage plants would be approximately $(Can.) 1 million and $(U.S.) 12 million in each country, respectively. A total annual savings of about $(Can.) 5 million and $(U.S.) 17 million is indicated for the combined Lake Erie-Lake Ontario-St. Lawrence River basin.

The costs of industrial waste control to correct the existing backlog of needed works in both countries are estimated to be $(Can.) 27 million and $(U.S.) 478 million (Table 6.8.1). Additional financial costs must be anticipated for maintenance and operation of these facilities as they are completed.

Although no detailed cost estimates have been made, separation of combined municipal sewers would require large sums of capital. In the Canadian portion of the lower lakes basin approximately $(Can.) 600 million is needed, while about $(U.S.) 4,500 million is required in the United States. These figures do not include the costs of separating building service connections which in total would be very large. Because of the extremely high cost of sewer separation, more economical methods of controlling pollution from combined sewers need to be developed. In 1964 a survey of the problem of control of pollution from combined sewers indicated the extremely high

Table 6.8.2 Annual costs of phosphorus removal for sewage treatment plants of capacity 1.0 mgd or greater (in millions of dollars)

Level mg/l conc. of phosphorus	CANADA 80	90	95	USA 80	90	95
	% removal					
	Lake Erie - Detroit - St. Clair River system					
10	0.90	1.08	1.21	13.30	15.70	17.57
3	0.26	0.31	0.35	5.27	6.31	7.37
	Niagara River - Lake Ontario - St. Lawrence River system					
10	4.02	4.82	5.41	4.31	5.08	5.89
3	1.15	1.38	1.55	1.60	1.73	2.00
	Basin total					
10	4.92	5.90	6.62	17.61	20.78	23.46
3	1.41	1.69	1.90	6.87	8.04	9.37

Savings with removal of detergent phosphorus for the Lake Erie basin

	Canada		USA
	1.21		17.57
	-0.26		- 5.27
	$0.95		$12.30

Savings with removal of detergent phosphorus for entire lower lakes basin

	Canada		USA
	6.62		23.46
	-1.41		- 6.87
	$5.21		$16.59

cost involved in sewer separation in the United States (Department of Health, Education and Welfare, 1964). As a result of this study, the Federal Water Pollution Control Administration was authorized to carry out a research and development grant and contract program. Projects were supported for the development of new or improved methods of controlling the discharge of untreated or inadequately treated sewage or other wastes from storm water discharges. As of January, 1969, 54 projects have been funded, totalling over 22 million dollars. It is expected that these research programs will lead to economically feasible methods for handling the problems in the future.

Recognizing that the financing and construction of the needed works will extend over the next few years, a construction period from 1970 to 1978 has been used to provide an example of costs in terms of current dollars (Table 6.8.3). If the total costs of industrial and municipal waste treatment were to be expended about equally each year over the period 1970 to 1978, having regard for the recommended staging of phosphorus removal facilities, the total for Canada and the United States would become $(Can.) 271 million and $(U.S.) 1,618 million, respectively, allowing 4 percent for annual increase in costs. This does not provide for waste control facilities to serve future industrial developments which are estimated to be 3 to 5 percent or as high as 10 percent of the total capital investment in new industrial plants. If the costs of combined sewer separation systems were to be included, total expenditures in current dollars in the order of $(Can.) 1 billion and $(U.S.) 7.3 billion would be required.

Replacement of phosphorus by an environmentally harmless substance in detergent formulations will achieve an immediate reduction in total phosphorus inputs. This measure would enhance the degree of control by securing phosphorus removals from uncontrolled waste or drainage sources; such as overflows from combined sewers and those sources that cannot be connected to municipal sewage collection systems.

A complete assessment of the future costs of pollution abatement in the lower Great Lakes drainage system is not possible at this time for a variety of reasons, three of which are:

(a) the costs of pollution abatement required for the upper Great Lakes to limit further increases in the phosphorus output of Lake Huron are unknown. It is probable that removal of phosphorus from detergents would achieve the amount of reduction necessary for the foreseeable future.

(b) the costs of land required for sewage services are unpredictable.

(c) programs need to be developed for the control of phosphorus and sediment accumulations from sources of livestock wastes, soil and riverbank erosion. It will be necessary to demonstrate to the farmer, land owner, and construction contractor the economic benefits of improved management of livestock, soil and land.

While not of the same order of magnitude as the preceding considerations, such problems as oil spills, waste treatment for commercial vessels, disposal of waste heat from the thermal generation of power, and alternatives for disposal of dredging spoils are specific areas for which the eventual costs remain unknown. As a result of a recent study of the pollution problems associated with dredging in the United States, the Corps of Engineers has developed a 10 year program to deposit polluted dredgings from 35 Great Lakes harbours in dyked areas (United States Army, Corps of Engineers, 1969). The cost of constructing the dyked areas is estimated to be about 70 million dollars with increased operating costs of about 5 million a year. It will take 2 or 3 years to complete this program and the storage capacity provided should accommodate dredged material for at least 10 years. The success of all these measures will depend inevitably upon the willingness of the public to pay for the increased costs of water pollution control.

Table 6.8.3 Estimated capital requirements for municipal waste and industrial waste treatment over period to 1978 (in millions of dollars).

	CANADA		UNITED STATES	
	Total 1968 dollars	Total[1] to 1978	Total 1968 dollars	Total[1] to 1978
Municipal				
Backlog	37	47	335	368
Upgrading and replacement	108	137	295	372
Phosphorus control	40	53	265	333
Industrial	27	34	478	545
TOTALS		271		1,618
Combined Sewer separation	600	730	4,500	5,700
TOTALS		1,001		7,318

[1]Current dollars

7. INSTITUTIONAL ARRANGEMENTS AND LEGISLATION

7.1 INSTITUTIONAL ARRANGEMENTS

Informal arrangements exist for coordination of Great Lakes research, such as the Great Lakes Study Group, the International Association for Great Lakes Research and international coordination of action programs and planning activities through the International Joint Commission. In the past the International Joint Commission has coordinated specific studies at particular times when urgent problems have arisen. There is at present no provision for continuing international coordination of water use planning in the Great Lakes basin.

As population pressures build in the Great Lakes basin, an increasing number of difficult decisions must be made on the location and growth of communities and industry within the basin and especially on the shores of Lakes Erie and Ontario. These and other planning decisions such as the recommendations of the International Great Lakes Levels Board (International Joint Commission) will affect the state of the shared water resource in increasingly important ways - the quality of lake water being only one of the criteria. It seems obvious that just as Canada and the United States have each formed basin planning boards or commissions for some of the major basins within their own borders, planning at an international level is a necessity for the Great Lakes.

The International Joint Commission should consider possible ways of establishing a continuing arrangement to coordinate internationally the planning for water pollution control in the Great Lakes, recognizing the necessity for:

(a) water quality objectives and plans for their attainment

(b) recommendations for legislation

(c) contingency planning for oil and toxic material spills

(d) monitoring and surveillance

(e) engineering development of waste treatment and environmental technology

(f) research.

7.2 LEGISLATION

1. Federal, provincial and state legislation should be reviewed and revised where necessary to recognize the fact that waste sources from one or more areas of jurisdiction may collectively cause pollution in other regions.

2. Compatible legislation should be sought by the various governments to control water pollution from all classes of boats and vessels.

In the United States, waste discharges from pleasure craft are presently regulated by some states in which the craft are licensed or registered. Commercial vessel discharges are subject to limited federal controls.

In Canada, the Ontario Water Resources Commission, has legislation governing pleasure craft waste disposal. The Marine Regulations Branch of the federal Department of Transport, in consultation with other federal agencies, is also preparing regulations designed to control discharges of sewage and garbage from all vessels within Canadian waters. These regulations will set standards for sewage discharge which could be met by either an onboard treatment system, or by containment of the wastes. Discharge of oil by vessels is already covered by legislation, and in 1967, 24 successful prosecutions were carried out for infraction of oil pollution prevention regulations.

3. The Province of Ontario and the Great Lakes states should develop compatible policies for safeguarding water quality in advance of any extensive oil and gas exploration and production activities in the United States sectors of Lake Erie and Lake Ontario.

In the United States the Great Lakes submerged lands are recognized by law as state owned. Leasing for oil and gas exploration and production is the responsibility and right of each state owning such lands. Michigan and Pennsylvania have pollution control regulations or policies governing oil and gas drilling in their respective states. Ohio has developed regulations for drilling on its submerged lands but has indefinitely postponed any promulgation of them. New York has developed regulations but they have not yet been formally adopted.

Ontario regulations governing licensing call for the proper disposal of waters and oil recovered from wells and for plugging of dry wells. Liability insurance must be held in the event of compensation claims for damages caused by drilling or production operations. These control measures are considered as meeting the necessary protection for the Ontario waters of Lake Erie.

4. Legislation should be enacted to control the use of herbicides and pesticides affecting the waters of the lower Great Lakes basin.

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APPENDICES

Appendix 1.1 Municipal waste discharges direct to Lake Erie 1966-67 (short tons/year).

Municipalities	Map index[1]	Existing treatment	Sewage flow (mgd)	Population served with sewers (X1000)	BOD_5	Solids Total	Solids Susp.	Total[2] nitrogen (N)	Total[2] phosphorus (P)	Chlorides[2]
				WESTERN BASIN						
Ontario										
Kingsville	M-1	Lagoon	0.3	3.5	36	45		5	1	14
Leamington	M-2	Primary	2.4	9.4	354	250		64	20	975
Ohio										
Camp Perry	M-9	Secondary	0.16	-	20	5		3	2	8
Port Clinton	M-10	Intermediate S-C	1.45	7.5	177	120		52	13	230
Lakeside	M-11	Intermediate	-	2.9	40	20		3	2	4
TOTAL					627	440		127	38	1,231
				CENTRAL BASIN						
Ontario										
Ontario Hospital	M-3	Secondary	0.08	1.0	2	5		10	1	13
Port Stanley	M-4	None	0.15	1.4	25	31		3	1	10
Port Burwell	M-5	None	0.10	.7	14	17		2	0	5
Ohio										
Sandusky	M-12	Primary S-C	5.2	34.2	1,400	800		240	60	520
East Erie Co. SD	M-13	Primary S	0.03	-	600	10		4	9	10
Lorain	M-14	Primary S	10.95	78.5	1,600	1,320		540	150	1,200
Avon Lake	M-15	Intermediate C	1.9	12.3	490	220		80	9	190

Appendix 1.1 (Continued)

Municipalities	Map index[1]	Existing treatment	Sewage flow (mgd)	Population served with sewers (X1000)	BOD_5	Solids Total	Solids Susp.	Total[2] nitrogen (N)	Total[2] phosphorus (P)	Chlorides[2]
Rocky River SD 6	M-16	Intermediate S	4.8	56.0	740	480		390	90	860
Cleveland Westerly	M-17	Primary S-C	34.1	300.0	7,000	6,300		2,100	410	4,600
Cleveland Easterly	M-18	Secondary S-C	122.0	630.0	4,300	3,900		3,400	1,300	9,600
Euclid	M-19	Intermediate S	14.6	123.4	1,800	1,800		860	140	1,900
Willoughby-Eastlake	M-20	Intermediate S	2.9	37.3	280	330		260	50	570
Lake County SD Willoughby-Mentor	M-21	Intermediate S	1.82	32.5	150	170		220	40	500
Lake County SD 1	M-22	Primary S	1.14	7.5	100	50		50	7	110
Geneva-on-the-lake	M-23	Primary S	-	.7	70	50		5	9	10
Ashtabula	M-24	Intermediate S	5.0	25.1	730	20		170	50	380
TOTAL					19,301	15,503		8,334	2,326	20,478

Appendix 1.1 (Continued)

Municipalities	Map index[1]	Existing treatment	Sewage flow (mgd)	Population served with sewers (X1000)	BOD_5	Solids Total	Solids Susp.	Total[2] nitrogen (N)	Total[2] phosphorus (P)	Chlorides[2]
EASTERN BASIN										
Ontario										
Port Rowan	M-6	None	0.1	.8	14	17		2	0	5
Port Dover	M-7	Primary	0.28	3.2	53	40		14	2	37
Crystal Beach	M-8	Secondary	0.4	2.0	8	7		7	1	28
Pennsylvania										
Erie	M-25	Secondary S-C	40.0	140.0	1,200	640		750	300	2,100
New York										
Ripley	M-26	Primary S	0.1	1.3	570	170		9	4	20
Dunkirk	M-27	Primary S-C	4.3	18.2	1,500	920		130	40	290
Hamburg Twp.	M-28	Primary	1.9	-	270	80		-	20	-
Wanakah	M-29	Primary S	0.25	-	90	50		10	4	30
Mt. Vernon	M-30	Primary S	0.3	-	70	50		30	4	60
TOTAL					3,775	1,974		952	375	2,570
TOTAL FOR LAKE					23,703	17,917		9,413	2,739	24,279

[1]Separate sewer system; C= Combined sewer system; S-C= Separate and combined sewer system.

[2]Estimates based on population served.

Appendix 1.2 Principal industrial waste discharges direct to Lake Erie 1966-67 (short tons/year).

Industries	Map index[1]	Existing treatment	Flow[2] (mgd)	BOD_5	Solids Total	Solids Susp.	Total nitrogen (N)	Total phosphorus (P)	Chlorides
WESTERN BASIN									
Ontario									
H.J. Heinz Co. of Canada	I-1	Screening	1.1	2,035	4,440	1,020	61	10	237
Michigan									
Enrico Fermi* (Laguna Beach)	I-5		190	-	-	-	-	-	-
Consumer Power (Erie)			385						
Ohio									
Toledo Edison (Toledo)	I-6			-	-	-	-	-	-
TOTAL WESTERN BASIN				2,035	4,440	1,020	61	10	237
CENTRAL BASIN									
Ontario									
Olmstead Fisheries 1961 Ltd. (Wheatley)	I-2	Screening	0.4	467	690	360	35	7	310
Ohio									
U.S. Gypsum (Gypsum)	I-7		0.9	**	600	600			-
Aluminum & Magnesium (Sandusky)	I-8		0.13	**	-	**	-	-	-
TRW (Euclid)	I-9		**	-	**	**	-	-	-
Diamond Shamrock (Painesville)	I-10		10	-	7,880	1,130	130	-	4,470

Appendix 1.2 (Continued)

Industries	Map index[1]	Existing treatment	Flow[2] (mgd)	BOD_5	Solids Total	Solids Susp.	Total nitrogen (N)	Total phosphorus (P)	Chlorides
Midland Ross IRC (Painsville)	I-11		29	1,590	50,050	3,650	-	-	7,300
Detrex Chemical Ind. Chlorine & Alkali Plant (Ashtabula)	I-12		4.6	-	120	120	-	-	1,800
Union Carbide Linde Div. - Welding Materials Plant	I-13		1.3	-	3,050	140	-	-	-
Union Carbide - Metals Div.	I-14		5.6	-	-	**	-	-	-
Ohio Edison (Lorain)	I-15		121	-	-	**	-	-	-
Cleveland Electric Illuminating (Avon)	I-16		890	-	3,100	3,100			-
Cleveland Electric Illuminating (Cleveland)	I-17		455	-	970	970			-
Cleveland Municipal (Cleveland)	I-18		173	-	-	-			-
Cleveland Electric Illuminating (Eastlake)	I-19		505	-	6,400	6,400			-
Cleveland Electric Illuminating (Ashtabula)	I-20		690	-	220	220			-
TOTAL CENTRAL BASIN				2,057	73,080	16,690	165	7	14,150

Appendix 1.2 (Continued)

Industries	Map index[1]	Existing treatment	Flow[2] (mgd)	BOD_5	Solids Total	Solids Susp.	Total nitrogen (N)	Total phosphorus (P)	Chlorides
				EASTERN BASIN					
Ontario									
Algoma Steel Corp. (Canadian Furnace Div.)	I-3	None	3.0	27	5,525	1,895			TR
International Nickel Co. of Canada	I-4	Neutralization	0.2	33	36,310	310			TR
Pennsylvania									
Erie Reduction (Erie)	I-21		0.02	2	4	2			-
Hammermill (Erie)	I-22		20	11,300	96,700	15,300			-
Pennsylvania Electric (Erie)	I-23		144	-	34	34			-
New York									
Seneca Westfield Maid (Westfield)	I-24		0.5	**	-	**			-
Bethlehem Steel (Lackawanna)	I-25		350	950	63,900				-
Hanna Furnace (Buffalo)	I-26		26	-	-	**			-
Niagara Mohawk	I-27		461		-	-			
TOTALS EASTERN BASIN				12,312	202,473	81,441	226	17	14,387
TOTALS FOR LAKE				16,404	279,993	99,151	226	17	14,387

* Intermittent operation
** Discharge but quantity unknown
\- Data not available
TR Trace
1 Map index refers to Appendices 1.9, 1.10, 1.11
2 Ontario sources in imperial gallons; New York sources in U.S. gallons

Appendix 1.3 Other industrial waste discharges direct to Lake Erie 1966-67 (short tons/year).

Industries	Iron	Dissolved iron	Sulphate	Sulphite	Ether solubles	COD	Cyanide	Phenols	Other
				WESTERN BASIN					
Ontario									
H.J. Heinz Co. of Canada						-		-	
Michigan									
Enrico Fermi* (Laguna Beach)						-		-	Heat**
Consumer Power (Erie)									Heat 1,472 BTU/hour x 10^6
Ohio									
Toledo Edison (Toledo)						-		-	Heat*
TOTAL WESTERN BASIN									
				CENTRAL BASIN					
Ontario									
Olmstead Fisheries 1961 Ltd. (Wheatley)						1,350		-	Oil 50
Ohio									
United States Gypsum (Gypsum)						-		-	Heat**
Aluminum and Magnesium (Sandusky)						-		-	Metals**
TRW (Euclid)						-		-	
Diamond Shamrock (Painesville)						-		3	

Appendix 1.3 (Continued)

Industries	Iron	Dissolved iron	Sulphate	Sulphite	Ether solubles	COD	Cyanide	Phenols	Other
Midland Ross IRC (Painesville)						-		-	Oil 780 Zinc 1,200 pH 2.3-3.8
Detrex Chemical Ind. Chlorine and Alkali Plant (Ashtabula)						-		-	
Union Carbide Linde Div. - Welding Materials Plant						-		-	Copper 2 pH 0.0-11.0
Union Carbide - Metals Div.						-		-	pH 8.2-12.6
Ohio Edison (Lorain)						-		-	Heat**
Cleveland Electric Illuminating (Avon)						-		-	Heat**
Cleveland Electric Illuminating (Cleveland)						-		-	Heat**
Cleveland Municipal Cleveland						-		-	Heat 920
Cleveland Electric Illuminating (Eastlake)						-		-	Heat**
Cleveland Electric Illuminating (Ashtabula)						-		-	Heat**
TOTAL CENTRAL BASIN						1,350		3	
EASTERN BASIN									
Ontario									
Algoma Steel Corp. (Canadian Furnace Div.)	2,830					365		-	Calcium 530

Appendix 1.3 (Continued)

Industries	Iron	Dissolved iron	Sulphate	Sulphite	Ether solubles	COD	Cyanide	Phenols	Other
International Nickel Co. of Canada						1,240	0.3	-	Nickel 105 Calcium 1390 Copper 18
Pennsylvania									
Erie Reduction (Erie)			9,300			-		-	
Hammermill (Erie)						-		-	
Pennsylvania Electric (Erie)						-		-	Heat 720
New York									
Seneca Westfield Maid (Westfield)						-		-	
Bethlehem Steel (Lackawanna)						2,010	170	120	pH 4.0-7.0 Heat** Oil 5,650
Hanna Furnace (Buffalo)						-		-	Heat** Oil**
Niagara Mohawk						-		-	Heat 2,200
TOTALS EASTERN BASIN	2,830		9,300			3,615	170.3	120	
TOTALS FOR LAKE	2,830		9,300			4,965	170.3	123	

*Intermittent operation

**Discharged but quantity unknown

-Data not available

Appendix 1.4 Tributary waste discharges to Lake Erie 1966-67 (short tons/year).

Tributaries	Flow (cfs)	Population served with sewers (X1000)	BOD_5	Solids Total	Solids Susp.	Total nitrogen (N)	Total phosphorus (P)	Chlorides
WESTERN BASIN								
Ontario - Michigan								
Detroit River			91,000	30,600,000	1,600,000	126,000	17,600	3,300,000
Michigan								
Huron River			400	74,800	1,800	300	430	18,000
River Basin			500	95,700	4,700	700	345	26,000
Ohio								
Maumee River			20,000	3,400,000	2,000,000	12,000	2,687	130,000
Portage River			700	114,400	27,400	500	164	6,000
TOTAL			112,600	34,284,900	3,633,900	139,500	21,227	3,480,000
CENTRAL BASIN								
Ontario								
Kettle Creek	160*	21.0	1,210	71,327	5,890	1,380	29	9,080
Catfish Creek	142*	4.5	350	56,586	5,858	175	23	2,786
Big Otter Creek	264	7.2	1,900	346,700	33,700	1,100	102	2,200
Ohio								
Sandusky River			5,700	600,000	150,000	7,300	567	32,000
Huron River			400	156,000	46,000	400	134	5,300
Vermilion River			200	90,000	17,000	300	70	4,400
Black River			700	81,000	15,000	1,000	269	8,100
Rocky River			1,400	160,000	30,000	1,000	260	21,000
Cuyahoga River			8,900	509,000	89,000	4,600	2,600	79,000

Appendix 1.4 (Continued)

Tributaries	Flow (cfs)	Population served with sewers (X1000)	BOD_5	Solids Total	Solids Susp.	Total nitrogen (N)	Total phosphorus (P)	Chlorides
Chagrin River			500	125,000	35,000	200	148	4,800
Grand River			1,300	1,510,000	210,000	800	104	680,000
Ashtabula River			200	24,600	4,600	100	14	2,800
Conneaut Creek			400	45,100	9,100	100	36	5,700
TOTAL			23,160	3,775,313	651,148	18,455	4,356	857,166
EASTERN BASIN								
Ontario								
Big Creek	209	3.6	200	53,600	2,600	160	9	2,500
Dedrick Creek	29.6	0	40	4,600	500	20	2	90
Lynn River	104*	8.7	260	23,200	1,200	160	10	1,000
Nanticoke Creek	56*	1.3	280	14,400	500	60	4	150
Sandusk Creek	46*	1.6	60	9,200	700	70	6	140
Grand River	1,820*	278	3,900	448,000	32,000	1,710	1,310	32,600
New York								
Cattaraugus Creek			6,000	370,000	140,000	2,700	101	17,000
Buffalo River			13,000	434,000	74,000	5,000	318	59,000
TOTAL			23,720	1,357,000	251,500	9,880	1,760	112,480
LAKE ERIE TOTALS			159,480	39,417,213	4,536,548	167,835	27,343	4,449,646

*Estimated

Appendix 1.5 Municipal waste discharges direct to Lake Ontario and St. Lawrence River 1966-67 (short tons/year).

Municipalities Lake Ontario	Map index[1]	Existing treatment	Sewage[2] flow (mgd)	Population served with sewers (X1000)	BOD_5	Solids Total	Solids Susp.	Total nitrogen (N)	Total phosphorus (P)	Chlorides
Ontario										
North Niagara Peninsula Region										
Niagara-on-the-lake	M-1	Lagoon	0.2	2.94	2	167	5	3	2	21
St. Catharines -Port Weller	M-2	Primary	6.5	65.0	937	7,770	1,410	453	89	1,100
- Port Dalhousie	M-3	Primary	3.0	30.0	372	3,160	372	138	36	509
Beamsville	M-4	Secondary	0.3	3.8	15	167	25	16	5	55
N. Grimsby										
- Grimsby Beach	M-5	Secondary	-	0.5	4	52	4	5	1	7
- Grimsby Biggar	M-6	Lagoon	0.1	0.5	3	140	5	3	1	13
Northwestern Lake Ontario										
Hamilton	M-7	Primary	36.1	283	3,360	38,900	3,950	1,060	193	6,520
Burlington										
- Skyway	M-8	Secondary	3.9	(	50	3,960	35	86	40	776
- Drury Lane	M-9	Secondary	1.5	(65.4	15	2,160	22	46	20	268
- Elizabeth Gdns.	M-10	Secondary	0.8	(	20	700	15	25	11	144
Oakville										
- Trafalgar	M-11	Secondary	2.5	30.0	41	2,600	36	143	16	470
Mississauga										
- Clarkson (1)	M-12	Secondary	1.3	9.1	32	1,560	44	59	15	175

Appendix 1.5 (Continued)

Municipalities Lake Ontario	Map index[1]	Existing treatment	Sewage[2] flow (mgd)	Population served with sewers (X1000)	BOD_5	Solids Total	Solids Susp.	Total nitrogen (N)	Total phosphorus (P)	Chlorides
Metropolitan Toronto Region										
Mississauga										
- Lakeview (2)	M-13	Secondary	9.9	67.1	1,070	12,600	976	400	98	2,300
Metro Toronto										
- Long Branch	M-14	Secondary	0.8	(	58	928	133	50	13	200
- Humber	M-15	Secondary	50.5	(1,690	2,230	57,600	2,890	2,250	391	17,000
- Main	M-16	Secondary	147	(	10,600	240,000	20,700	5,100	965	94,700
Central Lake Ontario										
Pickering										
- Bay Ridges	M-17	Secondary	1.0	12.5	25	1,120	34	57	15	137
Whitby										
- Ontario Hospital	M-18	Secondary	0.2	0.5	3	145	4	7	1	22
Port Hope	M-19	Secondary	1.3	8.6	40	1,470	78	32	13	294
Trent River Region										
Trenton	M-20	Primary	1.0	13.8	200	1,100	102	40	11	99
Trenton										
- Canadian Forces Base	M-21	Secondary	0.9	4.0	9	542	13	20	7	50

Appendix 1.5 (Continued)

Municipalities Lake Ontario	Map index[1]	Existing treatment	Sewage[2] flow (mgd)	Population served with sewers (X1000)	BOD_5	Solids Total	Solids Susp.	Total nitrogen (N)	Total phosphorus (P)	Chlorides
Bay of Quinte Region										
Picton	M-22	Secondary	0.8	4.8	30	612	15	25	8	60
Picton - Canadian Forces Base	M-23	Secondary	0.1	2.0	2	73	2	2	1	5
Belleville	M-24	Primary	6.6	33.0	397	5,600	650	220	55	831
Deseronto	M-25	None	-	1.8	61	230	70	8	2	23
TOTAL CANADIAN LAKE ONTARIO LOADING			276.3	2,328.3	19,576	383,561	31,625	10,248	2,009	125,779
New York										
Youngstown	M-26	Primary	0.19	1.8	37	-	-	5	2	18
Wilson	M-27	Primary	0.24	1.3	47	-	-	6	2	23
Rochester	M-28	Primary	80.0	375.0	21,900	108,000	44,900	2,830	889	18,700
Irondequoit	M-29	Secondary	1.42	13.0	75	1,390	30	89	32	36
Webster	M-30	Primary	1.37	11.0	135	274	188	17	10	1,360
Oswego	M-31	None	1.30	13.4	394	-	-	48	17	966
TOTAL AMERICAN LAKE ONTARIO LOADING			84.52	415.5	22,588	109,664	45,118	2,995	952	21,103

Appendix 1.5 (Continued)

Municipalities St. Lawrence River	Map index[1]	Existing treatment	Sewage[2] flow (mgd)	Population served with sewers (X1000)	BOD_5	Solids Total	Solids Susp.	Total nitrogen (N)	Total phosphorus (P)	Chlorides
Ontario										
Kingston Twp.	M-32	Secondary	0.7	12.5	15	617	15	25	12	77
Kingston	M-33	Primary	11.2	54.0	1,020	14,200	1,060	722	86	2,820
Brockville	M-34	Primary	3.7	19.3	185	2,630	231	106	22	472
Prescott	M-35	None	0.5	5.4	180	675	225	23	6	68
Cardinal	M-36	Secondary	0.2	2.0	36	207	34	7	2	20*
Iroquois	M-37	Primary	0.6	1.1	183	834	64	11	2	54
Morrisburg	M-38	Primary	0.5	2.0	11	357	15	11	3	25
Osnabruck Twp.	M-39	Secondary	-	3.3	1	27	1	7	2	13
Long Sault	M-40	Secondary	0.2	1.5	2	102	2	4	1	10
Cornwall	M-41	Primary	4.5	44.4	1,620	6,060	2,020	205	53	607
TOTAL CANADIAN ST. LAWRENCE RIVER LOADING			22.1	145.5	3,253	25,709	3,667	1,121	189	4,166
New York										
Cape Vincent	M-42	None	0.10	1.0	31			4*	1*	15*
Clayton	M-43	None	0.25	2.5	76			9*	3*	37*
Alexandria Bay	M-44	None	0.25	2.5	76			9*	3*	37*

Appendix 1.5 (Continued)

Municipalities St. Lawrence River	Map index[1]	Existing treatment	Sewage[2] flow (mgd)	Population served with sewers (X1000)	BOD_5	Solids		Total nitrogen (N)	Total phosphorus (P)	Chlorides
						Total	Susp.			
Morristown	M-45	None	0.06	0.5	17			2*	1*	8*
Ogdensburg	M-46	Primary	1.65	17.0	327			41*	14*	165*
Waddington	M-47	Primary	0.11	0.92	22			3*	1*	10*
TOTAL AMERICAN ST. LAWRENCE RIVER LOADING			2.42	24.42	549			68*	23*	272*
TOTAL DISCHARGE (CANADIAN AND UNITED STATES)			24.52	169.92	3,802			1,189	212	4,432

*Estimated

[1]Notation used to locate waste sources on Appendices 1.9, 1.10, 1.11

[2]Ontario sources in imperial gallons New York in U.S. gallons

Appendix 1.6 Principal industrial waste discharges direct to Lake Ontario and St. Lawrence River 1966-67 (short tons/year).

Industries Lake Ontario	Map index[1]	Existing treatment	Flow[2] (mgd)	BOD_5	Solids Total	Solids Susp.	Total nitrogen (N)	Total phosphorus (P)	Chlorides
Ontario									
North Niagara Peninsula Region									
Louth Twp.									
- Culverhouse Canning Ltd.	1-1	None	0.1	91	167*	16	1	-	-
Saltfleet Twp.									
- E.D. Smith & Sons	1-2	Screening, Aerated Lagoon	0.2	15	70	7	1	-	-
Northwestern Lake Ontario									
Hamilton									
- Steel Co. Canada Ltd. (Parkdale)	1-3	Settling Waste Segregation	0.1	1	100	5	2	1*	31
- Steel Co. Canada Ltd. (#2 Rod Mill)	1-4	Segregation of Wastes, Scale Pit and Lagoon	6.9	21	2,830	380	7	1	314
- Firestone Tire & Rubber	1-5	None	0.2	5	220	16	-	0	-

Appendix 1.6 (Continued)

Industries Lake Ontario	Map index[1]	Existing treatment	Flow[2] (mgd)	BOD_5	Solids Total	Solids Susp.	Total nitrogen (N)	Total phosphorus (P)	Chlorides
- Domtar Chemicals Ltd.	1-6	Oil Separators, Waste Segregation, Biological Treatment of Phenolic Wastes	0.1	7	67	7	-	-	3*
- National Steel Car Corp. Ltd.	1-7	Settling	0.1	4	135	2	-	-	40*
- Stanton Pipes Ltd.	1-8	Settling & Filters	0.1	1	24	5	1*	-	9*
- Dominion Foundries & Steel Ltd.	1-9	Lagoon, Activated Sludge Plant	70	6,210	91,300	26,200	11,000	4*	370*
- Canadian Industries Ltd.	1-10	Lagoon, Neutralization & Effluent Recirculation	1.3	26	4,430	84	104*	16	719
- Steel Co. Canada Ltd.	1-11	Lagoons, Oil Skimmers Phenol Recovery Units Scale Pits & Segregation of wastes	248.4	5,970	227,000	28,800	4,880*	13*	1,200*
- International Harvester Co. Canada Ltd.	1-12	Settling	2.4	52	2,260	358	-	7*	-

Appendix 1.6 (Continued)

Industries Lake Ontario	Map index[1]	Existing treatment	Flow[2] (mgd)	BOD_5	Solids		Total nitrogen (N)	Total phosphorus (P)	Chlorides
					Total	Susp.			
- Canadian Vegetable Oil Processing Ltd.	1-13	Process Wastes to Municipal Sewer, Cooling Water to Bay	1.3	45	515	27	13*	1*	-
Oakville									
- Shell Canada Ltd.	1-14	API Oil Separators Sludge Ponds, Clarifiers, Retention Ponds	0.8	33	1,900	36	190*	1	230
- B.P. Refinery Canada Ltd.	1-15	Lagoon, API Separator Secondary Treatment & Activated Carbon Treatment	0.6	17	1,650	18	53	0	447
- Sterling Faucet Canada Ltd.	1-16	Settling	-	-	13	0	1*	-	-
- Ford Motor Co. Canada Ltd.	1-17	Holding Tanks	4.5	135	2,480	1,920	29	7	21
- Ford Motor Co. Canada Ltd. STP	1-18	Activated Sludge Plant	0.4	2	194	3	4	1	30
Mississauga									
- St. Lawrence Cement Co.	1-19	Cooling Water only - Discharged to Lake	1.1	-	856	87	1	-	-

Appendix 1.6 (Continued)

Industries Lake Ontario	Map index[1]	Existing treatment	Flow[2] (mgd)	BOD_5	Solids Total	Solids Susp.	Total nitrogen (N)	Total phosphorus (P)	Chlorides
- The British American Oil Co.	1-20	API Separators, Oil Traps, Biological Treatment	9.6	1,450	13,500	1,470	180	18	2,180
Port Credit - Texaco Canada Ltd.	1-21	Settling, API Separators, Chemical Treatment	25.2	140	11,800	502	161	12	1,450
Metropolitan Toronto Region									
Port Credit - St. Lawrence Starch Co. Ltd.	1-22	Screening, Centrifuge, Wet Wells	1.2	6,090	6,960	1,650	352	47	1,040
Missisauga - Lakeview Generating Station	1-23	Settling	1081	-	1,920	537	42	-	102
Metro Toronto - Maple Leaf Mills Ltd.	1-24	(	0.9	7	535	34	5	-	-
- Canada & Dominion Sugar Co. Ltd.	1-25	(	0.2	1	86	10	-	-	-
- Victory Soya Mills Ltd.	1-26	(Process Wastes to (Sanitary Sewer (Uncontaminated (Cooling Water to (Lake	4.3	64	2,180	212	45*	3	-

Appendix 1.6 (Continued)

Industries Lake Ontario	Map index[1]	Existing treatment	Flow[2] (mgd)	BOD_5	Solids Total	Solids Susp.	Total nitrogen (N)	Total phosphorus (P)	Chlorides
- Continental Can Co. Canada Ltd. #1	1-27	(((	1.8	541	2,550	985	41	4*	188
- Continental Can. Co. Canada Ltd. #2	1-28	(((	1.8	385	2,260	1,240	40*	4	169
- Canadian Johns-Manville Co. Ltd.	1-29	Lagoon	1.4	9	480	80	-	1	-
Central Lake Ontario									
Whitby									
- Lake Ontario Steel Co. Ltd.	1-30	Settling	1.4	5	3,040	2,060	0	0	179*
Oshawa									
- General Motors Canada Ltd.	1-31	Process Wastes to Sanitary Sewers Cooling Water to Lake	0.2	4	16	2	2	0	-
Port Hope									
- Eldorado Mining & Refining	1-32	Nitric Acid Recovery, Settling	0.9	4	1,140	181	135*	1	4
Cobourg									
- Marbon Chemical Div.	1-33	Settling & Neutralization	0.4	82	722	31	4*	0	24

Appendix 1.6 (Continued)

Industries Lake Ontario	Map index[1]	Existing treatment	Flow[2] (mgd)	BOD_5	Solids Total	Solids Susp.	Total nitrogen (N)	Total phosphorus (P)	Chlorides
Trent River Region									
Murray Twp.									
- Knox Gelatine Canada Ltd.	1-34	Equalization Pond	0.2	9	241	9	3	1	29
Trenton									
- Stokely Van Camp Canada Ltd.	1-35	Screening	0.1	100	500*	50	5	0	-
- Trenton Cold Storage Ltd.	1-36	Process Waste to Sanitary Sewer Cooling Water to Lake	0.01	30	60*	6	1	-	-
- Trenton Dyeing & Finishing Co. Ltd.	1-37	None	0.1	32	127	9	1	0	5
Bay of Quinte - Lake Ontario									
Picton									
- Proctor-Silex Ltd.	1-38	None	0.1	2	36	1	-	-	-
- Lake Ontario Port Cement	1-39	Settling	2.1	6	791	125	4	0	38
Belleville									
- Union Carbide Canada Ltd.	1-40	Settling	2.9	878	1,600	191	374	1	94
Sidney Twp.									
- Canada Cement Co. Ltd.	1-41	Settling	3.4	26	2,980	789	8	25	137

Appendix 1.6 (Continued)

Industries Lake Ontario	Map index[1]	Existing treatment	Flow[2] (mgd)	BOD_5	Solids Total	Solids Susp.	Total nitrogen (N)	Total phosphorus (P)	Chlorides
Millhaven - Canadian Industries Ltd.	1-42	Settling, Oil Skimmers	7.3	626	5,590	345	59	16	-
Deseronto - Metcalfe Foods Ltd.	1-43	Screening	0.2	70	85	27	2	0	-
N. Marysburgh Twp. - Waupoos Canning Ltd.	1-44	Lagoon	0.02	3	13	3	0	-	-
TOTAL CANADIAN LOADING TO LAKE ONTARIO			405.4	23,199	395,067	68,550	17,736	185	9,053
New York									
Oswego - Hammermill Paper Co.	1-45	None	2.5	704	3,390	1,720	1	1	128
TOTAL AMERICAN LOADING TO LAKE ONTARIO			2.5	704	3,390	1,720	1	1	128

Appendix 1.6 (Continued)

Industries St. Lawrence River	Map index[1]	Existing treatment	Flow[2] (mgd)	BOD_5	Solids Total	Solids Susp.	Total nitrogen (N)	Total phosphorus (P)	Chlorides
Ontario									
Kingston									
- Dupont of Canada Ltd.	1-46	None	9.3	87	3,710	77	8	0	0
Gananoque									
- Cow & Gate (Canada) Ltd.	1-47	Equalization & Waste Skimming	0.2	9	58	4	2	0	0
Brockville									
- Brockville Chemical Ind. Ltd.	1-48	Retention, Neutralization	0.3	22	1,880	109	1,710	2	186
Augusta Twp.									
- Dupont of Canada	1-49	None	30.2	6,060	22,300	788	2,440	0	800*
- Dupont of Canada (STP)	1-50	Extended Aeration	0.02	13	58	12	2	0	8
Cardinal									
- Canada Starch Co. Ltd.	1-51	None	5.4	1,930	5,100	190	66	7	1,180
Morrisburg									
- Sea-Way Chemicals Ltd.	1-52	API Separator	0.03	1	14	2	0	-	2
Cornwall									
- Courtaulds (Canada) Ltd.	1-53	None	13.0	3,480	88,800	2,880	164	11	25,300

Appendix 1.6 (Continued)

Industries St. Lawrence River	Map index[1]	Existing treatment	Flow[2] (mgd)	BOD_5	Solids Total	Solids Susp.	Total nitrogen (N)	Total phosphorus (P)	Chlorides
- Domtar Pulp & Paper Ltd.	1-54	Barking Wastes, Screened & Centri Cleaners	50	37,000	140,000	24,000	54	8*	14,000*
TOTAL CANADIAN LOADING TO ST. LAWRENCE RIVER			108.5	48,602	261,920	28,062	4,446	28	41,476
New York									
Ogdensburg									
- Diamond National Corp.	1-55	None	4.0	1,220	6,240	3,470	1	13.6	390
Massena									
- Reynolds Metal Co.	1-56	None	9.0	136	3,540	316	11	7.1	477
- General Motors Corp.	1-57	Settling, Oil Separation	3.0	51	928	92	5	-	114
TOTAL AMERICAN LOADING TO ST. LAWRENCE RIVER			16.0	1,407	10,708	3,878	17	20.7	981

*Estimated

1 Notation used to locate waste sources on Appendices 1.9, 1.10, 1.11

2 Ontario sources in imperial gallons
New York sources in U.S. gallons

Appendix 1.7 Other industrial waste discharges direct to Lake Ontario and St. Lawrence River 1966-67* (short tons/year).

Industries	Iron	Dissolved iron	Sulphate	Sulphite	Ether solubles	COD	Cyanide	Phenols	Others
Lake Ontario									
Steel Co. Canada Ltd. (Parkdale)	12		42		1	10		0	Chromium 19 Alkalinity 42
Steel Co. Canada Ltd. (#2 Rod Mill)	150	1	314		16	3,000			
Firestone Tire & Rubber	1								
Domtar Chemicals Ltd.					1	27		2	Alkalinity 4
National Steel Car Corp. Ltd.	14	12			2	3		1	
Stanton Pipes Ltd.	0.2								
Dominion Foundries & Steel Ltd.	14,019	97	121		4,590	11,925	82	60	Alkalinity 17,337
Canadian Industries Ltd.	35	26	1,409			507			Fluoride 400 Zinc 12 Alkalinity 1,270
Steel Co. Canada Ltd. (Hilton)	9,580	1,057			7,389	38,412	193	281	Sulphide 96
International Harvester Co.	19				44	683			
Canada Vegetable Oil Processing Ltd.					13				
Shell Canada Ltd.	6		868	13	9	260	TR	0.2	
B.P. Refinery Canada Ltd.	1		687	1.6	37	113	0.6	0.1	
Sterling Faucet Canada Ltd.			1		TR				Chromium TR
Ford Motor Co. Canada Ltd.			754		42	1,142			Copper 6 Chromium 8

Appendix 1.7 (Continued)

Industries	Iron	Dissolved iron	Sulphate	Sulphite	Ether solubles	COD	Cyanide	Phenols	Others
St. Lawrence Cement Co.			183		18				Lead 4 Alkalinity 196
The British American Oil Co.			1,881	60	167	4,417	6.0	7.0	Sulphide 2 Fluoride 178
Texaco Canada Ltd.			2,285		175	198		0.9	
St. Lawrence Starch Co. Ltd.			219	229	155	12,477			Sulphide 3 Sodium 200
Lakeview Generating Station	35		930		18	135		TR	
Maple Leaf Mills Ltd.	0.5		175			8			
Canada and Dominion Sugar Co. Ltd.			21			10			
Victory Soya Mills Ltd.					47	331			
Continental Can Co. Canada Ltd. #1			200		75				
Continental Can Co. Canada Ltd. #2			240		26	3,930			
Canadian Johns - Manville Co. Ltd.	2		41			51			Sulphide 5
Lake Ontario Steel Co. Ltd.	8				TR				
General Motors Canada Ltd.					0.7	16.4			
Eldorado Mining and Refining Ltd.	16		86			29.0			Uranium-238 2 Arsenic 5 Copper 0.1 Cobalt 0.1

Appendix 1.7 (Continued)

Industries	Iron	Dissolved iron	Sulphate	Sulphite	Ether solubles	COD	Cyanide	Phenols	Others
Marbon Chemical Div. Borg - Warner Canada Ltd.			350			253		0.2	Magnesium 13
Trenton Dying and Finishing Co. Ltd.					16	82			
Knox Gelatine Canada Ltd.						22			
Proctor - Silex Ltd.								0.0	Nickel 0.9 Chromium 1 Alkalinity 8
Lake Ontario Port Cement						21		0.5	
Union Carbide Canada Ltd.						2,762		160	
Canada Cement Co. Ltd.					12				
Canadian Industries Ltd.	651				25			0.1	
New York									
Hammermill Paper Co.								(.3-5.9 µg/l)	
TOTAL	24,549.7	1,193	10,807	303.6	12,878.7	80,824.4	281.6	513	
St. Lawrence River									
Dupont of Canada Ltd. (Kingston)						317		0.2	
Cow & Gate (Canada) Ltd.						17			
Brockville Chemical Industries Ltd.								TR	Chromium 0.7
Dupont of Canada						12,081		0.7	Copper 31 Lead 10

Appendix 1.7 (Continued)

Industries	Iron	Dissolved iron	Sulphate	Sulphite	Ether solubles	COD	Cyanide	Phenols	Others
Courtaulds (Canada) Ltd.			21,058			6,937			Sulphide 200 Zinc 66
Reynolds Metal Co.								(81 µg/l)	
General Motors Corp.								(3.5 µg/l)	
Diamond National Corp.								(179 µg/l)	
TOTAL			21,058			19,352		0.9	

*All loadings reported in tons per year unless otherwise noted. Where concentrations are shown, flow figures are not available.

Appendix 1.8 Tributary discharges direct to Lake Ontario and St. Lawrence River 1966-67 (short tons/year).

Tributaries Lake Ontario	Flow (cfs)	Population served with sewers (X1000)	BOD_5	Solids Total	Solids Susp.	Total nitrogen (N)	Total phosphorus (P)	Chlorides
Niagara River	195,000			42,800,000	5,030,000	95,300	7,700	5,200,000
North Niagara Peninsula and Niagara River Region								
Four Mile Creek	13*	-	56	3,030	688	59	3	38
(1) Welland Canal	1,230	17.4	2,490	350,000	56,000	1,120	116	42,400
(2) Twelve Mile Creek	6,400	3.0	44,500	1,810,000	217,000	7,670	587	180,000
Twenty Mile Creek	80	0.8	220	28,600	5,190	311	23	1,480
Forty Mile Creek	17	5.5	179	7,700	552	54	16	732
Northwestern Lake Ontario								
Redhill Creek	84	280	556	8,040	865	219	24	2,020
Spencer Creek	59	14.5	112	19,200	2,670	28	6	2,040
Grindstone Creek	26	1.3	55	10,400	2,260	38	2	548
Bronte Creek	119	-	73	15,000	2,200	94	4	747
Oakville Creek	88	13.4	240	23,100	3,430	280	11	2,140
Credit River	280	28.9	828	104,000	10,700	599	48	6,920
Stoney Creek	6.3	-	32	3,870	330	39	9	392
Metropolitan Toronto Region								
Mimico Creek	14.5	5.0	141	9,180	1,500	51	8	1,520
Etobicoke Creek	46*	51.5	93	12,400	357	134	25	596
Humber River	164	7.2	470	53,700	11,300	209	29	8,100
Don River	111	154	1,040	52,500	4,580	603	147	7,740
Highland Creek	25.3	108	63	9,060	808	102	39	162

Appendix 1.8 (Continued)

Tributaries Lake Ontario	Flow (cfs)	Population served with sewers (X1000)	BOD_5	Solids Total	Solids Susp.	Total nitrogen (N)	Total phosphorus (P)	Chlorides
Central Lake Ontario								
Rouge River	58.3	5.5	41	3,560	443	22	2	703
Duffin Creek	79.7	13.9	188	10,900	908	29	2	498
Carruthers Creek	11.2*	-	11	1,590	69	5	0	130
Lynde Creek	29.3	-	76	6,500	3,610	18	6	349
Pringle Creek	8*	14.6	216	2,470	96	23	9	471
Oshawa Creek	40.2	63.2	197	10,100	638	79	8	934
Harmony Creek	50	-	379	7,340	560	301	97	206
Bowmanville Creek	64.6	6.0	152	12,300	584	158	20	730
Graham	26*	-	13	1,480	116	9	0	61
Gamaraska River	104	-	249	13,300	813	75	4	525
Gage Creek	19*	-	5	813	29	4	0	35
Cobourg Brook	50*	11.0	185	5,920	527	81	8	586
Wilmot Creek	27.5*	-	28	4,300	838	21	1	106
Shelter Valley	26.5*	-	25	6,470	330	20	1	129
Colborne Brook	18*	0.8	10	1,730	127	8	0	83
Butler Creek	7*	2.5	21	1,250	60	5	1	105
Smithfield Creek	12*	-	7	1,610	172	4	0	108
Trent River Region								
Trent River	4,170	70.0	15,600	542,000	38,500	2,630	150	26,600
Bay of Quinte								
Moira River	941	3.6	6,020	168,000	18,000	468	27	6,500
Millhaven Creek	81*	-	38	4,750	263	13	1	440
Collins Creek	80*	-	28	5,050	290	10	1	550
Wilton Creek	55.8*	-	36	6,930	887	22	2	813

Appendix 1.8 (Continued)

Tributaries Lake Ontario	Flow (cfs)	Population served with sewers (X1000)	BOD_5	Solids Total	Solids Susp.	Total nitrogen (N)	Total phosphorus (P)	Chlorides
Salmon River	318	-	220	19,300	1,600	105	5	845
Napanee River	279	4.5	316	23,600	2,100	163	15	1,270
TOTAL CANADIAN DISCHARGE TO LAKE ONTARIO EXCLUDING NIAGARA RIVER	15,319	885.1	75,209	3,381,043	392,473	15,861	1,457	300,152

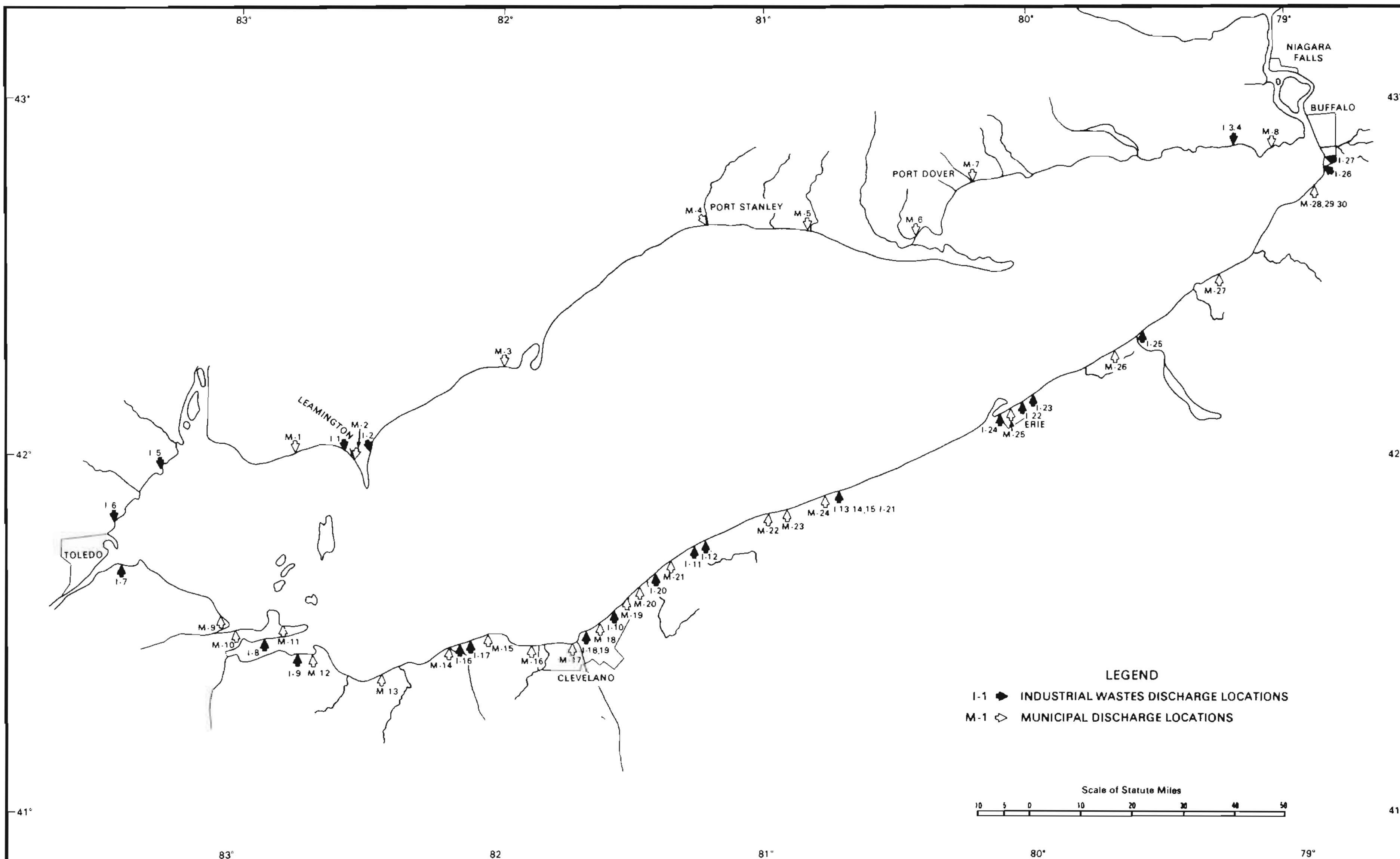
**Includes Hamilton STP Flow
*Estimated
(1) Phenol 10.5
(2) Phenol 183,000

Tributaries Lake Ontario	Flow (cfs)	Population served with sewers (X1000)	BOD_5	Solids Total	Solids Susp.	Total nitrogen (N)	Total phosphorus (P)	Chlorides
United States								
Black River	3,828	48.7	21,000	427,000	91,000	2,940	181	11,600
Eighteen Mile Creek	94*	-	471	31,400	4,350	243	21	4,820
Genesee River	2,726	66.3	16,300	1,050,000	318,000	6,610	314	77,000
Johnson Creek	126*	-	327	36,500	3,940	337	14	3,650
Oak Orchard Creek	288*	-	427	66,600	4,070	347	19	5,540
Oswego River	6,200	544.0	19,900	3,540,000	334,000	6,420	619	1,080,000
Sandy Creek	79*	-	127	18,400	2,210	94	18	2,190
Salmon Creek	43*	-	118	13,500	1,230	91	27	2,210
Salmon Creek (Central)	54*	-	108	20,300	1,190	54	10	985
Salmon River	890*	-	2,170	75,200	16,800	762	13	4,250
Walcott Creek	35*	-	155	15,900	856	102	60	1,900
Miscellaneous Tributary Drainage	800*	528.4	1,950	145,200	21,354	1,000	94	12,855
TOTAL UNITED STATES DISCHARGE INTO LAKE ONTARIO	15,163	1,197.4	63,053	5,440,000	799,000	19,000	1,390	1,207,000

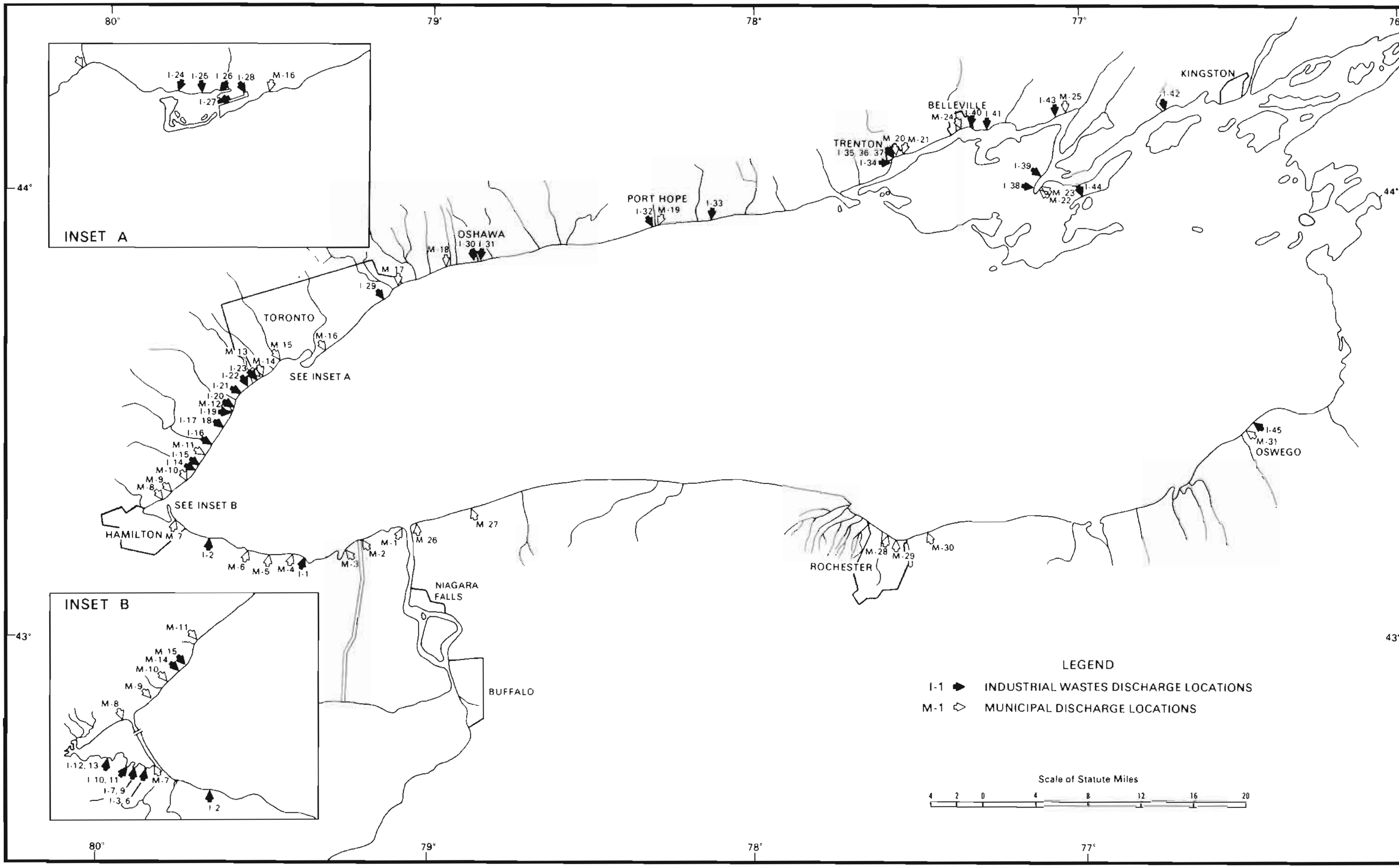
Appendix 1.8 (Continued)

Tributaries St. Lawrence River	Flow (cfs)	Population served with sewers (X1000)	BOD_5	Solids Total	Solids Susp.	Total nitrogen (N)	Total phosphorus (P)	Chlorides
Canada								
Little Cataraqui River	30*	-	76	5,700	443	20	2	732
Cataraqui River	218*	0.9	326	22,700	3,120	87	7	2,140
Gananoque River	198*	5.4	305	28,700	3,020	98	7	1,570
TOTAL CANADIAN DISCHARGE TO ST. LAWRENCE RIVER	446*	6.3	707	57,100	6,583	205	16	4,442
United States								
Grass River	1,131	-	3,530	123,000	30,500	627	58	3,740
Oswegatchie River	2,722	-	7,830	285,000	49,100	1,613	58	8,100
Raquette River	2,096	-	7,920	155,000	54,000	1,374	60	7,790
TOTAL UNITED STATES DISCHARGE INTO ST. LAWRENCE RIVER	5,949	68*	19,280	563,000	133,600	3,614	176	19,630

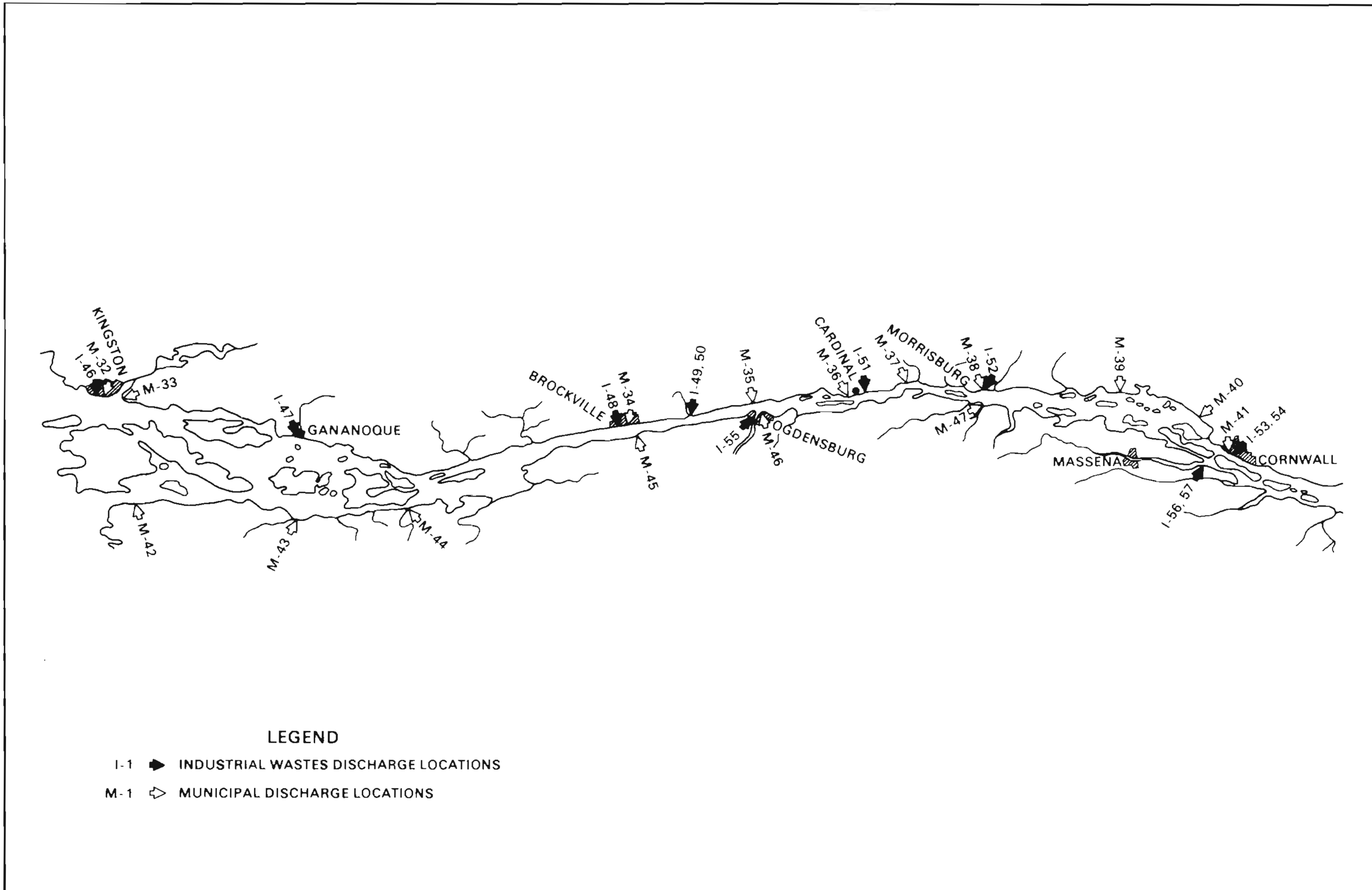
*Estimated



Appendix 1·9 Sources and locations of municipal and industrial wastes - Lake Erie



Appendix 1·10 Sources and locations of municipal and industrial wastes - Lake Ontario.



Appendix 1. 11 Sources and locations of municipal and industrial wastes - International section of the St. Lawrence River

APPENDIX 2.1

SUMMARY OF LOWER LAKES DATA

LAKE ERIE

			Millions	
Basin population:	1966	USA	10.4	10.4
		CAN	1.4	1.4
	1986 (est.)	USA	15.4	15.4
		CAN	2.0	2.0

Lake Characteristics	English Units	Metric Units
Elevation, mean 1940-59	570.6 ft	173.9 m
Area: lake surface	9,970 mi^2	25,821 km^2
land drainage	29,650 mi^2	76,790 km^2
Volume	110 mi^3	458 km^3
Depth: maximum	210 ft	64 m
mean	58 ft	17.7 m
Outflow, mean annual	194,000 cfs	5,490 m^3/sec
Replenishment time	2.6 yr	2.6 yr
90% removal time (conservative pollutant)	6-7 yr	6-7 yr
Loading, total-P, 1967:		
entire lake	30,000 short tons/yr	27,300 metric tons/yr
per unit lake surface area	9.4 lb/acre.yr	1.6 g/m^2.yr
% retention in lake	84	84
% municipal and industrial	70	70
Loading, total-N, 1967:		
entire lake	194,000 short tons/yr	176,000 metric tons/yr
per unit lake surface area	61 lb/acre.yr	6.8 g/m^2.yr
% retention in lake	56	56
% municipal and industrial	30-40	30-40

LAKE ERIE BASINS

Lake Characteristics	W. Basin	C. Basin	E. Basin
Total dissolved solids, mg/l, mean	170	185	190
Specific conductance, μmhos/cm, 25°C, mean	280	310	320
Alkalinity, mg $CaCO_3$/l, mean	100	100	100
Turbidity, JTU	10-5	2	2
Total-N, μg N/l, mean	740	470	470
Total-P, μg P/l, mean	50	30	20
Deepwater sediments:			
% organic-carbon, lake range	0.2	0.2-3.6	
Eh (0-5 cm) volts, range		Entire lake range .288 - .147	

APPENDIX 2.2

LAKE ONTARIO

			Millions	
Basin population:	1966	USA	2.3	2.3
		CAN	3.8	3.8
	1986	USA	2.8	2.8
	(est.)	CAN	4.8	4.8

Lake characteristics	English units	Metric units
Elevation, mean 1940-59	245.2 ft	74.7 m
Area: lake surface	7,340 mi^2	19,009 km^2
land drainage	24,800 mi^2	64,229 km^2
Volume	393 mi^3	1,638 km^3
Depth: maximum	802 ft	244 m
mean	276 ft	84 m
Outflow, mean annual	232,000 cfs	6,565 m^3/sec
Replenishment time	7.9 yr	7.9 yr
90% removal time (conservative pollutant)	21-22 yr	21-22 yr
Loading, total-P, 1967:		
entire lake	14,000 short tons/yr	12,700 metric tons/yr
per unit lake surface area	6.0 lb/acre.yr	0.65 g/m^2.yr
% retention in lake	78	78
% municipal and industrial	56	56
Loading, total-N, 1967:		
entire lake	173,000 short tons/yr	157,000 metric tons/yr
per unit lake surface area	73 lb/acre.yr	8.3 g/m^2.yr
% retention in lake	35	35
% municipal and industrial	30	30

Lake characteristics	English units	Metric units
Total dissolved solids, mean	-	196 mg/l
Specific conductance, 25°C, mean	-	320 μmhos/cm
Alkalinity, mean	-	92 mg $CaCO_3$/l
Turbidity, JTU	-	0.2-2.5
Total-N, lake mean range	-	400-600 μg N/l
Total-P, lake mean range	-	13 μg P/l
Deepwater sediments:		
% organic-carbon, lake range	1.9-5.0	1.9-5.0
Eh (0.5 cm) volts, range	+0.16 to -0.03	+0.16 to -0.03

APPENDIX 3.1

GLOSSARY OF TERMS

Algae	-	primitive photosynthetic plants. In freshwater they occur both as microscopic forms suspended in water (phytoplankton) and as filaments attached to rocks and other substrates.
B.O.D.	-	biological (or biochemical) oxygen demand. The amount of oxygen in milligrams per litre, required by organisms and for the aerobic biochemical decomposition of organic matter present in water. BOD_5 is the biochemical oxygen demand over a period of five days.
Cladophora	-	a branched, filamentous green alga which has special hold-fast organs. It grows in enriched waters, attached to rocks or other suitable substrate in inshore or shallow lake regions. In highly enriched waters it forms dense nuisance mats of growth.
Diatoms	-	one of the most important groups of microscopic algae found in freshwater. Diatoms are distinguished by their silica cell walls (consisting of two halves, one fitting into the other like a box and its lid) and by their yellow or brown coloration.
Coliform bacteria	-	a group of bacteria common in fecal wastes, but also including forms associated with plants and grains.
Curie	-	a unit of radioactivity, being the quantity of radium emanation in equilibrium with one gram of radium.
microcurie	-	one millionth of a curie
picocurie	-	one millionth of a microcurie
Epilimnion	-	the uniformly warmer and turbulent superficial layer of a lake when it is thermally stratified during summer. (Fig. 3.2). The layer above the thermocline.

Hypolimnion	-	the uniformly cold and deep layer of a lake when it is thermally stratified during summer (Fig. 3.2). The layer below the thermocline.
Limnology	-	the scientific study of fresh waters, especially lakes.
Littoral	-	the shoreward region of a body of water.
Midge	-	a tiny insect of the family Chironomidae. Midges commonly spend the greater part of their life in the larval stage living on the bottom of lakes or streams. Bloodworms are the larvae of one important group of midges.
mg/l	-	milligrams per litre.
Plankton	-	the assemblage of micro-organisms, both plant and animal, which live (floating, drifting or swimming) in the open water region of lakes and rivers.
phytoplankton	-	the plant portion of the plankton (unicellular algae of various kinds).
zooplankton	-	the animal portion of the plankton.
Redox	-	abbreviation for oxidation-reduction.
Radionuclide	-	a radioactive species of an atom characterized by the constitution of its nucleus and hence by the number of protons, the number of neutrons, and the energy content.
Seiche	-	oscillating periodic movements of water in a lake.
Thermal stratification	-	the layering of warm (lighter) water over cold (heavier) water in lakes during summer.
Thermocline	-	the transition layer (Fig. 3.2) of rapid temperature change between the upper warm water layer and the cold deep water layer.

Virus	-	a particulate infective agent smaller than accepted bacterial forms, usually invisible by light microscopy, incapable of propagation in inanimate media and multiplying only in susceptible living cells. Causative agent of many important diseases of man, lower animals, and plants, e.g., poliomyelitis, foot and mouth disease, tobacco mosaic.
μg	-	microgram (one millionth of a gram).
μg/l	-	micrograms per litre.
$g/cm^2.yr$	-	grams per square centimetre per year.

Trophic Lake Types and Eutrophication

Depending on the degree of plant nutrient enrichment and resulting biological productivity, lakes are generally classified into three intergrading types: Oligotrophic, Mesotrophic and Eutrophic.

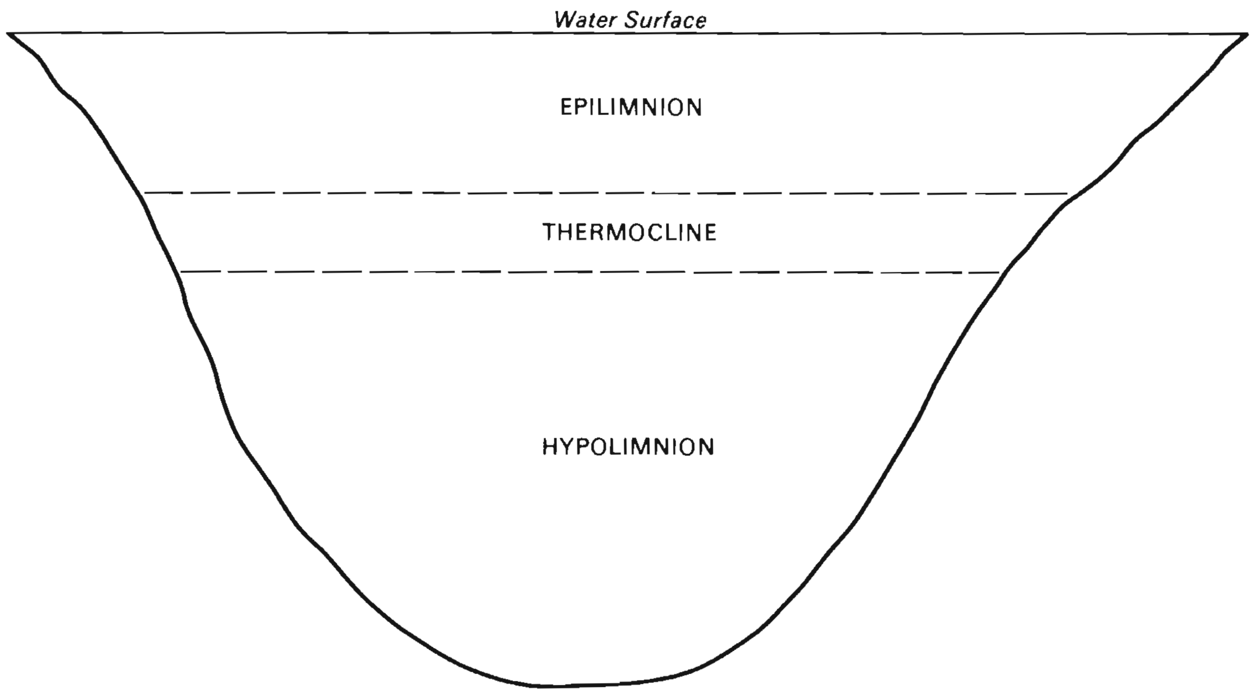
Oligotrophic lakes are poorly supplied with plant nutrients and support little plant growth; as a result, biological production is generally low, their waters are clear and the deeper waters are well supplied with oxygen throughout the year.

Eutrophic lakes are richly supplied with plant nutrients and support a heavy growth of plants; as a result, biological productivity is generally high, the waters are turbid because of dense growths of algae in the water, and deeper water becomes deficient in oxygen in the summer due to decomposition of the abundant organic material produced.

Mesotrophic lakes are intermediate in their characteristics between oligotrophic and eutrophic: that is, they have a moderate supply of plant nutrients, and moderate plant growth and biological production.

These three lake types represent an intergrading series from oligotrophic, through mesotrophic and eutrophic. If the supply of plant nutrients to an extremely oligotrophic lake is progressively increased, the lake will become more mesotrophic in character; with further enrichment it will eventually become eutrophic.

Eutrophication is the process of progressively becoming more eutrophic with increasing enrichment in the supply of plant nutrients. It refers to the whole complex of changes which accompanies increasing enrichment with plant nutrients. The end result is always the same: the production of dense nuisance growths of algae and aquatic weeds which generally degrade water quality and render the lake useless for many purposes.



EPILIMNION - the warm (lighter) upper layer of water.

THERMOCLINE - the transition layer of rapid temperature change between the upper warm water layer and the deep cold water.

HYPOLIMNION - the deep cold (heavier) water zone below the thermocline.

Fig 3·2 Section of a typical lake during summer, showing the three zones resulting from thermal stratification.