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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 3: Lake Ontario and the International Section of the St. Lawrence River

International Lake Erie Water Pollution Board

International Lake Ontario-St. Lawrence River Water Pollution Board

N J. Campbell

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report to the INTERNATIONAL JOINT COMMISSION on the

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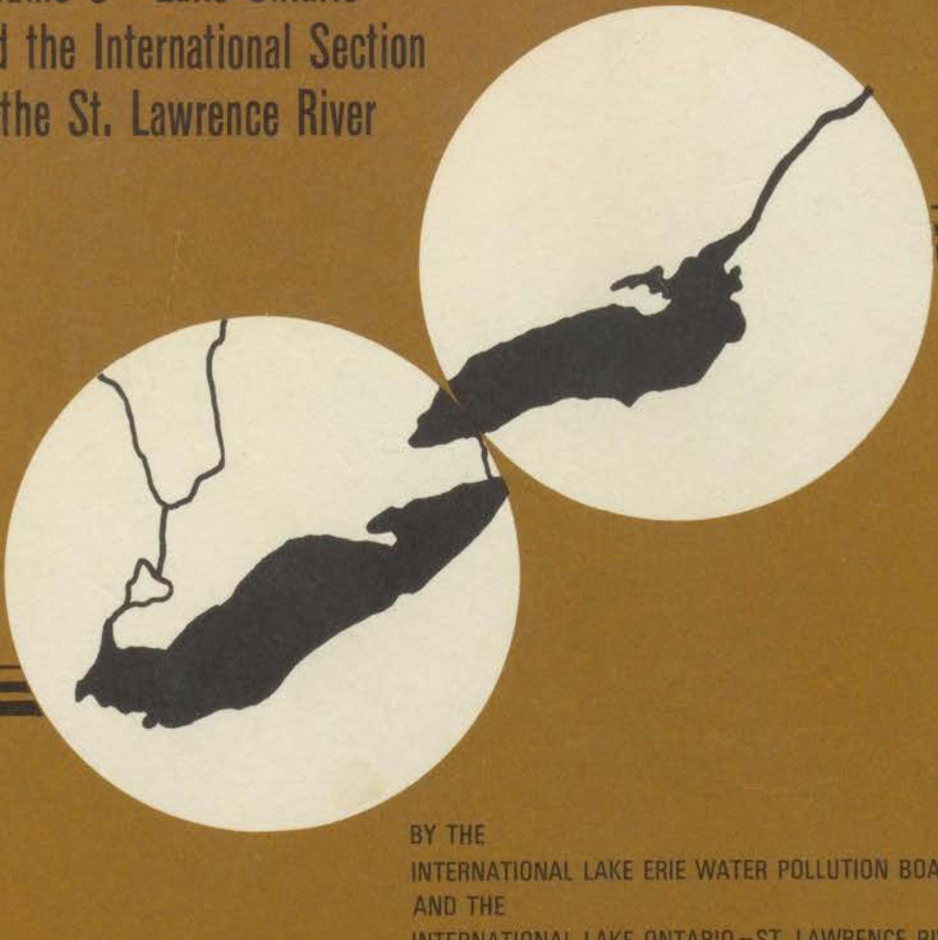
POLLUTION OF LAKE ERIE, LAKE ONTARIO AND THE INTERNATIONAL SECTION OF THE ST. LAWRENCE RIVER

Volume 3—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

report to the INTERNATIONAL JOINT COMMISSION on the

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

Volume 3

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

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INTRODUCTION

The first comprehenisve 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

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[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.

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 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 developement 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.

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[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

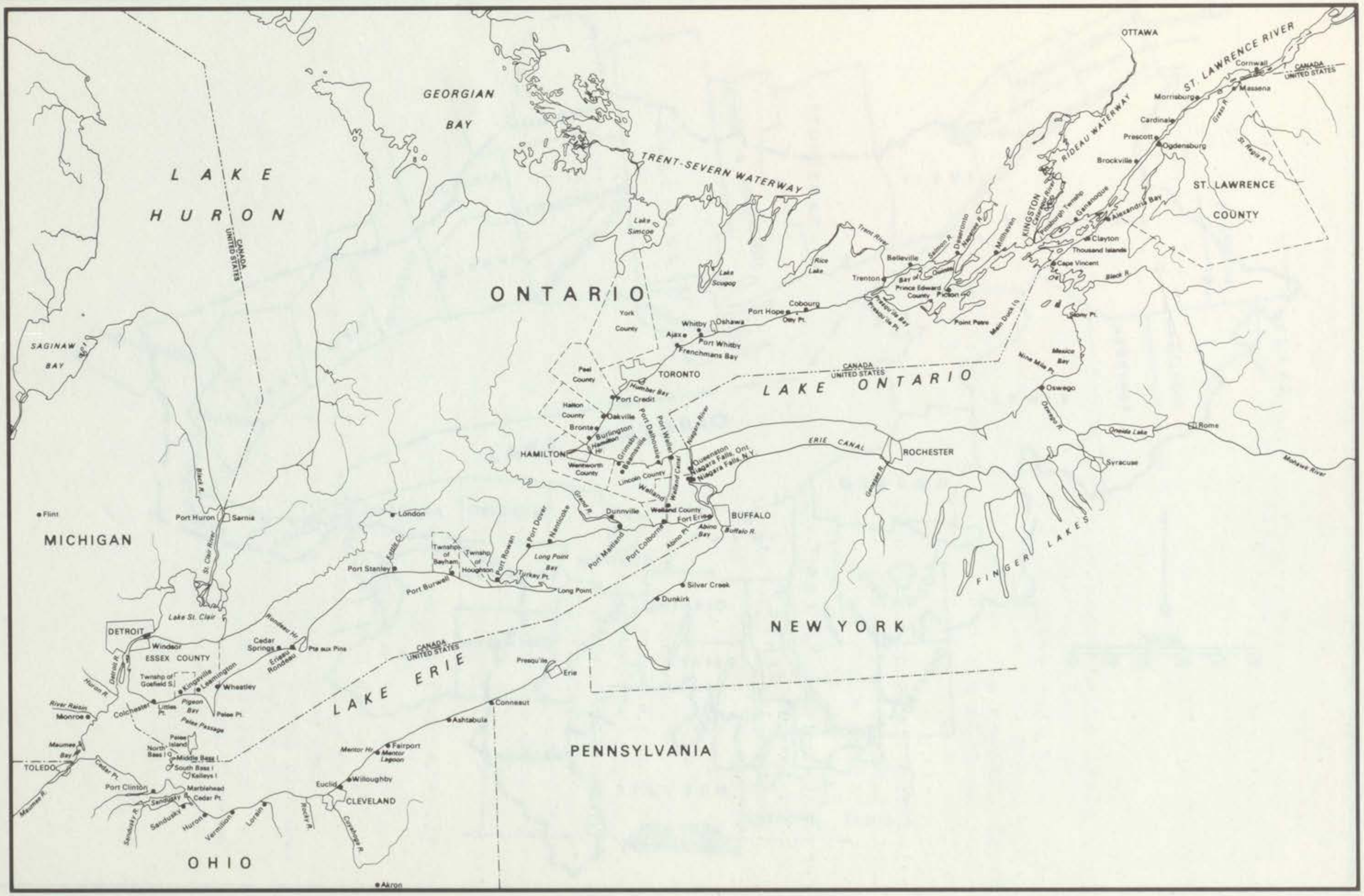
Since the work of the Advisory Boards was initiated, semi-annual reports have been submitted to the Commission to apprise it of the Boards' progress.

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 activities; 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.

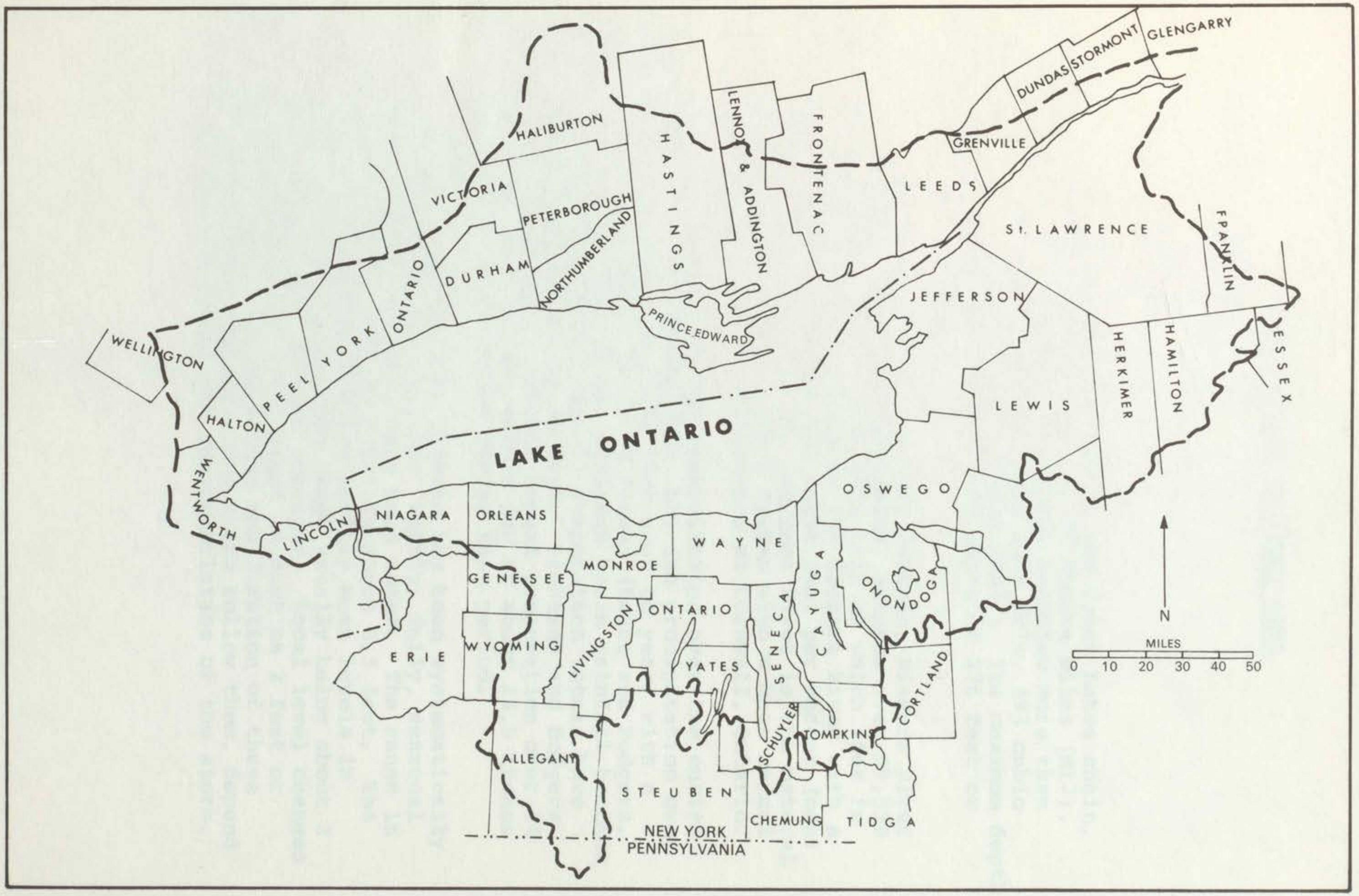
A second interim report was prepared by the Advisory Boards and submitted to the Commission in June, 1968. The report reiterated the conclusions stated in the 1965 report and noted the achievements in pollution abatement since that time. A number of other pollution reports commissioned by federal, state 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.



Geographical reference map for Lake Erie and Lake Ontario.



Counties of the Lake Ontario drainage basin.

1. DESCRIPTION OF STUDY AREA

1.1 PHYSICAL FEATURES

1.1.1 Hydrology

Lake Ontario, the last in the Great Lakes chain, is the smallest in surface area, 7,340 square miles (mi^2), or 19,009 square kilometres (km^2), but contains more than three times the volume of water than Lake Erie, 393 cubic miles (mi^3) or 1,638 cubic kilometres (km^3). Its maximum depth is 802 feet (244 metres) with a mean depth of 276 feet or 84 metres (Fig. 1.1.1).

The land area of the Lake Ontario, Niagara River and St. Lawrence River drainage basins, extends over 29,520 mi^2 (76,457 km^2), a little less than half of which lies in Canada. The major river inflow is the Niagara River with a mean annual discharge of 195,000 cubic feet per second (cfs) at Queenston, Ontario. The St. Lawrence River is the natural outlet for the entire Great Lakes System with a mean annual outflow of 232,000 cfs, as determined at Cornwall, Ontario.

The average annual precipitation over the entire Great Lakes basin is 31.2 inches, but the precipitation over Lake Ontario is quite variable from year to year, with a yearly average of about 28 to 33 inches (Bruce and Rodgers, 1962). About one half of the drainage basin rainfall becomes streamflow (Brunk, 1964). Annual evaporation totals have been estimated in a variety of ways. Richards and Rodgers (1964) have estimated an average annual evaporation over 14 years of about 27.4 inches, with a low of about 15.5 inches and a high of about 36 inches during that period.

The level of Lake Ontario has been systematically measured since 1860 (Fig. 1.1.2). Hourly, daily, seasonal and longer period variations have been noted. The range in monthly mean values (1860 to 1964) is about 6.5 feet. The normal annual cycle features low monthly mean levels in winter and highs in summer, the range usually being about 2 feet, but as high as 3 feet on occasion. Local level changes due to storm action may also depart as much as 2 feet or more from the mean. The magnitude and duration of these surges, and the decay oscillations which follow them, depend upon local topography and the characteristics of the storm.

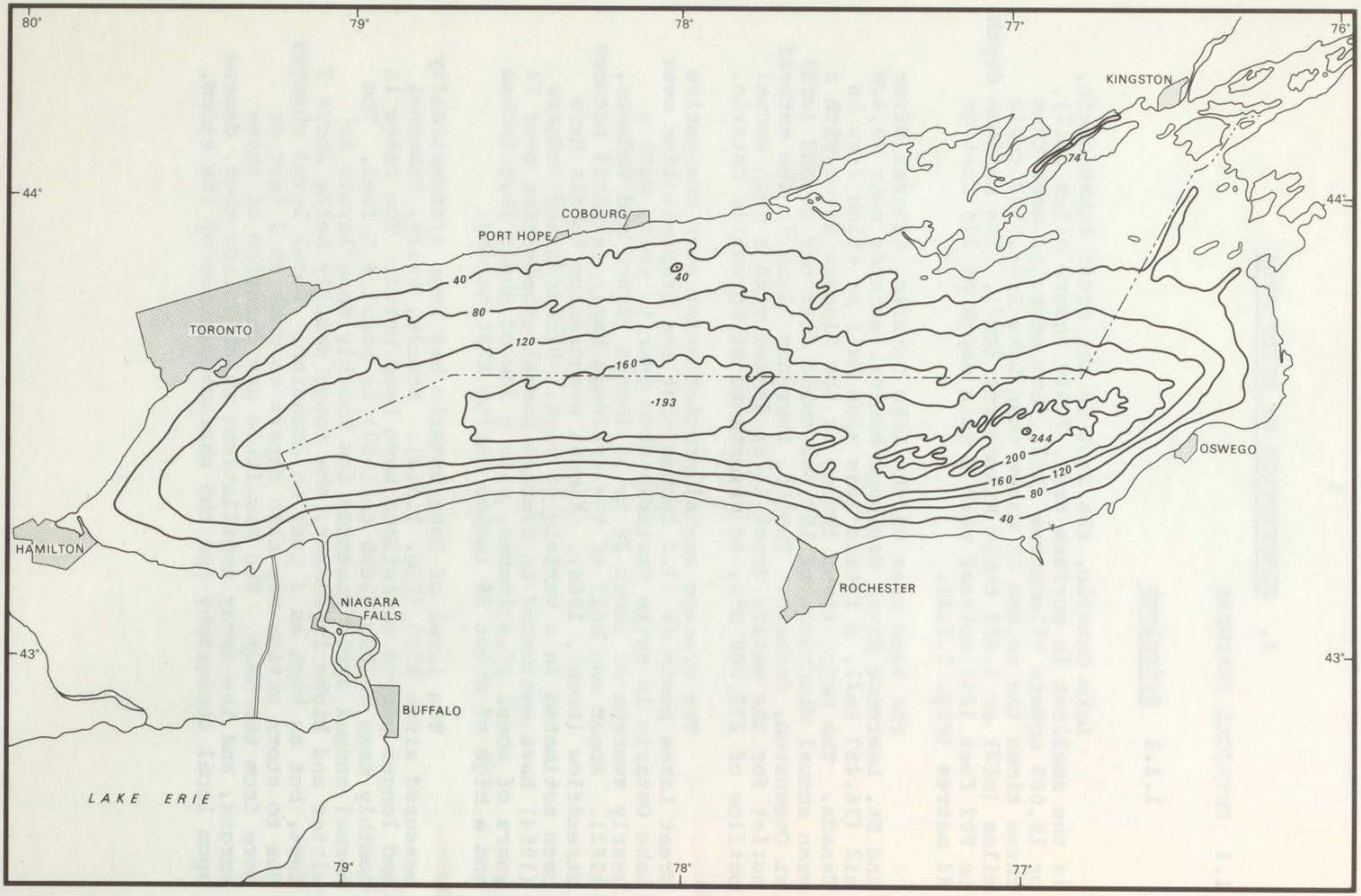


Fig. 1.1.1 Lake Ontario bathymetry (metres).

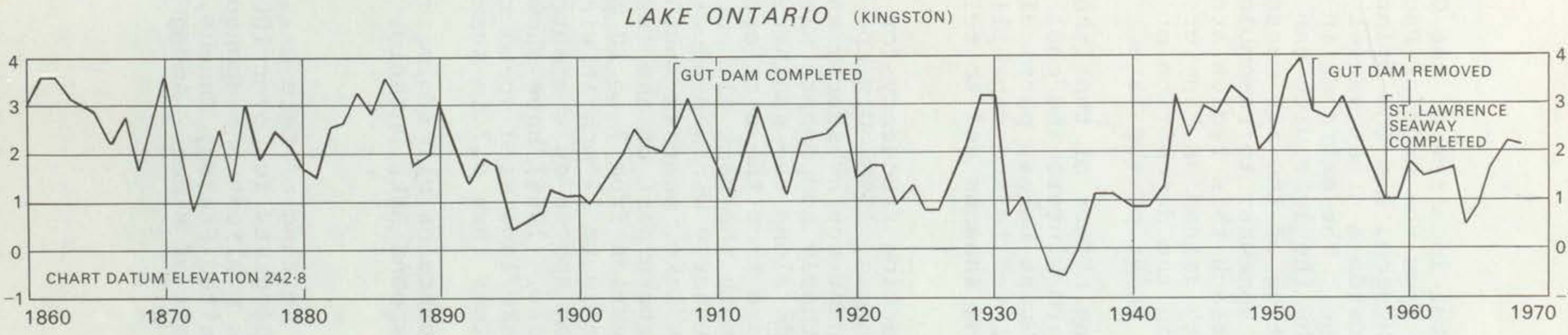


Fig. 1. 1. 2 Yearly mean water level variations (in feet) referred to the International Great Lakes Datum, 1955.

1.1.2 Climate

The continental location of the Great Lakes basin is such that air masses from the Arctic, Pacific Ocean, Western North America, Gulf of Mexico, and the Atlantic Ocean can converge upon it and provide a great variety and range of meteorological conditions. The extremes in these conditions are, however, tempered by the lake with the result that the continental characteristics of the air masses passing through the region are modified somewhat to resemble a maritime climate. Storms which reach this region are frequently rejuvenated by the energy gained as they cross the large lakes, often resulting in the deposition of large amounts of rain or snow on the lee sides of the lake.

The moderating effect of the lakes on air temperature results in relatively warm winters and cool summers in the shoreline areas of the Great Lakes, particularly along the lee shores. This is related to the capability of lakes to store heat during heating seasons and to release it during cooling periods.

The wind direction frequency for the Lake Ontario region during winter (Thomas, 1953; U.S. Dept. of Commerce, 1959) indicates predominant southwesterly and westerly winds. A high frequency of northerly components along the northern shore and southerly winds along the southern shore also occur. The lowest frequencies are from the east and southeast. In summer, the pattern is much the same although high frequencies of northwesterly and northerly winds predominate in the northwestern part of the lake, whereas southwesterly winds dominate in the northeastern part of the lake. The average wind speed on the lake varies from 7 to 10 miles per hour (mph) in summer and from 10 to 12 mph in winter. Wind speeds over the lake differ from speeds at the surrounding land stations. Richards *et al.*, (1966) have shown that these effects can result in lake/land wind speed ratios greater than 3.0 in winter and less than 0.7 in summer.

Table 1.1.1 contains climatological data for selected land stations around Lake Ontario.

1.1.3 Geology

The geologic setting of Lake Ontario has been examined by numerous geologists for over 100 years and is described extensively in publications sponsored by the Geological Surveys of United States, Canada, New York State, and the Ontario Department of Mines. Among numerous works,

Table 1.1.1 Climatological data for two stations around Lake Ontario

T - Toronto (City) Ont., Latitude 43°40'N, Longitude 79°24'W
R - Rochester (Airport) N.Y., Latitude 43°07'N, Longitude 77°40'W

	Air Temp. (°F)		Wind				Precip. (inches)		Rel. Humidity (percent)	
	T	R	mph T	dir T	mph R	dir R	T	R	T	R
Jan	24.5	24.7	14.7	W	11.0	WSW	2.72	2.36	76	78
Feb	24.0	24.0	14.4	W	11.1	WSW	2.31	2.42	74	77
Mar	32.2	33.0	13.9	NW	10.9	WSW	2.58	2.96	65	75
Apr	43.8	44.5	13.0	NW	10.1	WSW	2.55	2.64	60	70
May	55.1	56.4	10.4	NE	8.9	SW	2.65	2.64	63	69
Jun	65.5	66.6	9.1	SW	8.0	SW	2.70	2.85	63	68
Jul	70.8	71.2	8.3	SW	7.5	SW	3.23	3.09	67	68
Aug	69.0	68.9	8.4	SW	7.0	SW	2.39	2.48	68	72
Sep	61.6	62.0	9.6	E,NW	7.6	SW	2.67	2.66	72	75
Oct	50.2	50.8	10.0	SW	8.4	SW	2.29	2.50	73	75
Nov	39.2	39.7	13.0	SW	9.9	WSW	2.55	2.74	73	77
Dec	28.4	28.2	14.4	SW	10.4	WSW	2.29	2.40	74	78
yr	47.0	47.5	11.6	SW	9.2	WSW	30.93	31.74	69	74
(a)	30	(b)	18	18	86	10	30	(b)	10	17

(a) years of record (b) 1921-50 mean.

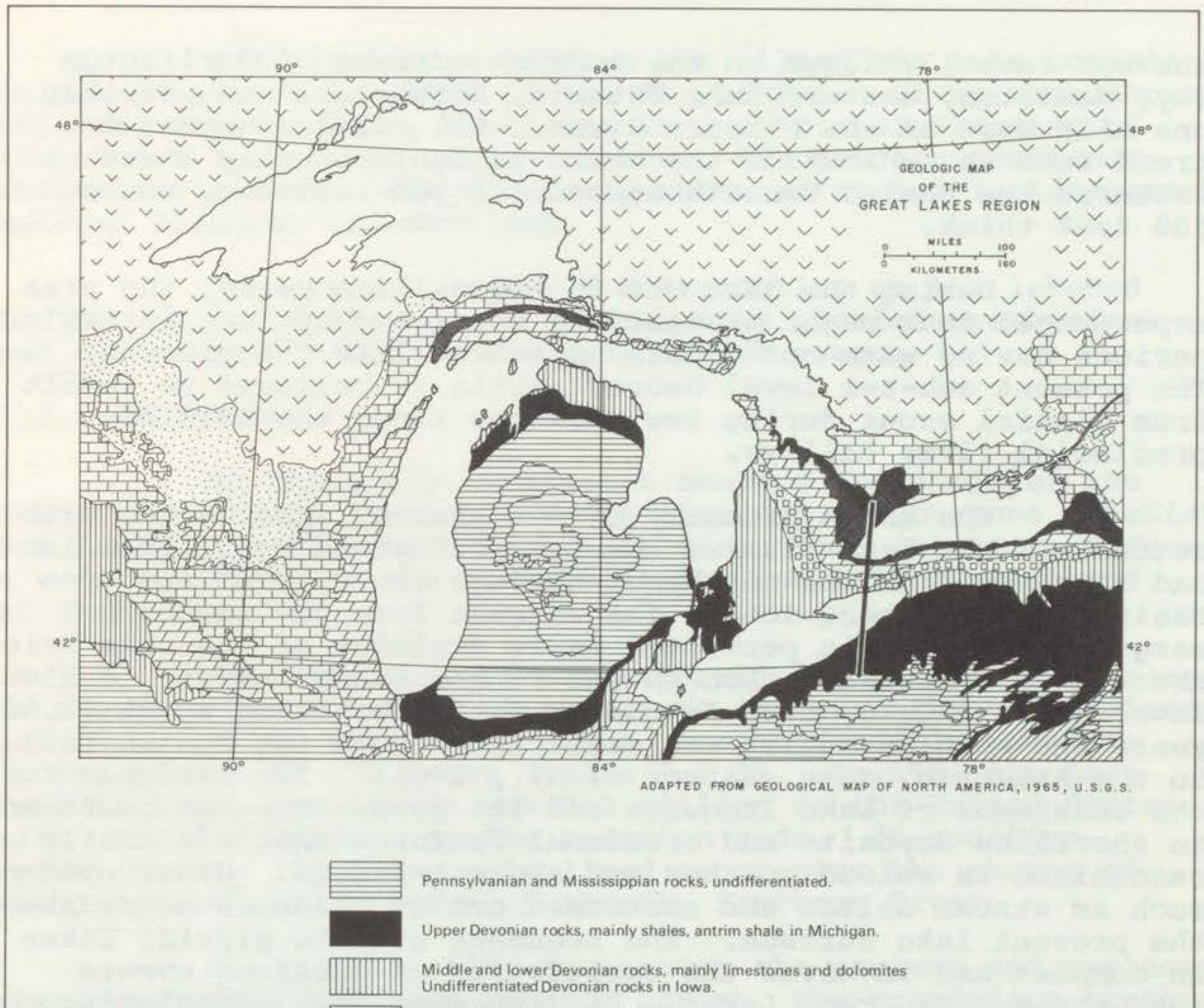
Climatology and weather services of the St. Lawrence Seaway and Lakes, U.S. Dept. of Commerce, Weather Bureau, Technical paper #35, pp. 61-65, 1959.

those of Spencer (1890), Coleman (1900, 1904, 1937a, 1937b), Fairchild (1909) and Kindle (1925) may be cited as pioneer contributions to the geology of Lake Ontario and vicinity. The first comprehensive treatise on the late-glacial history of the Great Lakes was that by Leverett and Taylor (1915). Notable summaries in more recent years are those by Hough (1958, 1963), Fisher *et al.* (1961) and Hewitt (1966).

The location and orientation of the lake basin are related to bedrock type and structure as shown in Fig. 1.1.3. The basin is an erosional feature entirely. It is preferentially situated along an outcrop band of soft erodable Ordovician shale bedrock. Marine sedimentary rock strata of Cambrian to Silurian age (600 to 400 million years), largely composed of shale and limestone underlie Lake Ontario. These strata lap to the north onto a complex of older igneous and metamorphic rocks known as the Canadian Shield. Exposed Shield rocks occur less than 100 miles north of western Lake Ontario, cross the eastern end of the basin near Kingston, and outcrop in northern New York State as the Adirondack Mountains. The prominent Niagara Escarpment capped by the resistant Middle Silurian Lockport Dolomite forms the southern and western limits of the Ontario basin. The rock strata dip gently southward (about 21 feet/mile) under much of the basin; in the small northeastern basin near Kingston, strata tend to strike northwest and dip southwest. All strata dip towards the Paleozoic Appalachian geosyncline in New York and Pennsylvania in which the Paleozoic sediments reach thicknesses of several miles. The basin of Lake Ontario appears to be excavated in the relatively soft Ordovician shale at Queenston resulting in an east - west trough with a steep southern slope (probably the eroded edge of Queenston shale) and a shallow northern slope controlled by the dipping bedding planes of the durable underlying Trenton - Black River limestone.

Preliminary results of seismic surveys reveal a mantle of unconsolidated sediment 30 to 65 feet thick over bedrock in offshore areas. Nearshore, the rock is often exposed on the lakebed. Regionally, the form of the bedrock basin resembles that of the present lake bed topography shown in Fig. 1.1.1. Although most of the Paleozoic sediments are only slightly altered, some faulting has been observed.

Following the Paleozoic era of marine sedimentation, the seas withdrew leaving a land surface exposed to meteorological erosion for an extended period of up to 300 million years. It is probable that a major drainage system developed on this land surface. A major valley was probably excavated along the length of present Lake Ontario. Seismic



ADAPTED FROM GEOLOGICAL MAP OF NORTH AMERICA, 1965, U.S.G.S.

ADAPTED FROM CARMAN, 1946

Fig. 1.1.3 Geologic map of the Great Lakes region and cross-section of Lake Erie and Lake Ontario.

surveys reveal valleys on the bedrock surface of Burlington Bay, Hamilton, eastern Lake Ontario, Rochester, and possibly one mile west of the Niagara River. All valleys appear to trend from shore towards the basin trough. Locally these features are buried beneath unconsolidated sediments up to 300 feet thick.

During the last one to two million years, the area experienced four major glaciations separated by long interglacial periods having warm non-glacial climates like the present. The present sub-sea level bedrock basin is believed to result from glacial scour during ice advances along the axes of preglacial river valleys.

The known ancestry of the present lake begins with retreat of the last glacier about 13,000 years ago. This ice had advanced from the northeast through the Ontario and Erie basins as a coherent lobe. Ice retreat from the southern margins of the basin permitted early drainage of the Lake Erie area to pass eastward through the Finger Lakes region. A high level glacial lake, Lake Iroquois, was established about 12,000 years ago when an outlet was deglaciated down the Mohawk Valley to the Atlantic Ocean (Karrow *et al.*, 1961). The evidence for the existence of Lake Iroquois and its successors can be found in shoreline deposits and erosional features that are easily recognized as raised beaches and shore terraces. Other evidence such as stream deltas and abandoned outlet channels occur above the present lake surface. The sequence of late glacial lakes is complex and involves the correlation of numerous events over the entire Great Lakes - St. Lawrence area. Beginning about 11,000 years ago, Lake Iroquois was lowered through a succession of levels as the continuing ice retreat opened new eastward outlets into the Lake Champlain Valley.

During the period of ice retreat and continuing to the present, the whole Ontario basin underwent crustal uplift in response to glacial unloading. Uplift is proceeding differentially, the northeastern area rising relative to the southwest area. About 10,000 years ago when the St. Lawrence Valley became ice free, the Ontario basin drained by its present route for the first time. The St. Lawrence River threshold was still depressed relative to the rest of the basin, hence the early Lake Ontario was a low level phase with a water surface estimated to be 248 feet or more lower than the present lake. Thus, early Lake Ontario was very close to present sea level. It is possible that salt water of the Champlain Sea episode entered the Ontario basin for a short period although no direct evidence for a marine incursion has been found.

Differential uplifting has tilted the Lake Ontario basin upwards at the head of the St. Lawrence River throughout the past 10,000 years, resulting in a continual flooding of shorelines and stream valley mouths. The process continues today at a reduced rate presently measured at 5.8 inches/century between Kingston and Hamilton.

The present sediment distribution on the lakebed is the result of erosion of the previous glacial overburden and sedimentation during the past 10,000 years.

1.2 POPULATION

In the early nineteenth century the whole of the Great Lakes basin supported fewer than 300,000 persons (MacNish and Lawhead, 1968). The basin has since been transformed from a hunting ground of the Indians to the industrial heartland of North America.

In 1966, approximately 30 million people lived along or near the Great Lakes, or about one in every three Canadians and one in eight Americans. This is a hundredfold increase in population in 150 years (Table 1.2.1). In 1966 the Lake Ontario basin population was 2.3 million on the United States side, and 3.8 million on the Canadian side. In addition, approximately 156,000 people lived on or near the shores of the international section of the St. Lawrence River.

Table 1.2.1 also summarizes the present and projected populations for the Lake Ontario basin. The population pressures are expected to be similar for the Lake Ontario basin as for the Lake Erie basin, with the population doubling in the United States and tripling in Canada in the next 60 years. This reflects a rate of growth of 1.3 percent per year on the United States side and 3.8 percent per year on the Canadian side.

The greatest population pressure lies in an arc at the western end of the lake from the Niagara frontier through the western end of Lake Ontario 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. In the United States portion of the basin in 1960, 67 percent of the population was urban or living in settlements of 1,000 or more. By 2020, this is expected to increase to 79 percent. Information on the degree of urbanization in the Canadian portion of the basin is not readily available, but is assumed to be of the same order as the remainder of the province (77 percent) as reported by Stone (1967). In 1966, six counties, Welland, Lincoln,

Table 1.2.1 Population summary for Great Lakes basin (After MacNish and Lawhead, 1968).

		Basin population (in millions)	
Year	Canada	United States	Total
*1810	.1	.2	.3
1860	1.1	1.2	2.3
1910	2.5	11.3	13.8
1960	6.0	25.8	31.8
**2000	13.7	43.3	57.0

*Includes both immigrant and Indian populations; based mainly on statements in Encyclopedia Britannica, representing orders of magnitude only.

**Preliminary projections, from presently available information.

Population summary for Lake Ontario and International Section of the St. Lawrence River basins.

	Basin population (in millions)	
	Canada	United States
1960	3.2	2.1
1966	3.8	2.3
1986	4.8	2.8
**2020	9.8	4.3

United States figures are based on data provided by the Federal Water Pollution Control Administration, Great Lakes Regional Office. Canadian figures are based on census data of the Dominion Bureau of Statistics (1961) and information provided by the Ontario Water Resources Commission from data and forecasts of the Ontario Department of Municipal Affairs, the Ontario Department of Economics and Development, and the Metropolitan Toronto Region Transportation Study.

Wentworth, Halton, Peel and York contained 80 percent of the population in the Canadian portion of the Lake Ontario basin, and will contain 86 percent of this population by the year 2020. The expected rate of growth in these countries is significantly higher than the predicted 1.1 percent rate of growth for the remainder of the province. High rates of growth are also expected in the Rochester, Niagara and Syracuse areas.

A megalopolis stretching from Rochester to Oshawa may be a reality by the end of this century and such a development will have far reaching effects on the water resources of the basin.

1.3 LAND USE AND DEVELOPMENT

The drainage basin of Lake Ontario and the international section of the St. Lawrence River covers an area of approximately 7,715,000 acres within the province of Ontario and 10,368,000 acres in the United States. A large portion of the land in the basin lies within the Pre-Cambrian shield, much of which is not suitable for agricultural purposes. However, its scenic beauty has led to a valuable tourist industry.

1.3.1 Agricultural

Approximately 26 percent of the Canadian land area (2,020,000 acres) and 45 percent of the United States (4,718,000 acres) are devoted to a wide variety of agricultural uses. The prevalent field crops are hay, oats, mixed grain, corn, barley and wheat. The Niagara Peninsula and southern shore are well suited for their orchards and vineyards. Vegetable, beef, dairy and poultry farming are also common throughout the watershed. The realized gross income from agriculture was estimated to be 239 million dollars in 1966 for Canada and 373 million dollars in 1964 for the United States. The total agricultural acreage can be broken down into the following broad classifications.

	Canada	United States
Crop	1,432,000	3,090,000
Fallow and Other	46,000	457,000
Pasture	542,000	1,171,000
Total	2,020,000 acres	4,718,000 acres

1.3.2 Industrial

In 1964 products manufactured in the Canadian basin contributed an estimated gross value of 2.8 billion dollars to the economy. In the United States the gross value of manufacturing was 4 billion dollars for 1963. The dominant industries for the basin as a whole are steel, automotive and transportation, paper, rubber products, chemical, photographic equipment, and petroleum. Power production is quite extensive in Ontario with 20 municipally and provincially owned hydroelectric installations producing 1,900 megawatts (Mw) and 86 United States plants with a capacity of 1,400 Mw in 1966. Two Canadian thermal electric installations produce 2,768 Mw and six United States plants produce 1,165 Mw of power. Nuclear generating stations are presently under construction, one near Ajax east of Metropolitan Toronto, Ontario, one near Oswego, and another near Rochester, New York. The United States plants were scheduled for completion in 1969. There is also a proposed plant site near Cayuga Lake, New York and Bath, Ontario.

1.3.3 Recreational

Some 37,000 acres in Ontario are devoted specifically to public recreation in the watershed. Privately-owned lands in the Pre-Cambrian Shield around the inland lakes are extensively used for recreation. Generally low water temperatures along the northwest shore restrict the recreational use of Lake Ontario to a considerable degree. Nonetheless, the lakefront parks and recreation areas are very popular. Of 424,000 acres in recreational areas in the United States, 365,000 are available for general use. The Adirondack Forest contains much of this area.

1.3.4 Municipal

Urbanization is occurring rapidly in many parts of the area especially in the region extending from Metropolitan Toronto to the Niagara Peninsula. Approximately 563,000 acres of land are either urbanized or so designated at present. Of this total 492,000 acres are residential and support a population of 3,263,000 persons. The Rochester and Syracuse areas are centres of growth in the United States basin. Urban and other non-agricultural areas in the basin utilize 1,193,000 acres and support a population of 1,341,000.

1.3.5 Forestry

Reforestation and woodlands occupy 526,000 acres of the Canadian drainage basin. The reforestation areas generally are managed by the Province under agreements with the counties or townships. Forested areas in the United States amount to 4,033,000 acres, the majority being in the northeastern portion where the Adirondack Forest Preserve is located. Other state and county forests are scattered through the basin, but most of the land is privately owned.

1.4 WATER USES

1.4.1 Public Water Supply[1]

At the present time a population of approximately 2.6 million Canadians obtains water from Lake Ontario and utilizes 325 million gallons per day (mgd) from the lake. The United States usage is 69 mgd for 302,000 people. The greatest demand arises from urban development located on the shore of the lake, although inland municipalities are beginning to develop Lake Ontario water supply systems. The Canadian population of the international section of the St. Lawrence River utilizing the river as a source of water is approximately 148,000, and in the United States 53,000 persons. The corresponding total water consumption from the river averages 25 mgd and 6 mgd, respectively.

The locations of the various municipal water systems, the population served, and the treatment provided are summarized in Table 1.4.1 for the entire basin. In general, the commercial, industrial and institutional water demands increase with the size of the community often constituting the major part of the total consumption in the large urban centres.

Most of the municipal water purification plants on Lake Ontario provide extensive treatment. Coagulation, sedimentation, filtration and chlorination facilities are common to most plants; however, a few plants only filter and chlorinate the lake water before pumping it into the distribution system. The amount of treatment is dictated by the raw water quality and the required quality of the treated water. Taste and odour control facilities are often necessary, especially in the highly industrialized northwestern section of the lake where industrial waste discharges create problems. Careful planning is required in the location of waterworks intakes in this area in order to minimize the problems associated with the waste discharges.

A unique water purification problem is encountered in the Bay of Quinte where the water quality suffers from enrichment of the bay, heavy algal concentrations and inadequate depths for water intakes. In order to obtain acceptable water

[1] Water use data have been updated since the printing of Volume 1.

Table 1.4.1 Public water supply summary.

Area	Population served (thousands)	Average consumption mgd	*Treatment provided other than disinfection
Lake Ontario			
Canada			
Ajax	11.0	1.73	Conventional
Beamsville	4.5	.29	Conventional
Belleville	31.0	4.97	Conventional
Bowmanville	8.5	.66	Coagulation
Burlington	47.0	5.39	Conventional, Taste & Odour Control
Cobourg	10.5	2.09	Conventional
Desoronto	2.0	.34	Nil
Grimsby	6.0	.93	Conventional
Hamilton	278.0	62.16	Conventional, Taste & Odour Control
Metro Toronto	1,825.0	218.40	Conventional, Taste & Odour Control
Oakville	46.0	4.46	Conventional, Taste & Odour Control
Oshawa	81.0	9.40	Conventional, Taste & Odour Control
Pickering (Twp.) (Scott Plant)	2.5	.50	Conventional
Picton	6.0	.97	Conventional, Taste & Odour Control
Port Credit	8.0	.67	Conventional, Taste & Odour Control
Port Hope	8.5	.88	Conventional
Mississauga (Twp.)	107.0	9.13	Conventional, Taste & Odour Control
Vineland	1.0	.16	Conventional
Whitby	15.0	1.59	Conventional
TOTAL CANADIAN		324.72	

Table 1.4.1 (cont'd)

Area	Population served (thousands)	Average consumption mgd	*Treatment provided other than disinfection
United States			
Wilson	13.0	.18	Conventional
Lyndonville Public Water Supply - Yates	10.0	.10	Conventional
Brockport Hamilton	12.0	2.00	Conventional, Taste & Odour Control
Hilton Public Water Supply - Parma	1.7	.20	Conventional
Eastman Kodak-City of Rochester Combined intake Greece	43.0	8.0	Conventional, Taste & Odour Control
Rochester	160.0	20.0	Conventional
Monroe County Water Authority	200.0	32.0	Conventional, Taste & Odour Control
Ontario	3.0	.35	Nil
Williamson	7.0	1.3	Conventional
Sodus	5.0	.30	Nil
Sodus Point	1.1	.15	Conventional
Wolcott	1.6	.24	Conventional
Onondaga County Water Authority - Oswego	26.0	9.0	Nil
Sackets Harbour	1.3	.13	Filtration
Albion	5.9	1.0	Conventional, Taste & Odour Control
TOTAL U.S.		74.95	

Table 1.4.1 (cont'd)

Area	Population served (thousands)	Average consumption mgd	*Treatment provided other than disinfection
St. Lawrence River			
Canada			
Brockville	19.5	4.01	Microstraining
Cornwall	44.5	9.50	Conventional
Cornwall (Long Sault)		.27	Nil
Gananoque	5.5	.68	Taste & Odour Control
Iroquois	1.0	.58	Nil
Kingston	69.5	8.57	Conventional
Morrisburg	2.0	.31	Nil
Osnabruck (Ingleside) (Twp.)	1.0	.07	Nil
Prescott	5.5	.71	Taste & Odour Control
TOTAL CANADIAN		24.70	
United States			
Cape Vincent	9.0	.18	Nil
Clayton	2.0	.80	Nil
Alexandria Bay	1.9	.40	Taste & Odour Control
Morristown	6.0	.05	Nil
Ogdensburg	16.0	3.0	Filtration
Diamond National Corp. (Ogdensburg)	.46	.001	No Information
Massena	16.0	1.5	Conventional
Aluminum Company of America-Massens	3.2	.20	No Information

Table 1.4.1 (cont'd)

Area	Population served (thousands)	Average consumption mgd	*Treatment provided other than disinfection
United States			
Reynolds Metal Co.			
Roosevelton	.69	.07	No Information
General Motors			
Massena	.75	.10	No Information
TOTAL U.S.		6.301	

*Conventional Treatment refers to: Coagulation, Sedimentation and Filtration.

Area Designation
Twp. - township

quality from the bay, fine screening and taste and odour control facilities are required in addition to chlorination, coagulation, sedimentation and filtration facilities.

Water purification on the St. Lawrence River ranges from simple chlorination to complete treatment and includes fine screening in one instance. Here again the degree of treatment is dictated by the local raw water quality and the required quality of the treated water.

1.4.2 Industrial Water Supply

The location of the supplies and the amount of water obtained by industry from Lake Ontario and the international section of the St. Lawrence River are contained in Table 1.4.2.

In comparing the relative amounts of water used for cooling and processing it is noted that 91 percent of the total industrial withdrawal from Lake Ontario is for cooling purposes. In the St. Lawrence River only 53 percent is used for cooling. The principal reasons for this disparity are the degree of industrialization and the types of industry served.

The major industrial use of water from Lake Ontario occurs at the west end of the lake. Of particular significance are the two thermal generating stations in the Metropolitan Toronto region; the Lakeview and R.L. Hearn Generating Stations which utilize a combined total of 1,680 mgd of cooling water in producing 2,700 Mw of electricity. This use alone will represent 80 percent of the total Canadian industrial water withdrawal from Lake Ontario. In addition a third generating station which will be nuclear-fueled with an output of 2,160 Mw is under construction just east of Metropolitan Toronto.

Several United States industries use lake water, but by far the greatest single use is by thermal generating plants at Oswego and Rochester. These plants produce up to 850 Mw of electricity and use about 720 mgd of cooling water. Two nuclear plants being built on the lake will produce a total of 950 Mw of power.

There is one Ontario hydroelectric generating station, the Robert H. Sanders Generating Station on the international section of the St. Lawrence River near Cornwall. This station produces 910 Mw of electricity as does the Robert Moses Plant in New York State.

Table 1.4.2 Industrial water supply summary.

Area	Company	Average annual supply Process mgd	 Cooling mgd
Lake Ontario			
Canada			
Sidney (Twp.)	Canada Cement Co. Ltd.	0.40	2.00
Belleville	Union Carbide Canada Ltd.	0.30	2.60
Mississauga	British American Oil Co. Ltd.	9.60	20.00
	St. Lawrence Cement Co. Ltd.		1.10
Hamilton	Canadian Industries Ltd.	1.50	
	Canadian Veg. Oil Processing Ltd.		1.20
	Dominion Foundries and Steel	36.00	34.00
	International Harvester Co. of Canada	1.80	0.40
	National Steel Car Corp. Ltd.	0.04	0.10
	Steel Co. of Canada Ltd. (Hilton Wks)	130.00	110.00
	Steel Co. of Canada Ltd. (#2 Rod Mill)	0.80	4.00
Kingston	Dupont	0.10	9.90
Oakville	British Petroleum Refinery Canada Ltd.	0.90	0.90
	Ford Motor Co. of Canada	3.80	0.70
	Shell Canada Ltd.	0.52	0.18
Picton	Lake Ontario Cement	0.30	1.70
Port Credit	Regent Refining Canada Ltd.	1.30	26.70
	St. Lawrence Starch Co. Ltd.	0.90	0.30
Millhaven	Canadian Industries Ltd.	2.40	14.10
Port Hope	Eldorado Mining and Refining Co. Ltd.	0.01	0.72
Toronto	Canada & Dominion Sugar	0.23	
	Canada Iron Co. Ltd.		0.20
	Canadian Johns-Manville	2.00	
	Canadian Liquid Carbonic		1.30
	Canada Malting		0.20
	Continental Can (Commissioner St.)	1.70	0.30
	Continental Can (Polson St.)	1.70	0.10
	R.L. Hearn Gen. Sta.		600.00
	Lakeview Gen. Sta.	1.00	1,080.00
	Maple Leaf Mills		0.20
	Victory Soya Mills Ltd.		4.30
TOTAL CANADIAN		197.30	1,917.20

Table 1.4.2 (cont'd)

Area	Company	Average annual supply Process mgd	 Cooling mgd
United States			
Oswego	Hammermill Paper Co.	0.95	0.95
	Oswego Generating Sta.		430.00
Rochester	Russell Generating Sta.		290.00
TOTAL U.S.		0.95	720.95
St. Lawrence River			
Canada			
Augusta (Twp.)	Brockville Chemical	0.34	0.29
	Dupont	0.30	30.20
Cardinal	Canada Starch	3.00	3.00
Cornwall	Courtauld's Co. Ltd.	4.00	9.00
	Domtar	33.00	17.00
Gananoque	Cow and Gate	0.17	0.29
TOTAL CANADIAN		40.81	59.78
United States			
Ogdensburg	Diamond National Corp.	3.00	0.20
Massena	General Motors Corp.		2.50
	Reynolds Metal Co.	4.35	3.20
TOTAL U.S.		7.35	5.90

1.4.3 Transportation

Lake Ontario, along with the rest of the Great Lakes, serves as a heavily travelled commercial waterway. The growth in commerce and in the water transportation facilities, illustrates the continued expansion of the economy which supports them.

The Montreal - Lake Ontario and the Welland Canal sections of the Seaway showed increases in the 1966 cargo tonnage of 13.5 and 11.0 percent, respectively, over 1965 (St. Lawrence Seaway Authority, 1966). In 1966 there were 7,341 transits of the upper St. Lawrence section. Out of this number, 2,087 transits stopped in Lake Ontario, and the remaining 5,254 continued through the Welland Canal. There was a total of 8,714 transits of the Welland Canal, and 3,460 of these were interlake trips that did not continue into the St. Lawrence River. The total tonnage through the Welland Canal in 1966 was over 59 million tons, with lake carriers accounting for 79 percent of the tonnage and ocean vessels carrying 21 percent.

The ports of Toronto and Hamilton account for the major portion of Canadian traffic in Lake Ontario. There were 1,795 vessel movements with the cargo handled totalling over 5 million tons in Toronto during 1967. In the same year, Hamilton handled 1,509 vessel movements with a total cargo of over 10 million tons. Three United States ports handled 1.7 million tons in 1966.

Traffic on the upper St. Lawrence River continues to establish new records since the Seaway came into full operation in 1959. Freight traffic increased 133 percent from 21 million tons in 1959 to 49 million tons in 1966.

1.4.4 Agricultural Water Supply

The only significant agricultural water use from Lake Ontario and the international section of the St. Lawrence River is for irrigation. The maximum withdrawal rate from Lake Ontario, authorized by OWRC as of April 1968, was 14.1 mgd. The irrigation of farm crops, orchards and market gardens accounts for most of the agricultural consumption. Tree nurseries, golf courses and pastures are also irrigated. On the Canadian side of the St. Lawrence River, the authorized pumping rate is limited to 150,000 gallons per day for sprinkler systems on several golf courses. The actual amount of water used during any year is usually less than the amount permitted and is dependent upon the type of crop, its maturity, and upon meteorological and soil conditions. Use of water from Lake Ontario for agriculture in the United States is negligible.

1.4.5 Recreation and Aesthetics

The recreational activities pursued in Lake Ontario and the St. Lawrence River are principally boating, swimming, picnicking and camping, Fig. 1.4.1. Boating is popular all along the Lake Ontario shoreline wherever there are good natural harbours and stretches of lakefront free of hazards. Centres such as Niagara, Hamilton, Toronto, Belleville, Kingston, Oswego and Rochester are favourite "ports of call". The beautiful Thousand Islands Region in the St. Lawrence River is an excellent boating area offering good facilities to the boating enthusiast.

Along the lake shore and the St. Lawrence River there are some 4,500 acres of recreational land in Canada and 28,500 acres in the United States. New sites are being surveyed especially in the vicinity of large urban centres where most of the existing parks are overcrowded.

1.4.6 Propagation of Aquatic Life and Wildlife

In Lake Ontario, both commercial and sport fishing are confined primarily to the waters around Prince Edward County and the eastern end of the lake. Commercial fishing consists mainly of gill netting which has been declining for the last 30 years (Table 2.4.8). The commercial catches in recent years are as follows:

Year	United States (pounds)	Canada (pounds)
1963	233,000	2,008,000
1964	267,000	2,015,000
1965	217,000	2,646,000
1966	237,000	1,645,000

The estimated totals for 1967 indicated that the Canadian catch totalled about 1,833,000 pounds with a landed value of $245,000. This would indicate an increase in catch and value of 13 and 12 percent, respectively. United States catches increased to 284,000 pounds and were valued at $63,000 in 1967. There has been a decline in the prime species of cisco, whitefish and pickerel. Perch, carp, eel and smelt now form a major part of the catch.

Commercial fishing mainly trawling and hoopnetting is carried out on the St. Lawrence River to a limited extent. The catch is relatively insignificant when compared with that of Lake Ontario. While sport fishing in the river for species

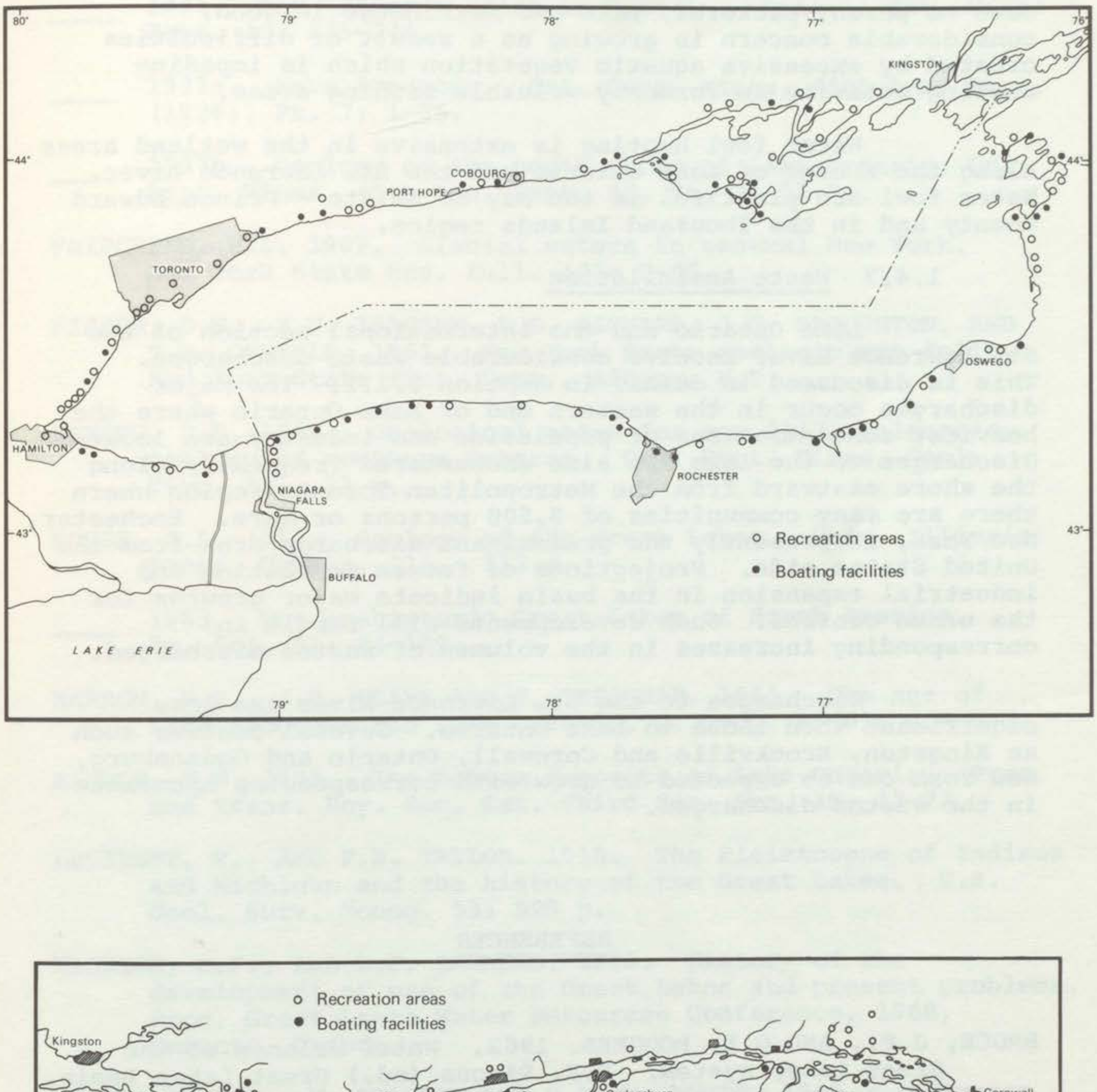


Fig. 1.4.1 Lake Ontario and the St. Lawrence River recreation areas.

such as perch, pickerel, pike and maskinonge is good, considerable concern is growing as a result of difficulties created by excessive aquatic vegetation which is impeding angling activity in formerly valuable fishing areas.

Water fowl hunting is extensive in the wetland areas along the shores of Lake Ontario and the St. Lawrence River. Water fowl are plentiful in the Bay of Quinte - Prince Edward County and in the Thousand Islands region.

1.4.7 Waste Assimilation

Lake Ontario and the international section of the St. Lawrence River receive considerable waste discharges. This is discussed in detail in Section 3.1.1. The major discharges occur in the western end of Lake Ontario where the heaviest concentrations of population and industry are located. Discharges to the lake are also encountered frequently along the shore eastward from the Metropolitan Toronto region where there are many communities of 8,500 persons or more. Rochester, New York, is presently the predominant discharge area from the United States side. Projections of future population and industrial expansion in the basin indicate major growths for the urban centres. Such developments will result in corresponding increases in the volumes of wastes discharged.

Discharges to the St. Lawrence River are less significant than those to Lake Ontario. Several centres such as Kingston, Brockville and Cornwall, Ontario and Ogdensburg, New York can be expected to grow with corresponding increases in the wastes discharged.

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2. LAKE CHARACTERISTICS - PRESENT STATE AND TRENDS

2.1 PHYSICS

2.1.1 Thermal Regimes

The thermal structure of Lake Ontario is continuously in a state of flux. The greatest changes are generated by the yearly climatic cycle. Superimposed thereon are many types of periodic and random fluctuations of higher frequencies. The yearly cycle itself can be considered as a perturbation on long term variations induced by changes in climate and aging of the lake.

Little is known at present about the extent to which these processes are influenced by human activities. On a local scale increases in the water temperature occur in the vicinity of cooling water outlets of power plants. A long term build-up of the average temperature of the lake, due to the increasing use of lake waters as a cooling agent for nuclear power generators, is considered unlikely. An increase of the average surface temperature by only a few tenths of a degree Celsius (°C) would greatly increase the heat losses from the lake surface by such processes as long-wave radiation, evaporation and conduction. This increase in heat loss would tend to dissipate heat originating from existing or anticipated man-made sources, thus minimizing effects on the whole water body.

The higher frequency fluctuations in the thermal structure, those which are superimposed on the yearly cycle, are induced by meteorological factors. Strong winds, for example, can cause upwelling at the windward shores by causing a displacement of the surface waters in a leeward direction, and, in summer, a tilting of the thermocline. This effect is most noticeable when the lake is well stratified; and it may, in summer, cause temporary local reductions in surface temperature by as much as 12 to 15°C to a low of 4°C. Changes in wind stress or barometric pressure may cause both surface and internal oscillations. Dominant among the internal oscillations, which manifest themselves as fluctuations in the thermocline depth over a range of up to 8 metres or more (Mortimer, 1968), are frequencies around and above the inertial period of 17.4 hours (Verber, 1966; Hamblin and Rodgers, 1967), and, to a lesser extent, those with a period of 4 to 8 days related to the passage of weather systems. These oscillations are coupled with large internal displacements of the water and are, together with the wind-induced turbulence and residual currents, effective agents in increasing mixing over the entire area of the lake.

The yearly cycle is the most important perturbation determining the thermal structure of the lake. It consists of two phases, a heating phase lasting roughly from mid-March to mid-September, and a cooling phase during the remaining part of the year (Rodgers and Anderson, 1961 and 1963). Processes taking place during these phases are determined by, or related to, the heat balance. Changes in the thermal structure throughout the year can be described in terms of the four seasons of lake-climatology which correspond in time roughly to the four calendar seasons.

The heating phase begins by mid-March. In winter all water cools to a temperature below the temperature of maximum density of 4°C. In late March or early April the surface temperature starts rising in the shallow, nearshore waters. The onset of spring can, in a lake-climatological sense, be defined by the appearance of a ring of water with a temperature above 4°C along the shores in late April or early May. The transition zone between these warm nearshore waters and the cold midlake waters has been described as a thermal bar (Rodgers, 1966a). This is a convergence zone, extending from surface to bottom, and it is characterized by strong horizontal temperature gradients at the lake surface (gradients up to 7°C over 100 metres have been reported by Rodgers, 1966a). On the nearshore side of the thermal bar a thermocline develops, separating the rapidly warming surface water from the deep water, which remains at a temperature close to the temperature of maximum density. The thermal bar moves gradually but steadily towards the middle of the lake until it dissipates in late May or early June, due to heating of the mid-lake surface water to a temperature above that of maximum density. Relatively strong horizontal gradients around a temperature minimum may persist over the deeper parts of the lake until the end of June. Typical surface temperature distributions for these phases are shown in Fig. 2.1.1 and 2.1.2.

On the offshore side of the thermal bar vertical mixing extends from surface to bottom, but on the nearshore side it is restricted to within the epilimnion (Rodgers, 1966a, 1966b) by the development of the thermocline. The areal extent over which pollutants entering the lake can be mixed is temporarily reduced when the thermal bar separates the nearshore waters from the main body of the lake. Its offshore movement, however, is fairly rapid and the nearshore ring of water will cover at least half the area of the lake within 2 1/2 to 4 weeks after the emergence of the thermal bar (Rodgers, 1966a; Sweers, 1969).

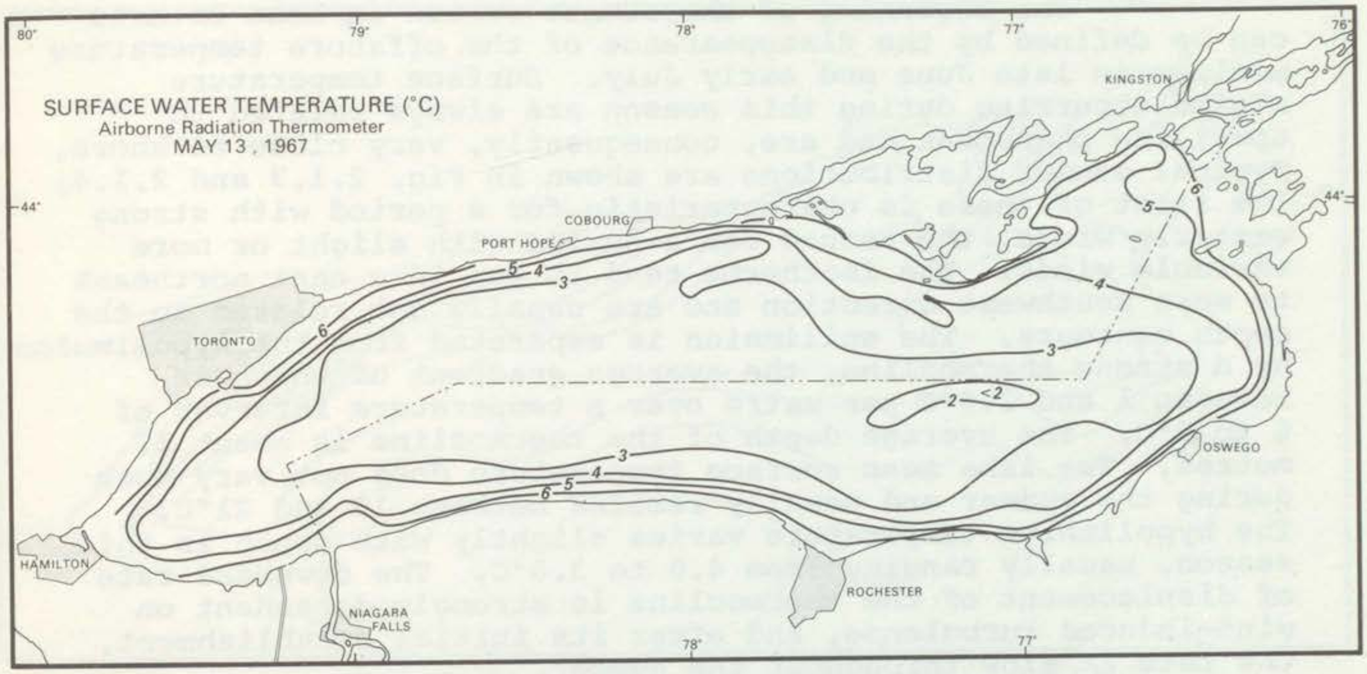


Fig. 2.1.1 Surface water temperature (°C) for May 13, 1967 (After Richards *et al.*, 1969).

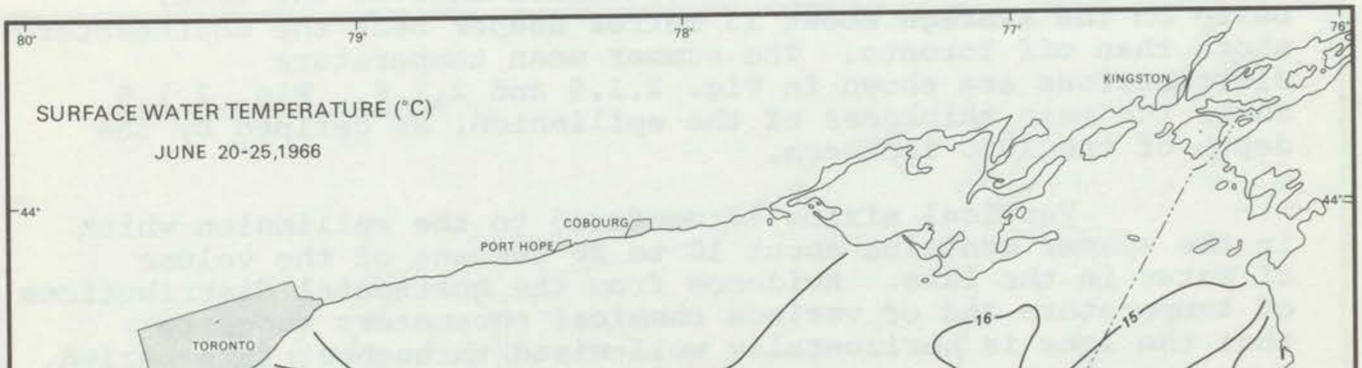


Fig. 2.1.2 Surface water temperature (°C) for June, 1966

The beginning of the summer season in Lake Ontario can be defined by the disappearance of the offshore temperature minimum in late June and early July. Surface temperature minima occurring during this season are always related to upwelling phenomena and are, consequently, very close to shore. Typical summer distributions are shown in Fig. 2.1.3 and 2.1.4; the first of these is characteristic for a period with strong westerly winds, the second for a period with slight or more variable winds. The isotherms tend to run in a east northeast to west southwest direction and are usually not related to the depth contours. The epilimnion is separated from the hypolimnion by a strong thermocline, the average gradient of which is between 1 and 2.5°C per metre over a temperature interval of 6 to 8°C. The average depth of the thermocline is about 17 metres. The lake mean surface temperature does not vary much during the summer and usually remains between 18 and 21°C. The hypolimnion temperature varies slightly with depth in this season, usually ranging from 4.0 to 3.8°C. The downward rate of displacement of the thermocline is strongly dependent on wind-induced turbulence, and after its initial establishment, the rate is slow throughout the summer.

Local characteristics of the thermal structure are largely determined by the predominantly westerly winds (average westerly component about 5 feet per second for Toronto International Airport). As a result the average surface temperature is about 6°C lower in the vicinity of Toronto than in the southeastern end of the lake, and the thermocline slopes by about 5.5 cm/km over the longitudinal axis of the lake, being on the average about 13 metres deeper near the southeastern shore than off Toronto. The summer mean temperature distributions are shown in Fig. 2.1.5 and 2.1.6. Fig. 2.1.6 shows the mean thickness of the epilimnion, as defined by the depth of the 10°C isotherm.

Vertical mixing is confined to the epilimnion which in the summer contains about 10 to 20 percent of the volume of water in the lake. Evidence from the horizontal distributions of temperature and of various chemical parameters suggests that the lake is horizontally well-mixed throughout this period.

The cooling phase starts in the last half of September. In particular, the onset of autumn in a lake-climatological sense is characterized by a relatively sudden drop in the mean surface temperature to a value well below 17°C, coupled with an increase in the rate of descent of the thermocline and a decrease in the intensity of the maximum vertical temperature gradient. This usually occurs after a period of strong winds in late September or early October, but

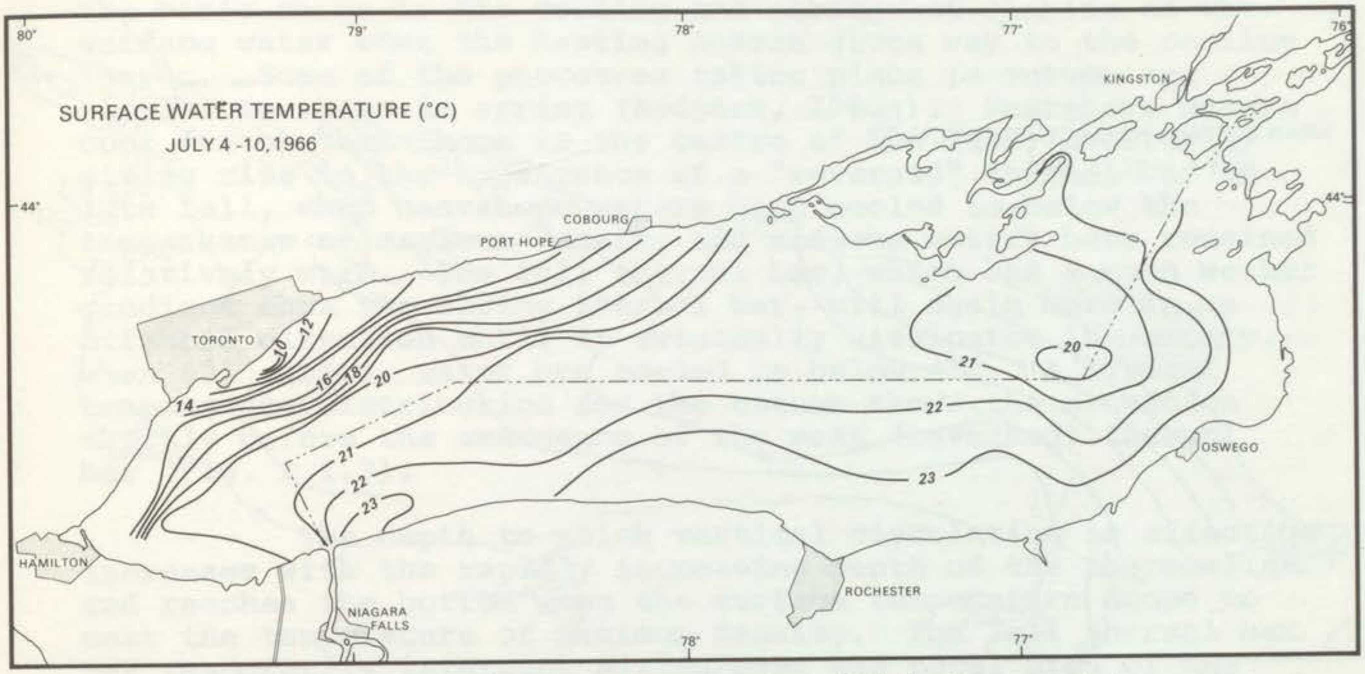


Fig. 2.1.3 Surface water temperature (°C) during a period of relatively strong westerly winds, July, 1966.

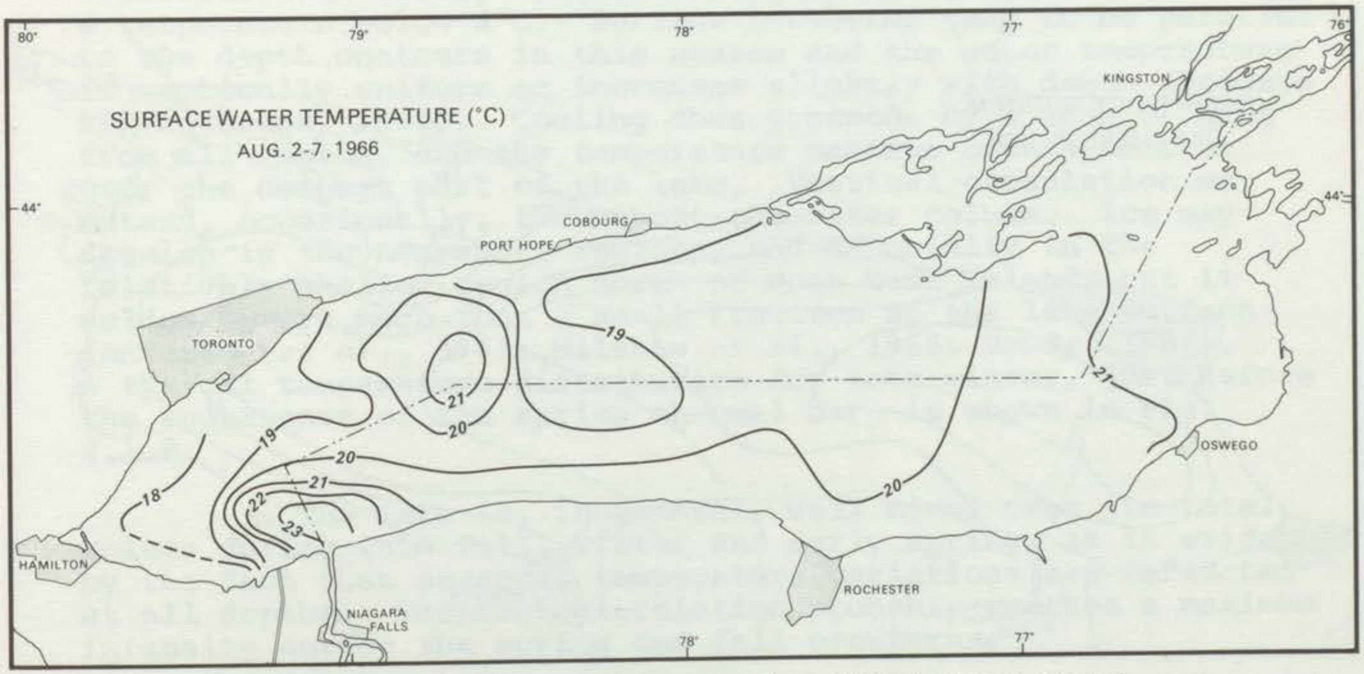


Fig. 2.1.4 Surface water temperature (°C) during a period of variable winds, August, 1966.

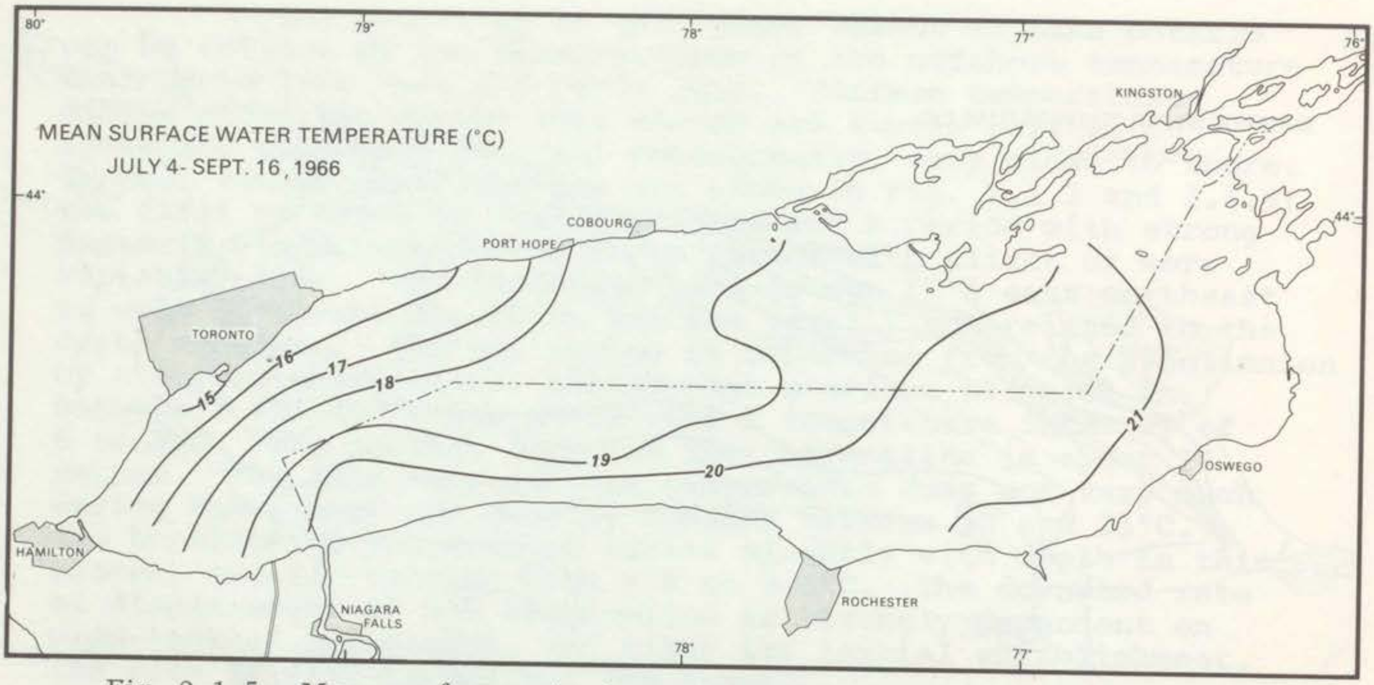


Fig. 2.1.5 Mean surface water temperature (°C) for July - September, 1966.

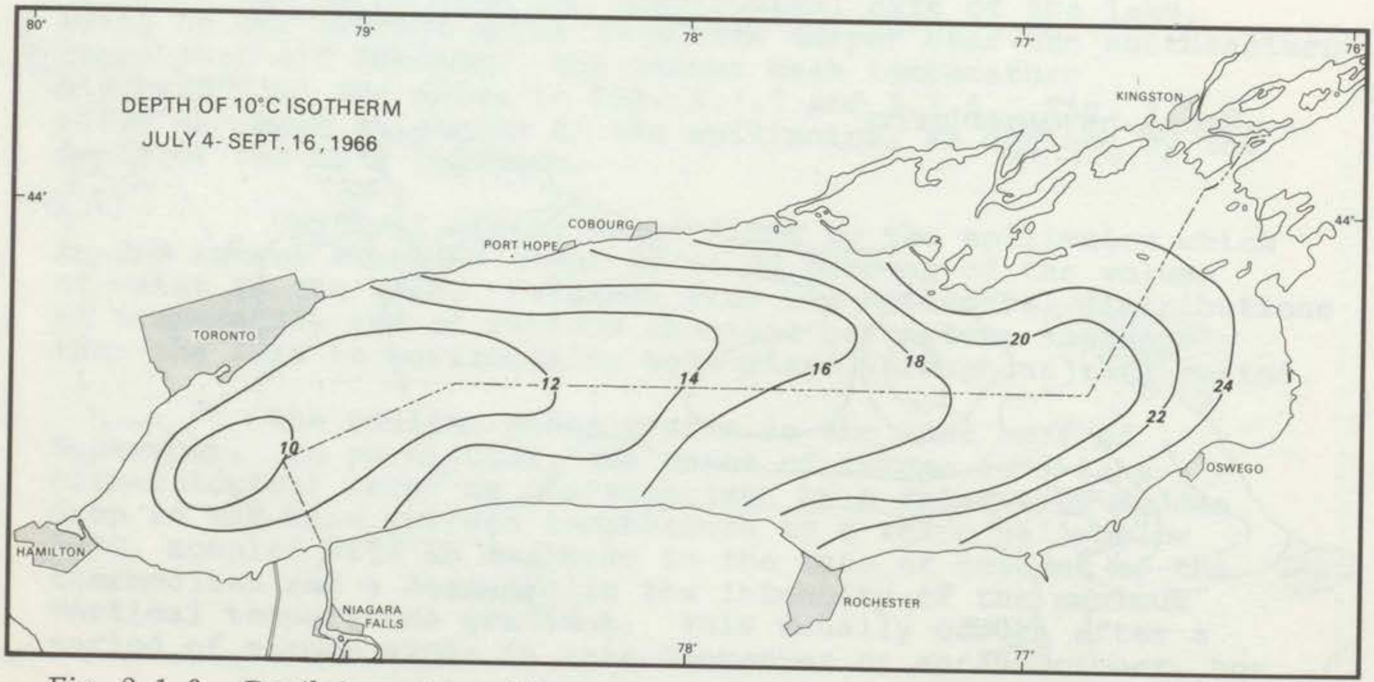


Fig. 2.1.6 Depth in metres of the mean 10°C isotherm for July - September, 1966.

the basic cause is the cooling and subsequent sinking of the surface water when the heating season gives way to the cooling season. Some of the processes taking place in autumn are similar to those in spring (Rodgers, 1966a). Nearshore waters cool faster than those in the centre of the lake, eventually giving rise to the appearance of a "reversed" thermal bar in late fall, when nearshore waters have cooled to below the temperature of maximum density and midlake waters have remained relatively warm. The fall thermal bar, which has a much weaker gradient than the spring thermal bar, will again move in an offshore direction until it eventually dissipates in January, when all surface water has cooled to below 4°C. A typical temperature distribution for the autumn shows the situation shortly before the emergence of the weak (reversed) thermal bar (Fig. 2.1.7).

The depth to which vertical circulation is effective increases with the rapidly increasing depth of the thermocline and reaches the bottom when the surface temperature drops to near the temperature of maximum density. The fall thermal bar may temporarily interrupt mixing over the total area of the lake, but its effect on the rate of dilution of a pollutant is even less important than that of the spring thermal bar. This is due to its lesser intensity as well as to the fact that the water on the inshore side of the fall thermal bar is not stratified.

The onset of the winter can be defined, in a lake-climatological sense, by the cooling of all surface water to a temperature below 4°C. Surface isotherms tend to be parallel to the depth contours in this season and the water temperature is vertically uniform or increases slightly with depth (Rodgers and Anderson, 1963). Cooling thus proceeds by a loss of heat from all depths, and the temperature maximum occurs near or over the deepest part of the lake. Vertical circulation may extend, occasionally, throughout the water column. Ice may develop in the nearshore regions, and especially in the relatively shallow region north of Main Duck Island, but it seldom covers more than a small fraction of the lake surface (Anderson *et al.*, 1961; Wilshaw *et al.*, 1965; Rondy, 1967). A typical temperature distribution for late winter, just before the appearance of the spring thermal bar, is shown in Fig. 2.1.8.

The lake is, in general, well mixed over its total volume during late fall, winter and early spring, as is evidenced by the fact that seasonal temperature variations are reflected at all depths. Vertical circulation probably reaches a maximum intensity during the spring and fall overturns.

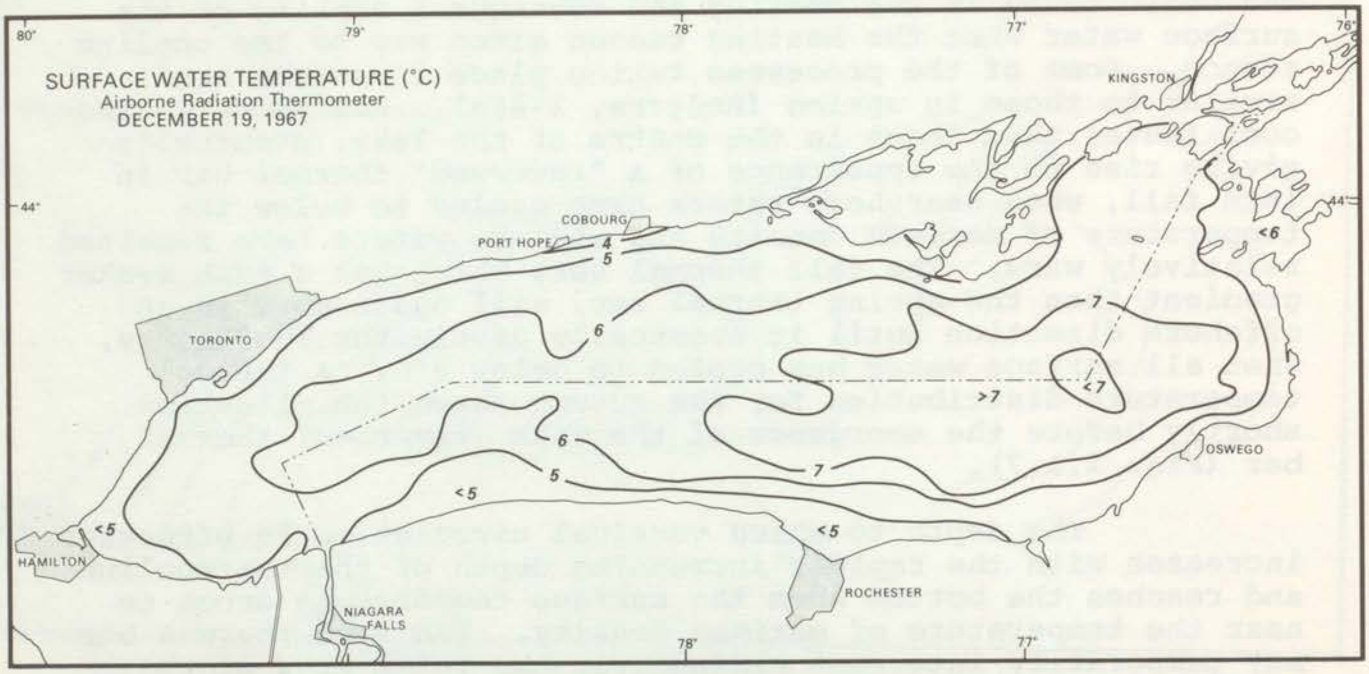


Fig. 2.1.7 Surface water temperature (°C) distribution in late autumn (After Richards *et al.*, 1969).

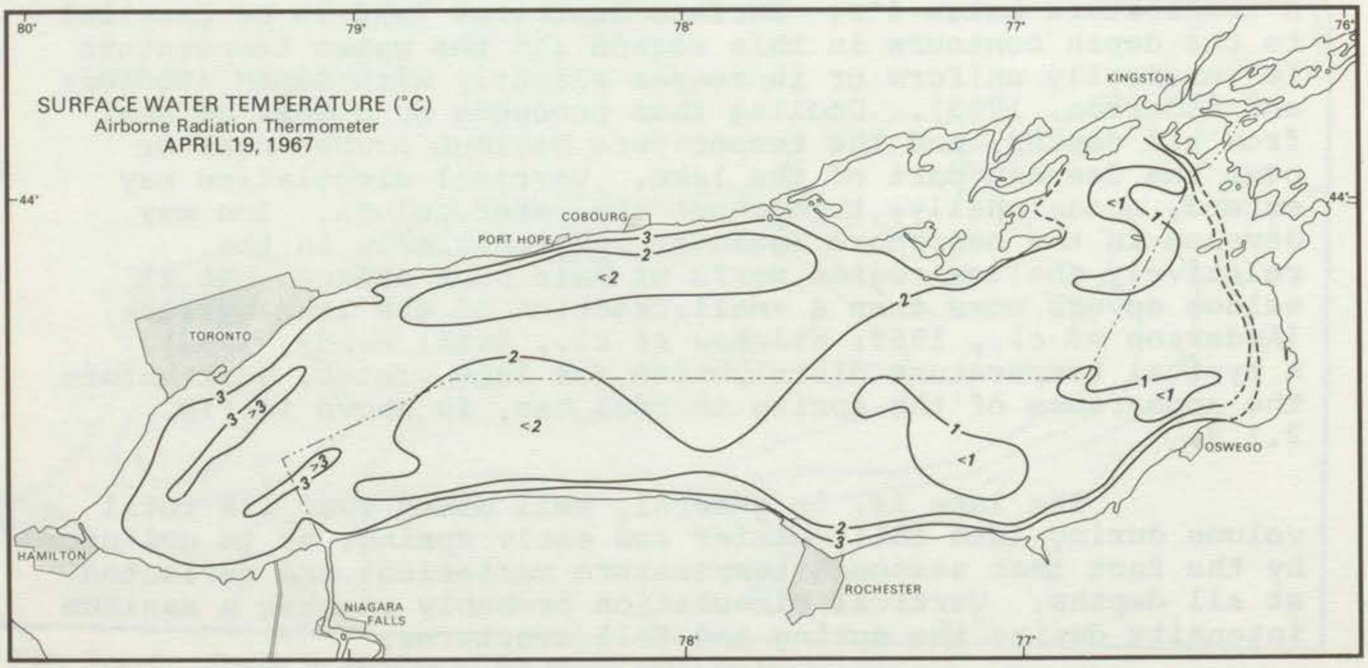


Fig. 2.1.8 Surface water temperature (°C) distribution in late winter (After Richards *et al.*, 1969)

2.1.2 Circulation and Water Movement

The major factors driving lake circulation are wind stress, density differences arising mainly from water temperature variations, gradient flow of Niagara River water to the St. Lawrence River outlet, and barometric pressure differences over the lake. Of these, the wind stress is the most important.

The flow itself is modified by various factors, the rotation of the earth (Coriolis effect), local bottom and shore topography, and bottom and internal friction. For Lake Ontario, the dimensions of the basin and hence the scale of flows is sufficiently large that the Coriolis effect is important.

During summer and fall, the prevailing winds are from the west and southwest. During winter and spring, the prevailing winds are from the west and northwest while the net transport is approximately from the west. Theoretical studies (Ekman, 1905; Sverdrup *et al.*, 1942) have predicted that the near surface current travels 45° to the right of the wind direction in the northern hemisphere, and that the net mass transport (Ekman transport) is at right angles to the right of the wind direction. Field studies on Lake Ontario have shown that the surface currents travel between 0° and 70° to the right of the wind in open water, with an average around 20° to 30°, at 2 to 3 percent of the wind speed (Bruce, 1960; Matheson, 1963; Hamblin and Rodgers, 1967).

Temperature effects on the circulation manifest themselves in various ways. In the spring, and to a lesser extent in the fall, a "thermal bar" is usually set up (Section 2.1.1). The nearshore warm water is separated in the spring from the midlake cold water by a fairly sharp temperature discontinuity (Rodgers, 1965; Federal Water Pollution Control Administration, 1967). The region of the 4°C isotherm is postulated to be an area of localized convergence and sinking, Fig. 2.1.9. The water between the shore and the "bar" itself is composed of the inshore waters so that mixing with the waters in the centre of the lake does not occur. This condition can persist for many weeks as the "bar" moves out into the centre of the lake by the advection of the warm shore waters outwards (Rodgers, 1968).

For about seven months of the year, the Niagara River water is warmer, and hence, less dense than the lake water. This results in the confinement of the river flow to the surface layers, as indicated by temperature records from that area. The river inflow from the Niagara River appears to produce localized water masses which normally cannot be identified beyond about 30 miles from the river.

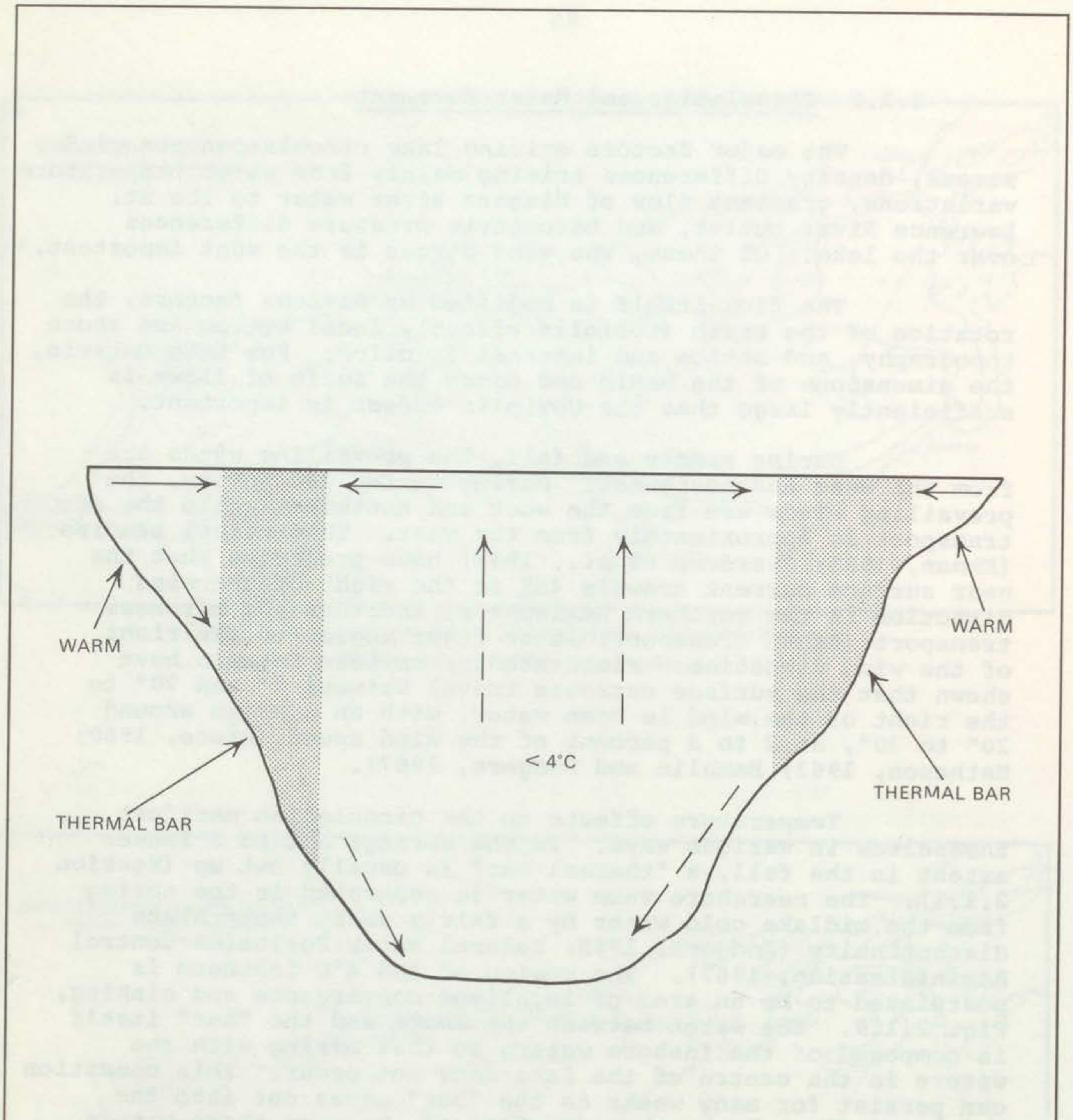


Fig. 2. 1. 9 Circulation associated with the thermal bar (After Rodgers, 1965).

The Coriolis effect enters in the Ekman transport, as noted before and produces the tendency for strong flows in the Great Lakes to be confined to a given shore (Ragotzkie, 1966; Csanady, 1967). In Lake Ontario, this is the southern shore and for reasons of continuity and boundary effects, return transports occur either along the opposite shore or in deep waters. These flows are usually in opposite directions to those of the prevailing winds. Friction dissipates the energy in the flow, so that a decrease of wind strength leads to a slow decay of the currents set in motion by the winds.

2.1.3 Direct and Indirect Circulation Determinations

Direct circulation determinations may be made by direct measurements of current, by use of drift objects, drogues, current meters or other equipment. Indirect circulation determinations are those inferred from distributions of temperature, which can be used for "dynamic height calculations" to determine speeds and directions of geostrophic or quasi-geostrophic currents (Von Arx, 1962). In conjunction with direct measurements, the indirect method can provide useful supplementary information on long-term behaviour. In the absence of direct measurements, indirect techniques can still provide qualitative information on net flows.

The circulation of the lake is divided into three parts for purposes of description: surface currents, considered as currents in the upper 10 metres, intermediate currents below about 10 metres, to about 10 or 20 metres from the bottom, and bottom currents in the 10 to 20 metre bottom layer. The choice is not entirely arbitrary. The surface currents are strongly dependent on wind conditions, especially during summer stratification, while the bottom currents which result from mass imbalances in the area, are modified by bottom friction and topography.

Surface Currents

Studies of surface currents on Lake Ontario were carried out in the early 1890's by drift bottles and drogues (Clark, 1891, 1892; Harrington, 1895). More recent investigations making use of drogues and drift cards were carried out by Matheson (1963), Matheson and Anderson (1965), Storr (1964), Hamblin and Rodgers (1967), FWPCA (1967), OWRC (1968), and unpublished studies by EMR.

All recent drift card data were analyzed for the summer period, and a mean summer circulation inferred (Fig. 2.1.10). The surface flow is in general counterclockwise with

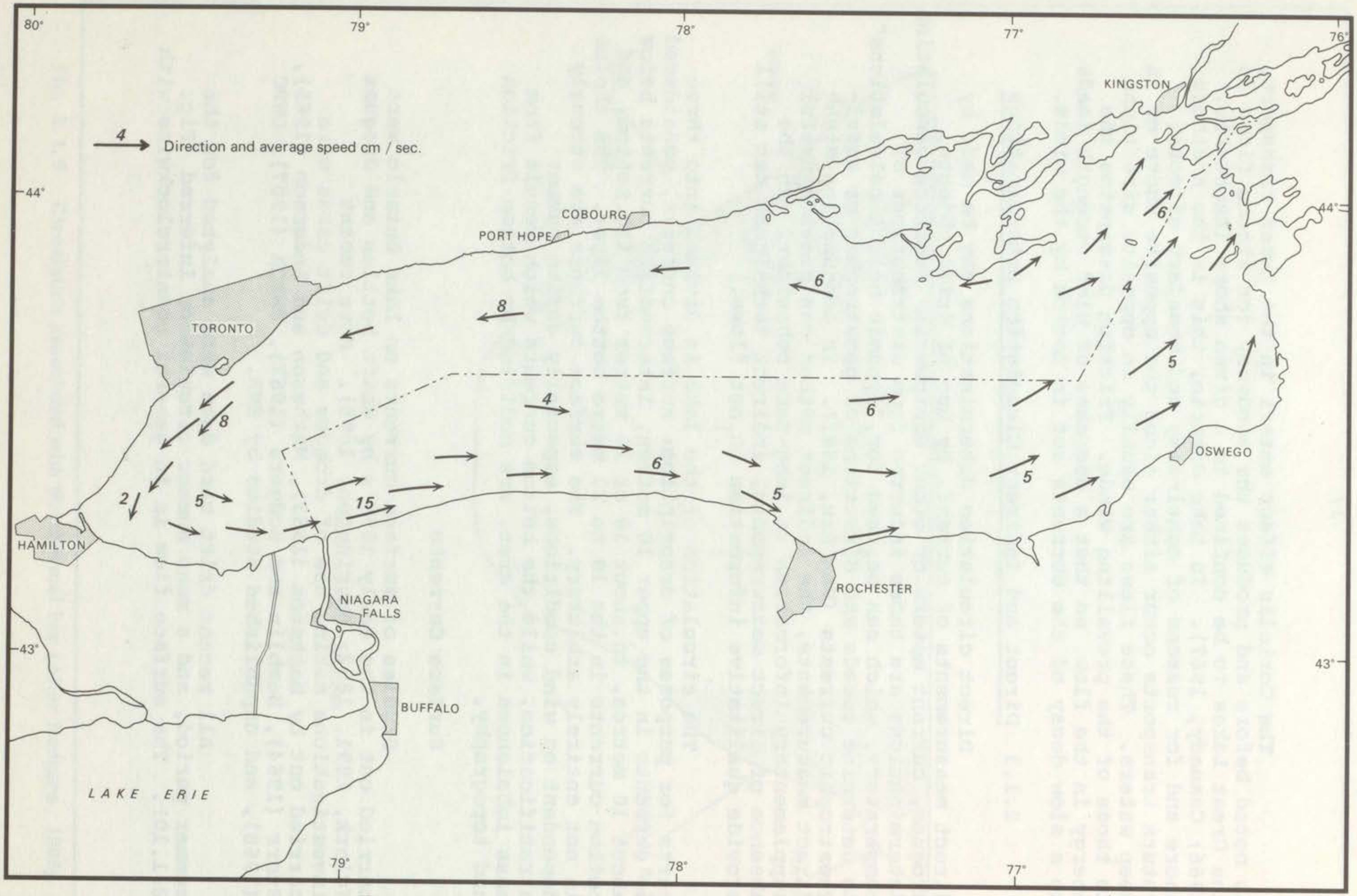


Fig. 2.1.10 Summer surface circulation as inferred from drogue and drift card observations, 1963 - 1967.

mean speeds of about 5 cm/sec and a range of from 0 to 25 cm/sec. However some special features of the surface circulation and exceptions to the mean pattern should be noted. In studies off Rochester, Storr (1964) found that under easterly winds, local westerly currents were observed as well as localized westerly return flows along the shore near Nine Mile Point at Oswego. Hamblin and Rodgers (1967) found that a direct flow across the lake from Toronto to Port Weller could be postulated in some conditions, with a localized area of convergence off Port Weller.

Drogue studies within 5 miles of the mouth of the Niagara River in 1967, showed the existence of two general regimes of flow (Fig. 2.1.11). Winds from the westerly quadrant cause a nearshore high speed flow eastwards along the shore and a slow northwest flow across a sand bar near the mouth of the river. This flow turns eastwards west of the river mouth. Maximum speeds of about 25 cm/sec were recorded about 2 to 3 miles offshore but strong currents did not persist beyond a distance of 5 miles. A clockwise gyre east of the river mouth is coupled with a strong northwesterly flow across the bar when winds occur from the eastern quadrant. Infrared imagery supports these observations revealing, in addition, a flow extending far out into the lake, almost to the Oakville-Port Credit area. Niagara River water tends to spread out over the lake in the western basin with easterly winds, whereas under westerly winds it tends to be confined to the southern shore. A possible flow of deep cold water toward the river bar may exist for the former wind condition as noted by Anderson and Rodgers (1959). This water may be entrained by the surface flow and transported back into the main body of the lake.

In summary, the pattern of net surface flow in the lake indicates a counterclockwise circulation, with flows parallel to the northern and southern shores. This suggests that for a mean circulation, surface contaminants originating in the Oshawa-Toronto-Hamilton area move eastward to the Niagara River outlet which adds water containing higher concentrations of chemicals than the main lake water. The two water masses will flow along the southern shore mixing with the water in the main body of the lake as the water masses move eastward. The Niagara flow is usually indistinguishable chemically from the main body of the lake by the time it passes Thirty Mile Point. Under easterly winds the Niagara flow spreads into the western basin and may be detected almost to the north side of the lake.

Surface currents react quite rapidly to changes in wind speed and direction. The flow pattern can change in a

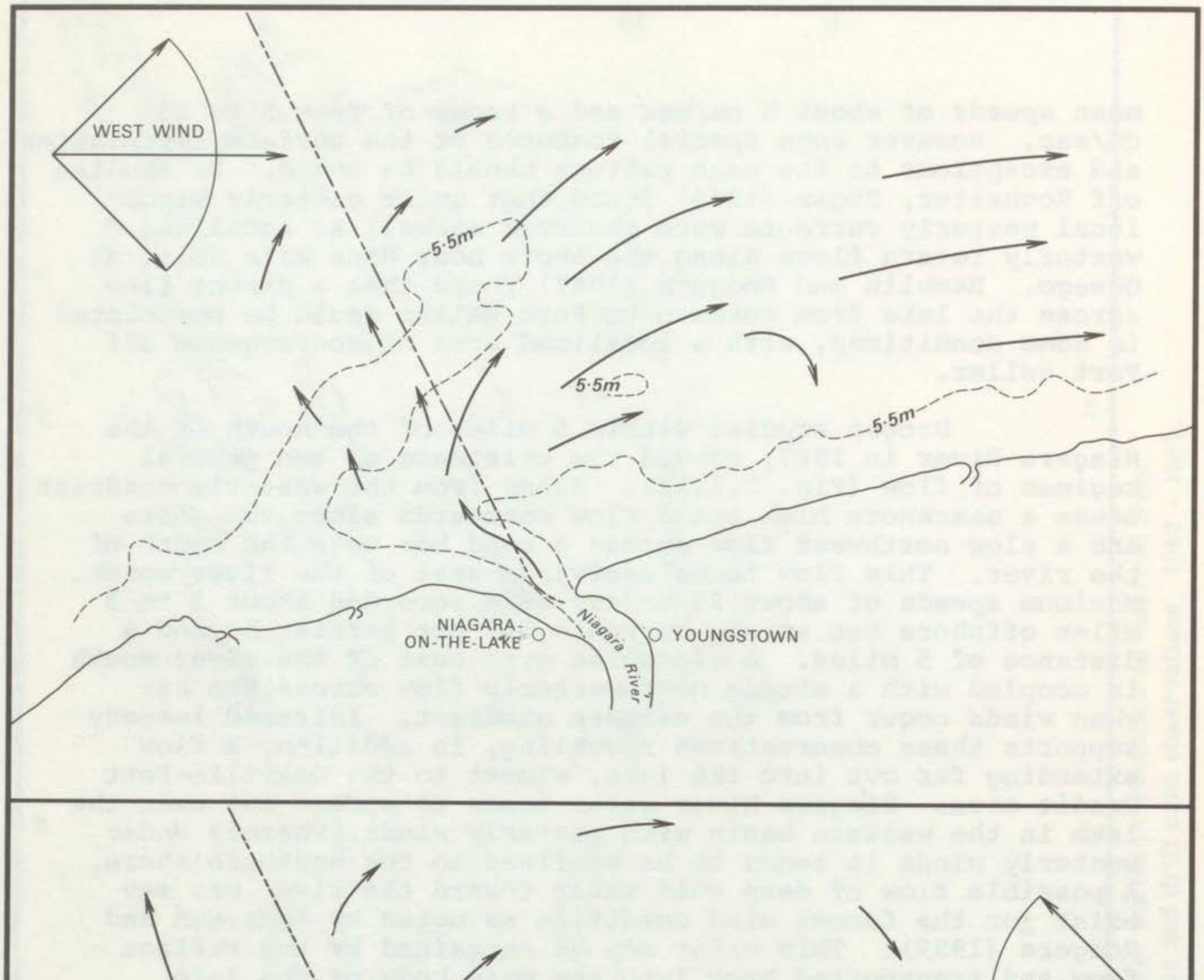


Fig. 2. 1. 11 Flow from the Niagara River during periods of westerly and easterly wind conditions, 1967.

period of less than four hours (Ontario Water Resources Commission, 1968). Examples of short-term, wind-induced circulation patterns for various wind directions are shown in Fig. 2.1.12 and 2.1.13.

Intermediate Circulation

The mean summer and fall circulation in the main body of the lake below 10 metres is characterized by a general counterclockwise flow down to depths of about 120 metres (Fig. 2.1.14). A relatively strong westerly flow appears along the northern shore, originating south of Point Petre. In Mexico Bay at the eastern end of the basin, there is evidence of a small clockwise gyre. The circulation in the eastern basin at depths greater than about 120 metres is characterized by a counterclockwise flow (Fig. 2.1.15).

During the summer the net circulation results in some recirculation of water back to the western end of the lake via the southern United States shore. The concentrations of chemical constituents increase as the flow passes large urban areas and the Niagara River. Only a part of this flow passes out through the St. Lawrence River, the remainder being recirculated back to the north shore and western basin.

The response time of wind induced circulation patterns varies for surface waters and intermediate waters. Surface circulation patterns can change in less than four hours whereas the response time for deep waters may be up to 40 hours. A given circulation pattern may last from hours to days but seldom for as long as a week.

The winter and spring net circulation is characterized by a near surface flow to a depth of about 20 to 25 metres towards the east and a return flow at greater depth in the western area of the lake. The water body being unstratified at this time of year is almost homogeneous. The return "bottom" flow presupposes an area of upwelling in the western end of the lake, and some convergence and sinking in the eastern end. The winter net circulation indicates that water in the vicinity of the Toronto-Hamilton-Port Weller area moves eventually to the eastern end of the lake, the majority of it then being returned in a deep flow.

Bottom Circulation

Bottom drifters have been employed by Hamblin and Rodgers (1967) and others (Federal Water Pollution Control Administration, 1967) to determine bottom currents. Since the

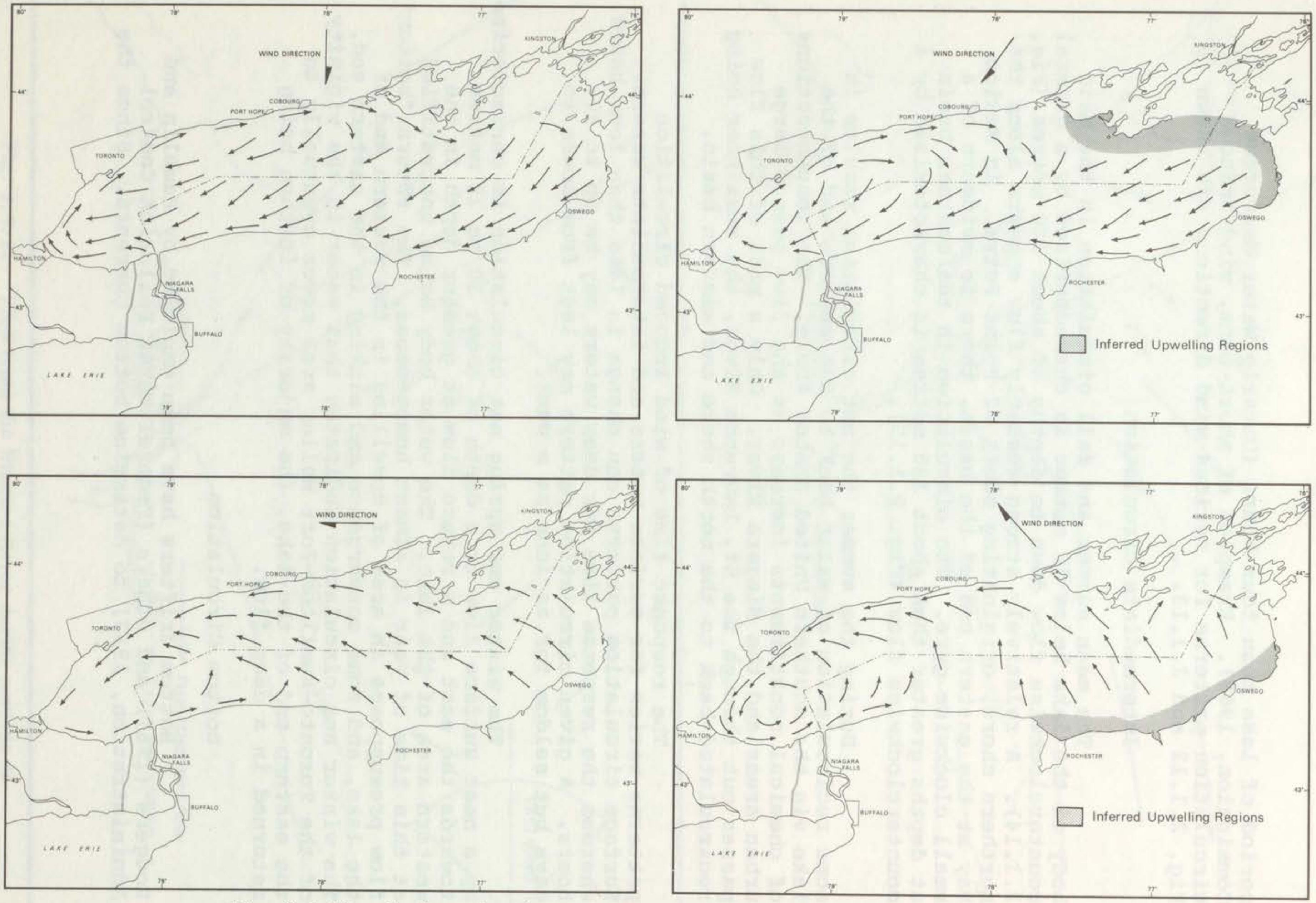


Fig. 2. 1. 12 Surface circulation patterns under different wind conditions, 1967.

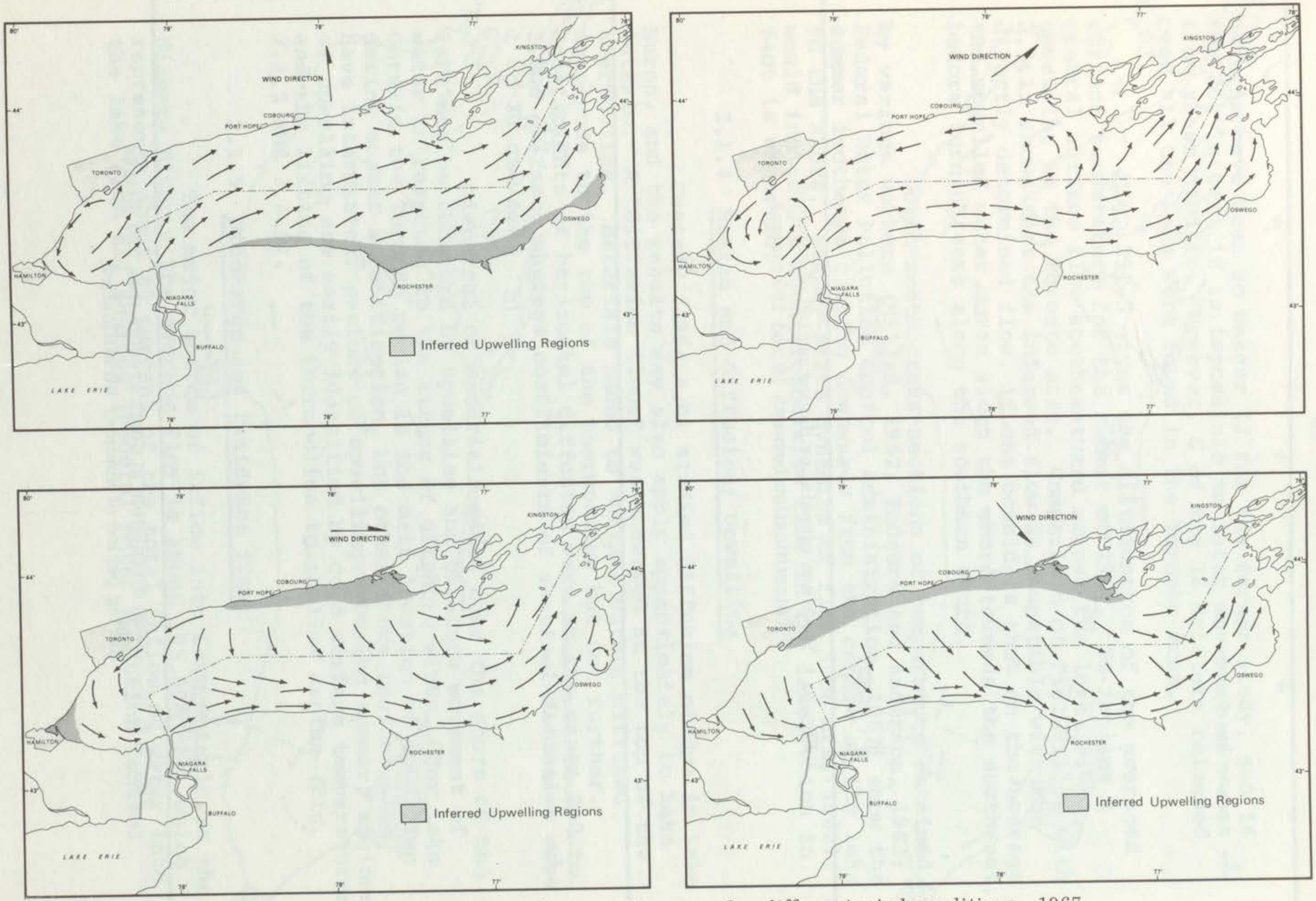


Fig. 2.1.13 Surface circulation patterns under different wind conditions, 1967.

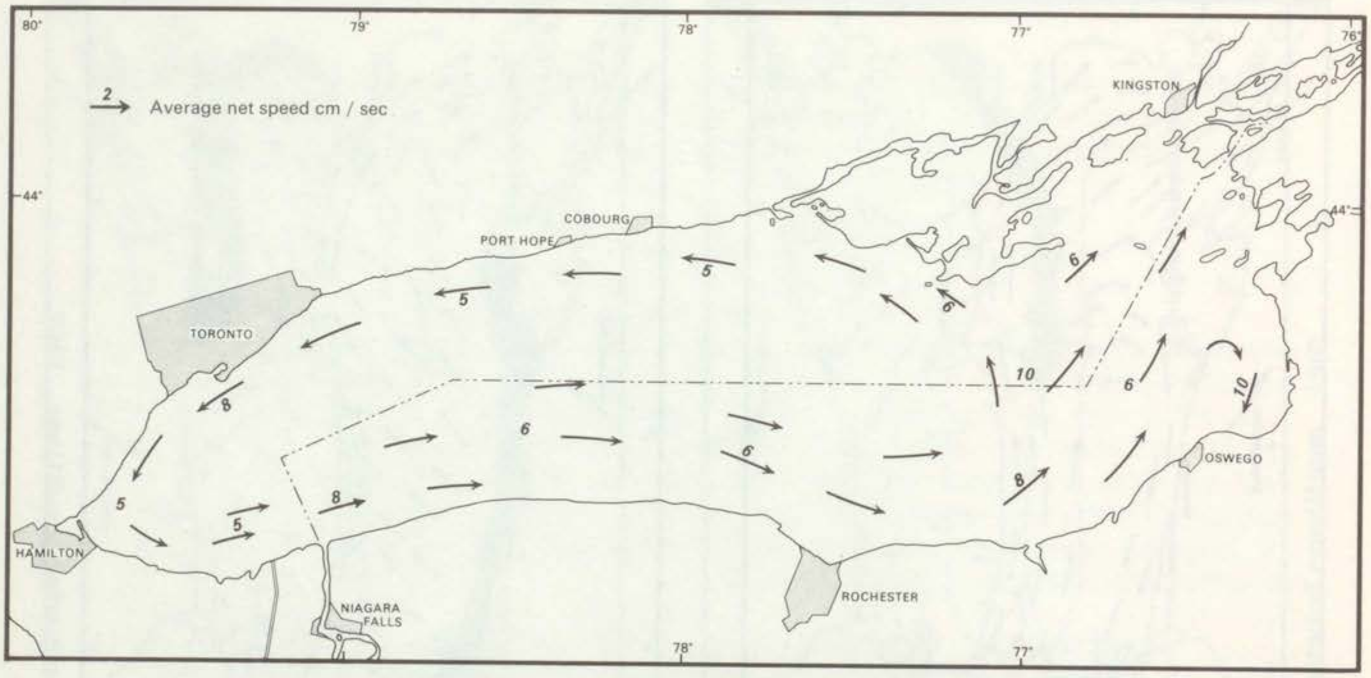


Fig. 2. 1. 14 Mean circulation during period of summer stratification between 10 and 120 metres.

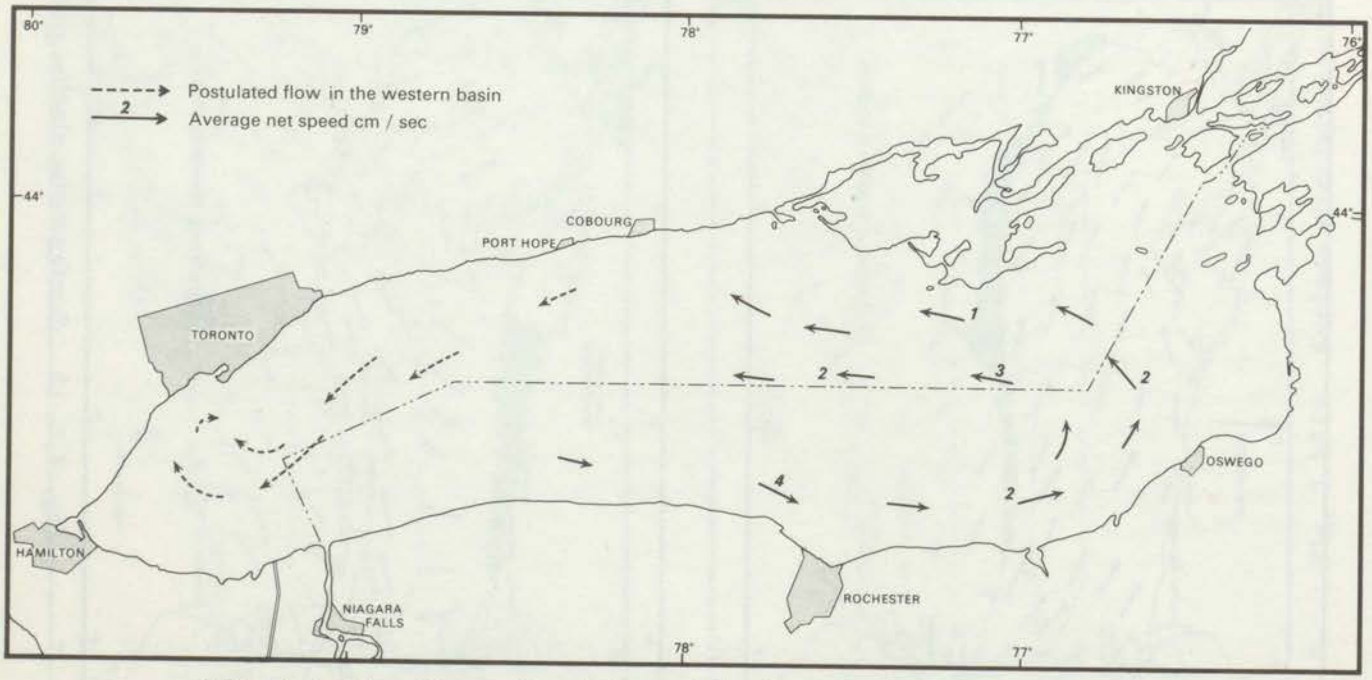


Fig. 2. 1. 15 Mean circulation at depth greater than 120 metres during period of summer stratification.

returns have been so meager (2 for the former study, and 16 for the latter) it is impossible to infer movement of water from these studies. However, 6 of the 16 drifters released over all the lake were found in the Toronto area.

Fig. 2.1.5 gives the distribution of the averaged surface temperature for the summer of 1967. It implies a general surface flow southeastward across the lake, with upwelling in the Toronto area. Comparison of Fig. 2.1.14 with 2.1.15 shows that the inferred flow is compatible with the directly determined flow, if one considers that on the average the upwelled water moves along the shore towards the southwest, before turning east along the southern shore.

North-south cross-sections of temperature obtained by various workers (Millar, 1952; Rodgers and Anderson, 1963; Federal Water Pollution Control Administration, 1967) show the summer isotherms sloping downwards from the centre of the lake to the shore. Steady-state dynamics of flow (Von Arx, 1962), would indicate a counterclockwise flow in the lake, which in fact is observed.

2.1.4 Mixing and Diffusion; Upwelling

Csanady (1964 a,b) studied diffusion of dye in Lake Huron, and the results may also apply approximately to Lake Ontario. A "diffusion floor" was observed at the top of the thermocline. Materials added to surface waters diffused downwards to the top of the thermocline but not further. Coefficients of horizontal diffusion were in the range 250 to 2,000 cm^2/sec, whereas coefficients of vertical diffusion were 1 to 30 cm^2/sec.

Dispersal of materials added near the shore of the lake may be enhanced by upwelling and offshore movement of water in response to the stress of offshore winds. For Lake Ontario the Toronto region is the main location of upwelling during summer stratification, but other shore regions also have intermittent periods of upwelling. During summer, regions of upwelling are easily identified by cold surface temperatures, and the lifting of the thermocline to shallow depths (Fig. 2.1.5 and 2.1.6).

2.1.5 Discharge and Residence Time

The major source of inflow into Lake Ontario is the Niagara River. The average flow is about 195,000 cfs, which represents about 80 percent of the total inflow of water into the lake from all sources (Federal Water Pollution Control

Administration, 1967). The rest of the inflow is from runoff, other rivers, and rainfall. Outflow from the lake is primarily the St. Lawrence River, with an average discharge rate of about 232,000 cfs. Other water losses are primarily through evaporation which amounts to about 19,000 cfs.

The concept of "residence time" or time required to displace the water in a lake, is still somewhat vague, and can be looked at from different points of view. If a simplistic approach is taken, where one considers an inflow of fresh or clean water replacing the water in the lake, with no mixing or loss from the lake, then a "residence time" of 8.4 years is obtained by dividing the lakes' volume by the average discharge rate (Federal Water Pollution Control Administration, 1967). Clearly, this is physically an unrealistic approach, since in the actual situation, mixing occurs, and part of the inflow flows out the St. Lawrence River without completely reaching the same composition as the lake water. Furthermore, during conditions of summer stratification, the inflow is confined mostly to the top, or epilimnetic water, so that little mixing occurs with the deep water below.

Rainey (1967) made the physically more realistic assumptions that:

> "the precipitation on the lake just equals the evaporation; therefore, the flow rate (R) to and from the lake is the same;
>
> the concentration of pollutants in the streams entering the lake (C_1) is constant; and
>
> the pollutants are added to the lake itself at a constant rate (Q) and are distributed so that their concentration (C_2) is uniform throughout the volume (V) of the lake. A material balance around this lake system gives the relationship of the change in the concentration of pollutants in the lake with time (T):
>
> $$C_2 = C_2^\circ \exp(-RT/V)\ [C_1 + (Q/R)]\ [1 - \exp(-RT/V)]$$
>
> where C_2° is the concentration of pollutants in the lake at the initial time (T = 0)."

Inserting appropriate values for Lake Ontario gives about 20 years for the reduction of initial concentrations by 90 percent, if the inflow into the lake were completely pure water, and no stratification existed. Correcting the equation for summer conditions, and estimating the "residence time" for the yearly cycles of stratification, gives an increase of only about 1 or 2 years, to about 21 to 22 years for a 90 percent reduction. Hence, vertical stratification does little to alter the "residence time" (Sweers, 1969).

The above values, although physically more realistic, should be treated with the caution they deserve by virtue of the assumptions made. They point out the fact that even if all the water flowing into Lake Ontario were made pure, it would still take many years before the concentrations of chemicals and dissolved solids dropped well below present levels. Lake Ontario ultimately receives the output from the other four Great Lakes, so that upstream conditions dominate the water quality of the lake. Thus water quality control has to be applied to all lakes simultaneously.

2.1.6 Analytical Models

A complete prediction of movement of materials in Lake Ontario would require an accurate mathematical model and sufficient data to define initial boundary conditions. A physically realistic model of Lake Ontario circulation must take into account the main driving forces, overlake winds, and inflow-outflow, as well as the modifying forces on the circulation, Coriolis-effect, stratification, friction, and the basin shape. This will require a model of formidable complexity.

Analytical models have been used extensively in the past to obtain solutions to oceanographic problems, and in the last decade, have been increasingly employed to study circulation patterns in idealized "model" lakes. Most of these models are time-independent, providing solutions for steady-state conditions only. Csanady (1967, 1968) and Birchfield (1967) have developed models for simplified lake shapes. One of the more interesting features of Csanady's models is the prediction of a "coastal jet", a narrow band of water which has a much higher speed than the water further out. This feature was apparent in a rotating model with no wind or frictional forces ("free" modes of motion) and with assumed wind stresses.

Other workers have developed analytical models of shorter period free motions such as internal waves on the thermocline (Mortimer 1963, 1965, 1968) and wind set-up and seiches (Harris, 1957; Platzman, 1963; Platzman and Rao, 1964; Rao 1967).

From the above discussion it is clear that we are still far from obtaining physically realistic solutions by modeling for any of the Great lakes. To date only the mathematically tractable, and hence the simpler cases have been considered. Numerical models appear to offer much promise, and there is little doubt that studies eventually will provide one or more models for lake circulation which will give time-dependent, and physically realistic solutions to the actual problems at hand. These models, when successfully tested against field data, will allow fairly accurate predictions to be made of the circulation present at any given time, without having to rely on empirical relationships derived statistically from large masses of data. Furthermore, they will have provided valuable insights into the actual processes involved in lake-wide circulation.

2.2 SEDIMENTOLOGY

Study of the sediments of a lake can provide knowledge about the nature of a lake and its evolution. In areas of deposition, the sediment column can be interpreted as a history of the lacustrine environment. The sequence of fossils and other lake debris entombed in sedimentary strata can indicate past changes and present trends in eutrophication, water levels, climate, lake chemistry and aquatic biota. Sedimentary processes involving erosion from the drainage basin and shore, dispersal by lake currents, sedimentation and genetic alterations in the lake bed are an integral part of the lake environment. The continuation of these processes through time, leads to an expansion of the lake margin and siltation of its basin, one manifestation of natural lake aging. Knowledge of these processes enables one to predict the path of travel and final resting place of particulate pollutants. Decomposition of organic material and other chemical changes within the surface sediment can release nutrient chemicals to the overlying lake waters. Because some of the effects of these processes are detrimental to water quality, they warrant study and should be understood as part of any pollution abatement program.

The study of Lake Ontario sediments is still in its infancy. Apart from Kindle's pioneer investigation (1925) of sedimentation in selected nearshore areas and traverses across the lake, very little is known of the regional distribution of sediment. Field investigations upon which the present report is based were undertaken in 1966 and 1967.

2.2.1 Lake Morphology

The general bathymetry is shown in Fig. 1.1.1. Ignoring the relatively shallow northeastern basin south of Kingston, Ontario, the main lake basin is virtually a simple elongated trough trending east-west. It is asymmetric in cross-section with its axis skewed southward.

2.2.2 Shoreline

The Lake Ontario shore is one of recent submergence. It is characteristically an eroded shore bluff. Where the bluffs are dissected by tributary streams, the stream valleys are commonly flooded and separated from the lakes by a sandy barrier beach. This is particularly evident on the southern shore. The eroded shore materials, largely of silt and clay grain size, probably contribute a major portion of sediment to the lake. A brief description of the shoreline is presented here, based in part on reports by Coleman (1937), Langford (1952), United States Army Engineers (1943, 1954, 1955a, 1955b) and the New York-New England Interagency Committee (1954).

Canadian Shore

The shore from the Niagara River to Hamilton is one of long smooth curves without prominent headlands or deep bays. Bluffs, which occur along much of the shore, commonly reach 20 to 30 feet in the eastern part but decrease westerly and disappear at Stoney Creek. The bluffs are composed entirely of unconsolidated clay and silt tills, or sand except for a short reach one to two miles west of Grimsby where red Queenston shale bedrock constitutes the shore bluff.

A massive bar of sand and gravel, nearly 4 1/2 miles long and 300 to 1,300 feet wide, joins the southern and northern shores between Stoney Creek and Burlington and impounds Hamilton Harbour to the west.

The northern lake shore from Burlington to Toronto is comparatively straight without prominent headlands or deep bays. Between Burlington and Oakville, the shore bluff is low, from 10 to 20 feet high, and is composed of red Queenston shale at its base with a thin covering of till or sand. From Oakville to West Toronto, a grey shale intermittently outcrops at the base of a shore bluff, largely composed of unconsolidated till, varved clay and sand strata. The shore bluff locally rises to 30 feet.

The Toronto shoreline was originally low, now it is largely filled and protected by seawalls and breakwaters. Toronto Harbour lies behind a hooked sandy spit known as Toronto Island. An account of the origin of Toronto Island, in which sand is eroded from the high bluffs to the northeast and is carried westward to be deposited at the terminus of the Toronto spit, is given by Coleman (1937).

Spectacular vertical shore bluffs rising over 300 feet at Scarborough are composed entirely of unconsolidated glacial and interglacial strata (Karrow, 1967). These sands, silts and clays are receding at an average rate of 16 inches/year. In view of their extreme height, the bluffs must be contributing sizeable amounts of sediment to the lake.

From Frenchman's Bay to 4 1/2 miles west of Port Hope the shore continues as a bluff composed of clay and sandy till sheets, in places overlain or interbedded with glaciolacustrine sands and varved clays. The bluffs are generally low but variable in height undulating between 10 and 100 feet. The shoreline of this reach is moderately irregular because of small headlands where zones of tough glacial sediment resist erosion.

Eastward to Brighton the bluffs diminish in height and continuity. The shoreline is one of headlands rising 13 to 50 feet above the lake separated by sandy beaches on low upland surfaces. Boulder concentrations are common off the headlands, whereas bedrock outcrop is scarce.

The irregular but stable coast between Brighton and the St. Lawrence River is controlled by Ordovician bedrock which outcrops almost continuously throughout this area. The limestone and shaley limestone beds which dip gently south to southwest were severely scoured and excavated during Pleistocene glaciations. Hence embayments and low shores tend to occur in areas of severe erosion or along shores where bedrock dips into the lake. Rock bluffs predominate in areas of resistant bedrock. Where large quantities of local sand occur, barrier beaches have been built across bays as along the east coast of Prince Edward County.

United States Shore

The southern shore of Lake Ontario from the Niagara River mouth to approximately 20 miles east of Rochester is an extremely regular shore bluff with a narrow beach of sand or gravel at its base. The eroding bluff is largely composed of glacial and lacustrine clay and fine sand strata overlying shale bedrock. It is generally 10 to 30 feet high, locally rising to 80 feet at Devils Nose. Along most of this shore where bedrock lies below lake level, shoreline recession is rapid, 5 feet/year. In the vicinity of Thirty Mile Point where rock rises above lake level and forms most of the bluff, erosion proceeds at a reduced rate, less than 1 foot/year. Eastward to Rochester low eroding bluffs of unconsolidated glacial sediments alternate with barrier beaches fronting swamps or marshes along the lakeshore. Shore bluffs of unconsolidated glacial sediments ranging in height from 10 to 50 feet stretch continuously from Rochester to Sodus Bay.

The shoreline truncates a well-developed drumlin field between Sodus Bay and Oswego. In this area drumlin axes are oriented north-south. Because the eroding lakeshore trends northeast, the shore is characterized by an undulating bluff, rising from near lake level in embayments between drumlins to over 150 feet on drumlin crests.

Low, resistant shore bluffs composed of glacial till overlying bedrock at or near lake level comprise much of the lakeshore from Oswego through Nine Mile Point to Little Salmon River.

The eastern shore, aligned north-south from Little Salmon River nearly to Stony Point, is a sandy coast and differs markedly from the remainder of the shoreline. The low coast, underlain with glacial tills, is characterized by numerous embayments with barrier beaches and massive sand dunes rising 50 to 100 feet behind the beaches.

The irregular coastline of the northeastern basin from Stony Point to Cape Vincent at the head of the St. Lawrence River is largely a resistant bedrock bluff of variable height. The nature of this shore, controlled by outcropping Lower Ordovician limestones, resembles the adjacent Canadian shore described earlier.

2.2.3 Bottom Deposits

The distribution of bottom sediments shown in Fig. 2.2.1 is based on the shipboard descriptions of gravity cores and grab samples collected in 1966 and 1967 (Lewis and McNeely, 1967). Echograms recorded during the bottom sampling cruises provided additional information on sediment distribution and thickness. Additional data were obtained from the OWRC and lake bottom notations on hydrographic charts, and sediment distribution maps (Kindle, 1925).

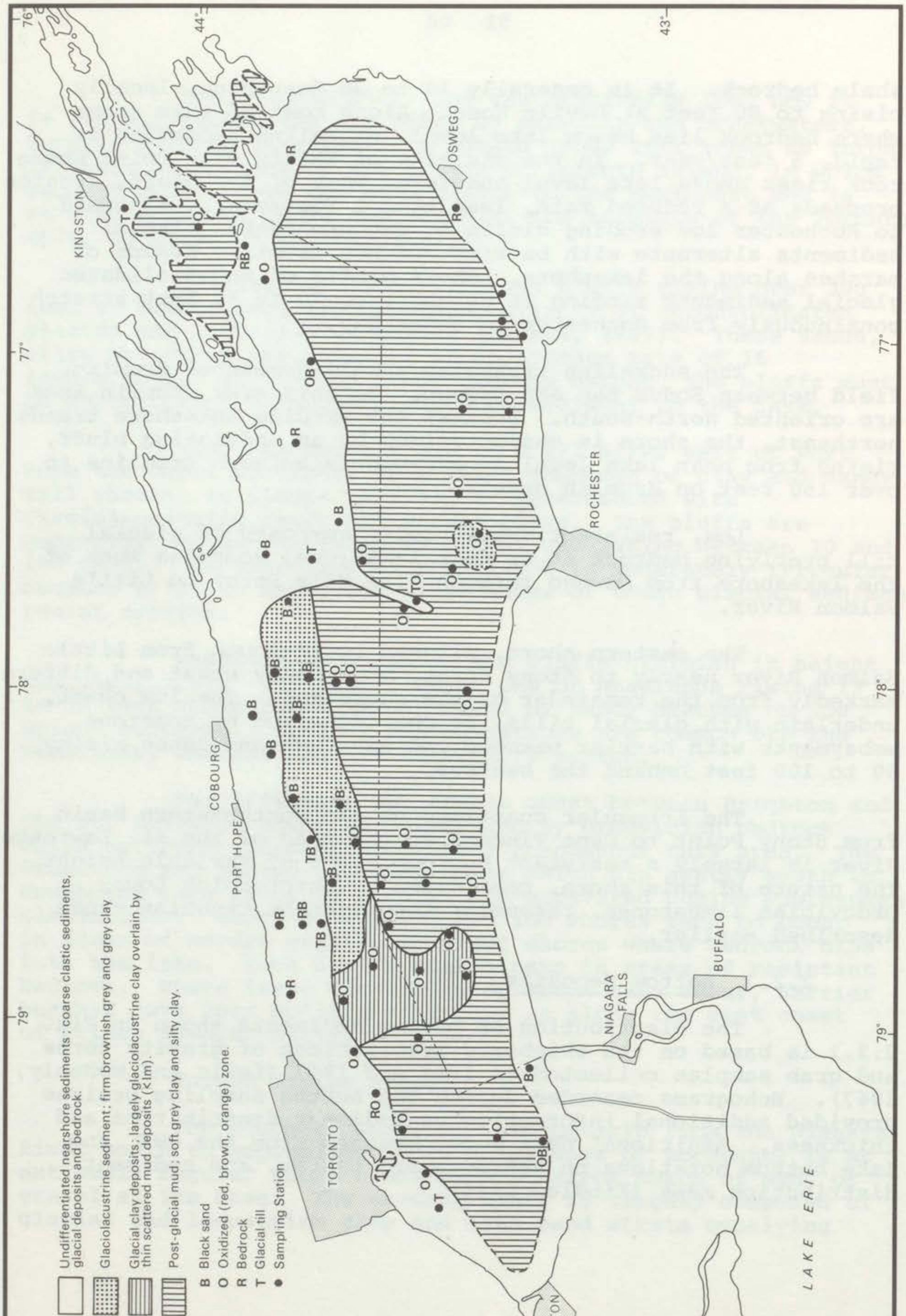


Fig. 2.2.1 Distribution of bottom sediments.

The surficial bottom sediments are divided into three major groups: complex nearshore sediments, glaciolacustrine clays, and post-glacial muds.

Complex Nearshore Sediments

These sediments, composed largely of modern and glacial sands, gravels and bedrock, occur in the form of a belt around the shoreline between 3 and 6 miles wide in the south and 9 to 12 miles wide in the north. The approximate water depths along the lakeward boundaries of this belt are 40 metres in the south and 40 to 100 metres in the north. Grain sizes range from silty fine sand to gravel. Samples commonly contain mollusc shells and shell fragments. These sediments are characteristically discontinuous and variable. At scattered locations there are limestone bedrock, shale bedrock, pebbly till and firm glacial lake clays.

A sediment survey early in 1968 revealed the presence of an extensive zone of surficial black sand in the complex nearshore sediments and in the sands overlying the glaciolacustrine clay adjacent to the northern shore. The black colour of the sand is due to a thin dark coating of unknown composition on quartz sand grains and rock fragments. The black sand zone lies 3 to 6 miles offshore with a width up to 15 miles. It parallels the northern shore from Toronto to Main Duck Island.

Glaciolacustrine Clays

Clay sediments deposited in pre-existing glacial lakes are exposed on the lake bed along the central part of the northern shore between the complex offshore sediments and the post-glacial muds. This outcrop zone occurs in water depths of 80 to 120 metres in the west and 40 to 100 metres in the east. A second area of glacial clay occurs north of Rochester within the mud zone in 100 to 180 metres of water on the south flank of the basin.

These fine-grained clays are greasy to the touch and have a stable grey or grey-brown colour. They are usually calcareous, but contain no organic detritus and have a greater strength (firmness) than the post-glacial muds. A glaciolacustrine origin for the clay is indicated by the occurrence of varve-like laminations, several ice-rafted limestone pebbles, and silt-clay pebbles of foreign lithology within the clay matrix.

A sorted silt or sand layer 1 to 5 centimetres thick commonly covers the clay deposit. In the region bounding the western and central sub-basins, a large area of the lake bottom is underlain by glaciolacustrine clay with a thin erratic cover of post-glacial mud. The mud is rarely thicker than 0.5 metres and usually contains an iron oxide bed within it.

Post-glacial Muds

Post-glacial muds, the deposits of largest areal extent, occur in the shallow northeastern basin and all offshore deep water areas. Some thin, discontinuous mud deposits are also known to occur in shallow depressions in the complex offshore sediment zone. The muds are soft compressible clays or silty clays which are usually medium grey in colour. Crude laminations composed of horizontally lined specks or pods of jet-black greasy clay (possibly ferrous sulphide and/or finely divided organic matter) commonly occur throughout the muds. In places, a finer more distinct lamination can be observed by textural and fracture variations and by X-radiography. The significance of this apparent cyclic sedimentation is under current study. The mud is assumed to be reduced because the laminated grey colour of a fresh moist surface becomes uniformly grey-brown after one or two hours of exposure to the atmosphere.

Several mud cores contained numerous pores up to several millimetres in diameter, presumably as a result of gas evolution accompanying organic decomposition in the mud. The content of organic matter ranges from 2 to 6 percent.

The mean particle diameter of the muds range from 10 to 8 phi, 1 to 4 microns, by definition phi = $-\log_2$ (mean particle diameter in millimetres) over large areas within the central trough of the lake (Fig. 2.2.2). In a narrow zone adjacent to the boundary of the complex nearshore sediments the mean particle size increases sharply. The lateral extent and thickness of the muds have been tentatively interpreted from echograms and are illustrated in Fig. 2.2.3.

A distinctive feature of many cores of the post-glacial mud was a single bed of predominately orange-coloured clay near the top of the mud column. The bed is laminated and some cores consist of interbedded grey, black and orange clay. The layer varies from 0.5 to 10 cm in thickness and is often stiff or crusty in consistency. The colour of the clay, presumably an iron oxide, is stable on exposure to the atmosphere unlike the colour of the enclosing muds. The bed occurs as a single unit at widespread localities throughout much of the

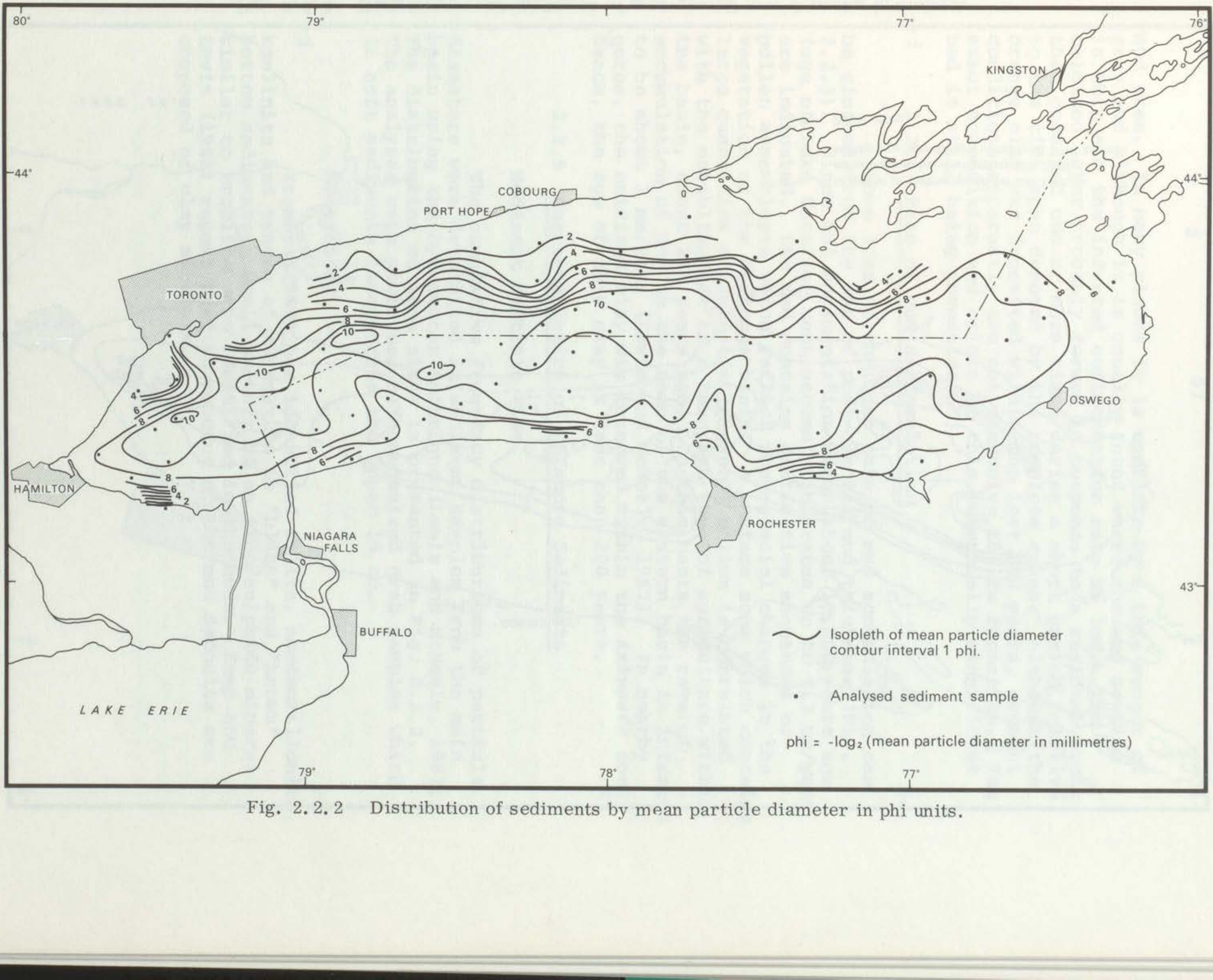


Fig. 2.2.2 Distribution of sediments by mean particle diameter in phi units.

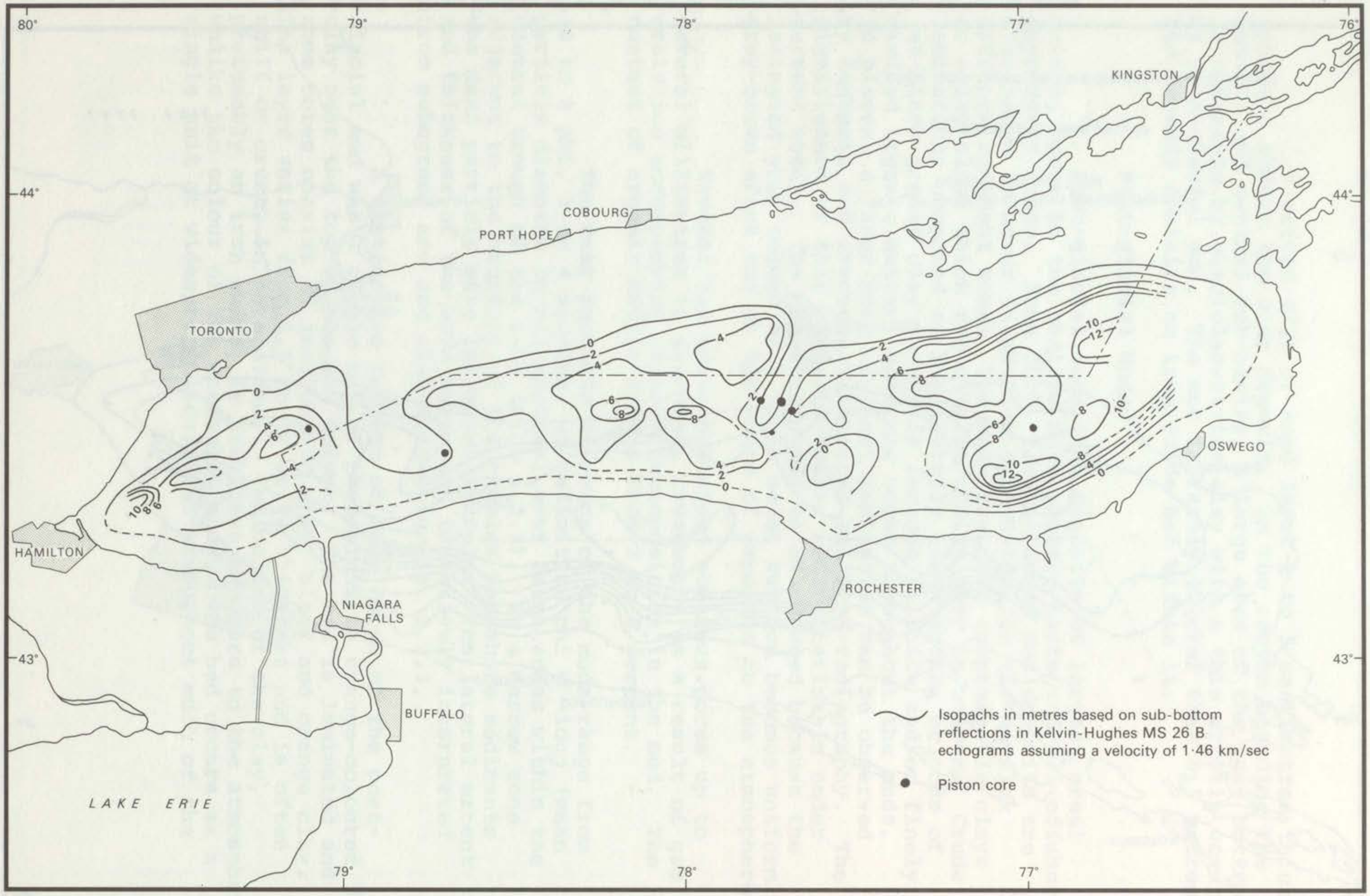


Fig. 2. 2. 3 Distribution and thickness of post-glacial mud deposits in metres.

mud area. In many places it is overlain by a thin veneer of grey mud although it is usually found where the mud section is thin and the inferred sedimentation rate is low. The oxidized layer probably formed in response to a regional event that occurred one or more times during a short period relative to the time span denoted by the complete cores. Although the orange clay was deposited within the last 200 years, present conditions apparently are not conducive to its formation. The exact composition and origin of this potentially significant bed is still being investigated.

2.2.4 Rate of Mud Sedimentation

Some idea of the mean rate of mud accumulation can be gleaned from the map of post-glacial mud thickness (Fig. 2.2.3). Since mud sedimentation began about 10,000 years ago (age of Lake Ontario) mean accumulation rates up to 1.3 mm/year are indicated. The mud contains distinctive sequences of pollen assemblages which reflect post-glacial changes in the vegetation of the drainage basin. A surface zone which contains large quantities of *Ambrosia* (ragweed) pollen is correlated with the establishment of a European type of agriculture within the basin, about 200 years ago. On this basis the rate of accumulation of mud in the deep of the eastern basin is inferred to be about 1 mm/year (Lewis and McNeely, 1967). In nearby cores, the oxidized clay was observed within the *Ambrosia* zone; hence, the age of this clay is less than 200 years.

2.2.5 Characteristics of Offshore Sediments

Sediment Particle Size

The cumulative frequency distributions of particle diameters were determined in sediment samples from the main basin using the hydrometer technique (Lewis and McNeely, 1967). The distribution of mean sizes is presented in Fig. 2.2.2. The analyses were performed on homogenized grab samples which in soft sediments incorporate the upper 15 cm.

Mineralogy

Kramer (1962) has identified illite, montmorillonite, kaolinite and traces of corrensite in "black" and "brown" bottom sediments. Small amounts of an iron sulphide mineral similar to troilite were identified in the muds. Kemp and Lewis (1968) report that 65 percent of the mud deposits are composed of clay minerals.

2.2.6 Redox Potential

Very little information is available at present on sediment redox potential throughout the lake. Kemp and Lewis (1968) report Eh potentials ranging from +0.163 to -0.032 volts and pH values of 7 to 8 in the uppermost 0.5 cm at nine stations along the lake's axis, in October, 1967. At the majority of stations Eh decreased with depth of burial. The average depth in the sediment at which the Eh changed sign was calculated to be 0.75 cm. Thus, for most stations oxidizing conditions prevail within the top centimetre of sediment. The change from oxidizing to reduced conditions was paralleled by a distinct change in colour in every case. The oxidized sediments were always a pale grey or brown colour whereas the strongly reduced sediments were black. The negative values in surface muds were located in centres of the mud basins. Usually the mud surface is capped by a thin oxidized microzone, believed to be rich in ferric hydroxide and ferric phosphate. This microzone forms a chemical barrier that keeps phosphate ions from the reduced sedimentary layer below from going into solution and also assimilates materials falling to the bottom. However, if the microzone is destroyed at times, and this possibility is real judging from the reported low Eh values, phosphate and ferrous ions may be recycled into the water mass from the sediment below.

2.2.7 Organic Matter

The surficial bottom sediments collected in 1966 were analyzed for their oxidizable organic content (Lewis and McNeely, 1967) by the modified Walkey-Black method (Jackson, 1958). Although the precision of the method is low, it is considered adequate for the purpose of a reconnaissance survey. Fig. 2.2.4 illustrates the areal distribution of organic matter. High organic matter content occurs in the centres of the basins of mud accumulation and in the western basin off the mouth of the Niagara River. The concentration of organic matter is low in areas of coarser sediment and in areas of fine-grained sediment adjacent to glacial clay outcroppings. In general, organic matter is greatest in the finest-grained sediments (Fig. 2.2.2, 2.2.4).

Recent studies by Kemp and Lewis (1968) on the relations between organic carbon, chlorophyll pigments and depth of burial in the sediment indicate that most of the chlorophyll presumably originating with plankton in the surface water, is partially decomposed by the time it reaches the lake bottom. Further decomposition within the sediment is shown by a rapid decrease in concentrations of organic carbon and

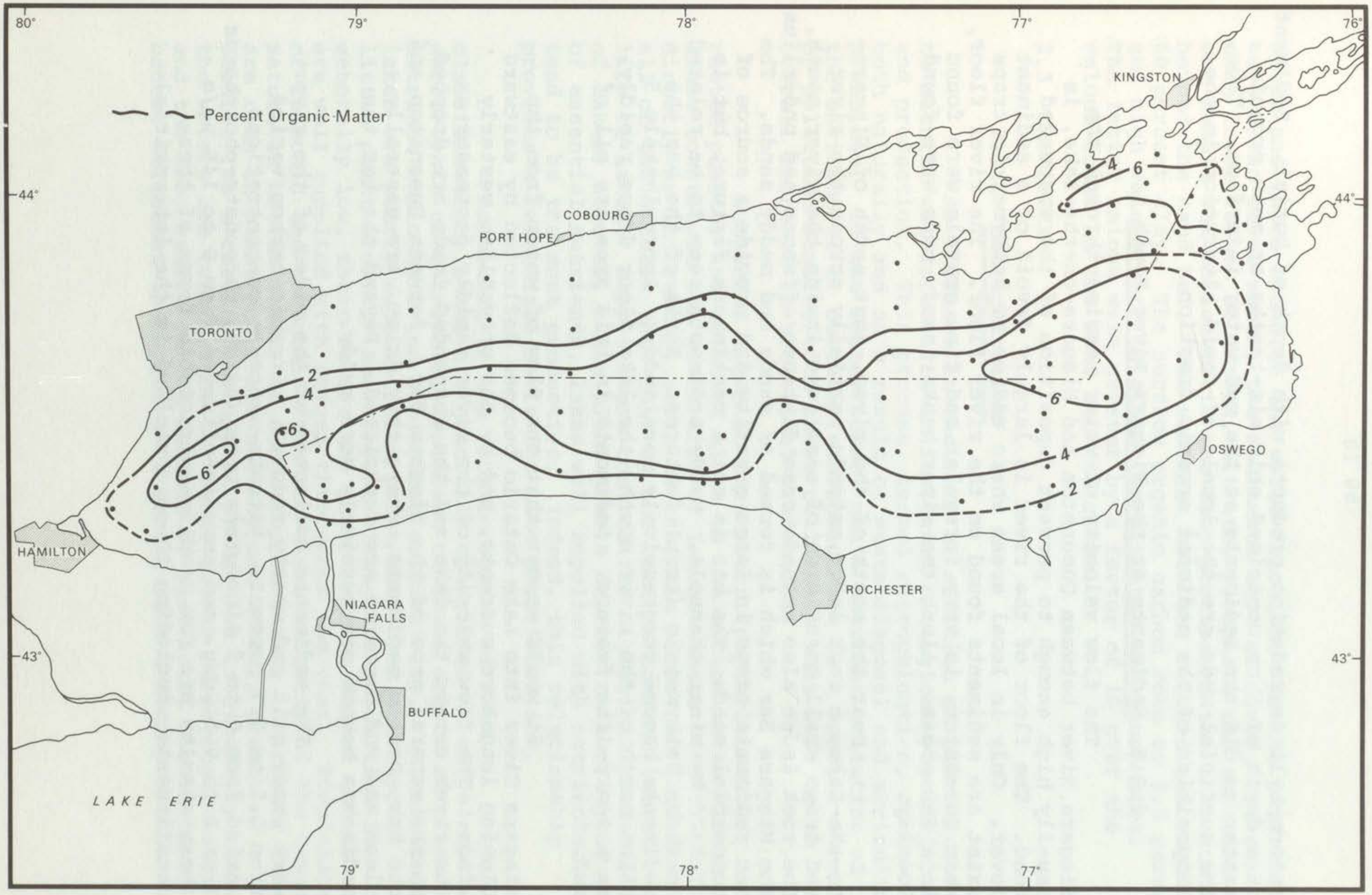


Fig. 2.2.4 Distribution of organic matter (percent) in surficial sediments.

chlorophyll degradation products with depth of burial. Sediment at a depth of 5 cm contained only six-tenths as much organic matter as did the sediments at the mud-water interface. Thus, the surficial muds are the locale of rapid alteration in the composition of the sediment organic fraction.

2.2.8 Sediments at the Niagara River Mouth

The flow velocity of water passing through the Niagara River between Queenston and Niagara-on-the-Lake, is usually high enough to prevent deposition of the suspended load. The floor of the river is largely devoid of a sediment cover. Only in local areas where eddies or bathymetric traps exist are sediments found on the river floor. The river floor, near Queenston, is very irregular and fine gravels were found in a few areas. Along the river banks, sandy muds were found locally.

Near the mouth of the river, just north of Niagara-on-the-Lake, a rock ledge extends partially across the river and traps small quantities of sand just inside the river mouth. The rock ledge also extends some distance offshore and underlies the Niagara Bar which is formed of sands and muddy sands. The bar sediments occur in large quantity and provide a source of commercial sand. The bar is not a continuous feature, but is crossed by minor channels. Muddy sediments seem to be related to these bathymetric (trap) features. North of the bar the sediments become progressively more muddy. Approximately 5 miles north of the river mouth, the lake floor drops rapidly, as a scarp-like feature. Sediments in this area are all of mud.

It would appear that the flow of water from the Niagara River into Lake Ontario becomes deflected by eastward flowing longshore currents, and by the prevailing westerly winds. The flow velocity of the river rapidly decreases as the river enters the lake and the suspended loads are dropped in the general area of the Niagara Bar. Between Queenston and the bar, bottom sediments, where they exist, are generally clean and mud deposits are restricted. Beyond the bar the sediments become progressively more muddy.

The sediments collected at the sides of the river were sandy silt and mostly reduced. Organic carbon varied from 0.5 to 2.7 percent. Nitrate-nitrogen concentrations varied from 0 to 2 micrograms/gram (μg/g), phosphate-phosphorus from 0 to 0.5 μg/g, and ammonia-nitrogen from 0 to 145 μg/g. These results are for readily-extractable forms of these constituents, including those contained in the interstitial water and those bound to the solid fraction. In the sand bar beyond the river mouth, the sediments were oxidized, and contained much lower values of carbon, nitrate, phosphate and ammonia. One sample was collected in the deep portion of the lake just beyond the sand bar. The sediment here was reduced and contained 60 percent clay. The surface organic carbon rose to 3.8 percent and high values were obtained for nitrates and phosphates. The latter anions were greater by a factor of 10 over the values found in the sand bar and river.

2.3 CHEMISTRY

2.3.1 Eutrophication

An increase in the rate of addition of plant nutrients to natural waters results in increased biological populations and production. This process, termed eutrophication, occurs both naturally and as a result of waste-disposal and agricultural practices. In the latter sense, man's nutrient pollution of the environment or cultural eutrophication is a special aspect of pollution dealing with those pollutants that lead to an overall increase in biological production.

Suspended algae in open water (phytoplankton), 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 main 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. Populations of salmonid and coregonid fish are characteristic of the oxygen-saturated bottom waters of oligotrophic lakes. 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 from the dense growth of phytoplankton, and the deep waters during periods of restricted circulation become deficient in oxygen as a result of the decomposition of great quantities of organic material produced. The low concentrations of dissolved oxygen in bottom waters during periods of restricted vertical circulation largely limit the fish fauna to warm-water species. In extreme cases of eutrophy, algae become so abundant as to cause offensive odours in bays, clog water intake lines, and generally reduce the water quality. Lakes become more eutrophic as their basins become filled with sediment. Lakes in regions of sedimentary rock drainage are more eutrophic in character than those in regions of igneous rock drainage. 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 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 used 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 over-emphasized. 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 easier to control. 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 other 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.

Lake Ontario, the last in the chain of Great Lakes, receives large quantities of pollutants from the upper lakes as well as from within its own drainage basin. Despite the large volume and dilution capacity of the lake, observed concentrations of conservative elements are higher in Lake Ontario than in any of the upper lakes. Non-conservative elements such as phosphorus, nitrogen and carbon are removed from the lake water by sedimentation. Because of this and other natural self-purification processes, the chemical characteristics of the water change only slowly despite large pollutional inputs from the Niagara River, Toronto, Rochester and Hamilton.

During the summmer, when Lake Ontario is stratified, the epilimnetic and hypolimnetic waters differ from one another in their chemical characteristics. In the spring and fall, the lake undergoes rapid vertical mixing, as do most deep lakes located in the temperate zone.

The lake can also be divided into two water quality zones: the nearshore zone and the main water body. The nearshore zone is affected by local pollution, tributary inflows and higher temperatures, giving rise to high biological activity and varying water quality along the shore. The main body of the lake, however, shows little direct influence from tributary streams other than the Niagara River. The lake is quite homogeneous, with little variation between the western and eastern basins.

The St. Lawrence River reflects the quality of water found in Lake Ontario. The volume of flow in the river is exceptionally large, averaging 232,000 cfs (6,570 m^3/sec). The flow of the river is broken up by the many islands situated in the river course, creating back-eddies and quiescent areas. Tributary streams and effluent discharges have a minor effect on the overall water quality but do cause localized pollution in embayments and protected areas.

At its source in the Kingston-Cape Vincent area, the river is stratified with little or no mixing occurring between the surface and the bottom. Near Alexandria Bay, the main channel becomes constricted causing the river to mix completely throughout the rest of its course. The turbulence in the main channel also aids in dispersing pollutants throughout the depth of the water, although, pollutants added on one side of the river do not immediately affect the water quality on the other side.

2.3.2 Nutrient Chemistry

Phosphorus

Phosphorus is an essential constituent of all living organisms. It occurs as a component of deoxyribonucleic acids (genes) which are involved in cellular reproduction. Ribonucleic acids, play an essential role in protein synthesis and form various intermediary compounds involved in the transfer of energy in respiration and photosynthesis. With the exception of some recently discovered compounds containing C-P bonds and micro-organisms that are capable of reducing phosphate to phosphine, the element occurs naturally on the earth only in a fully oxidized state. The forms of the phosphorus compounds present in lake water are imperfectly known. Most analyses have been restricted to relatively simple assays for orthophosphate and total-phosphorus.

In this report all concentrations of phosphorus compounds are expressed in terms of the element phosphorus. Orthophosphate-phosphorus (PO_4-P) refers to the phosphorus that occurs as orthophosphate ions (such as H_2PO_4, HPO_4, PO_4, $NaHPO_4$, $CaHPO_4$) in a filtered sample of water; total-phosphorus (total-P) refers to the phosphorus present as orthophosphate ions after acid digestion of an unfiltered sample of lake water and includes both inorganic orthophosphate and the phosphorus present in organic substances. The terms soluble phosphate-P and reactive phosphate-P are treated here as equivalents of orthophosphate-P.

All concentrations in the text and tables of this section are reported in μg phosphorus (P) per litre. The values in Fig. 2.3.1 to 2.3.6, however, are in μg phosphate (PO_4) per litre. To convert μg PO_4 to μg P, divide by 3.

Orthophosphate-phosphorus (PO_4-P)

There is very little historical information available on phosphorus in Lake Ontario. Sutherland and Kramer (1966) found orthophosphate values ranging from 10 to 29 μg/l in their study of mineral-water equilibria. In the offshore survey work undertaken for this report, data collected in 1965 by FWPCA gave values ranging from 6 to 33 μg PO_4-P/l with an average of 13 μg PO_4-P/l (Fig. 2.3.1, 2.3.2 and 2.3.3). (The reader should note that data shown in Fig. 2.3.1 to 2.3.6 are expressed as phosphate rather than phosphorus). Data collected in 1967 by NHW revealed values ranging from 0 to 37 μg PO_4-P/l with a median value of 2 μg PO_4-P/l in the surface water and 12 μg PO_4-P/l at 50 metres in the hypolimnion. Observations of nearshore waters by OWRC revealed significantly higher values than those observed in open water areas. In 1965, the FWPCA reported a band of phosphorus-rich water along the southern shore from the Niagara River to Oswego. In the immediate vicinity of the mouth of the Niagara River, and at Rochester, Sodus Bay and Oswego, orthophosphate ranged from 17 to 20 μg PO_4-P/l. OWRC observed orthophosphate values as high as 30 μg PO_4-P/l in the vicinity of the Niagara River from 1966 to 1967.

Similar observations were made along the northern shore by OWRC in 1966 and 1967. Values ranging from 15 to 130 μg PO_4-P/l were observed in the Toronto area. Phosphate values in the nearshore waters were generally higher in the western basin than in the eastern basin. In the latter case nearshore phosphate values were similar to those in offshore areas. The distribution of phosphorus in nearshore waters is discussed in detail in Section 3.2.

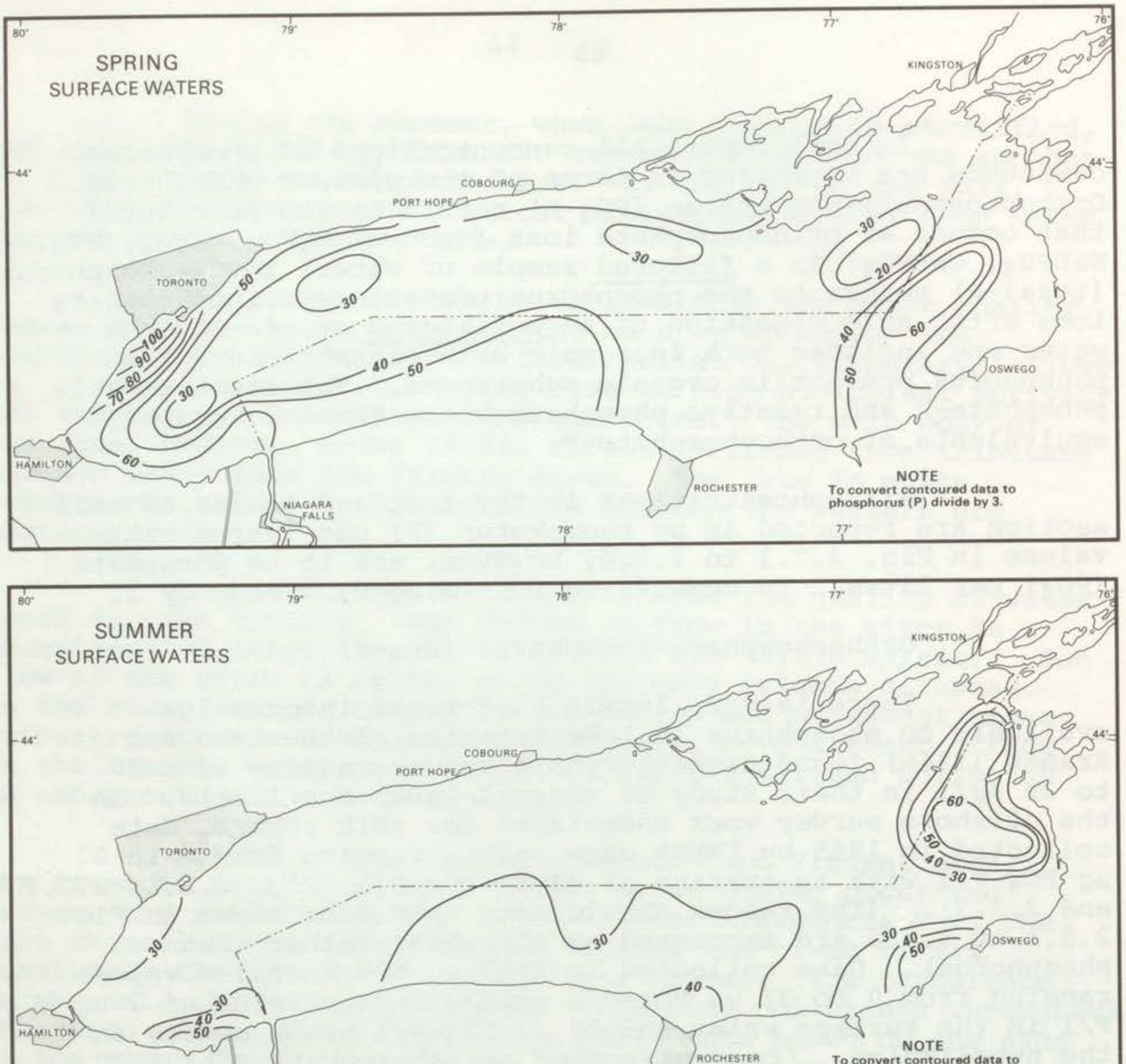
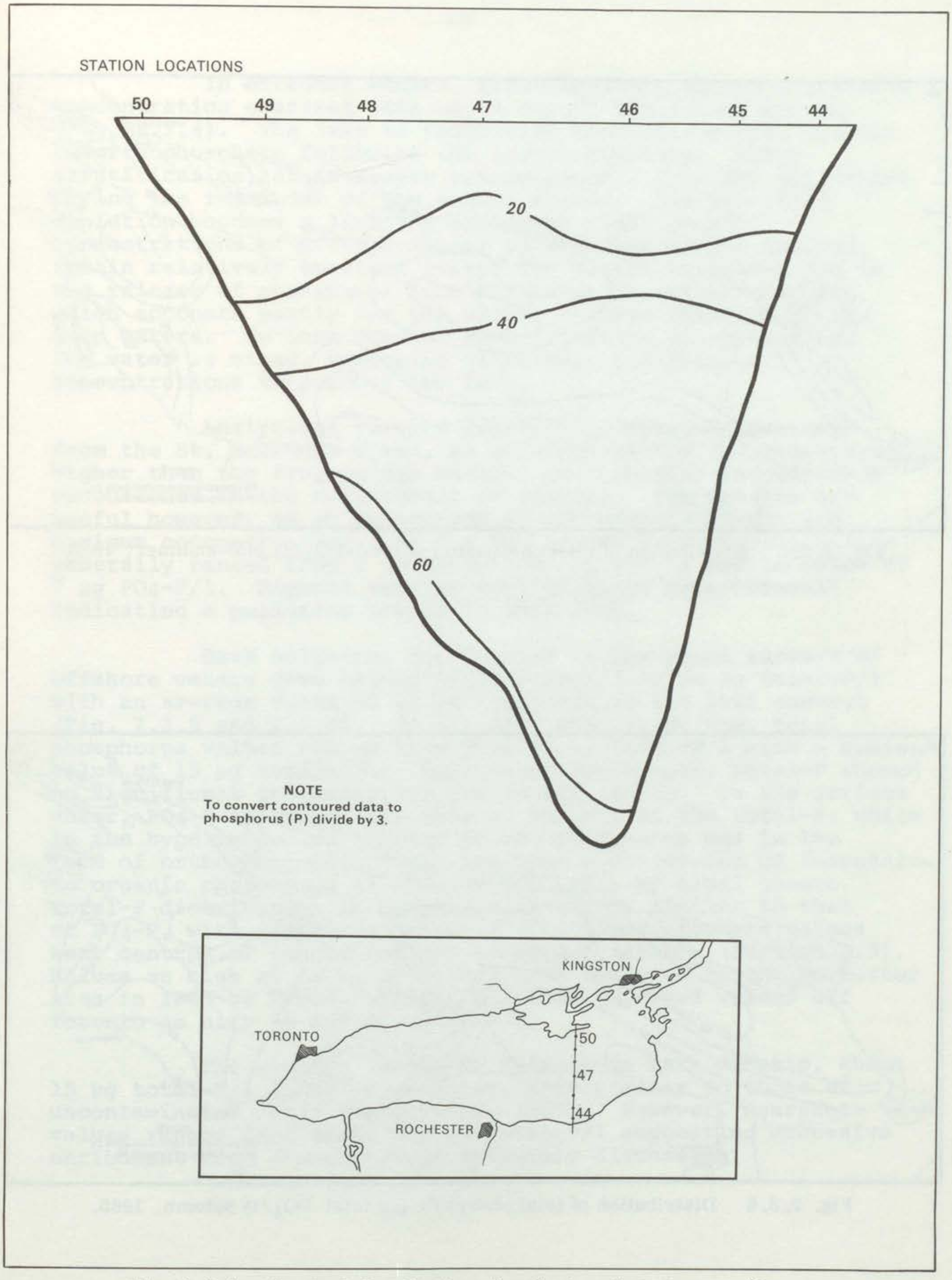
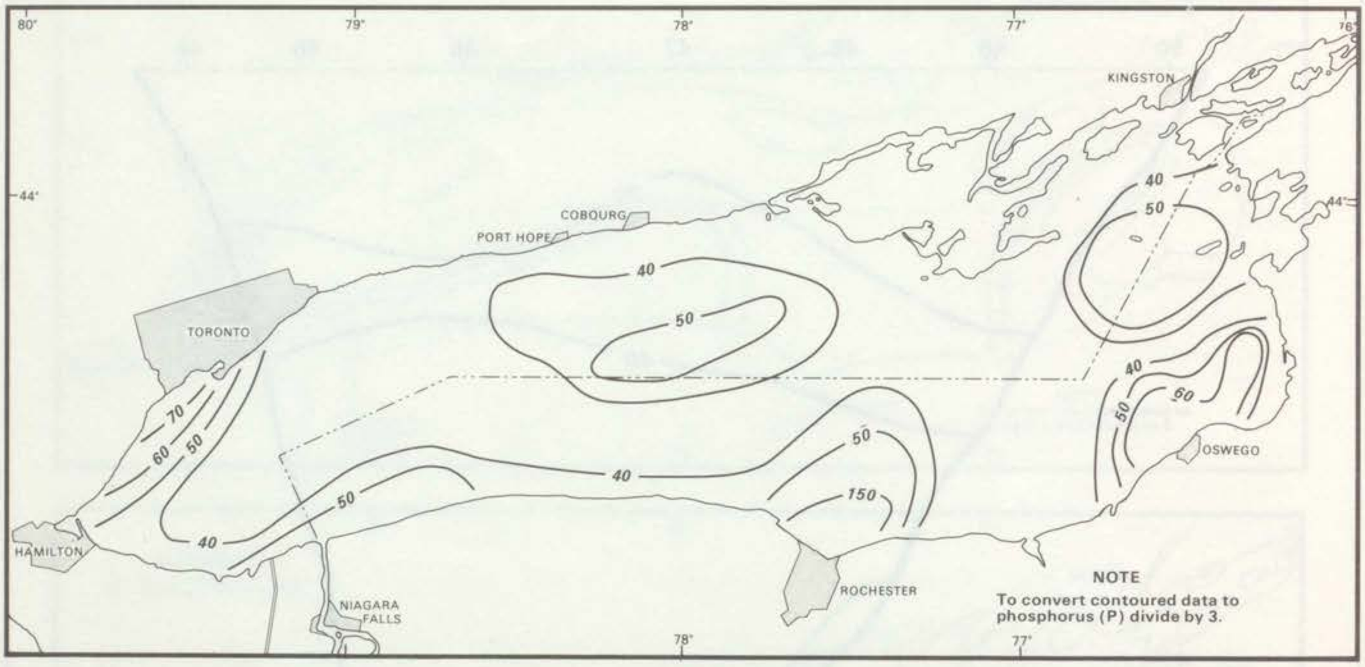


Fig. 2.3.1, 2.3.2, 2.3.3 Distribution of orthophosphate ($\mu g\ PO_4-P/1$) for spring, summer and autumn, respectively, 1965 in Lake Ontario.



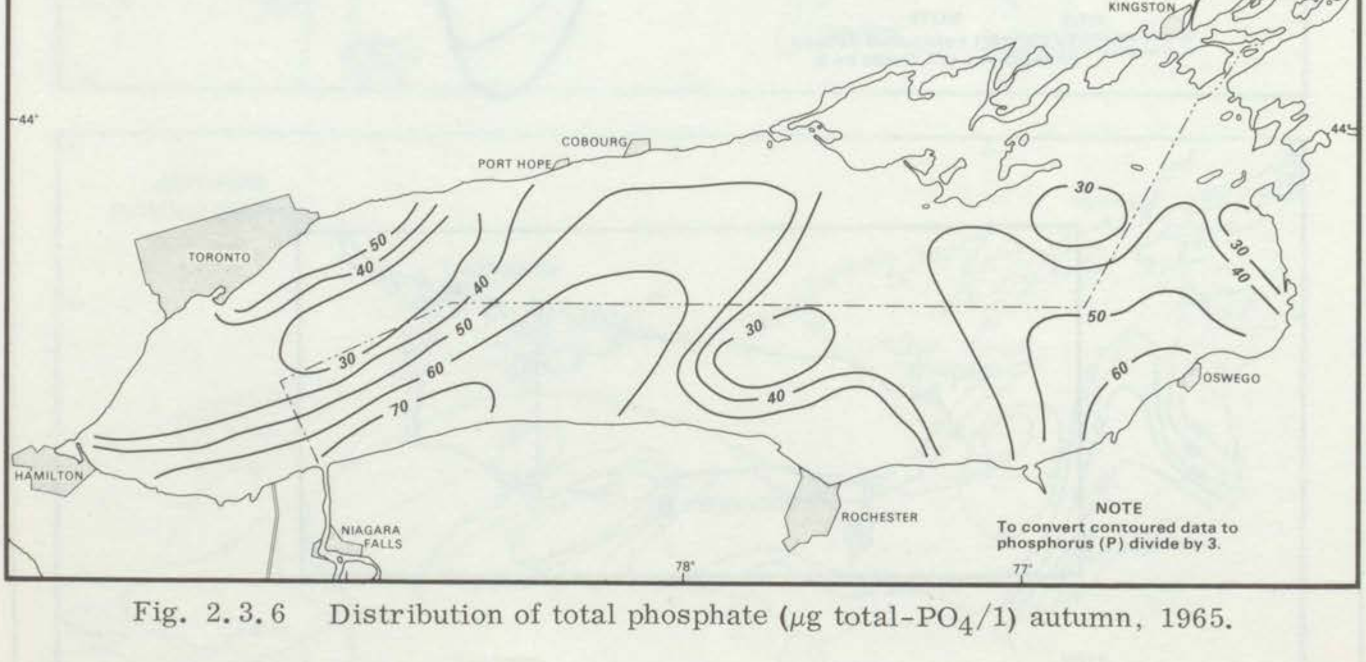
NOTE
To convert contoured data to phosphorus (P) divide by 3.

Fig. 2.3.4 Vertical distribution of orthophosphate ($\mu g\ PO_4/1$) in the eastern basin of Lake Ontario, summer of 1967.



NOTE
To convert contoured data to phosphorus (P) divide by 3.

Fig. 2.3.5 Distribution of total phosphate (μg total-PO_4/1) mid-summer, 1965.



NOTE
To convert contoured data to phosphorus (P) divide by 3.

Fig. 2.3.6 Distribution of total phosphate (μg total-PO_4/1) autumn, 1965.

In offshore waters, orthophosphate showed a definite concentration gradient with depth during the summer season (Fig. 2.3.4). The lake is relatively homogeneous with respect to orthophosphate following the spring overturn. After stratification, algae remove orthophosphate from the epilimnion during the remainder of the summer season. The resulting depletion becomes a limiting factor on algal growth. Concentrations of orthophosphate in the hypolimnion however, remain relatively constant except for slight increases due to the release of phosphorus from breakdown of sestonic debris, which accounts partly for the higher results obtained in the deep waters. In late October stratification disappears and the water is mixed, restoring relatively homogeneous concentrations throughout the lake.

Analytical results for orthophosphate-phosphorus from the St. Lawrence River, as measured by NHW in 1966, were higher than the true values because of turbidity interference encountered in the measurement of samples. The results are useful however, as an indication of approximate levels and maximum concentrations. In the St. Lawrence River, the values generally ranged from 0 to 10 µg PO_4-P/l with a median value of 7 µg PO_4-P/l. Highest results were obtained near Cornwall indicating a pollution source in that area.

Data collected for total-P in the FWPCA surveys of offshore waters gave values ranging from 3 to 50 µg total-P/l with an average value of 13 µg total-P/l in the 1965 surveys (Fig. 2.3.5 and 2.3.6). In the 1967 studies by NHW, total phosphorus values ranged from 9 to 24 µg total-P/l with a median value of 15 µg total-P/l. Unlike orthophosphate, total-P showed no significant concentration change with depth. In the surface water, PO_4-P accounted for only 23 percent of the total-P; while in the hypolimnion 63 percent of the phosphorus was in the form of orthophosphate. This suggests a conversion of inorganic to organic phosphorus in the surface water by algal growth. Total-P distribution in nearshore waters is similar to that of PO_4-P, with nearshore values 2 to 3 times offshore values near centres of population and tributary streams (Section 3.2). Values as high as 30 µg total-P/l were observed in the Rochester area in 1965 by FWPCA, whereas the OWRC observed values off Toronto as high as 150 µg total-P/l.

The average levels of total-P in Lake Ontario, about 15 µg total-P/l in offshore areas, were similar to those of uncontaminated lakes (Hutchinson, 1957). However, nearshore values ranged from 20 to 150 µg total-P/l suggesting excessive enrichment from shoreline and tributary discharges.

Nitrogen

Nitrogen, like phosphorus, is an essential constituent of all living organisms. It occurs as a component of all major classes of biochemical compounds and plays a unique role in the structure of proteins and enzymes. Nitrogen is present in organisms and lake waters in various oxidation states ranging from -3 (ammonia and amino groups) to +5 (nitrate). Most lake water analyses have been restricted to ammonia (NH_3), nitrite (NO_2), nitrate (NO_3), and Kjeldahl-N (NH_3-N plus organic-N). Total-N in this report refers to the sum of NO_2-N, NO_3-N and Kjeldahl-N. Kjeldahl-N was determined on unfiltered samples. All data are presented in terms of the element N.

There is an important supply of nitrogen salts (mainly ammonia and nitrate) from atmospheric precipitation, and the biological processes of nitrogen fixation and denitrification result in material transport of potential nutrient across the air-water interface.

Ammonia

Nitrogen existing as free ammonia or ammonium ion is expressed as ammonia-nitrogen (NH_3-N). Ammonia in lake waters is almost exclusively the result of bacterial decomposition of organic matter.

Some historical data on ammonia levels in Lake Ontario are available. Most of the data have been gathered in connection with municipal water and waste treatment facilities, and are therefore very localized in scope and may or may not indicate changes relating to the lake as a whole. Matheson (1962) reported that uncontaminated Lake Ontario water averaged less than 50 µg NH_3-N/l with several samples ranging from 0 to 10 µg NH_3-N/l. Schenk and Thompson (1965) reported changes of ammonia in raw water samples collected over 41 years at the Island Filtration Plant for the City of Toronto. The trend showed gradual increases in ammonia since 1923. The water supply at this plant is, however, very much influenced by localized pollution from the City of Toronto.

The FWPCA survey conducted in offshore waters of Lake Ontario in 1965 revealed an average ammonia level for the open lake of 60 µg NH_3-N/l with a maximum of 420 µg NH_3-N/l. In 1967 surface water ammonia values observed by NHW ranged from 0 to 240 µg NH_3-N/l with a median value of 30 µg NH_3-N/l. Slightly lower concentrations of ammonia were found in the hypolimnion.

In 1967, the observations by NHW of NH_3-N revealed high concentrations in surface waters near Toronto, Oswego and off the mouth of the Niagara River (Fig. 2.3.7). Similar observations have been reported by the FWPCA in nearshore waters at Rochester, and at the mouths of all tributary streams. OWRC has observed a similar phenomenon in Canadian nearshore waters. The distribution of ammonia in these waters is discussed in detail in Section 3.2.

Median values from each cruise in 1967 showed significant peaks in July and September (Fig. 2.3.8). These could be due to the breakdown of organic matter produced in algal blooms. Comparison of variations of ammonia and Kjeldahl-nitrogen show maximum concentrations of ammonia closely related to maximum peaks for Kjeldahl-nitrogen (Fig. 2.3.8 or 2.3.9). Data collected in 1967 show that NH_3-N averaged 10 percent of the Kjeldahl-N.

The concentration of ammonia found in Lake Ontario was less than 400 μg NH_3-N/l, a level that is regarded as pollutional (World Health Organization, 1963). A comparison of ammonia with bacterial counts shows a direct seasonal relation, confirming the bacterial breakdown of organic nitrogen to ammonia.

In the St. Lawrence River, in 1965, FWPCA found values for ammonia ranging from 10 to 420 μg NH_3-N/l. In 1967 the values observed by NHW (Fig. 2.3.10) ranged between 0 and 275 μg NH_3-N/l with a median value of 23 μg NH_3-N/l. These values are slightly lower than those of the source water (Lake Ontario).

Kjeldahl-Nitrogen

Total Kjeldahl-N refers to organic-N and ammonia-N present in unfiltered samples of water. Organic nitrogen in Lake Ontario is mainly derived from biological production with smaller amounts from the discharge of industrial and municipal wastes.

No significant data are available for Kjeldahl-N in Lake Ontario prior to 1960. In the 1965 surveys of offshore waters, FWPCA found total Kjeldahl-N to range from 0 to 800 μg N/l with a mean of 230 μg N/l. In 1967 NHW found values to range from 100 to 800 μg N/l with a median of 295 μg N/l at the surface and 225 μg N/l at 50 metres, in the hyplimnion. Values of total Kjeldahl-nitrogen were higher in nearshore than in offshore waters (Fig. 2.3.11). Turbidity was also high in nearshore waters, which suggests that the total Kjeldahl-N was

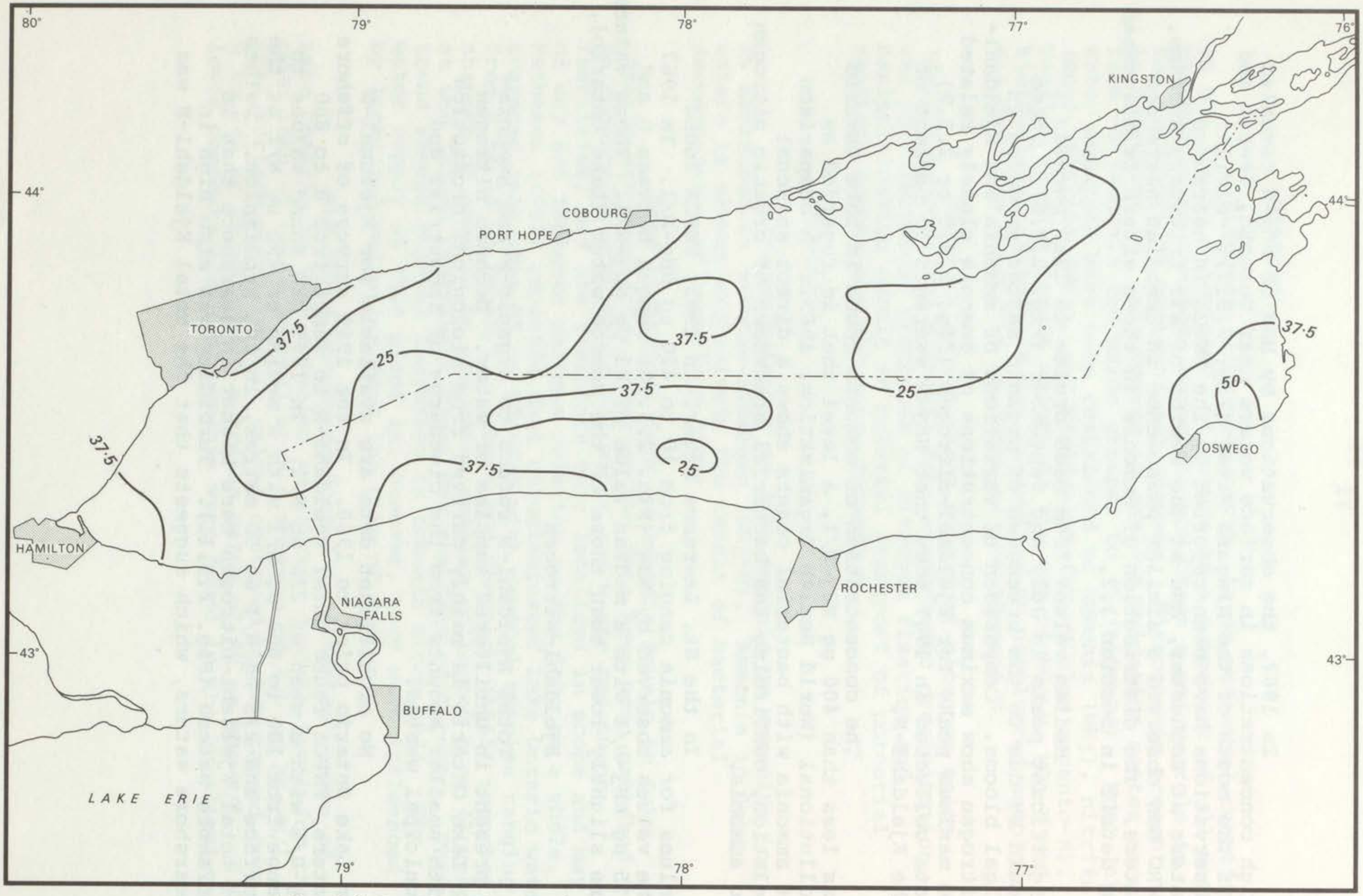


Fig. 2.3.7 Distribution of ammonia-nitrogen ($\mu g\ NH_3$-N/1) at 1 metre depth (average of 11 cruises, 1967).

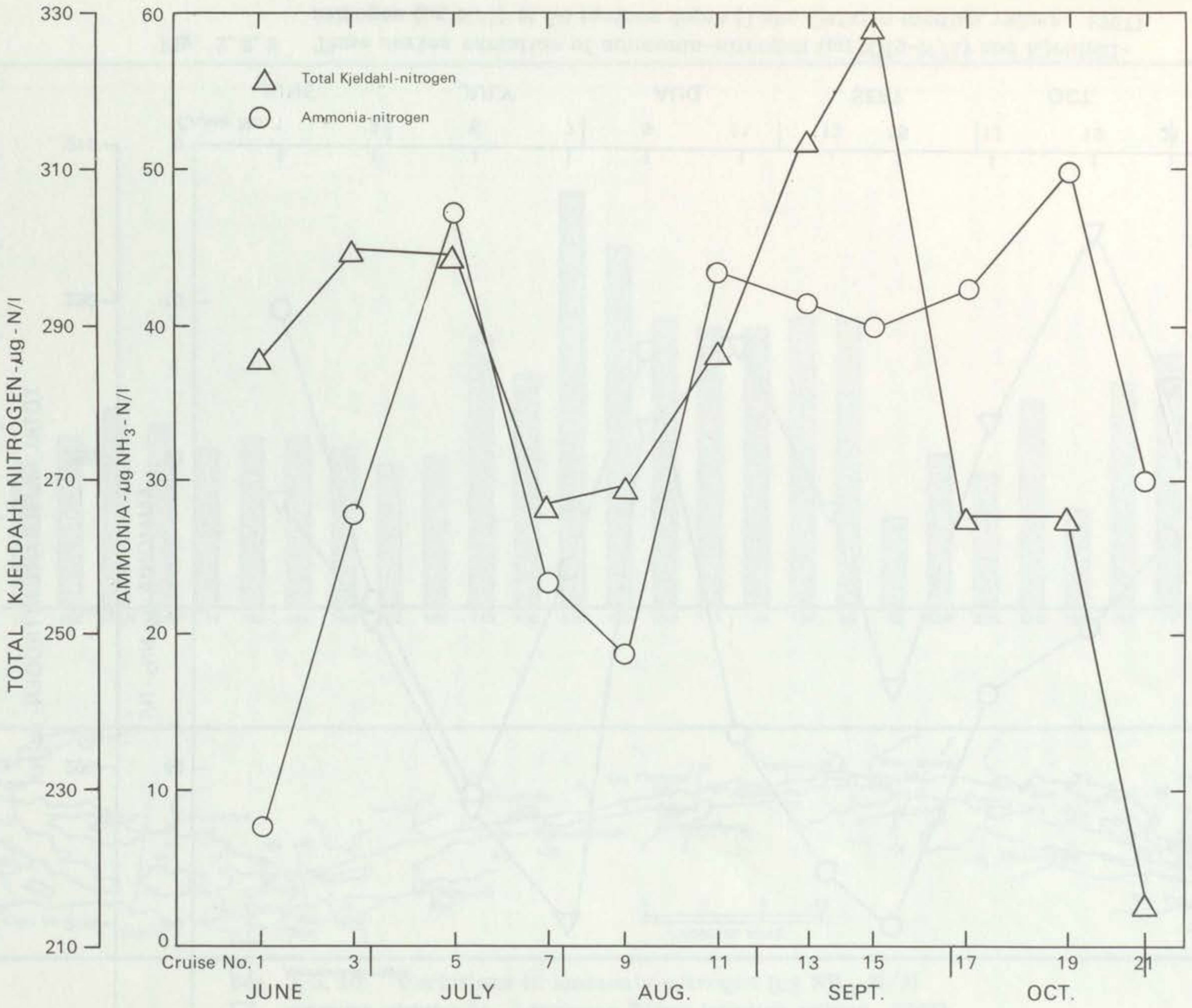


Fig. 2.3.8 Time series variation of ammonia-nitrogen (μg NH_3-N/1) and Kjeldahl-nitrogen (μg N/1) at 1 metre depth (Lake Ontario median values, 1967).

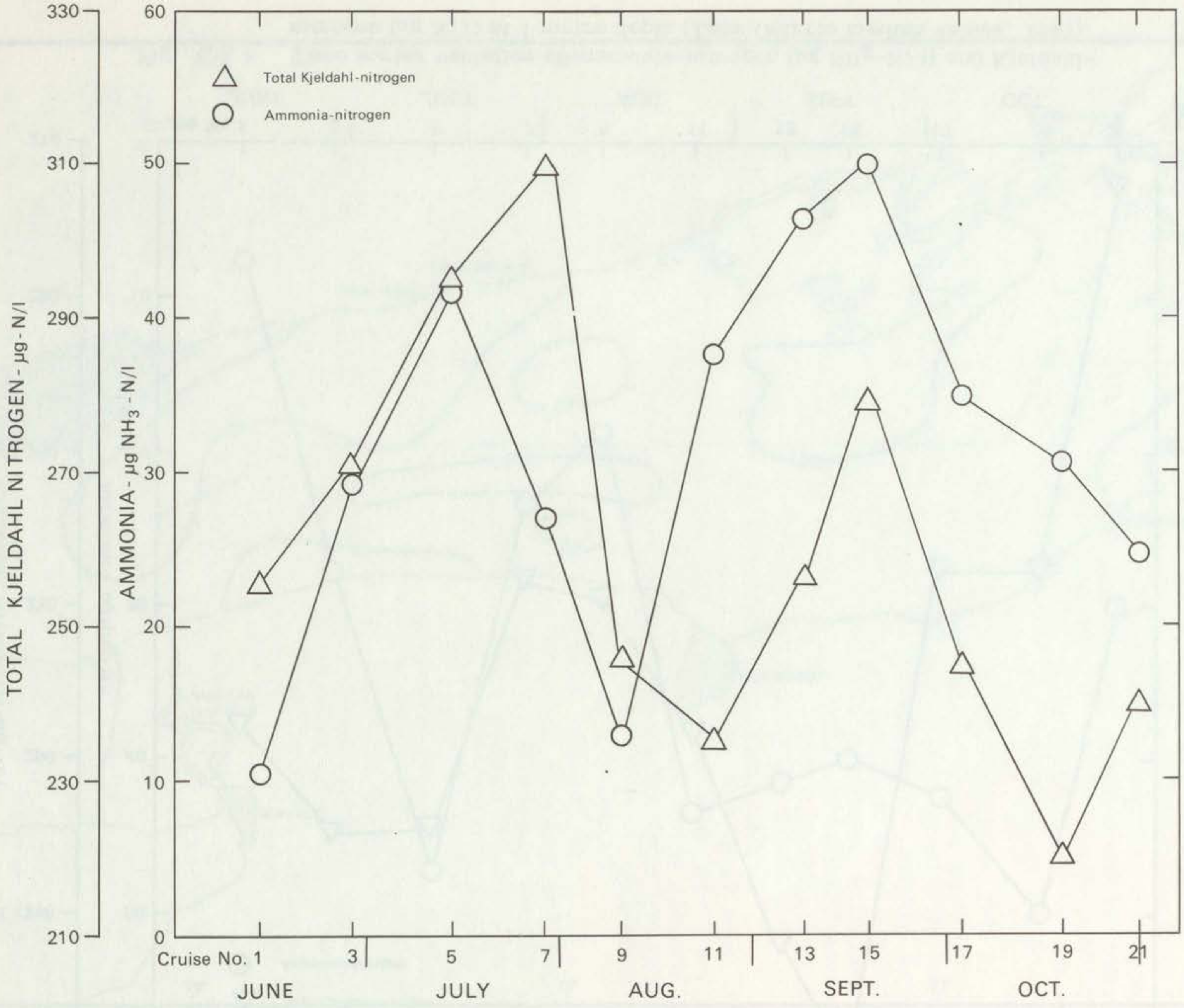


Fig. 2.3.9 Time series variation of ammonia-nitrogen (μg NH_3-N/1) and Kjeldahl-nitrogen (μg N/1) at 50 metres depth (Lake Ontario median values, 1967).

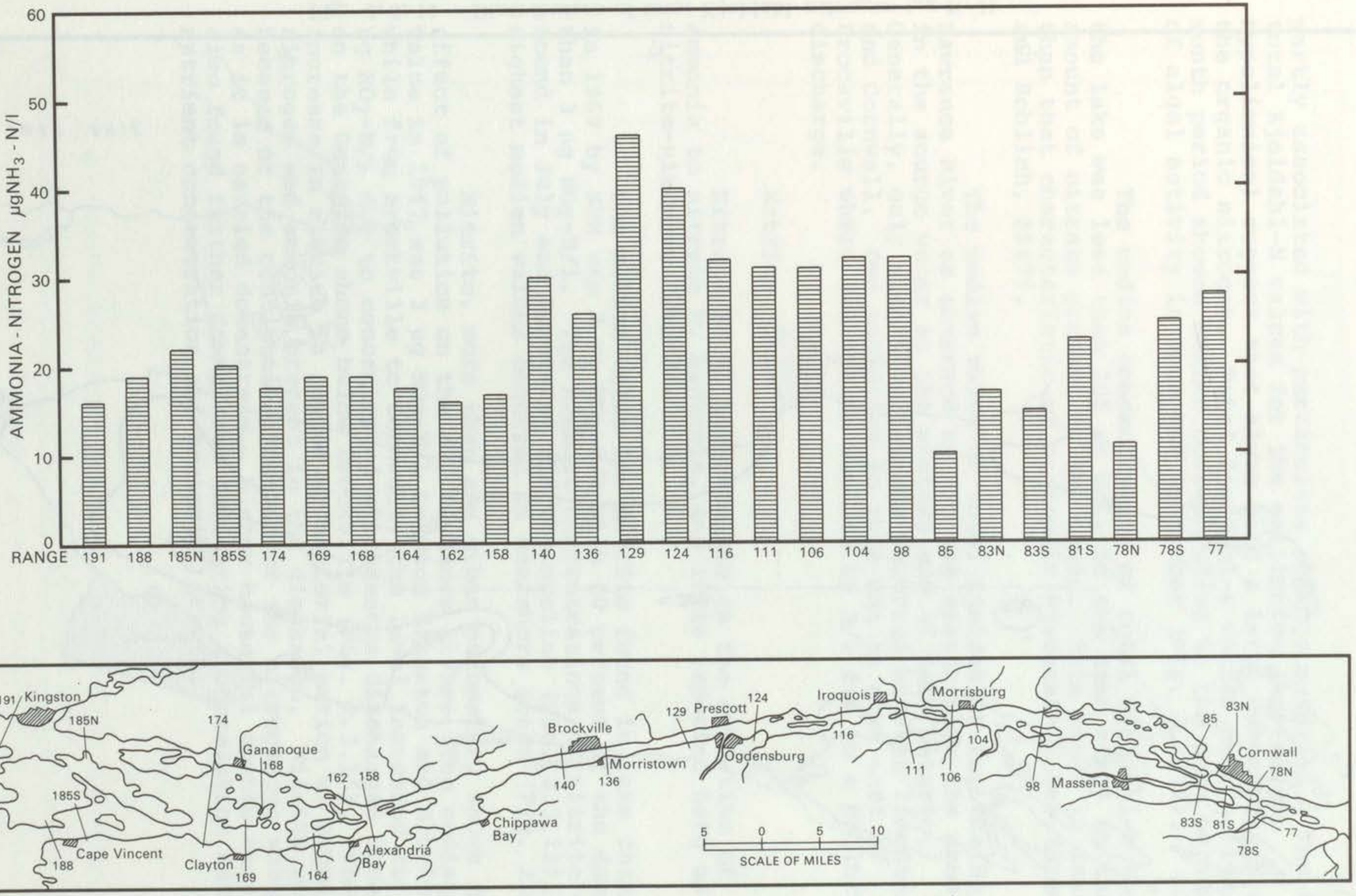


Fig. 2.3.10 Variations in ammonia-nitrogen ($\mu g\ NH_3\text{-}N/1$) in the St. Lawrence River (median values, 1967).

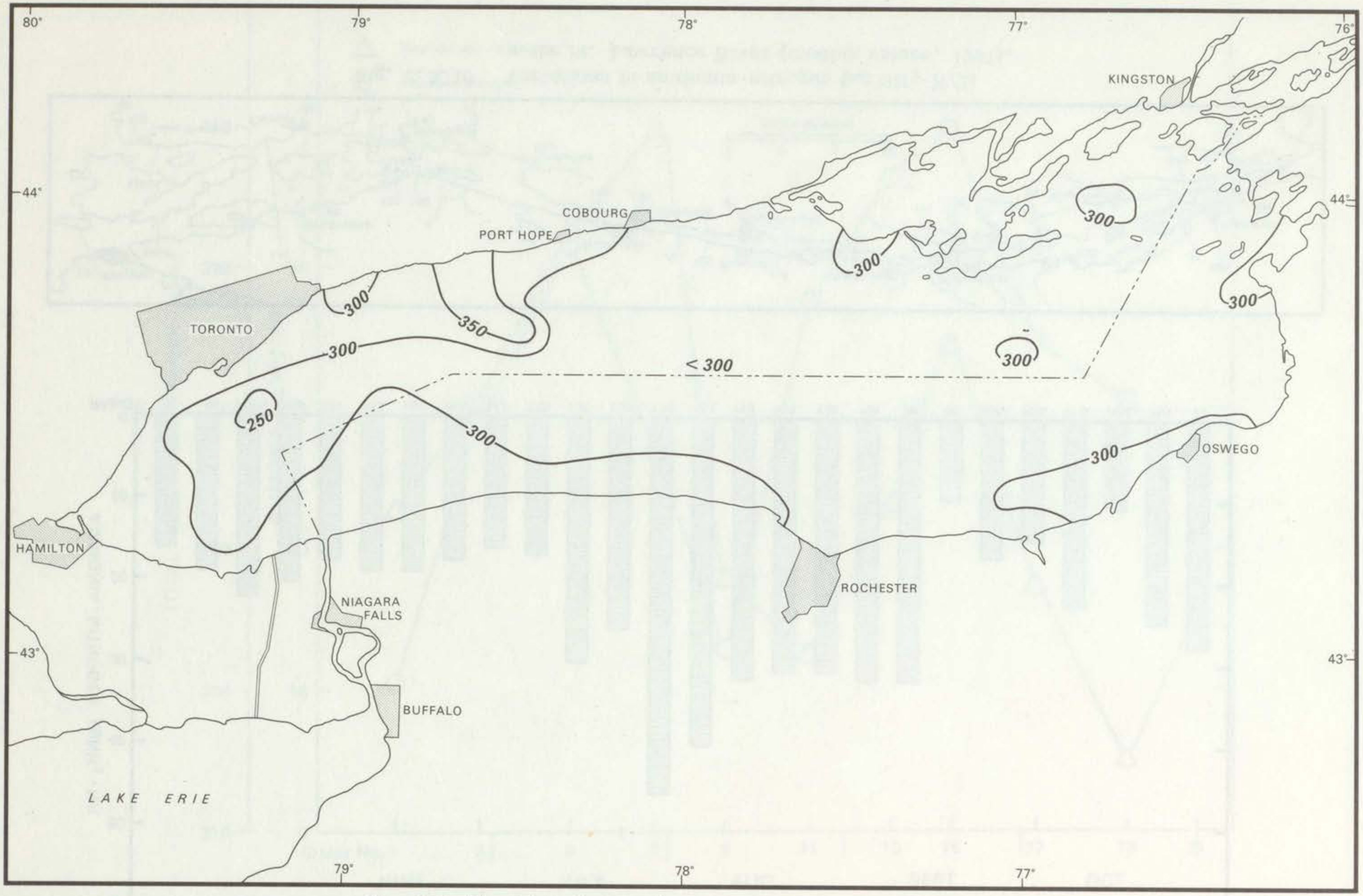


Fig. 2. 3. 11 Distribution of total Kjeldahl-nitrogen (μg N/1) at 1 metre depth (median values, 1967).

partly associated with particulate organic material. The high total Kjeldahl-N values for the epilimnion (*versus* the hypolimnion) suggest that algae make a large contribution to the organic nitrogen. Total Kjeldahl-N values over a five month period showed maxima corresponding to the peak periods of algal activity in June and September (Fig. 2.3.12).

The median concentration of total Kjeldahl-N for the lake was less than 300 μg N/l, in the same range as the amount of nitrate present in the water. This range is less than that characteristic of eutrophic Wisconsin lakes (Stewart and Rohlich, 1967).

The median value of total Kjeldahl-N for the St. Lawrence River as observed by NHW was essentially the same as in the source water at the western end of Lake Ontario. Generally, only slight variations occurred between Kingston and Cornwall. One exception to this was an area east of Brockville where the median was 360 μg N/l due to a pollutional discharge.

Nitrite

Nitrite is an intermediate in the oxidation of ammonia to nitrate by bacteria, and it is reported here as nitrite-nitrogen (NO_2-N).

The median value for nitrite found in Lake Ontario in 1967 by NHW was 2 μg NO_2-N/l with 80 percent of the data less than 3 μg NO_2-N/l. The highest concentrations of nitrite were found in July and August at the thermocline (Fig. 2.3.13). Highest median values occurred in nearshore areas (Fig. 2.3.14).

Nitrite, more than any other parameter, shows the effect of pollution on the St. Lawrence River. The median value in 1967 was 3 μg NO_2-N/l between Kingston and Brockville, while from Brockville to Cornwall, the level increased to 7 μg NO_2-N/l due to concentrated nitrogenous discharges located on the Canadian shore below Brockville (Fig. 2.3.15). The increase in nitrite is caused by bacterial action on organic nitrogen and ammonia present in the discharge. Nitrite persists because of the continual oxidation of the nitrogenous waste as it is carried downstream. Higher bacterial counts were also found further downstream indicating a correlation between nutrient concentration and bacterial growth.

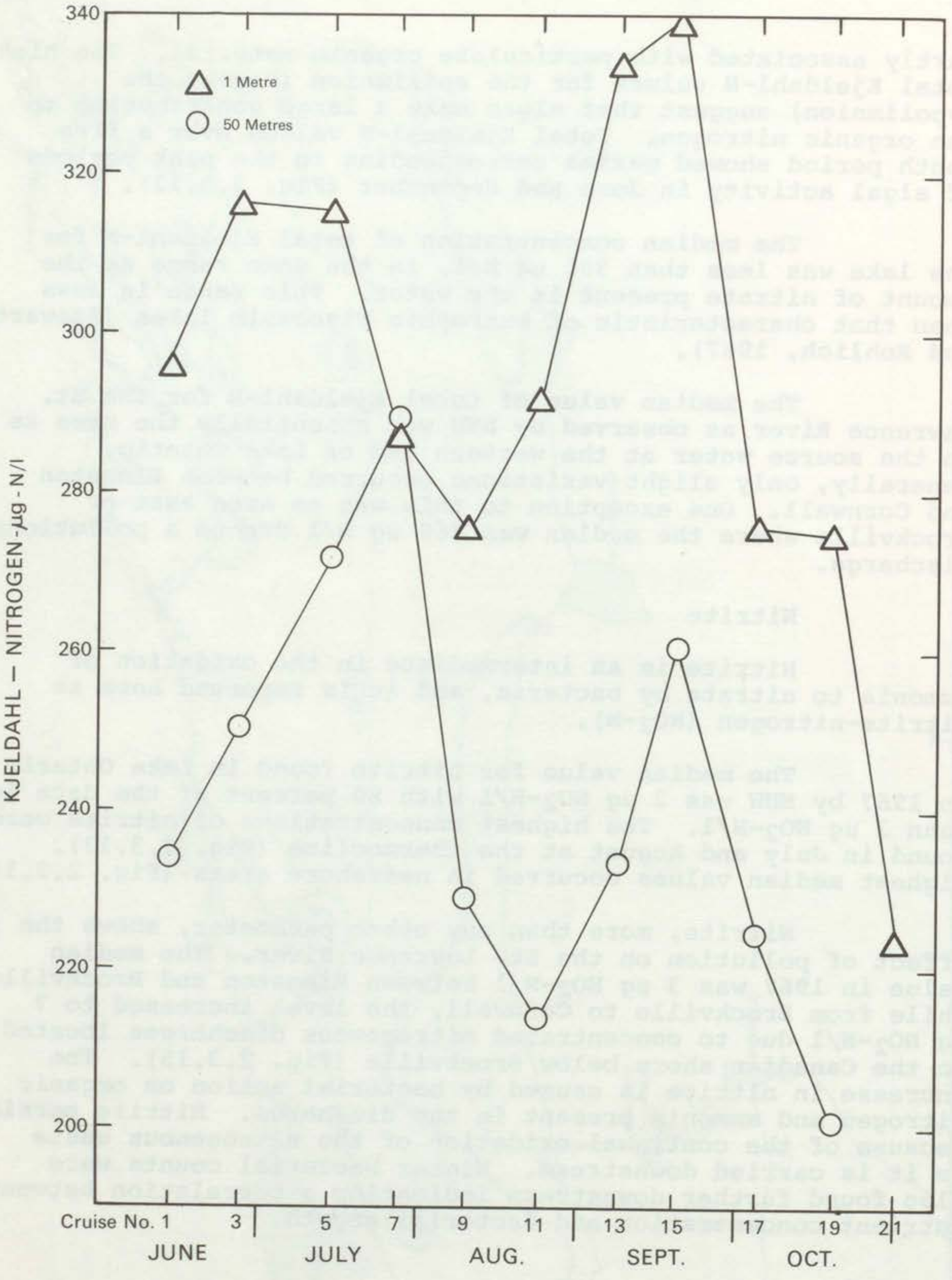


Fig. 2.3.12 Time series variation in total Kjeldahl-nitrogen (μg N/1) at 1 and 50 metres depth (Lake Ontario median values, 1967).

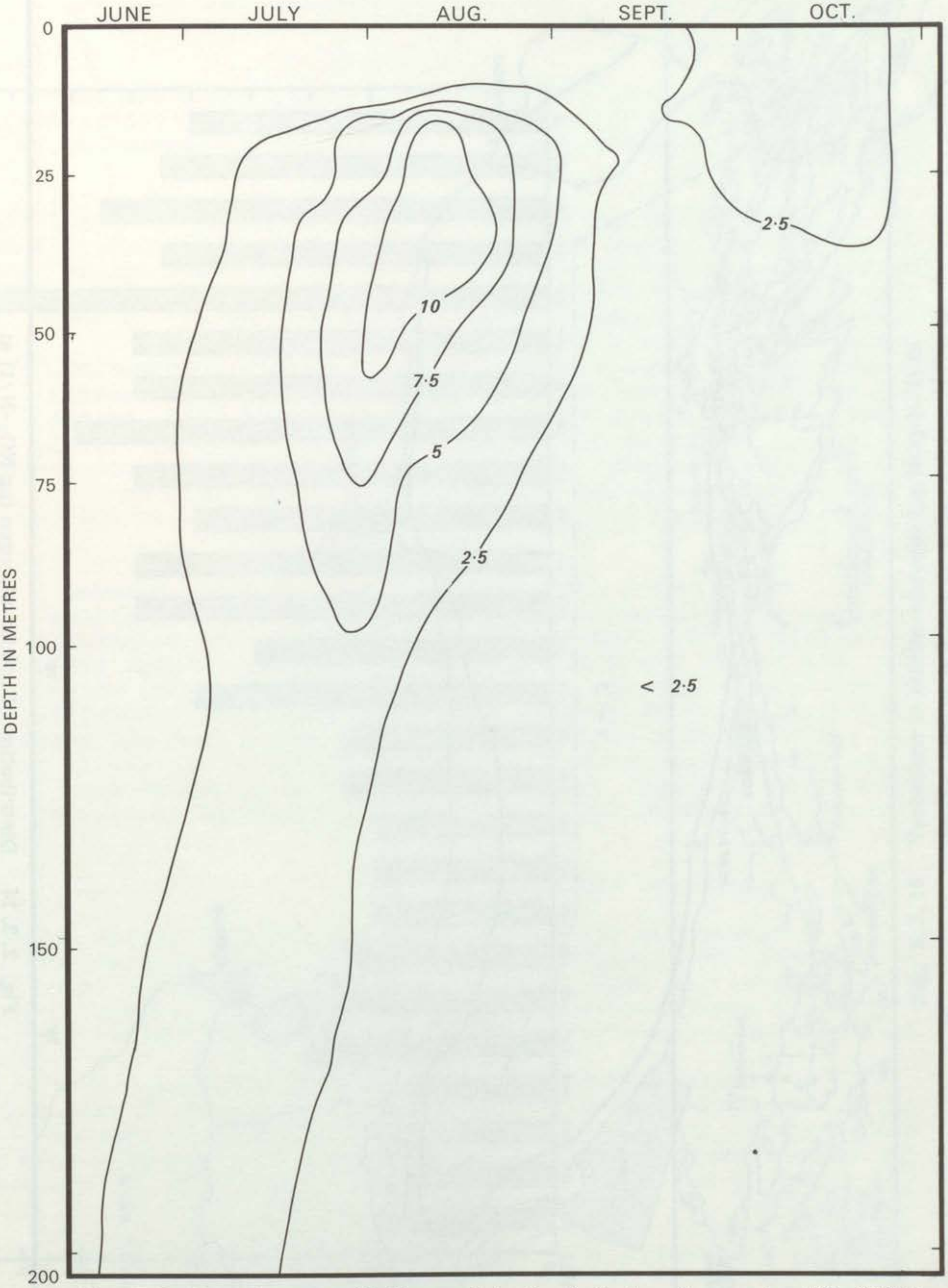


Fig. 2. 3. 13 Changes with time and depth of nitrite-nitrogen (μg NO_2-N/1) in Lake Ontario (Lake Ontario median values, 1967).

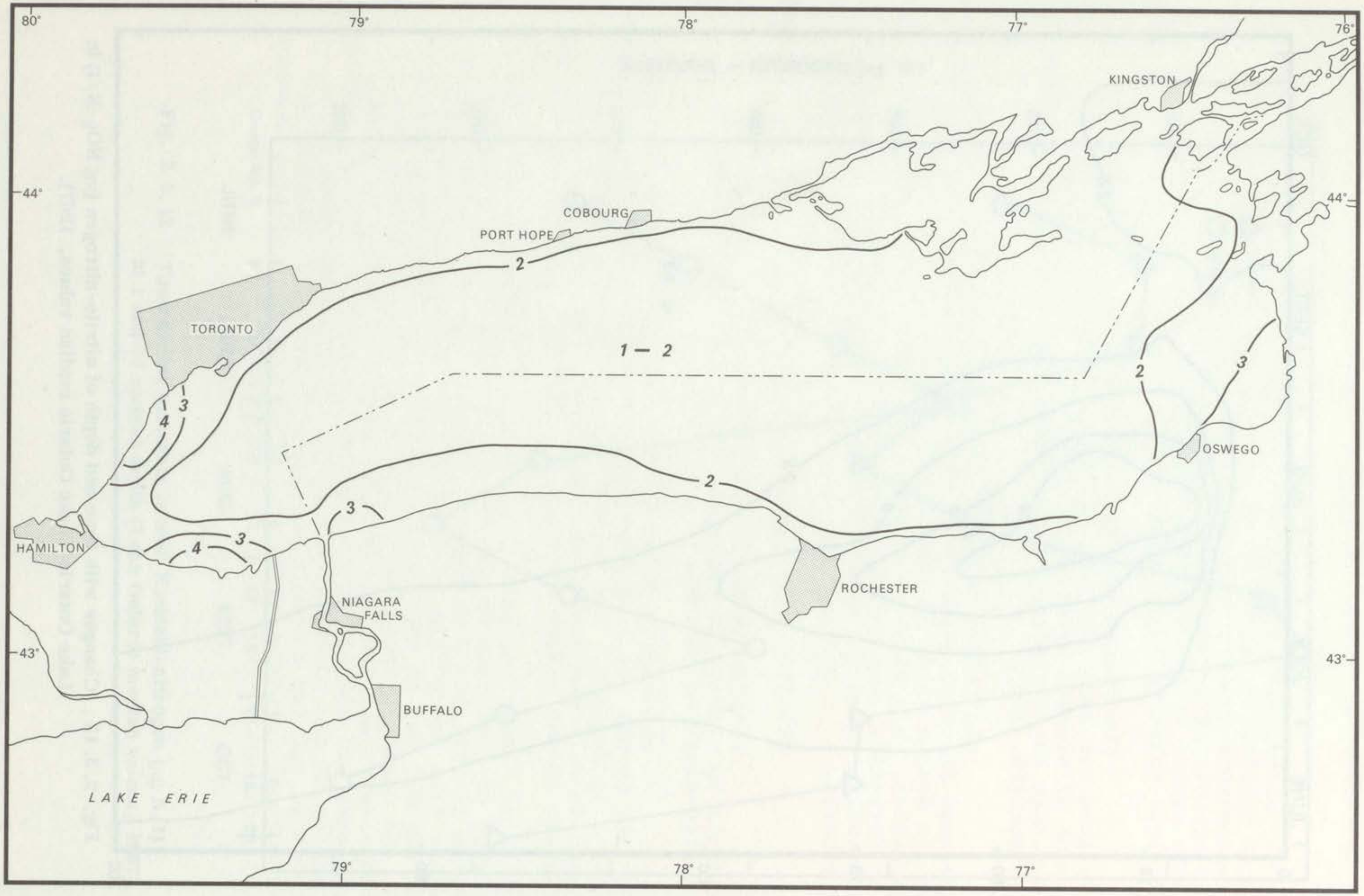


Fig. 2.3.14 Distribution of nitrite-nitrogen ($\mu g\ NO_2$-$N/1$) at 1 metre depth (Lake Ontario median values, 1967).

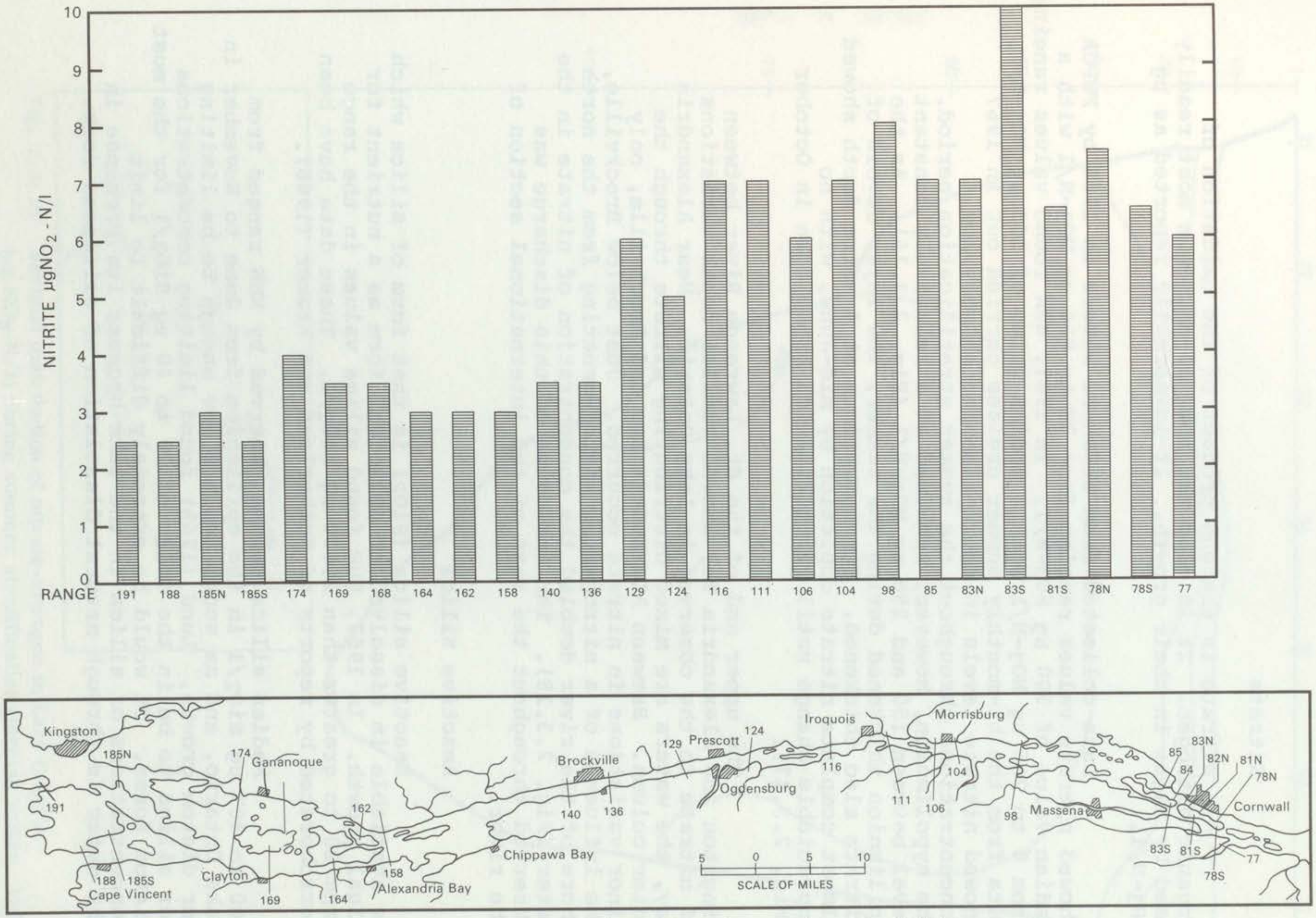


Fig. 2.3.15 Variations in nitrite-nitrogen ($\mu g\ NO_2$-N/1) in the St. Lawrence River (median values, 1967).

Nitrate

Nitrate is the end product of the oxidation of organic nitrogen. It is also the form of nitrogen most readily used by algae in their growth. It is normally reported as µg NO_3-N/l.

Data collected from offshore waters in 1965 by FWPCA showed nitrate values ranging from 30 to 870 µg NO_3-N/l with a median value of 300 µg NO_3-N/l. In 1967, NHW found values ranging from 0 to 285 µg NO_3-N/l with a median value of 165 µg NO_3-N/l. Data from the bi-monthly summer cruises carried out in 1967 showed nitrate levels in the epilimnion at very low concentrations throughout the summer stratification period. The hypolimnion, however, remained at a relatively constant level between 150 and 250 µg NO_3-N/l (Fig. 2.3.16). As the epilimnion thickened during the summer, the layer devoid of nitrate also thickened. Concentrations at 1 metre depth showed almost complete nitrate depletion by mid-June, with no appreciable change until stratification broke down in October (Fig. 2.3.17).

The upper end of the St. Lawrence River between Kingston and Alexandria Bay showed similar depth variations of nitrate to the observed in Lake Ontario. Near Alexandria Bay, the waters are mixed distributing nitrate through the water column. Between Alexandria Bay and Brockville, only minor variations in nitrate occurred. Just below Brockville, the influence of a nitrogenous waste emanating from the north shore of the river doubled the concentration of nitrate in the water (Fig. 2.3.18). The influence of this discharge was observed throughout the rest of the international section of the river.

Reactive Silica

Reactive silica (SiO_2) is that form of silica which is available in dissolved or colloidal form as a nutrient for algal growth. In 1967, NHW found silica values in the range from 20 to greater than 2,000 µg SiO_2/l. These data have been corroborated by reports of Sutherland and Kramer (1966).

Median silica values observed by NHW ranged from 100 to 400 µg SiO_2/l in the epilimnion from June to November in Lake Ontario, and as such, are not low enough to be limiting for diatom growth. Lund (1965) found limiting concentrations for silica to be in the order of 20 to 40 µg SiO_2/l for the most diatom forms. It would be extremely difficult to limit concentrations of silica in the lake because its presence in the water is through natural dissolution of siliceous rock.

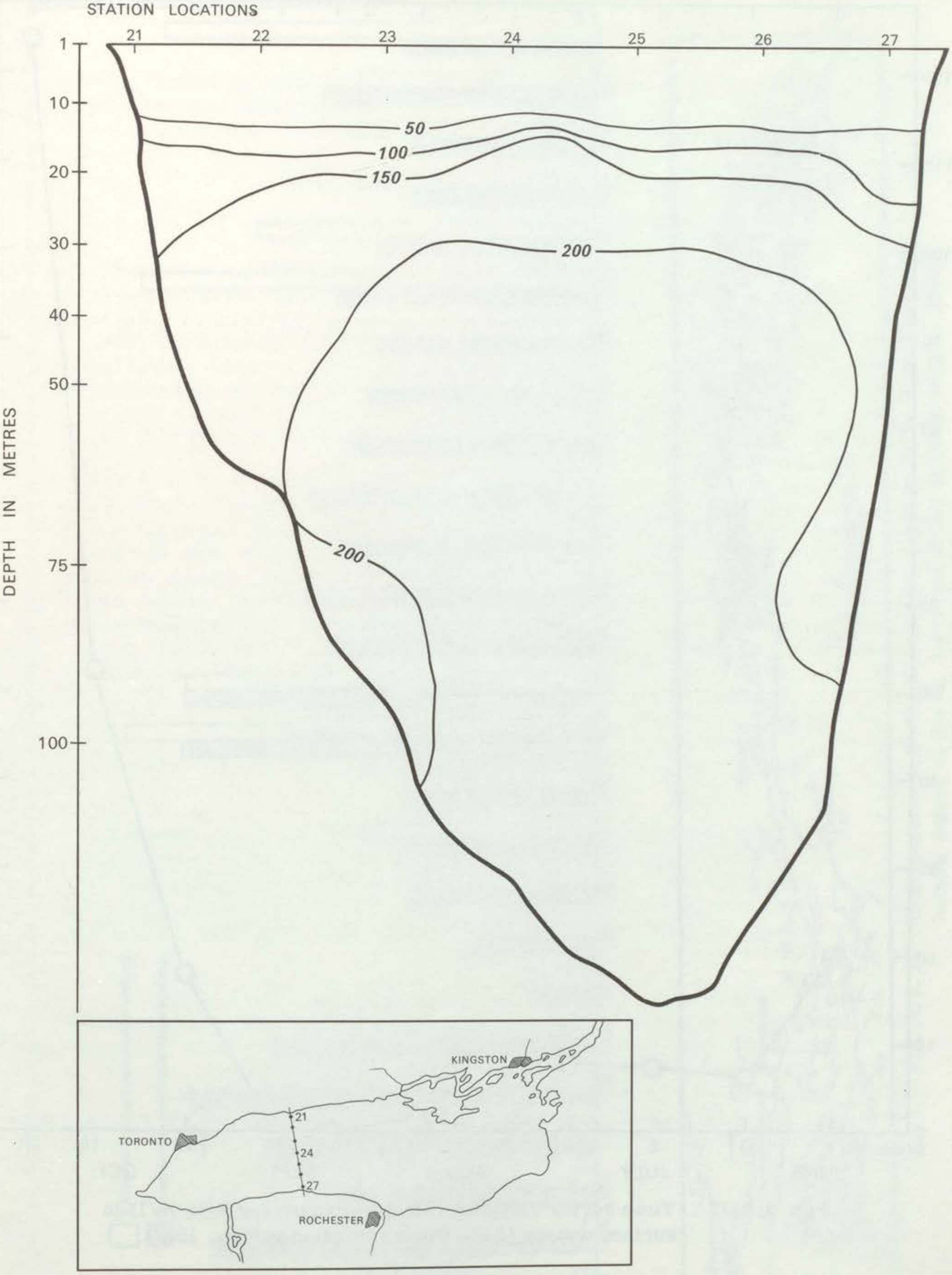


Fig. 2.3.16 Vertical distribution of nitrate-nitrogen in Lake Ontario (μg NO_3-N/1) during summer stratification (median values, 1967).

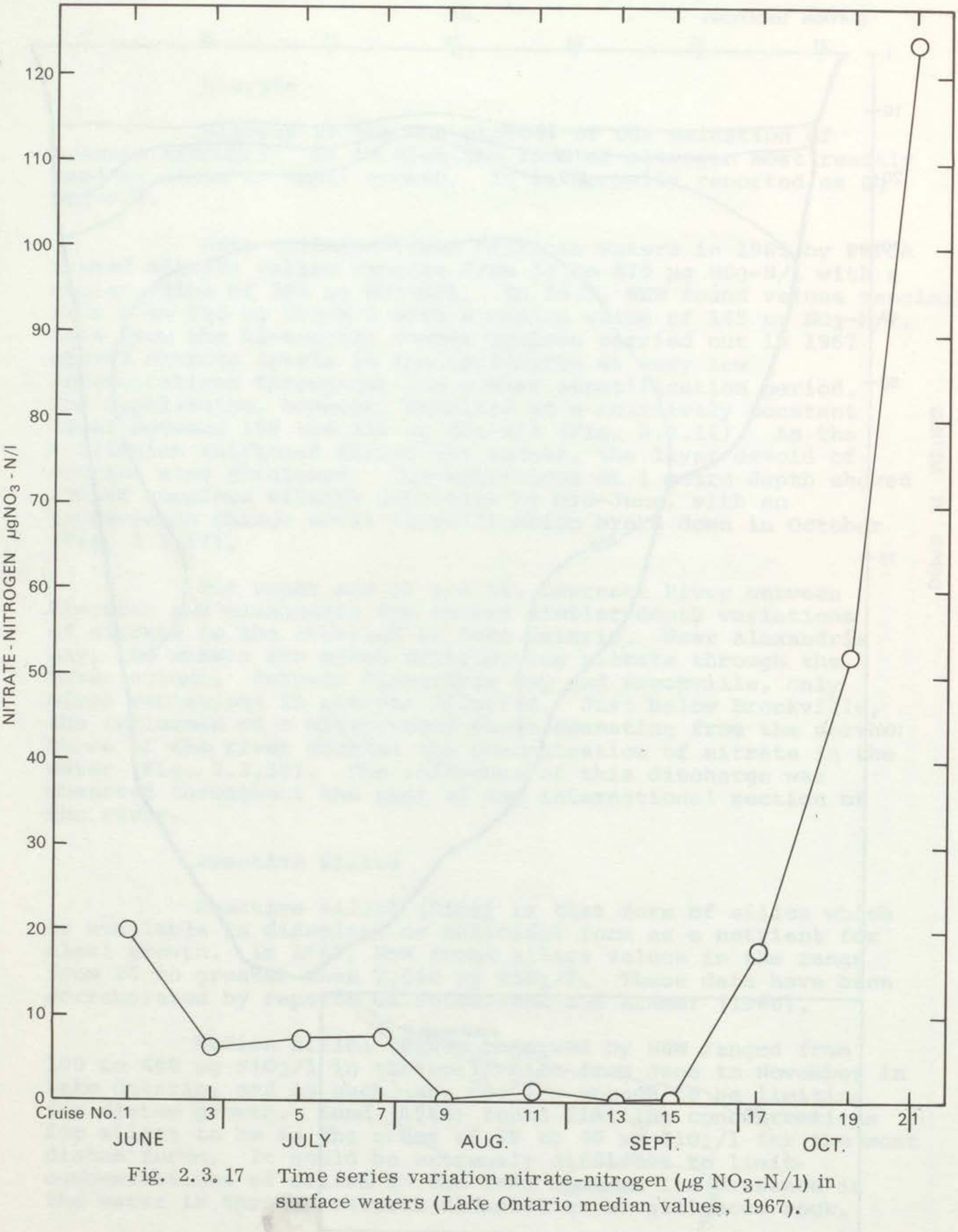


Fig. 2. 3. 17 Time series variation nitrate-nitrogen (μg NO_3-N/1) in surface waters (Lake Ontario median values, 1967).

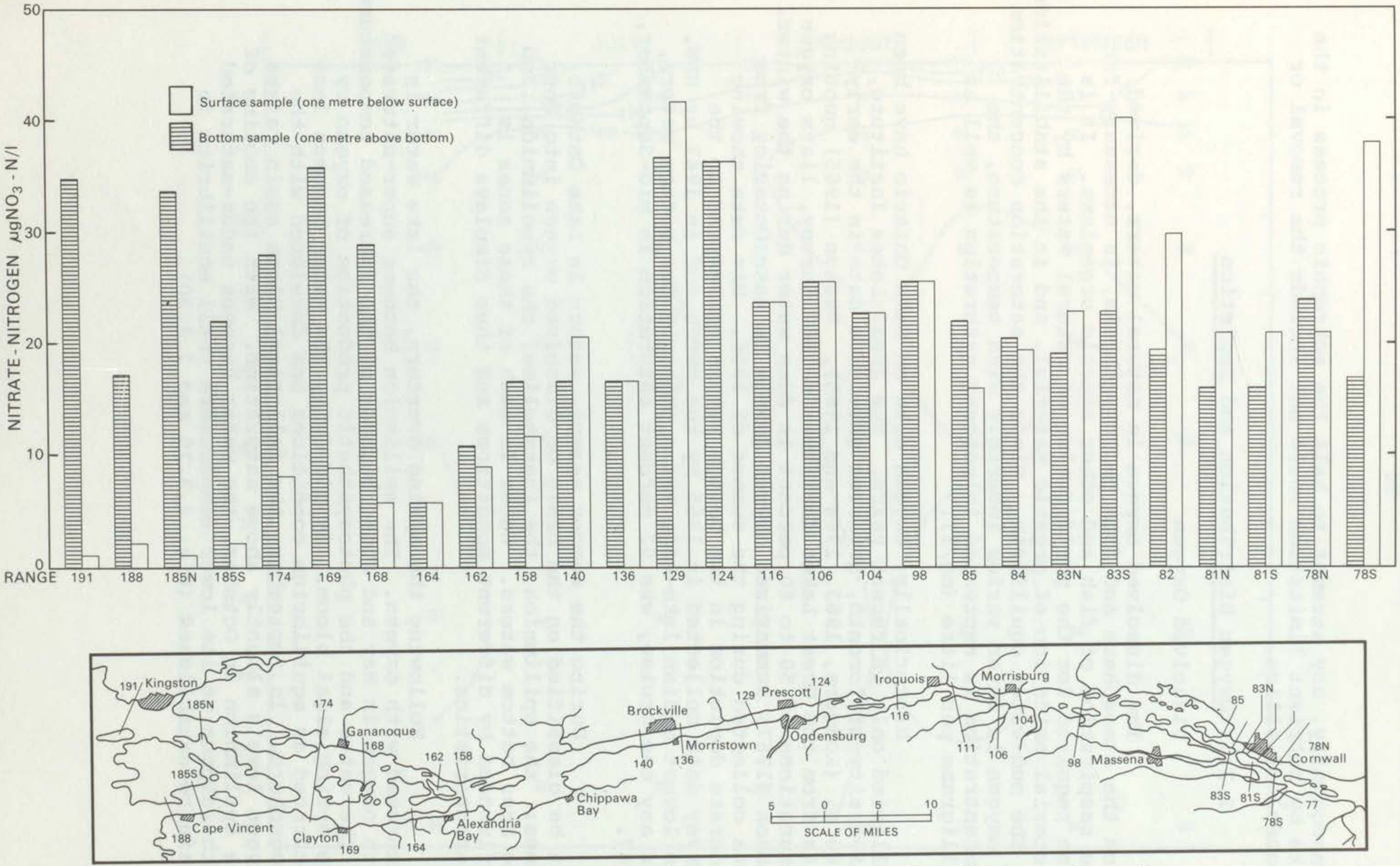


Fig. 2. 3. 18 Concentrations of nitrate-nitrogen ($\mu g\ NO_3$-N/1) in surface and bottom waters of the St. Lawrence River (median values, 1967).

Consequently, any attempt to halt the eutrophic process in the lake by nutrient limitation would not include the removal or control of silica.

2.3.3 Oxygen Distribution and Depletion

Dissolved Oxygen

The dissolved oxygen in natural waters, derived from the atmosphere and from photosynthesis, is necessary for the respiration of fish and other aquatic organisms. It is also required for the purification of natural waters by the bacterial oxidation of organic material, and in the stabilization of the mud-water equilibria. Since the saturation concentration of oxygen in water varies inversely with temperature, the concentration is expressed in percent saturation as well as milligrams per litre (mg/l).

Historically, oxygen data on Lake Ontario have been collected only in recent years. The Great Lakes Institute, University of Toronto, gathered extensive data in the early 1960's, (Rodgers, 1963, 1964 and 1965). Beeton (1965) quoting data from the Great Lakes Institute's 1962 Survey, lists oxygen saturations of 50 to 60 percent in deep water during the winter. Dobson (1967) summarized oxygen levels in Lake Ontario, from data collected during the summer of 1966. His data showing moderate depletion in the bottom waters correspond to the survey data collected in 1965 by the FWPCA and in 1967 by NHW. The lowest median lake-wide value observed for bottom waters, for any one cruise, was 82 percent saturation in mid-September, 1967.

During the summer season, waters in Lake Ontario can be classified on the basis of dissolved oxygen into four zones: the epilimnion, the thermocline, the hypolimnion, and the near bottom waters. Water in each of these zones is influenced by different conditions and thus displays different characteristics.

Following the spring overturn, the lake water is saturated with oxygen. The epilimnion becomes super-saturated with oxygen in May and June, because of the increased temperature of the water and the photosynthetic production of oxygen by the spring algal bloom. By mid-July, the water becomes less saturated as equilibrium conditions are developed with the atmosphere. In September, the fall algal bloom again raises oxygen levels slightly above saturation. With the cooling of the epilimnion in October, the water becomes under-saturated with respect to its lower temperature until equilibrium is again re-established (Fig. 2.3.19 and 2.3.20).

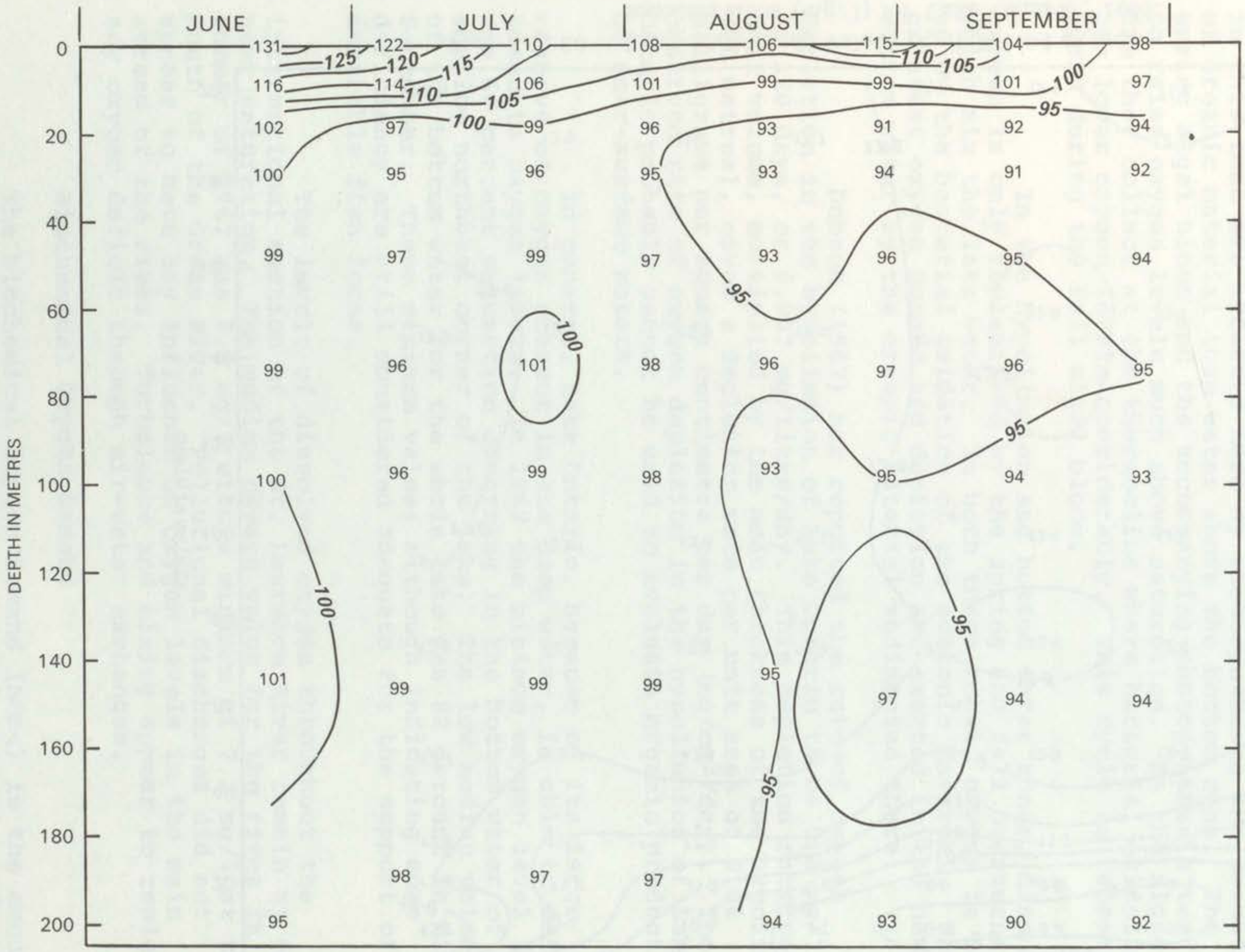


Fig. 2. 3. 19 Lake-wide mean values of percent saturation of oxygen for Lake Ontario, 1966.

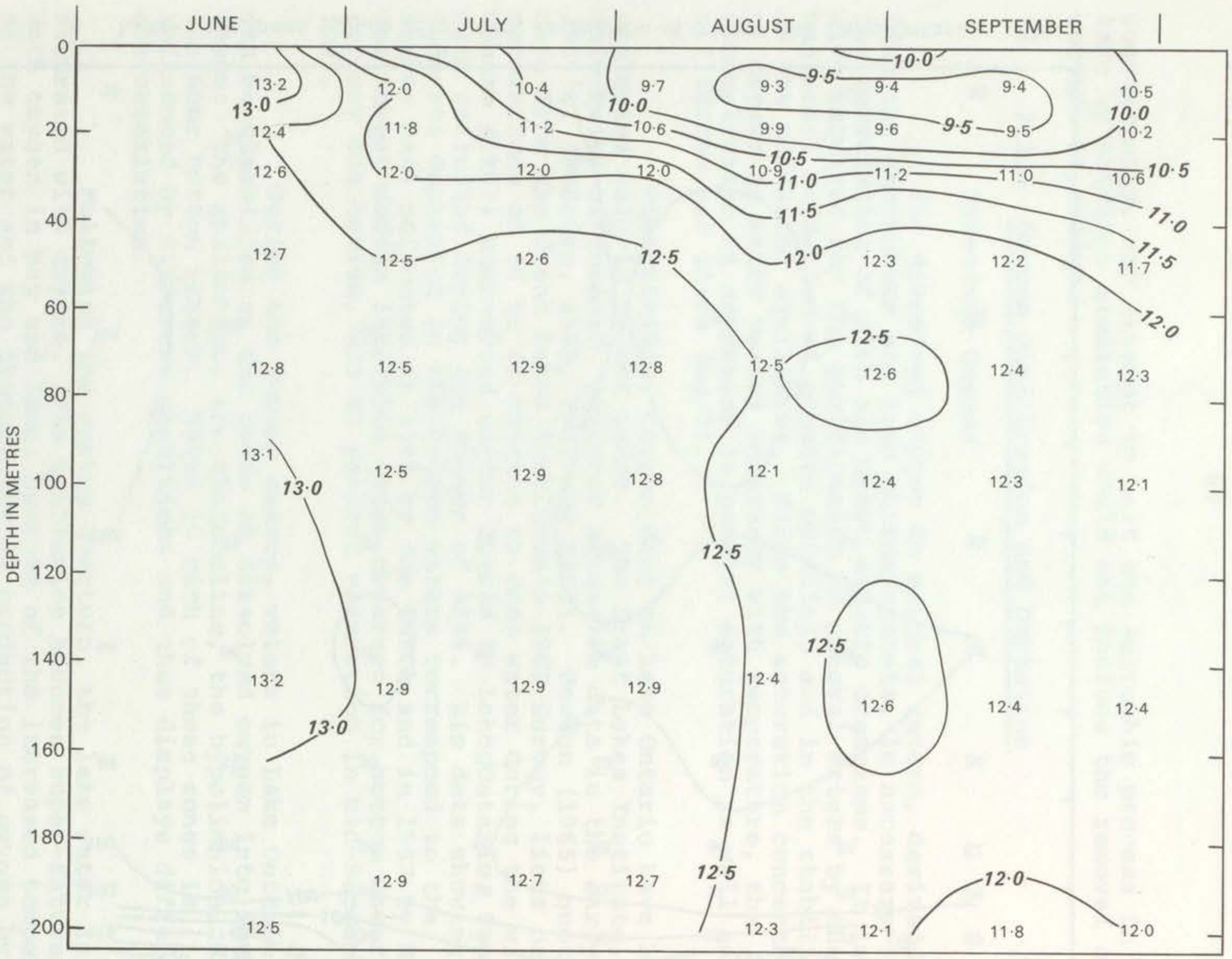


Fig. 2. 3. 20 Lake-wide mean values of dissolved oxygen concentration (mg/1) for Lake Ontario, 1966.

In the thermocline zone, the concentration of algae and the algal debris are usually the greatest. Oxygen levels in this zone are affected more by photosynthesis and oxidation of organic material than water above the bottom zone. The spring algal bloom and the accompanying photosynthesis tend to raise oxygen levels much above saturation. As the algae die they collect at the thermocline where bacterial oxidation can lower oxygen levels considerably. This cycle is repeated again during the fall algal bloom.

In the hypolimnion and bottom water zones, dissolved oxygen is only replenished by the spring and fall overturns, which mix the lake water. In both these zones, oxygen is used up by the bacterial oxidation of the sestonic material. The greatest oxygen demand and depletion are exerted in the near bottom water by the organic material sedimented there.

Dobson (1967) has reported the rate of oxygen depletion in the hypolimnion of Lake Ontario to be 0.8 mg/l in 120 days, or 0.007 mg/litre/day. This depletion rate per unit volume, multiplied by the mean thickness of the hypolimnion (80 metres), gives a depletion rate per unit area of 0.06 milligrams per square centimetre per day ($mg/cm^2/day$). The observed rate of oxygen depletion in the hypolimnion of Lake Ontario probably cannot be used to evaluate organic productivity of near-surface waters.

In general, Lake Ontario, because of its large reserve of oxygen present in the deep water, is able to maintain adequate oxygen levels. In 1967 the minimum oxygen level found was 60 percent saturation occurring in the bottom water of the shallow northeast corner of the lake. The low median value of the bottom water for the whole lake was 82 percent in mid-September. These minimum values although indicating some deficiency are still considered adequate for the support of desirable fish forms.

The levels of dissolved oxygen throughout the international section of the St. Lawrence River remain at or near saturation. The median oxygen value for the river in the summer of 1967 was 8.5 mg/l with a minimum of 7.2 mg/l at the mouth of the Grass River. Pollutional discharges did not appear to have any influence on oxygen levels in the main stream of the river. Turbulence and mixing appear to replenish any oxygen deficit through air-water exchanges.

Biochemical Oxygen Demand

The biochemical oxygen demand (BOD_5) is the amount of oxygen required for a five day bacterial oxidation of organic material in water at 20°C. It is measured in mg/l oxygen. In lakes with large depth-to-volume ratios the test for BOD_5 has only minor significance. The oxygen deficit which occurs in bottom waters over the season is a more significant measure of the effect of biodegradable organic matter on the lake.

Studies of Lake Ontario in 1965 by FWPCA and in 1967 by NHW consistently gave values below 2 mg/l which is near the accuracy limit of the test. In general, bottom samples gave higher values than other samples.

The levels of biochemical oxygen demand in the St. Lawrence River compare favourably with those found in Lake Ontario. As in the lake, the values obtained were near the accuracy limit of the tests. In general, values decreased slightly between Kingston and Cornwall (1.4 to 0.8 mg/l). The highest median value for the season was obtained below Gananoque.

BOD_5 is not considered to be a significant test at the levels presently found in the river.

2.3.4 Major Ions and Trace Elements

Beeton (1965) has compiled data from the Great Lakes which summarize concentrations and increases of major ions in each lake since 1850 (Fig. 2.3.21). In Lake Ontario little change is evident from 1854 to 1910. Since 1910, Lake Ontario, as well as Lake Erie, Huron and Michigan, have shown increases in sodium, chloride, calcium and sulphate (Table 2.3.1). The rate of increase for sodium and chloride has been accelerating since 1910, while for calcium the rate of increase has decreased since 1930 (Dobson, 1967). The overall ionic concentration rate increase for Lake Ontario is 4 percent per decade (Table 2.3.2).

The build-up of major ionic species at an accelerated rate since 1910 can be directly attributed to man's use of the Great Lakes as receiving water for municipal, industrial and agricultural wastes. The buildup of the major ions is not a serious problem in itself for the immediate future of the lake, but it does serve to indicate the large amount of organics and nutrients being discharged along with the major ions. The total ionic content is higher than the world wide river average 6.44 *versus* 2.83 milliequivalents per litre (Dobson, 1967) (Table 2.3.3), even though this is only 0.5 percent of the average sea water concentration. The largest portion of the ionic increase in the lake is made up of sodium and chloride.

The distribution of major ions throughout the lake seems to be very uniform. Except in shore areas or near

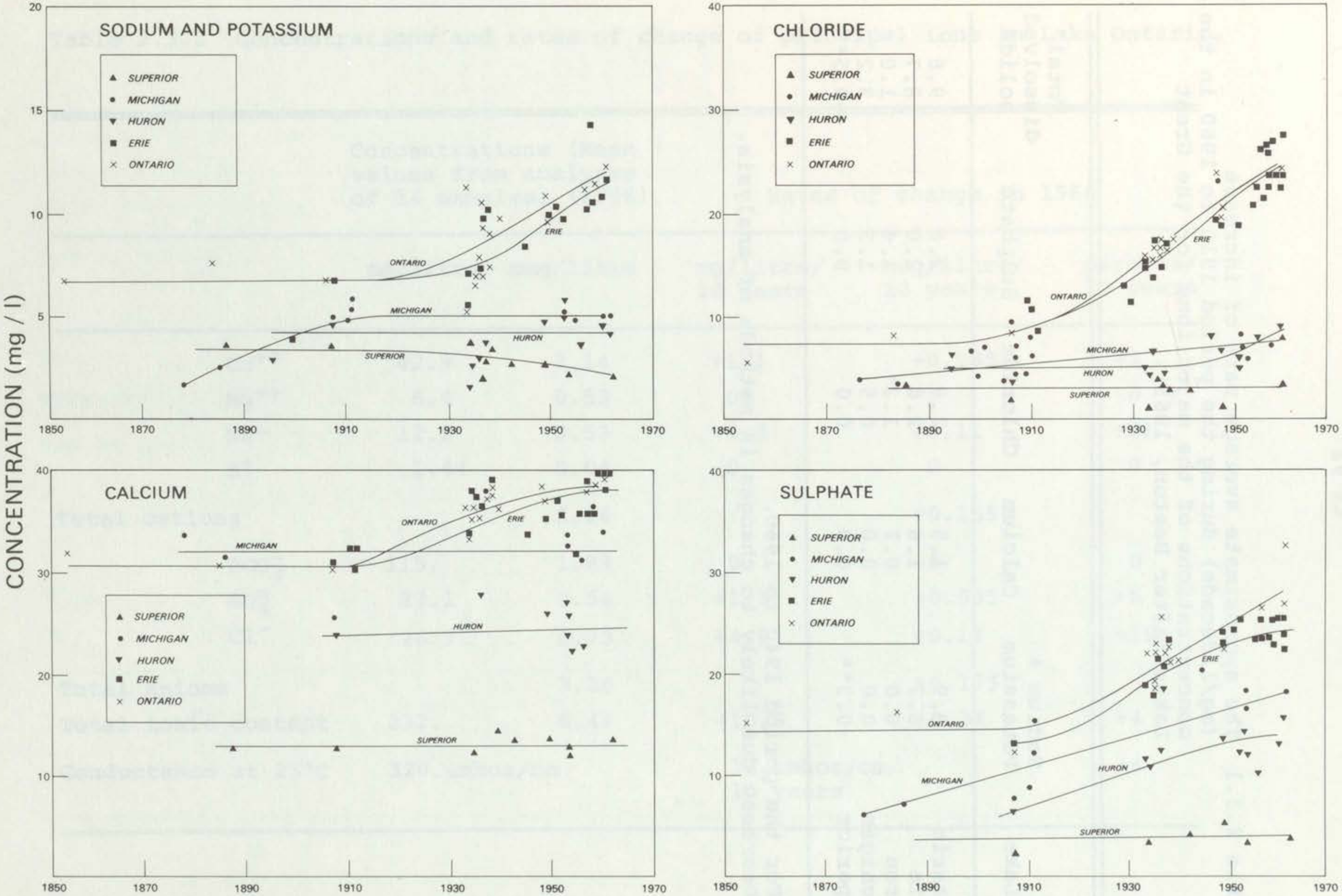


Fig. 2.3.21 Changes in the chemical characteristics of Great Lakes waters (After Beeton, 1965).

Table 2.3.1 The approximate average rate of increase (mg/l/decade) during the period 1910 to 1960 in the concentrations of the major ions for the Great Lakes (After Beeton, 1965).

Lake	Sodium + Potassium	Calcium	Chloride	Sulphate	Total dissolved solids
Ontario	0.9	1.5	2.9	2.6	9.6
Erie	0.7	1.6	2.8	2.0	8.7
Huron	0.0	0.2	1.2*	1.4	1.0
Michigan	0.0	0.0	0.5	1.3	3.2
Superior	-0.3**	0.0	0.0	0.0	-0.5**

*For the period 1940 to 1960.

**Decrease due likely to changes in methods of analysis.

Table 2.3.2 Concentrations and rates of change of principal ions in Lake Ontario.

	Concentrations (Mean values from analyses of 14 samples) (1966)		Rates of change in 1966		
	mg/litre	meq/litre	mg/litre/ 10 years	meq/litre/ 10 years	percent/ 10 years
Ca^{++}	42.9	2.14	+1.1	+0.055	+3
Mg^{++}	6.4	0.53	0	0	0
Na^{+}	12.2	0.53	+2.6	+0.11	+21
K^{+}	1.44	0.04	0	0	0
Total cations		3.24		+0.165	
HCO_3^-	115.	1.89	0	0	0
$SO_4^=$	27.1	0.56	+1.7	+0.035	+6
Cl^-	26.7	0.75	+4.9	+0.14	+19
Total anions		3.20		+0.175	
Total ionic content	232.	6.44	+10.3	+0.34	+4
Conductance at 25°C	320.µmhos/cm		12.µmhos/cm/ 10 years		+4

Table 2.3.3 The chemical composition of some natural waters (units are milliequivalents per litre).

	Rainwater in the Great Lakes basin	Lake Superior	World-average riverwater	Lake Ontario in 1966	Mean seawater*
Ca^{++}	0.052	0.65	0.75	2.14	21.0
Mg^{++}	-	0.24	0.34	0.53	109.0
Na^{+}	0.005	0.052	0.27	0.53	480.0
K^{+}	0.003	0.012	0.06	0.04	10.0
Sum of cations	-	0.95	1.42	3.24	620.0
Alkalinity	-	0.83	0.96	1.89	2.4
$SO_4^{=}$	0.063	0.075	0.23	0.56	57.6
Cl^{-}	0.004	0.039	0.22	0.75	560.0
Sum of anions	-	0.95	1.41	3.20	620.0
Total ionic content	-	1.90	2.83	6.44	1,240.0

*Salinity - 34.7 parts/thousand

outflows or tributary streams, the lake presents a very homogeneous ionic situation. A minor variation in concentration of calcium and alkalinity between surface and bottom water occurs throughout the lake during the summer stratification period. A likely explanation is the change in solubility of calcium carbonate with the rise in temperature, and its subsequent precipitation. Hardness, alkalinity and conductivity all show decreases in concentration in the warm epilimnetic waters.

Chloride

Chloride is present in water as the dissociated ion Cl^-. Chloride in natural water is leached from soil and rock by rainfall, however, chloride addition also occurs through the discharge of industrial and municipal waste and road de-icing operations. Chloride salts are very soluble and once in solution, the concentration is changed only through evaporation or dilution because there are almost no biogeochemical controls or regulation.

Since all discharges to the Great Lakes system eventually reach Lake Ontario before passing through the St. Lawrence River, the highest concentration of chloride is found in this lake. The concentration of chloride, as of the other major ions, was relatively constant before 1910. The value observed in 1907 was about 7 mg/l (Beeton, 1965). Extensive chloride analyses of offshore waters carried out for this survey by the FWPCA in 1965 and NHW in 1966 and 1967 gave median values of 25, 26 and 26.8 mg/l, respectively.

Chloride, as the other major ions, is evenly distributed throughout the lake. Minor fluctuations near the shore occur where the influence of tributary streams is observed (Section 3.2). Chloride is quite homogeneous with depth but does generally show slightly higher concentrations in the surface water. Although chloride is increasing in the lake, the concentration increase is not large enough to affect the water quality for most purposes in the foreseeable future.

The chloride levels found in the St. Lawrence River by NHW in 1966 and 1967 portray the levels found in Lake Ontario. No significant variations occur in the river between Kingston and Cornwall. The United States Public Health Service (1963) reported chloride levels at Massena, New York, of 19 to 28 mg/l.

Alkalinity

Alkalinity of natural waters is primarily due to the presence of carbonates and bicarbonates with other salts of weak acids adding a minor contribution. During algal activity, carbonate and hydroxide may also contribute appreciably to alkalinity in surface waters. Alkalinity is expressed here as the equivalent amount of calcium carbonate in mg/l.

Alkalinity is relatively constant throughout the central portion of the lake with median values of 90 mg/l in the epilimnion and 93 mg/l in the hypolimnion being observed by NHW. Results from nearshore areas show high alkalinity levels corresponding to greater algal activity in these waters. Surveys of the central lake during 1966 and 1967 do not suggest a long term increase in alkalinity.

The median alkalinity value observed by NHW in the St. Lawrence River was 89 mg/l, and falls in the same range as Lake Ontario surface water. Little variation occurred over the 1965 and 1966 seasons, and throughout the river between Kingston and Cornwall. Values obtained from the mouth of the Grass and St. Regis Rivers varied considerably from the main river flow but had no measurable effect on the main stream.

These findings substantiate the results of the United States Public Health Service (1963) in their annual compilation of data of their Water Pollution Surveillance System. Data collected from 1962 to 1963 showed alkalinities varying between 74 and 95 mg/l, with relatively low values being observed in April and May.

Total Hardness

The hardness of water is the total amount of calcium and magnesium present in water, expressed in terms of an equivalent amount of calcium carbonate in mg/l. It is present in water by the natural chemical and biological dissolution of calcium and magnesium carbonate from sedimentary rocks. Waters are commonly classified in terms of the degree of hardness. Lake Ontario water falls in the range of 75 to 150 mg/l and is therefore considered moderately hard.

Lake Ontario exhibits a slightly higher hardness than Lake Erie because it is the last major lake in the Great Lakes system. The median value observed by NHW in 1966 and 1967 was found to be 132 mg/l, with no significant variations occurring in different areas of the lake throughout the sampling seasons.

In the St. Lawrence River, hardness values are relatively consistent, ranging between 126 to 130 mg/l in surveys carried out by NHW in 1965, 1966 and 1967 and the United States Public Health Service (1963). Samples taken from the mouth of the St. Regis River had a median hardness value of 43 mg/l, but the flow of this tributary is too small to cause any change in the main stream.

Sulphate

Sulphate is the final oxidation state of sulphur reported here as mg/l sulphate (SO_4). It occurs naturally in water from the dissolution of sulphate-containing rocks, by the breakdown and oxidation of organic sulphur compounds and by the oxidation of hydrogen sulphide. It is also added in the waste water of industrial and municipal effluents. Sulphate can be broken down to hydrogen sulphide gas by sulphate-reducing bacteria under reducing conditions, and also precipitates out with calcium in concentrated solutions. It does not appear to be removed from solution to any extent in Lake Ontario.

Sulphate in Lake Ontario was relatively constant at 13 mg/l between 1850 and 1900, but since 1900 it has more than doubled to 27.5 mg/l in 1967 (Fig. 2.3.21). Dobson (1967), has indicated that the rate of increase has declined since 1930.

No horizontal or vertical distribution patterns were established for sulphate in Lake Ontario because of the small number of samples analyzed. Sulphate appears, however, to be relatively constant throughout the lake.

The levels of sulphate in Lake Ontario, although they are increasing, have no significance for foreseeable water usage.

Sodium and Potassium

Sodium and potassium, until the advent of flame photometry, were commonly measured together in water analyses. Beeton (1965), reported the levels of sodium and potassium as unchanged at 6 mg/l from 1850 to 1900. Since 1900 the sodium levels have risen at a rate similar to that of chloride (Fig. 2.3.21). Potassium, however, is still less than 2 mg/l and may be assumed to be relatively constant. The median sodium value found in 1967 by EMR was 12.2 mg/l. Sodium and potassium like the other major ions are evenly distributed throughout the lake with little horizontal or vertical variation. The increase of sodium, like chloride, points to man's usage of the lakes as receiving waters, but does not pose any immediate danger to the use of the lake or lake water for most purposes.

Iron

Iron present in rock and soil is released to natural water by bacterial reduction in the presence of organic matter. While ferrous iron is quite soluble in water, it is readily oxidized to the insoluble ferric state and precipitated out. In the waters of oxygen-rich lakes like Lake Ontario little iron is present due to this natural oxidation and sedimentation process.

Historically, total iron has been measured at water treatment plants in Lake Ontario for a number of years. The Ontario Water Resources Commission (OWRC) analyzed samples for total iron from the middle of Lake Ontario during the winter of 1962 to 1963. Values ranging between 50 to 200 µg/l were observed.

Data collected in the spring of 1967 by NHW gave values of total biologically available iron ranging from 4 to 25 µg/l with a median for the whole lake of 7 µg/l. Maximum values were found in the surface waters of the western basin (Fig. 2.3.22).

The trace metal studies carried out in connection with surveys of EMR included samples for total iron throughout the summer and fall of 1967. Median values obtained were 22 µg/l at the surface, 17 µg/l at 50 metres, and 14.5 µg/l at the bottom of the lake.

The levels of total biologically available iron found by NHW in surveys carried out in 1967 in the St. Lawrence River ranged from 2 to 20 µg/l and are similar to values found in Lake Ontario. United States Public Health Service data on total iron collected from 1962 to 1963 at Massena, New York, ranged from 3 µg/l to 171 µg/l.

Trace Elements

Trace metals were analyzed at three stations in Lake Ontario for seven cruises in the summer and fall of 1967. The data are presented in Table 2.3.4, listing median and maximum values. Except for samples from one cruise where sample contamination is suspected, all values fell well within the maximum allowable limits of potable water (World Health Organization, 1963).

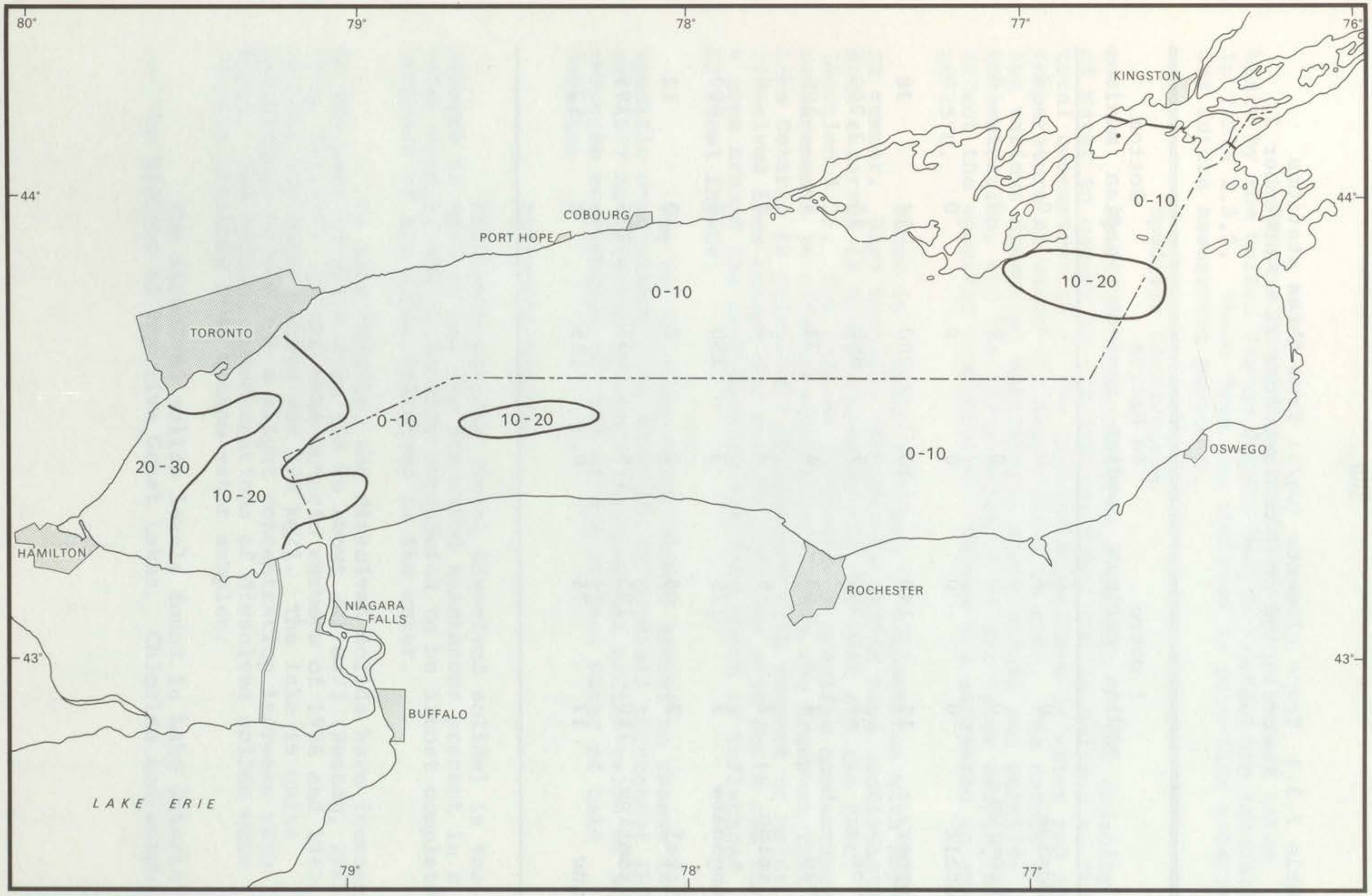


Fig. 2.3.22 Distribution of biologically available iron ($\mu g/1$) in surface waters, spring, 1967.

Table 2.3.4 Trace elements (μg/l) from three stations collected on 7 cruises June 11 to November 2, 1967.

	1 Metre		50 Metres		Bottom	
	median	maximum	median	maximum	median	maximum
Cadmium	0	2	0	2	0	2
Chromium	0	0	0	0	0	0
Cobalt	0	0	0	0	0	0
Copper	15	145	10	2,200	14	38
Iron	22	900	17	800	15	3,000
Lead	4	63	4	74	4	100
Lithium	2	6	2	5	3	6
Manganese	3	135	5	150	4	800
Nickel	2	6	2	6	2	12
Strontium	180	195	175	200	175	195
Zinc	17	75	8	185	8	120

Trace element data collected in the Great Lakes basin by the United States Public Health Service are tabulated in Table 2.3.5. These data are included as base-line material for future assessment purposes.

Specific Conductance

Specific conductance is a measure of the capacity of water to convey an electric current, and is related to the total concentration of the ionized substances in water and the temperature at which the measurement is made. The nature of the various dissolved substances, their actual and relative concentration, and the ionic strength of the water sample, all affect the specific conductance. Values are expressed in µmhos/cm at 25°C.

There is a minor increase in conductance with depth in summer. High specific conductance values have consistently been observed in nearshore waters by the OWRC and the FWPCA (Section 3.2). The lack of variation in specific conductance measurements in offshore waters reinforces the argument that Lake Ontario is relatively homogeneous with respect to major dissolved ions except for a minor increase with depth and for a zone around the periphery of the lake which is influenced by local inputs.

The St. Lawrence River showed almost no change in specific conductance from Kingston to Cornwall throughout 1966 and 1967 as observed by NHW. The seasonal median value of 316 µmhos/cm corresponds to that of the surface water of Lake Ontario.

Filtrable Residue

Filtrable residue (total dissolved solids) is the measure in mg/l of all the dissolved substances present in a water sample, and is usually considered to be almost completely composed of the salts dissolved in the water.

In Lake Ontario, the dissolved solids have increased in the past 50 years from 150 to about 200 mg/l (Beeton, 1965) (Fig. 2.3.23). In the Lake Ontario surveys of 1966 and 1967 by NHW, the median value was 196 mg/l. The lake is quite homogeneous except for a slight concentration increase with depth. The highest concentrations of dissolved solids were usually obtained from bottom water samples.

The dissolved solids levels found in Lake Ontario are the highest of the five Great Lakes. Chloride and sulphate

Table 2.3.5 Trace elements as measured at stations in the Great Lakes basin, (After United States Public Health Service, 1963).

	E Element	Symbol	St Lawrence R. at Massena		Lake Erie at Buffalo		Detroit R. at Detroit		St. Mary's R. at S. Ste. Marie		Lake Superior at Duluth	
Composite Interval			A	B	A	B	A	B	A	B	A	B
Results in mg/l	Fluorine	F	.33	3.05	.15	.10	.02	.05*	.15	.05	.05	.10
	Sodium	Na	13	12	12	11	4.0	3.7	6.2	1.9	2.0	2.5
	Potassium	K	1.6	1.3	1.7	1.2	1.2	1.0	0.9	0.4	0.9	0.5
Results in µg/l	Zinc	Zn	9	4	210	295	9	6	406	2	1*	5
	Cadmium	Cd	2*	2*	5	4	1*	1*	1*	1*	1*	1*
	Arsenic	As	18*	17*	17	19*	9*	11*	12*	5*	5*	8*
	Boron	B	23	23	31	27	10	12	13	8	8	11
	Phosphorus	P	27	8*	4	10*	7	6*	33	3*	22	6
	Iron	Fe	171	3*	84	7	62	12	168	3	66	6
	Molybdenum	Mo	4	4*	3*	11	15	3*	1*	1*	1*	5
	Manganese	Mn	.4*	1.7*	.8	1*	.5	1*	.6	3	3*	4*
	Aluminum	Al	--	84	--	11	--	6*	--	3	--	5
	Beryllium	Be	.05*	.04*	.04*	.05*	.02*	.03*	.03*	.01*	.01*	.02*
	Copper	Cu	2	8	56	37	9	7	28	6	4	3
	Silver	Ag	.4*	.4*	.3*	.5*	.2*	.3*	.2*	.1*	.1*	.2
	Nickel	Ni	1*	2*	2*	2*	1*	1*	28	1*	1*	1*
	Cobalt	Co	4*	2*	3*	2*	2*	1*	2*	1*	1*	1*
	Lead	Pb	9	4	4	5*	9	3*	6*	2*	1*	3*
	Chromium	Cr	10	25	1*	5*	1*	3*	1*	1*	1*	2*
	Vanadium	V	2*	8	2*	10*	1*	6*	1*	3*	1*	4*
	Barium	Ba	27	21	12	18	17	9	34	6	13	8
	Strontium	Sr	81	84	126	89	55	45	19	13	21	27

A = sampling interval October 1, 1962 to December 31, 1962. B = sampling interval April 1, 1963 to June 30, 1963.

* Actual value less than amount shown. Reported result indicates limit of sensitivity at which test was performed.

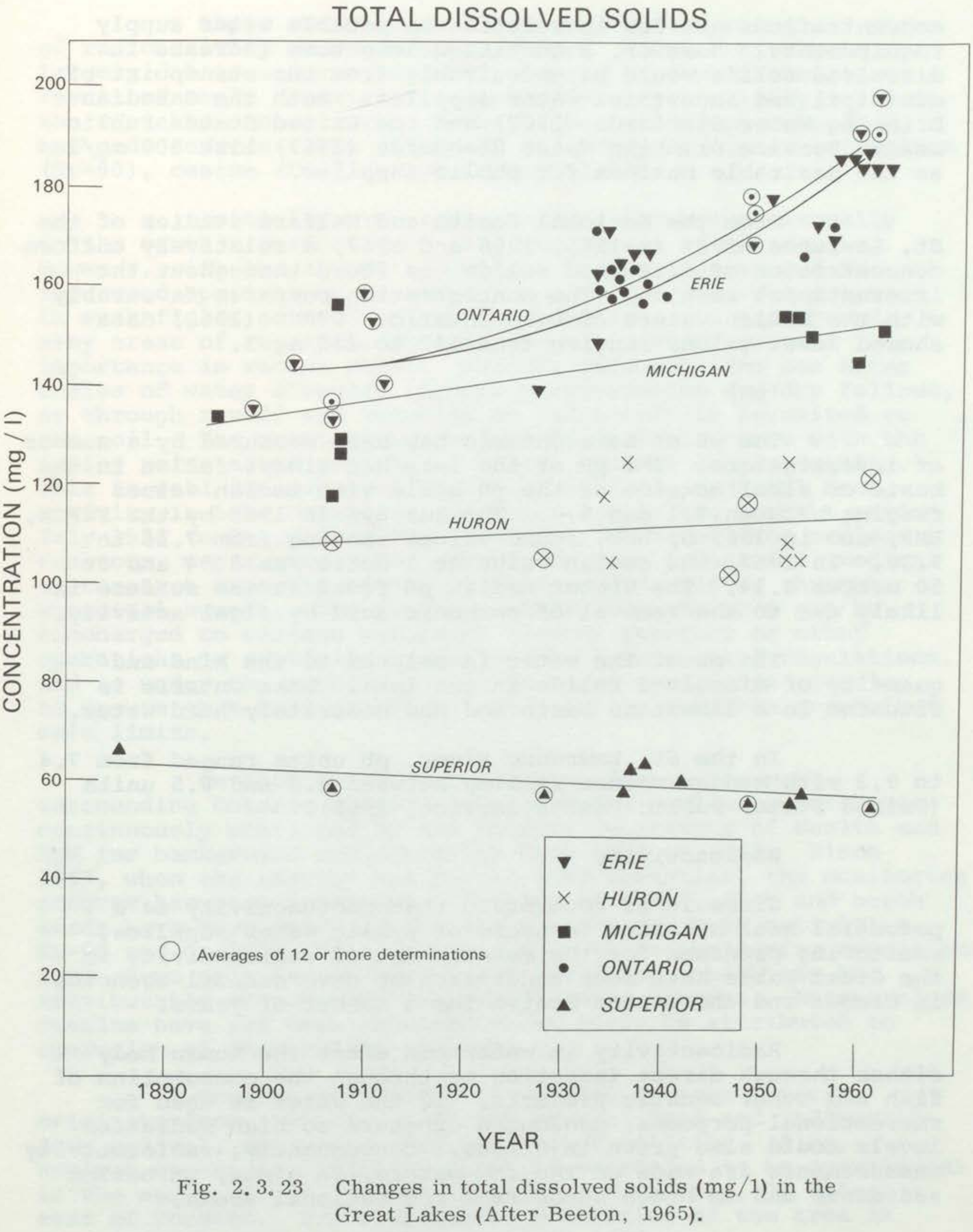


Fig. 2. 3. 23 Changes in total dissolved solids (mg/1) in the Great Lakes (After Beeton, 1965).

concentrations are low in relation to potable water supply requirements. However, a continued long term increase in dissolved solids would be undesirable from the standpoint of municipal and industrial water supplies. Both the Canadian Drinking Water Standards (1968) and the United States Public Health Service Drinking Water Standards (1962) list 500 mg/l as the desirable maximum for public supplies.

From the National Health and Welfare studies of the St. Lawrence River in 1965, 1966 and 1967, a relatively uniform concentration of dissolved solids was found throughout the international section. The concentration compares favourably with the median values of Lake Ontario. USPHS (1963) data showed lower values ranging from 142 to 212 mg/l.

(pH)

The pH of Lake Ontario has been measured by a number of investigators. The pH of the lake has always fallen in the basic or alkaline side of the pH scale with median values ranging between 7.1 and 9.0. The surveys in 1965 by the FWPCA, EMR, and in 1967 by NHW, found values ranging from 7.15 to 9.30. In 1967, the median value at 1 metre was 8.54 and at 50 metres 8.14. The higher median pH found at the surface is likely due to the removal of carbonic acid by algal activity.

The pH of the water is related to the kind and quantity of dissolved solids in the lake. Lake Ontario is situated in a limestone basin and has moderately hard water.

In the St. Lawrence River, pH units ranged from 7.4 to 9.3 with median values falling between 8.3 and 8.5 units (United States Public Health Service, 1963).

Radioactivity

Since it is recognized that radioactivity is a potential health hazard to users of public water supplies, monitoring programs for the measurement of radioactivity in the Great Lakes have been undertaken by governmental agencies in Canada and the United States for a number of years.

Radioactivity in water can enter the human body either through direct ingestion or through the consumption of fish and other aquatic products. If the water is used for recreational purposes, prolonged exposure to high radiation levels could also prove injurious. Consequently, radioactivity measurements are made on the raw waters, on biota, on bottom sediments and on beach sands from recreational areas.

Alpha and beta activity are the two principal forms of radioactivity encountered in water. Alpha activity is largely due to natural sources, whereas beta radiation is a result of man's activities. Generally, beta activity reflects the variable contamination from fallout and discharges from man-made sources. The principal fallout products are strontium (Sr-90), cesium (Cs-137) and iodine (I-131).

Initially, the radionuclides occurring naturally in the earth's surface were the main causes of concern. However, with the advent of nuclear weapon testing and the increased application of nuclear energy for peaceful purposes in such fields as nuclear reactors, medicine, industry and many areas of research, the problem has assumed greater importance in recent years. Fallout radionuclides can enter bodies of water directly through precipitation and dry fallout, or through runoff and leaching of radioactivity deposited on the soil. The greatest percentage of fallout occurs with the spring rains after periods of active nuclear weapon testing. This is well demonstrated in Fig. 2.3.24, where total beta activity in Lake Ontario at Hamilton is plotted for the period July 1958 to December 1965. Radioactive wastes from nuclear reactors, waste processing plants and from industrial, medical or research uses are either discharged directly or through municipal sewers. The amount of radioactivity that can be discharged to surface waters by nuclear reactors or other operations is carefully controlled by governmental regulations, and is under the regular surveillance of government agencies to ensure that radioactivity levels are held within prescribed safe limits.

On Lake Huron, for example, the environment surrounding Ontario Hydro's Douglas Point nuclear reactor was continuously monitored by the Ontario Department of Health and NHW for background radioactivity from 1963 to 1967. Since 1967, when the reactor was placed into operation, the monitoring program has been continued. Samples of water, fish and beach sands have been analyzed for gross alpha and beta activities, Sr-90 and Cs-137. Data obtained from these monitoring operations have shown only low levels of radioactivity, which can be attributable to uncontrollable background sources. No anomalous results have yet been obtained which could be attributed to operation of the nuclear reactor.

Sources of radioactive wastes to Lake Ontario originate from a uranium refinery at Port Hope and indirectly 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 east of Toronto. Pre-operational monitoring of the area in the vicinity of this station began in 1968.

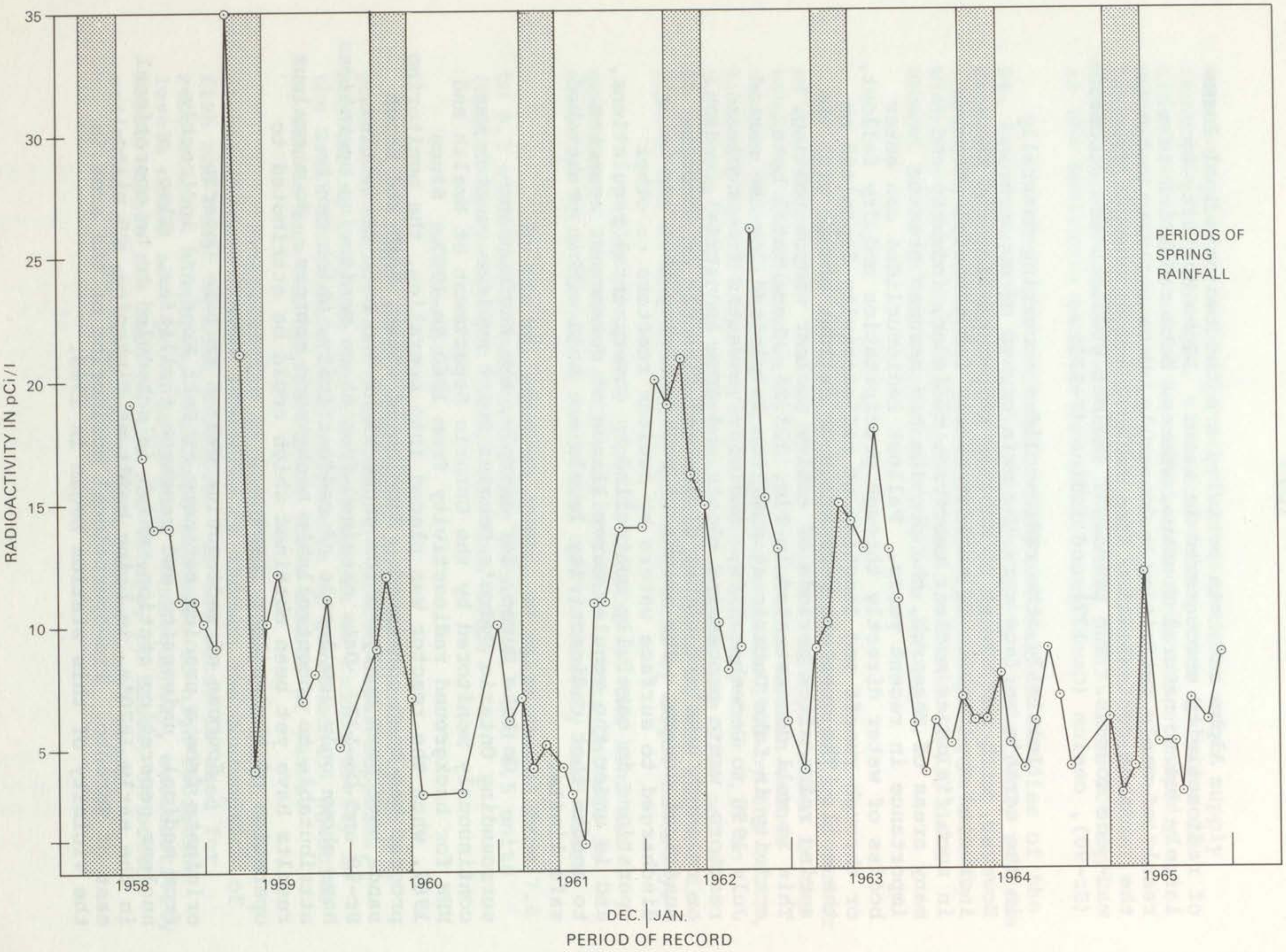


Fig. 2. 3. 24 Total beta radioactivity observations (pCi/1) measured by the Hamilton Municipal Laboratory, 1958 - 1965.

The concentrations of Sr-90 and Cs-137 in the Toronto drinking water were the lowest of all lake-derived sources studied in a national drinking water monitoring program of NHW. Average values over a four-year period for the Toronto supply were 1.02 pCi/litre (pCi/l) for Sr-90 and 0.17 pCi/l for Cs-137 compared to the national average of 2.20 pCi/l and 0.25 pCi/l respectively. The annual averages for individual sources given in Table 2.3.6, show the Sr-90 concentration in the Winnipeg supply to be approximately four times higher than the Toronto supply. The other supplies are substantially higher in Sr-90 content. There is also little difference in fallout radioactivity deposited in each area, as revealed through analysis of precipitation samples. It should be emphasized that all the values given are well below maximum permissible concentrations recommended by the International Commission for Radiological Protection.

2.3.5 Other Characteristics

Turbidity and Colour

Turbidity is a measure of the interference presented by suspended particles to the passage of light through water. Although it is related to the concentration of suspended solids, turbidity is dependent on the size and number of particles in the water rather than their weight. Turbidity results are generally expressed in Jackson Turbidity Units (JTU). Secchi disc measurements also give a measure of turbidity or water clarity by determining the depth in metres at which a circular white disk disappears from view, when lowered into the water.

Turbidity in natural water is caused by phytoplankton, clay, silt and organic debris suspended in the water. In Lake Ontario, the largest portion of the turbidity can be attributed to phytoplankton with only a small portion made up of clay and silt except at the time of spring runoff. Consequently, in Lake Ontario, turbidity observations reflect phytoplankton standing crop, and can, therefore, be used as a tool in estimating the state of eutrophication.

Few historical data are available on turbidity measurements in Lake Ontario, although Secchi disc measurements have been made for a number of years by Rodgers (1963, 1964, 1965). Both Secchi disc and turbidity measurements were made in 1966 and 1967 by EMR and NHW.

In 1967 turbidity measurements from Lake Ontario ranged between 0.2 and 2.5 JTU, while Secchi disc measurements ranged from 1.5 to 7.5 with a median value of 3.5 metres for the season.

Table 2.3.6 Summary results of strontium, Sr-90 (pCi/l) and cesium, Cs-137 (pCi/l) in tap water supplies derived from lakes

Supply	Source	Treatment	1964		1965		1966		1967	
			Sr-90	Cs-137	Sr-90	Cs-137	Sr-90	Cs-137	Sr-90	Cs-137
Winnipeg, Man.	Shoal Lake and Lake of the Woods	ammoniation and chlorination	2.62	0.49	5.42	0.30	4.39	0.19	3.72	0.13
Fort William, Ont.	Loch Lomond	chlorination	1.88	0.40	2.03	0.40	2.24	0.19	1.90	0.11
Toronto, Ont.	Lake Ontario off Toronto Island and Victoria Park	sedimentation, rapid sand filtration, chlorination, alum coagulation	0.85	0.24	1.08	0.24	1.13	0.15	1.01	0.05
St. John, N.B.	Loch Lomond	chlorination	1.77	0.53	1.65	0.27	1.35	0.23	1.14	0.09
St. John's, Nfld.	Windsor Lake	screening, liming, and chlorination	2.72	0.85	3.28	0.64	2.18	0.51	1.55	0.30

The areal distribution of turbidity measurements showed high turbidity in the nearshore areas, especially in the western basin and near the metropolitan centres of population (Fig. 2.3.25). The deep water areas of the lake in the central and eastern basins had relatively low median turbidities. The areal distribution is similar to the patterns found for Kjeldahl-nitrogen and non-filtrable residue and supports the view that turbidity in the offshore lake waters is largely a result of phytoplankton activity.

Seasonally, turbidity follows the pattern of phytoplankton blooms, with a peak occurring in July and early August, followed by a minor peak in September. Kjeldahl-nitrogen has a similar distribution although the fluctuations are less pronounced.

The studies made on turbidity indicate that this parameter can be used as an indicator of phytoplankton activity. The deep areas of Lake Ontario are relatively free of turbidity and indicate low productivity. Turbidities in the nearshore areas indicate high phytoplankton population but may also be influenced to some degree by the waste discharges from populated areas and by tributary streams. In general, Lake Ontario exhibits a good water quality in terms of turbidity.

Turbidity and Secchi disc readings in the St. Lawrence River are similar to those found in Lake Ontario. Values ranged from 1.5 to 3.0 JTU and from 1 to 7 metres for Secchi disc measurements. Minor increases in turbidity are evident below populated centres (Fig. 2.3.26 and 2.3.27).

Colour of natural waters is primarily due to algae and extracts from decaying leaves and other vegetable matter, but may also be caused by industrial and other man-made wastes. Colour is measured by an empirical scale reported in Hazen units.

The readings for colour in Lake Ontario, as observed by NHW in 1967, were consistently less than 5 Hazen units. No variation with depth or by season were observed in the lake. The value for colour in the St. Lawrence River was 5 Hazen units. High values of up to 70 units were measured at the mouths of the Grass and St. Regis Rivers, however, the flows of these tributary streams are relatively small and do not significantly affect the main river body.

Colour measurements reported by the United States Public Health Service (1963) ranged from 0 to 30 with most values being less than 5.

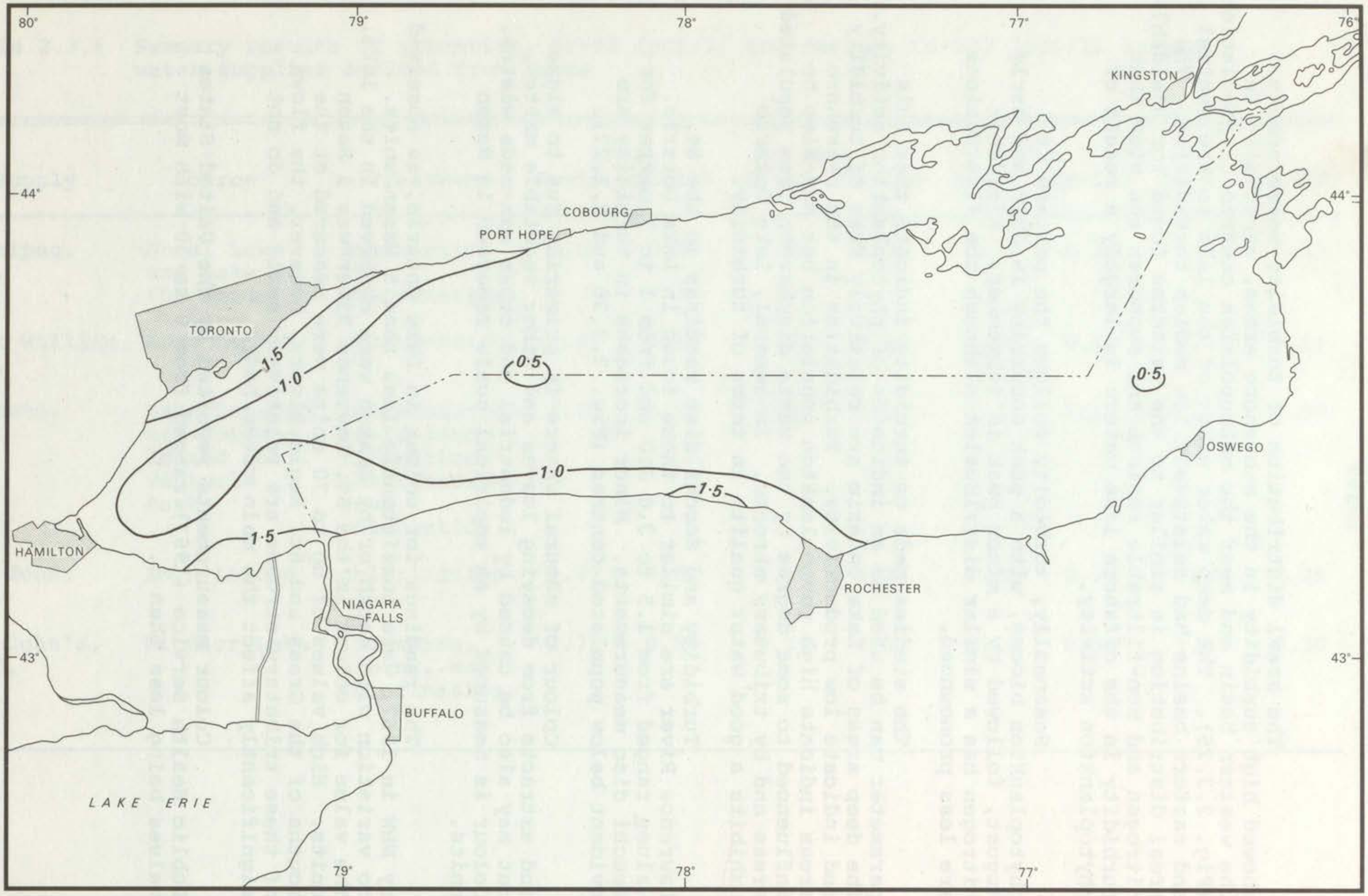


Fig. 2. 3. 25 Distribution of turbidity (JTU) in surface waters (median values, 1967).

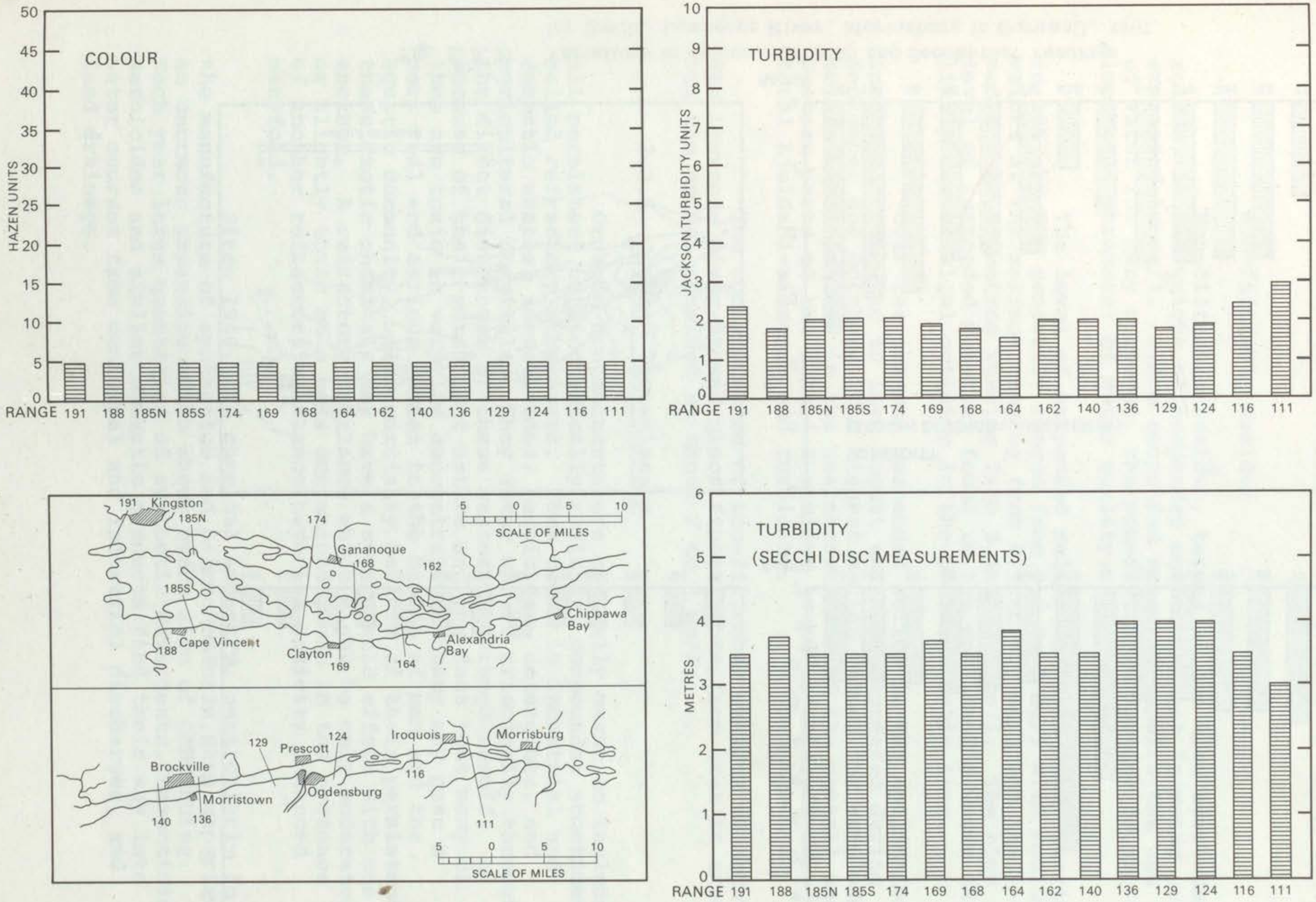


Fig. 2.3.26 Variations in colour, turbidity and Secchi disc readings for the St. Lawrence River, Kingston to Morrisburg, 1967.

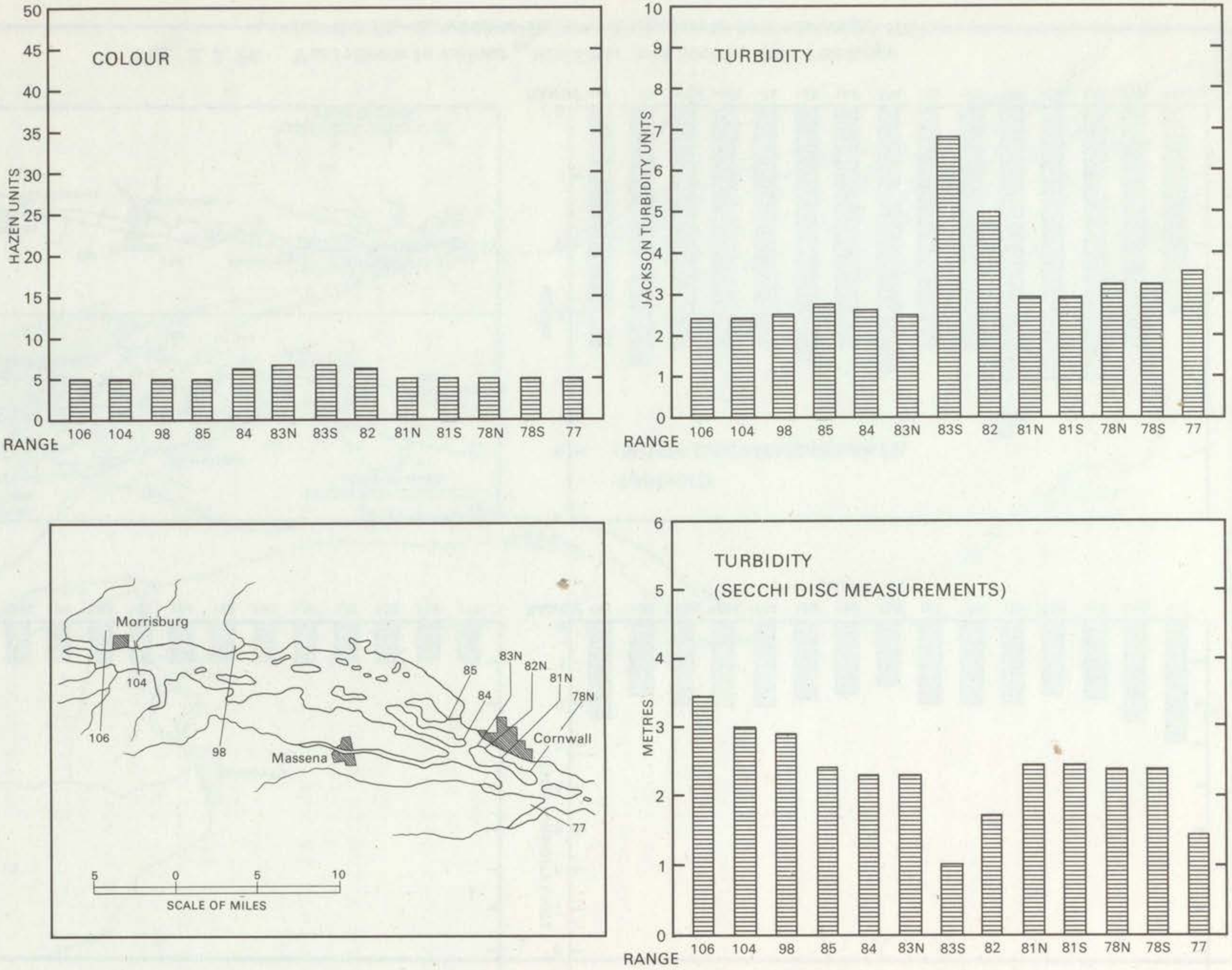


Fig. 2. 3. 27 Variations in colour, turbidity and Secchi disc readings for the St. Lawrence River, Morrisburg to Cornwall, 1967.

Non-filtrable Residue

Non-filtrable residue, termed at one time suspended solids, is the weight of suspended matter present in water expressed in mg/l. Since suspended material impairs the use of water for many purposes, the non-filtrable residue is an important parameter of water quality.

The level of suspended solids found in Lake Ontario in 1967 by NHW generally ranged from 0.5 to 5 mg/l with median values at the surface ranging from 0.9 to 4.3 mg/l and the medians at 50 metres ranging from 0.4 to 3.0 mg/l. The high level of suspended material found in the epilimnetic water is likely due to algal activity in the photosynthetic zone.

Over the season, suspended solids in the epilimnion increased from June to late August and then decreased during September and October. The highest median values for suspended solids were obtained in the nearshore areas of the central and western parts of the lake. A similar trend is observed for total Kjeldahl-nitrogen and turbidity.

The concentration of non-filtrable residue in the St. Lawrence River showed minor fluctuations from area to area, but the median remained at about 2 to 3 mg/l.

2.3.6 Organic Contaminants

Organic contaminants are generally meant to include all persistent or biochemically resistant compounds, sometimes called refractory substances. They occur in industrial and domestic wastes, insecticides, herbicides, detergents, and agricultural chemicals. They enter waters principally through the direct discharges of these wastes or through runoff. Because of their persistent nature and the fact that many of them are toxic in very low concentrations, they may pose a very real and serious threat to the health of man and the aquatic community. Also partially because of their persistency, these exotic chemicals may have a synergistic effect with one another. A refractory substance which might be only moderately or slightly toxic as a sole contaminant, can in the presence of another refractory substance have its toxicity enhanced manyfold.

Since 1940, the chemical industry, particularly in the manufacture of synthetics and petrochemicals, has experienced an enormous expansion which shows every sign of continuing. Each year large quantities of synthetic detergents, insecticides, herbicides and similar domestic products find their way into water courses from municipal and industrial discharges, and land drainage.

These substances many of which resist conventional waste treatment processes and natural purification are creating problems of tastes and odours in public water supplies. Fish kills caused by certain organic contaminants have been reported, while in other cases, they have been sufficiently high to seriously affect fish fertility.

The inevitable increase in water re-use will cause these organic contaminants or refractories to build up with a consequent deterioration in water quality. The problem is further complicated by a lack of information on the levels of these compounds for the Great Lakes. Analytical techniques for quantifying and qualifying these substances at their low levels in water are woefully inadequate, time-consuming and cumbersome.

One of the techniques presently in use for determining the presence of organic contaminants in water makes use of a low flow carbon filter which acts as an adsorption column, thereby removing and concentrating organic constituents from the water. The organics are subsequently recovered through elution with appropriate solvents - usually chloroform and ethyl alcohol. Constituents are then generally identified by infrared spectophotometric or chromotographic techniques. The most common way of reporting organic contaminants in water is in terms of micrograms per litre (µg/l) of carbon chloroform extract (CCE). Because of the possible low recovery efficiencies of the CCE test, reported values must be considered as minima, the actual values being equal to or greater than the reported values.

Since it is extremely difficult to analyze and define the chemical and toxicological nature of these materials, it is a desirable objective that the CCE be maintained at a low level. At concentrations of about 200 µg/l, unfavourable tastes and odours can be detected in water. In comparison, clean surface and ground waters contain about 25-50 µg/l of CCE. Highly coloured water may have somewhat higher concentrations. The most desirable condition is one in which the water supply to the consumer contains no organic residues.

Some data on CCE in the Great Lakes basin have been accumulated by the FWPCA. Table 2.3.7 summarizes these data for 1962 and 1963.

Data have also been obtained from Lake Ontario at the new Toronto Water Purification Plant between July 1, 1967 and May, 1968. The maximum and average concentrations of CCE for samples were 156 and 91 µg/l, respectively.

Table 2.3.7 Maximum concentrations of organic contaminants (CCE) in the Great Lakes basin, October 1, 1962 to September 30, 1963 - recovered by carbon filter technique, (After United States Public Health Service), results in μg/l.

Location	Month	Sampling intervals in days	Gallons filtered	Carbon chloroform extractables μg/l
St. Lawrence R. Massena, N.Y.	September	15	4,660	54
Lake Erie Buffalo, N.Y.	July	8	4,590	66
Detroit R. Detroit, Mich.	June	14	4,890	39
Lake Michigan Milwaukee, Wisc.	August	8	2,707	45
St. Mary's R. Sault Ste. Marie, Mich.	July	14	2,460	67
Lake Superior Duluth, Minn.	June	14	5,100	33

The United States Public Health Service Drinking Water Standards (1962), limit the amount of CCE in water to 200 µg/l. This is also the objective of the OWRC for potable waters under their jurisdiction. In most cases, including the source water for Lake Ontario, Lake Erie at Buffalo, and the St. Lawrence River at Massena, New York the observed CCE values are of the same order as those generally found in clean surface and ground waters. The recent observations near Metropolitan Toronto are higher than desirable but still within current objectives.

Pesticides and Herbicides

Pesticides are another form of organic contaminant which deserves particular attention. Since the introduction of DDT as an insecticide during World War II, the use of organic pesticides has increased enormously. In 1961, it was estimated that more than 9,000 commercial pesticide preparations were available in the United States. Certainly a large number are available today. Many such compounds resist degradation and when applied to foliage, soil, and water courses are translocated into rivers and their tributaries. Furthermore, heavy concentrations can contribute characteristic odours to water supplies and taint the flesh of fish since many of these herbicides and insecticides are highly odourous.

Herbicides and insecticides can reach potable water supplies from aerial spraying, runoff from agricultural areas, percolation through the soil to underground supplies, municipal wastes discharges, and from such food processing industries as canneries. Tests have demonstrated that some of these compounds can persist in the soil for periods longer than 5 years. Accumulations of such chemicals would not be expected to reach water supplies in large amounts from meadows, pasture lands, or other well-sodded areas. The greatest potential contribution of herbicides and insecticides by runoff is probably associated with erosion of cultivated or plowed areas.

Studies in the United States have revealed the presence of pesticides in the major rivers and lakes of that nation (Breidenbach *et al.*, 1967). Those measured were generally found in concentrations of less than 1 µg/l and they were usually the persistent chlorinated hydrocarbon compounds.

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. Observations made in 1965 and data collected elsewhere in the Great Lakes basin are summarized in Table 2.3.8.

Commercial applications of pesticides to land outrank substantially the amounts applied directly to water. However, the direct application of herbicides to water for aquatic weed control purposes is common practice in many areas.

The OWRC requires permits for the application of herbicides, algicides and other substances to water for the control of nuisance aquatic plant growths. The chemicals to be applied to water must be approved by the OWRC, and are tested extensively for their effects on fish and other aquatic life, prior to the issuance of permits.

The OWRC legislation was enacted in 1962. The quantities of herbicides permitted to be applied in the Great Lakes basin in 1967 were:

Herbicide	Pounds used	Total acreage treated
Reglone "A" (diquat)	416	113
Simazine	1,515	76
Kurosal (fenoprop)	133	10
Dalapon	52	4
2,4-D	621	31
Aquathol (endothal)	69	2
Aquathol Plus (endothal-fenoprop)	78	3

Only Pennsylvania and Michigan on the United States side have similar controls over the application of herbicides directly to water.

Though pesticide levels in the waters of the Great Lakes are not well-documented, comprehensive studies of pesticide levels in fish in each of the Great Lakes have been completed. The OWRC collected fish from the western, central (off Prince Edward County), and eastern (Kingston) portions of Lake Ontario between March 1966 and October 1967.

DDE Residues in Fish

Chlorinated hydrocarbon insecticides (dieldrin, aldrin, chlordane and DDT) are relatively resistant to chemical and biological attack and breakdown (Woodwill, 1967; McKee and Wolfe, 1963). DDT is, moreover, highly soluble in fats and

Table 2.3.8 Concentration of chlorinated hydrocarbon pesticides (μg/l) in Great Lakes waters, September 1965 (After Breidenbach *et al.*, 1967).

Location	Concentrations in μg/l								
	Dieldrin	Endrin	DDT	DDE	DDD	Aldrin	Heptachlor	Heptachlor epoxide	BHC
St. Lawrence River Massena, N.Y.	n.d.	n.d.	n.d.	n.d.	.010	n.d.	.031	.017	n.d.
Lake Erie Buffalo, N.Y.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	.002	n.d.
Maumee River Toledo, Ohio	.024	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Detroit River Detroit, Mich.	.018	n.d.	n.d.	.008	n.d.	n.d.	.015	P	n.d.
St. Clair River Port Huron, Mich.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Lake Michigan Milwaukee, Wisc.	.003	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Lake Superior Duluth, Minn.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

n.d. - Indicates none detected

P - Data are reported as presumptive in instances where the results of chromotography were highly indicative but did not meet all requirements for positive identification and quantification oils and is easily and rapidly absorbed and concentrated by organisms exposed to even minute concentrations (Mack *et al.*, 1964; Premdas and Anderson, 1963). For this reason, direct analyses of organisms are more sensitive and meaningful than results obtained from water analysis. The fish collected for this study between late March 1966 and mid-October, 1967 were analyzed for DDE or a derivative of DDT.

The results of the DDE determinations are presented in Table 2.3.9.

The DDE concentrations found in the fish samples collected from Lake Ontario were generally low. The DDE content ranged from 0.03 mg/kg in the muscle of a female black crappie to 68.90 mg/kg in the testes of a male northern pike. The majority of the determinations showed residue levels of less than 2.0 mg/kg. A few markedly higher values were recorded for the Bay of Quinte. The concentrations found in the muscle of male and female fish of the same species and sampling site were similar. With two exceptions, the gonadal tissue contained more DDE than the muscle tissue with no pronounced difference between the sexes.

Phenols

The term phenol as used in this report refers to phenol and phenolic type compounds which react with 4-aminoantipyrene to produce colour development. Phenol may occur in lake waters from natural and pollutional sources. Natural phenols are present in the oils secreted by algae while other phenols accumulate from discharges containing oil, plastic and coal waste products.

Phenol was measured in a survey of nearshore waters by the OWRC in 1967. Generally, phenol values decreased toward offshore areas being undetectable at many stations located 2 miles offshore (Section 3.2).

Phenol was measured in offshore waters by the Great Lakes Institute, University of Toronto in 1960 with values in the open lake ranging from 0 to 3 µg/l. The range found in 1967 by NHW was 0 to 15 µg/l with a median value just over 2 µg/l. In general, observed phenol values are in compliance with the objectives proposed in the Summary Volume.

The median values for phenol in the St. Lawrence River ranged from 1.2 to 2.4 µg/l except for a sampling point in the north channel below Cornwall which had a median value of 4.2 µg/l for the season. The upper section of the river between Kingston and Morrisburg consistently gave the lowest phenol readings. It is suspected that a minor phenol source

Table 2.3.9 Maximum, minimum and mean DDE values (mg/kg fresh weight) for fish samples of Lake Ontario.

Species	No. of fish in sample	Sex	Tissue^2	Result (mg/kg DDE)^1 max.	min.	mean
			Western basin			
Yellow Perch	2	Female	M(comp)	-	-	0.11
			G(comp)	-	-	1.10
White Bass	2	Undetermined	M(comp)	-	-	0.20
Common White Sucker	4	Female	M(comp)	-	-	0.12
			G(comp)	-	-	2.30
Smelt	6	Undetermined	Whole fish(comp)	-	-	1.40
			Prince Edward County			
Yellow Perch	2	Male	M	0.16	0.14	0.15
			G	4.80	0.52	2.66
	4		M	0.49	0.05	0.28
			G	3.50	0.86	2.42
White Perch	3	Female	M	0.53	0.05	0.35
			G	2.20	0.49	1.23
Whitefish	3	Female	M	1.10	0.85	0.98
			G	1.80	0.65	1.18
Black Crappie	2	Female	M	<0.05	0.03	0.04
			G	0.56	0.25	0.40
Yellow Walleye	1	Male	M	-	-	0.06
			G	-	-	0.95
Northern Pike	2	Male	M	1.30	0.62	0.96
			G	68.9	1.41	35.15
			Kingston			
Yellow Perch	3	Female	M	0.22	0.05	0.16
			G	3.50	0.91	2.46
White Perch	1	Male	M	-	-	1.60
			G	-	-	0.40
	2		M	0.70	0.41	0.55
			G	1.40	1.25	1.32
Rock Bass	1	Female	M	-	-	0.05
			G	-	-	0.75

Table 2.3.9 (cont'd)

Species	No. of fish in sample	Sex	Tissue[2]	Result (mg/kg DDE)[1] max.	min.	mean
		Bay of Quinte				
Yellow Walleye	6	Male	M	9.60	0.32	3.34
			G	4.30	0.50	1.77
	7	Female	M	5.70	0.95	1.88
			G	19.90	7.00	9.73
		Male	whole fish	-	-	1.00
Cisco	1	Male	M	-		0.45
			G	-	-	1.60
	2	Female	whole fish	1.80	1.20	1.50
White Perch	2	Male	whole fish	0.30	0.30	0.30
	1	Female	whole fish	-	-	1.40
Black Crappie	1	Male	M	-	-	0.07
			G	-	-	<0.50
	2	Female	M	0.08	0.05	0.06
			G	<0.50	0.21	0.35
Sheepshead	1	Male	whole fish	-	-	0.10
	2	Female	whole fish	7.0	6.0	6.5

[1] In this study a saponification procedure was used to extract pesticides from the fish tissue. Any DDT present was converted to DDE, the DDE remained unchanged, but any DDD present was completely destroyed. The use of this saponification procedure provided a rapid quantitative and qualitative screening technique. Therefore, values reported as DDE include DDT and DDE, but not DDD.

[2] M = muscle tissue
G = gonads

is discharging in the Cornwall area giving rise to the high values found there. The river water in general meets the proposed objectives.

2.4 BIOLOGY

The structure and composition of plant and animal communities within a particular lake environment result from the interaction of chemical, physical, and biological factors, both within and outside the lake basin. Since lakes are receiving basins for materials carried by rivers and streams, the nature of the substrate and the chemical characteristics of the impounded waters are influenced by the geochemical make-up of the watershed. These factors, in addition to the morphometry of the basin, current patterns, wave action, temperature and light, are important parameters affecting the distribution patterns and population dynamics of biological communities in lakes.

This section of the report combines a historical review of aquatic biological data with the results of more recent surveys conducted by the FWPCA and the OWRC. Additional information on the composition and distribution of zooplankton and benthic communities was provided by the Fisheries Research Board of Canada and the Great Lakes Institute of the University of Toronto. A section summarizing the present status and past changes in the fisheries of Lake Ontario over the years has been compiled from information prepared by the United States Public Health Service (based on records from the U.S. Bureau of Commercial Fisheries) and the Ontario Department of Lands and Forests. A survey on the effects of the Niagara River on the benthic communities near the mouth of the river was carried out by EMR and FWPCA with the cooperation of the New York State Department of Health. An authoritative publication on zooplankton in Lake Ontario by Patalas (1969) appeared in print too late for inclusion in this volume.

2.4.1 Organic Seston

Gravimetric determinations of suspended organic matter were conducted by FWPCA at five offshore stations during each of three cruises in 1965 to provide a gross estimate of standing crop. It was assumed that the bulk of the suspended organic matter consisted of phytoplankton, although contamination with organic debris sometimes occurred. The Millipore filter technique was used, estimating organic matter by the difference in sample weights before and after ignition.

Dry organic seston concentrations are provided in Table 2.4.1. The values ranged from 0 to 8,000 milligrams per

Table 2.4.1 Seston (particulate organic matter) concentrations in Lake Ontario, taken at one metre and expressed in milligrams dry weight per cubic metre of water.

Station number	Spring, 1965	Summer, 1965	Fall, 1965
10	600	*	8,000
17	400	*	1,000
23	0	0	1,800
31	200	600	800
37	0	400	400

*Sample not taken

cubic metre (mg/m^3) with a mean value of 1,100 mg/m^3. Anderson and Clayton (1959) conducted vertical plankton tows in Lake Ontario and obtained values ranging from 8 to 80 mg/m^3. Methodology must be taken into account when comparing these results. Anderson and Clayton used a No. 20 plankton net, which has a retention of only about 10 percent of that of the Millipore filter.

2.4.2 Phytoplankton

Planktonic algae are the primary producers of organic matter in lakes, converting the sun's energy into chemical compounds that in turn are used as food energy by animals and non-photosynthetic micro-organisms. Phytoplankton production and distribution are influenced by sunlight, nutrients, temperature, size, shape and slope of lake basin, type of substratum, water movements, and grazing by zooplankton.

Many inorganic elements are required for algal cell growth, including nitrogen, phosphorus, potassium, calcium, and iron. Provasoli (1958) indicated that vitamin B_{12}, thiamine, and certain other organic compounds are also necessary for the growth of some algae. Algae reproduce rapidly when phosphate is added to water and continue to reproduce as more phosphate is added. However, nitrogen and other nutrients must also be present if algal production is to continue. Sawyer (1954) concluded that when inorganic nitrogen concentrations of 0.30 mg/l (sum of NH_3-N, NO_2-N, NO_3-N) and orthophosphate-phosphorus concentrations of 0.01 mg/l (PO_4-P) were present in bodies of water at the start of the active growing season, nuisance algal blooms could be anticipated. Mackenthen (1965) suggested that the initial stimulus for algal production is supplied by dissolved phosphorus and that a continued high rate of nutrient supply does not appear to be necessary for sustained algal production. Re-cycling of nutrients within the lake basin may be sufficient to promote algal blooms for several years.

Knowledge of the species of algae found in lakes is important for an understanding of the eutrophication process, and for an evaluation of the general water quality of a lake. Certain species of the Chlorophyceae (green algae), the Chrysophyceae (yellow-brown algae), and Bacillariophyceae (diatoms) are common in oligotrophic lakes. On the other hand, some of the euglenoids, blue-greens, and other species of diatoms appear most often in nutrient-enriched waters of eutrophic lakes. Species of *Anacystis*, *Aphanizomenon*, *Stephanodiscus*, *Melosira* and *Fragilaria* often predominate in eutrophic lakes.

Algae interfere with water-oriented recreational activities, impair the aesthetic qualities of the water, are responsible for filter-clogging, taste and odour problems, and affect coagulation and sedimentation processes in water treatment.

There is a scarcity of published data on the composition of phytoplankton in Lake Ontario in comparison with the other Great Lakes. Hohn (1951), and Anderson and Clayton (1959) listed some of the major phytoplankters in the open lake. The only early quantitative studies are those of Tressler and Austin (1940). Tucker (1948) described both the quality and quantity of phytoplankton in the Bay of Quinte in 1945. McCombie (1967) studied the same body of water in 1964 and found no significant change in phytoplankton abundance from the 1945 values. At both times, however, the abundance was high.

Schenk and Thompson (1965) studied a few of the most abundant phytoplankters at the Island Filtration Plant of the Municipality of Metropolitan Toronto. There, the mean annual level of phytoplankton approximately doubled between 1923 and 1954, increasing at a rate of 5.6 areal standard units per millilitre per year (asu/ml/year). One areal standard unit (asu) is equal to an areal value of 400 square microns. Records maintained at the nearby R.C. Harris Filtration Plant indicated that between 1956 and 1966, the phytoplankton increased an average of 42 asu/ml/year. Nalewajko (1966) found that *Stephanodiscus tenuis Hust.*, *Melosira islandica O. Mull.*, and *Diatoma elongatum (Lyngb.) Ag.* were the most important forms from January 1964 to July 1965 in surface samples collected near Toronto Island. Nalewajko (1967) reported that algae were two or three times more abundant at nearshore stations in Lake Ontario, where *Stephanodiscus tenuis* was the major diatom, than at offshore stations. At offshore locations (further than six miles), *Melosira islandica* and *Asterionella formosa Hass.* were the dominant species while numbers of *Stephanodiscus tenuis* were substantially reduced.

The following material includes the results of phytoplankton analyses on samples obtained regularly at waterworks along the Canadian shore of Lake Ontario and at auxiliary nearshore and offshore stations. In addition unpublished data (Federal Water Pollution Control Administration and Fisheries Research Board) are also included for chlorophyll a in Lake Ontario surface waters.

For the period March 1966 through November 1967, phytoplankton analyses were completed on weekly samples from six waterworks along Lake Ontario between Grimsby and Kingston. In addition, samples were obtained from Brockville and Cornwall on the St. Lawrence River. Fig. 2.4.1 shows the location of the eight municipalities and tabulates the length and depth of the respective intakes. From May through September, 1967, samples were obtained from Hamilton Bay, the Bay of Quinte and along the shore of Lake Ontario.

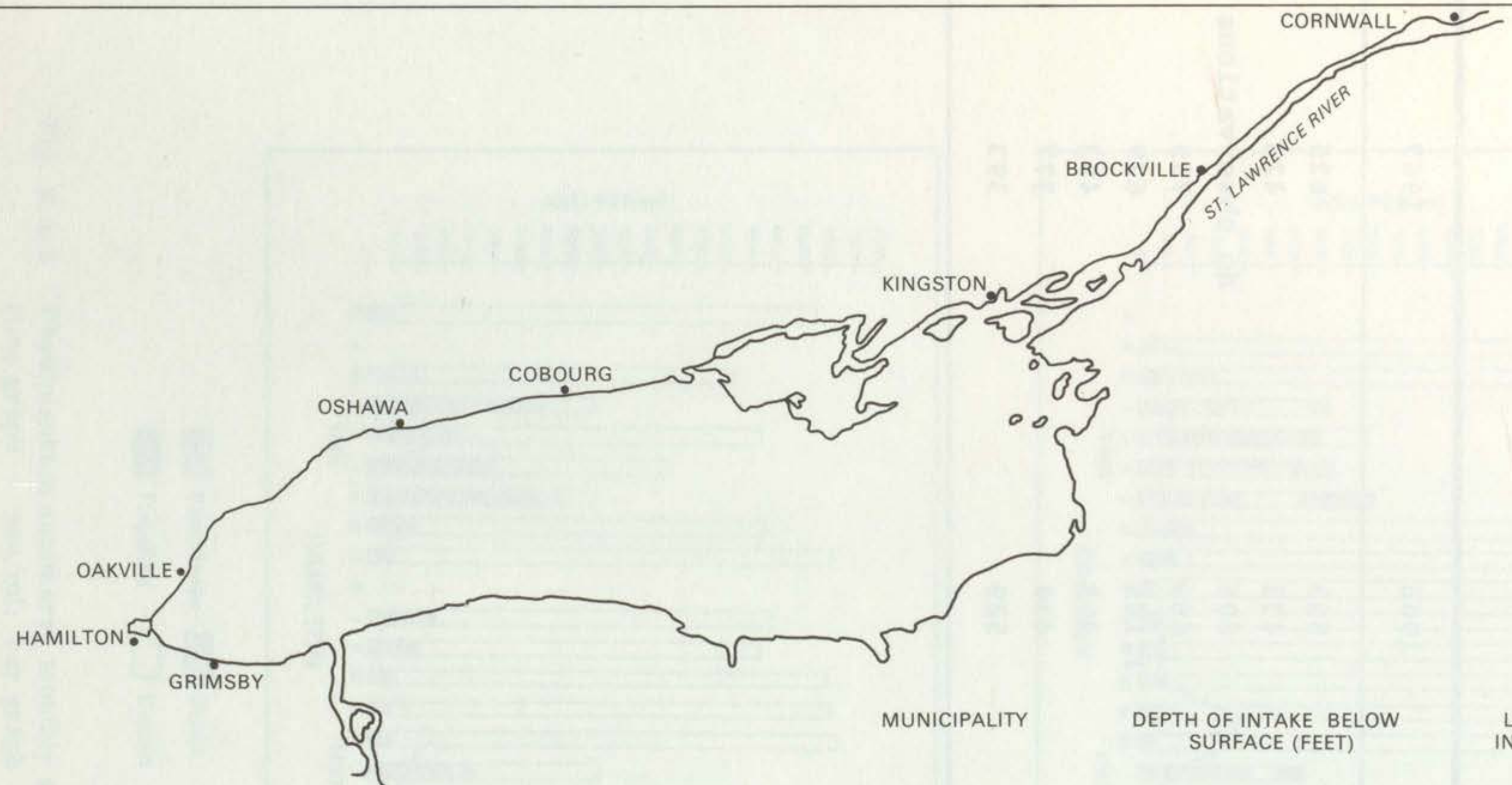
Results

Low averages characterized the yearly phytoplankton crops in municipal water intakes at either end of Lake Ontario and along the St. Lawrence River, while somewhat higher averages were recorded at Oshawa and Cobourg (Table 2.4.2).

Samples collected along the northern shore of Lake Ontario between Toronto and Prince Edward County indicated that the average standing crop of phytoplankton decreased from the western to the eastern end of the lake. An average of 679 asu/ml was obtained from 15 samples at five stations between Toronto and Oshawa. Fifteen samples from three stations near Cobourg averaged 602 asu/ml and 13 samples from four stations near Prince Edward County averaged 297 asu/ml.

In contrast to the inshore averages for Lake Ontario, high phytoplankton values were obtained from samples collected in Hamilton Bay and the Bay of Quinte. An average of 2,154 asu/ml was obtained from five samples at one location in Hamilton Bay. In the inner portion of the Bay of Quinte, a mean of 3,657 asu/ml was recorded from 20 samples at four locations, while an average of 2,921 asu/ml was obtained for five samples at one station in the outer bay. Samples collected from one station in Lake Ontario at the mouth of the Bay of Quinte averaged 677 asu/ml.

The bimodal seasonal pattern of plankton development in large lakes has been well documented by Chandler (1940, 1942, 1944) and Davis (1954, 1962). Pennak (1946) described the pattern as having a "...large spring pulse, a decreased population during the summer, a second, less pronounced, pulse in the autumn, and a very small population during the winter". The line graph on Fig. 2.4.2 depicts the seasonal phytoplankton patterns at eight municipalities. Numerical values for this graph (scaled on the left ordinate) represent the corresponding monthly phytoplankton averages measured in asu/ml.



MUNICIPALITY	DEPTH OF INTAKE BELOW SURFACE (FEET)	LENGTH OF INTAKE (FEET)
GRIMSBY	18	950
HAMILTON	29	2989
OAKVILLE	28	2400
OSHAWA	32	3030
COBOURG	21	920
KINGSTON	49	1200
BROCKVILLE	31	900
CORNWALL	40	OFF HYDRO DAM

Fig. 2.4.1 Location of eight municipal waterworks sampled for phytoplankton (1966-1967).

Table 2.4.2 The yearly mean standing crop (asu/ml) of phytoplankton at municipal water intakes.

	1966	1967
Grimsby	553	625
Hamilton	433	423
Oakville	606	No observations
Oshawa	683	709
Cobourg	1,109	679
Kingston	468	493
Brockville	439	377
Cornwall	529	393

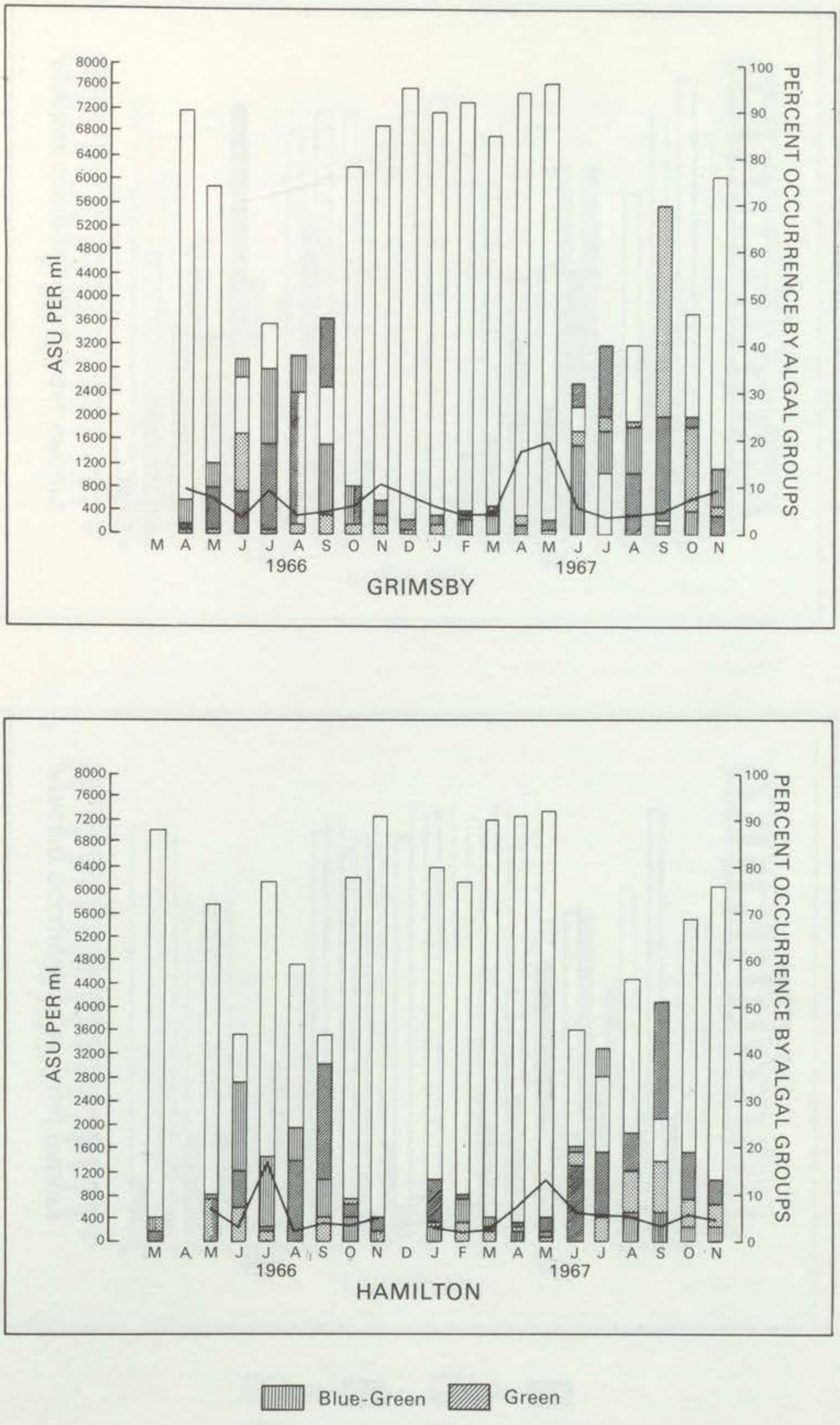


Fig. 2.4.2 Phytoplankton summary, monthly averages,
(line graph - asu/ml: bar graph - percent occurrence).

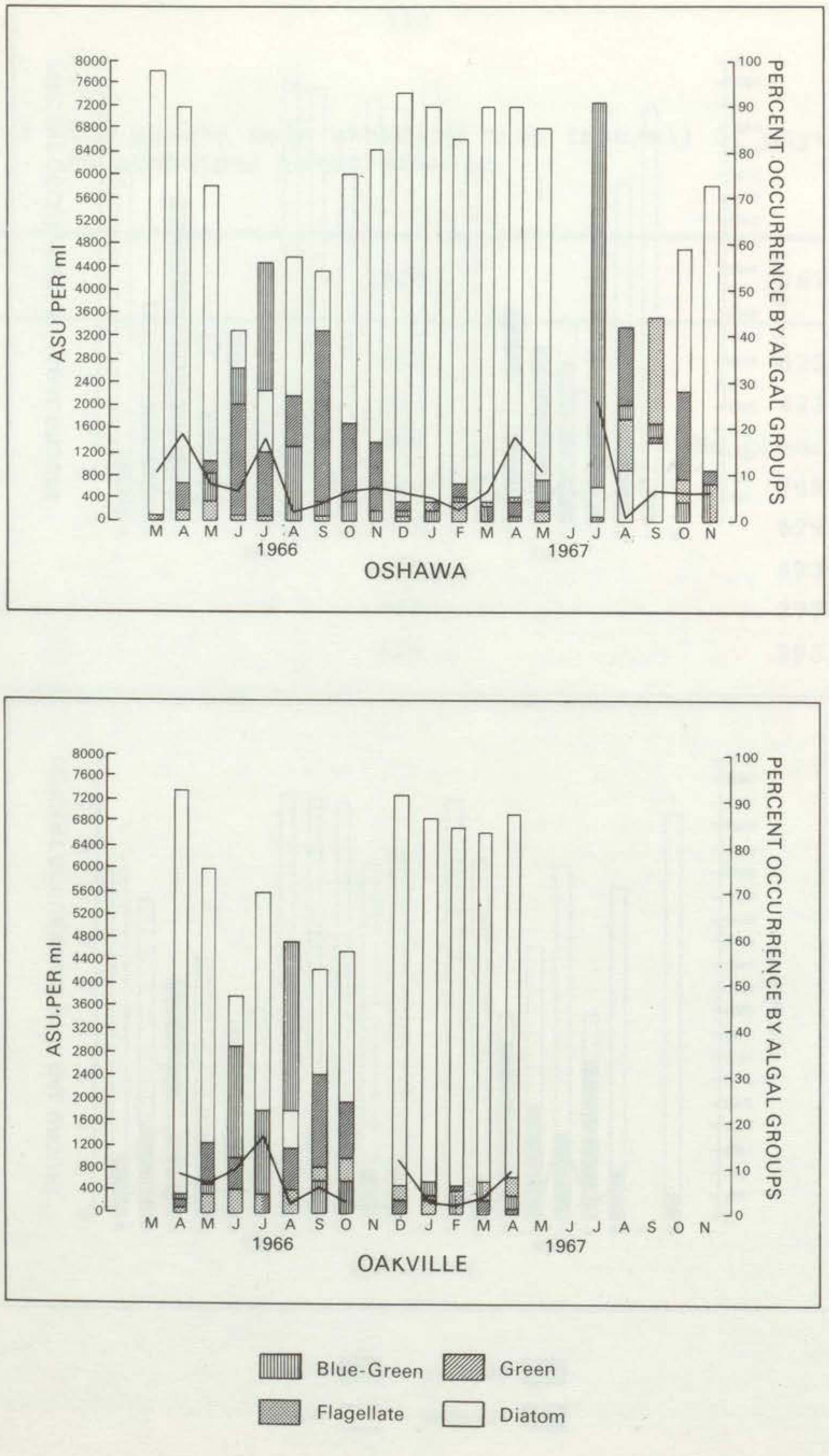


Fig. 2.4.2 cont'd

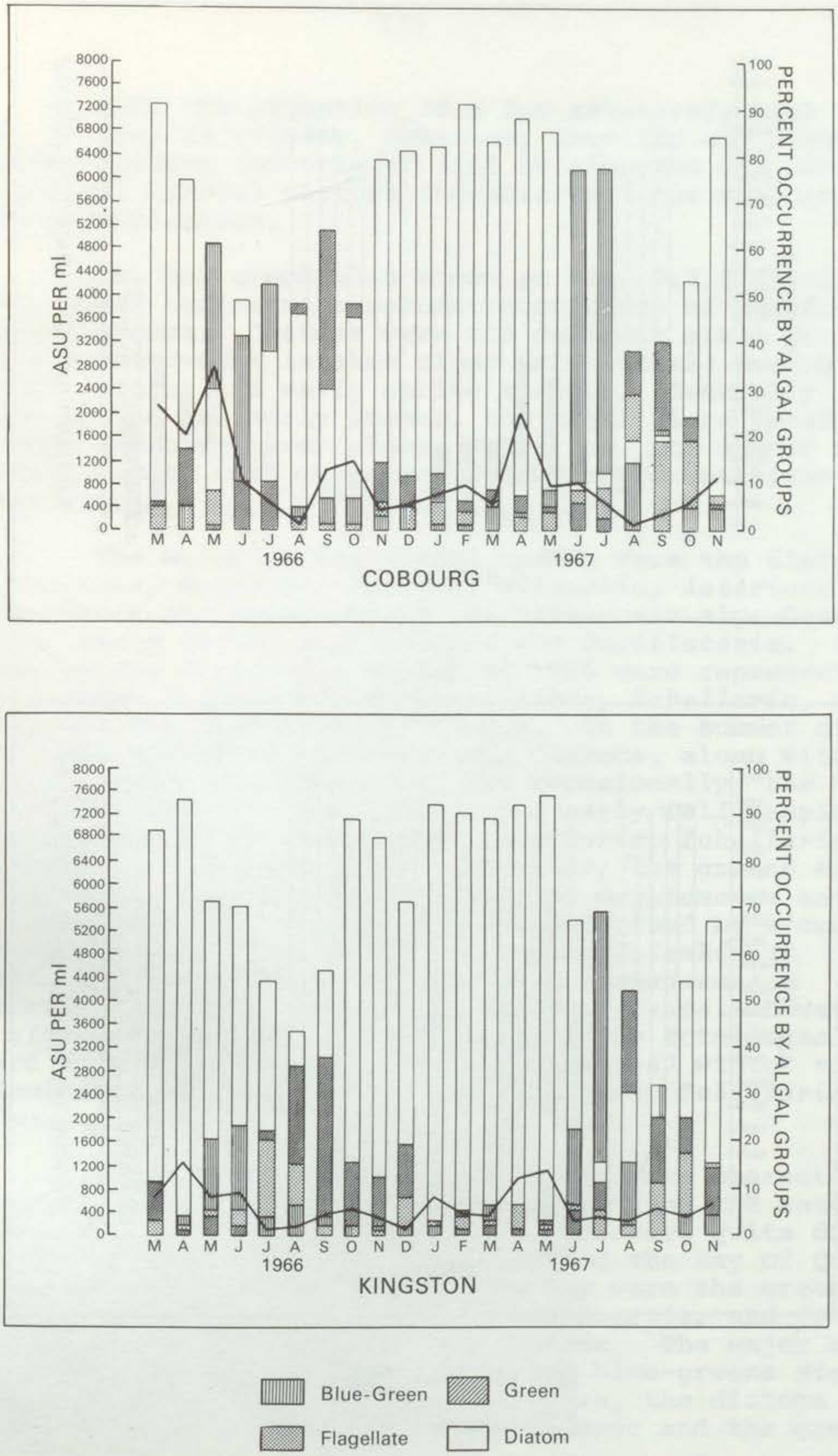


Fig. 2.4.2 cont'd

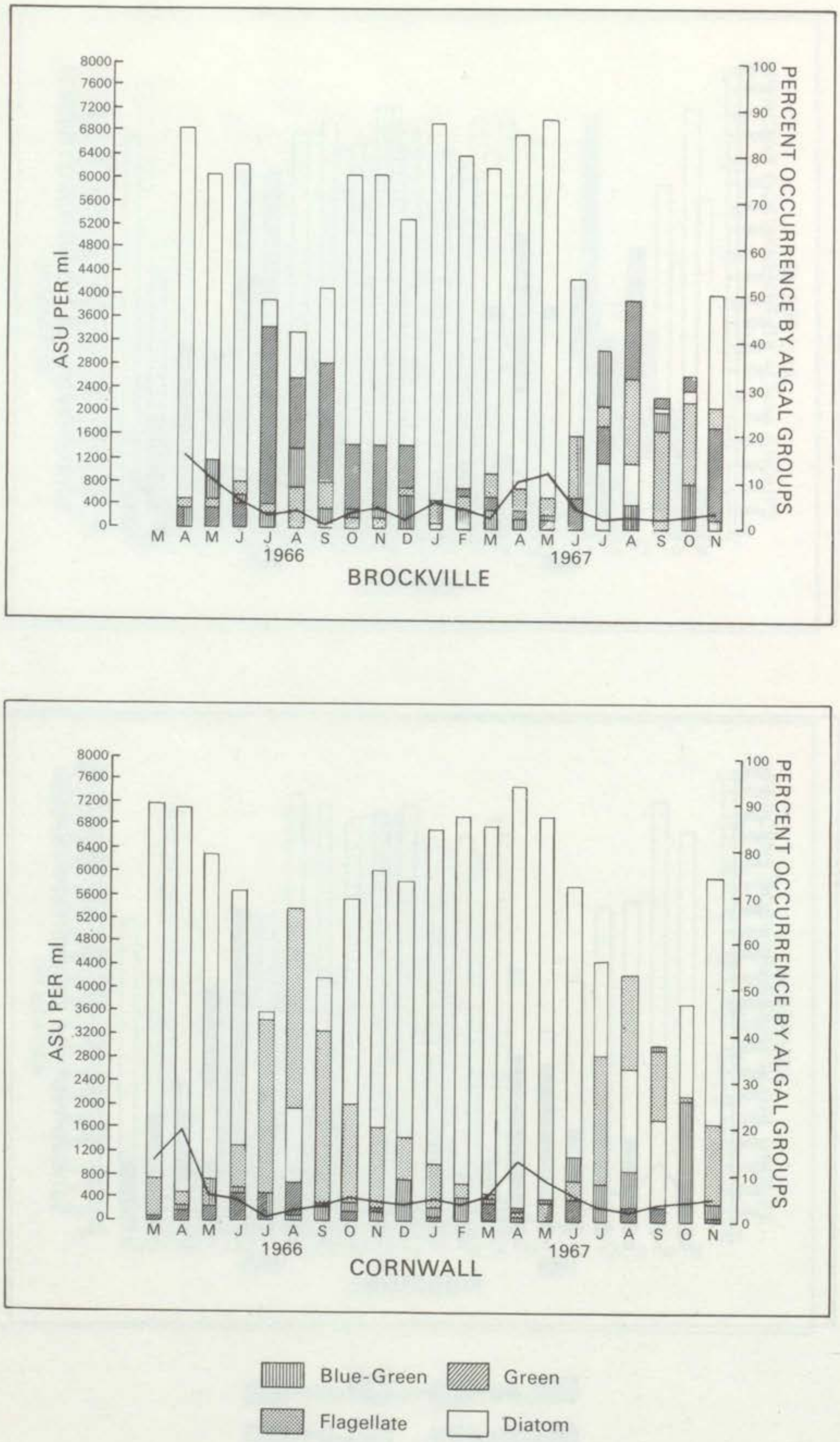


Fig. 2.4.2 cont'd

With the exception of a few relatively high counts in July of 1966 at Grimsby, Hamilton, Oakville and Oshawa and during January and July of 1967 at Kingston and Oshawa, the classical bimodal pattern characterized the standing crop of phytoplankton.

The bar graph also shown on Fig. 2.4.2 displays for each month the average percent occurrence of the four main algal groups. Diatoms were the dominant algal group at the six waterworks intakes along Lake Ontario during the late fall, winter and early spring seasons. Generally during the late spring and early summer, the algal flora consisted of diatoms and blue-green algae, while the late summer and early fall counts were characterized by representatives of all four groups.

The major genera during spring were the diatoms *Stephanodiscus*, *Melosira*, *Diatoma*, *Nitzschia*, *Asterionella* and *Tabellaria* and occasionally the blue-green alga *Oscillatoria*. The major genus during both summers was *Oscillatoria*. Subdominant genera during the summer of 1966 were represented by the diatoms *Fragilaria*, *Stephanodiscus*, *Tabellaria*, and *Melosira* and the flagellate *Dinobryon*. In the summer of 1967 the sub-dominants were the same diatoms, along with the filamentous green alga *Mougeotia* and occasionally, the blue-green *Gomphosphaeria*. Late summer and early fall samples were characterized by the diatoms *Fragilaria*, *Tabellaria*, *Stephanodiscus*, *Melosira* and *Asterionella*; the greens *Mougeotia* and *Dictyosphaerium*; and the flagellates *Cryptomonas* and *Dinobryon*. Summer and early fall counts were characterized by a number of nannoplanktonic green forms, including *Golenkinia*, *Micractinium*, *Actinastrum*, *Lagerheimia*, *Scenedesmus*, *Schroederia*, *Franceia*, *Tetraedron* and *Crucigenia*. However, these algae contributed only slightly to the total areal standard unit (asu) values. The 1966 and 1967 winter samples were dominated by *Fragilaria*, *Stephanodiscus*, *Tabellaria* and *Melosira*.

Samples at the inshore stations were characterized by an algal flora similar to that reported from the waterworks intakes. The generic composition was, however, quite different in samples collected from Hamilton Bay and the Bay of Quinte. The dominant summer forms in Hamilton Bay were the greens *Coelastrum*, *Oocystis*, *Crucigenia*, *Sphaerocystis*, and *Scenedesmus*, as well as the diatoms *Synedra* and *Diatoma*. The major algae reported from the Bay of Quinte were the blue-greens *Microcystis*, *Gomphosphaeria*, *Anabaena* and *Aphanizomenon*, the diatoms *Stephanodiscus*, *Melosira*, *Fragilaria*, *Tabellaria* and *Diatoma* and the green alga *Pediastrum*.

The concentration of chlorophyll a, a general indication of total algal abundance, in surface waters of Lake Ontario was measured in Canadian nearshore waters by OWRC using the method of Richards and Thompson (1952) on 360 samples from 137 stations, June to August, 1967. In all cases the concentrations were less than 5 mg/m^3 except for the Bay of Quinte, Hamilton Bay, and the mouth of the Niagara River where values of chlorophyll a ranged up to 34 mg/m^3. In many, but not all cases a parallel was observed between the concentrations of chlorophyll a and those of total phosphorus.

The results for 42 offshore stations occupied by the FWPCA in 1965 (Table 2.4.3 and Fig. 2.4.3) indicate that phytoplankton populations are characterized by a bimodal seasonal pattern with a definite spring (May) maximum, followed by a much reduced summer (July) crop, but with a noticeable increase occurring again in the autumn (September). The seasonal composition also showed considerable variation, although the green algae on a lake-wide basis were the dominant forms during all seasons.

The spring samples yielded a lake-wide mean in excess of 1,100 organisms/ml with the green algae constituting 53 percent of the total crop and diatoms 45 percent. The blue-greens were very sparse, contributing slightly over one percent of the total.

At the time of the summer cruise phytoplankton densities were reduced to a lake-wide mean of 290 organisms/ml dominated by green algae (67 percent), with diatoms reduced to about 18 percent of the total phytoplankton crop. The blue-greens had increased to a substantial 10.5 percent of the total standing crop.

An increased phytoplankton crop was indicated by the autumn samples which yielded a lake-wide mean of 650 organisms/ml, composed primarily of green algae (74 percent), with diatoms and blue-greens accounting for 18 and 6 percent, respectively.

The most abundant green algae recorded during the three cruises were *Ankistrodesmus*, *Scenedesmus* and *Chlamydomonas*. *Ankistrodesmus* was an important constituent of the total crop during all seasons, but *Scenedesmus* was most numerous during the spring and *Chlamydomonas* dominated the fall samples. The centric diatoms *Cyclotella*, *Stephanodiscus* and *Melosira* were among the most abundant diatoms during all three cruises, and several pennates, notably *Synedra*, *Asterionella* and *Tabellaria* were common components of the spring crop.

Table 2.4.3 Seasonal phytoplankton counts at 42 offshore stations in Lake Ontario during the spring, summer and autumn, 1965. Numerical values represent mean, high and low numbers of organisms per millilitre for each group for all stations during each season. Percentage values represent percent of total numbers of organisms contributed by each group during each sampling period.

	Diatoms			Green			Blue-green			Total phytoplankton		
	mean	high	low	mean	high	low	mean	high	low	mean	high	low
Spring												
May												
Numerical	492	1,418	84	587	2,222	0	15	84	0	1,104	3,696	372
Percentage	44.6			53.2			1.4					
Summer												
July												
Numerical	44	308	0	161	756	0	25	110	0	291	980	56
Percentage	18.4			66.9			10.5					
Autumn												
September												
Numerical	116	448	0	481	952	140	39	168	0	649	1,372	196
Percentage	17.9			74.0			6.0					

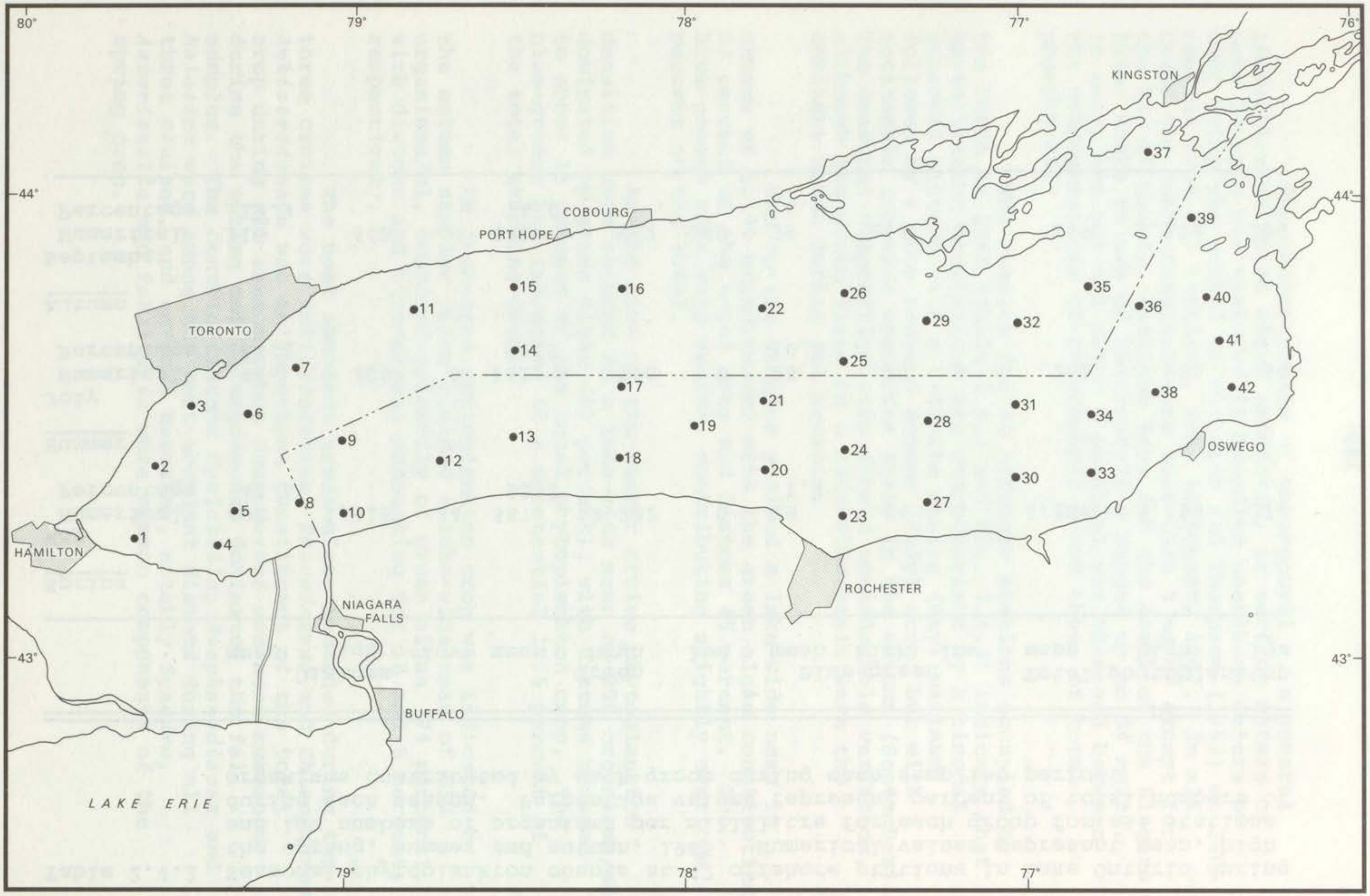


Fig. 2.4.3 Location of offshore biological sampling stations (1965).

During each of the three offshore cruises the standing crop composition showed only local variations with no major patterns depicted on a lake-wide basis.

The concentrations of chlorophyll a in the surface waters of Lake Ontario in 1965 as determined by FWPCA using the method of Richards and Thompson (1952) were as follows: a mean of 4.7 mg/m^3 with a range from 1.3 to 22.6 mg/m^3 based on 37 stations distributed throughout the lake in May; a mean of 6.6 mg/m^3 with a range from 2.6 to 15.2 mg/m^3 based on 42 stations distributed throughout the lake in July; and a mean of 8.9 mg/m^3 with a range from 4.3 to 14.1 mg/m^3 based on 26 stations distributed throughout the lake in September.

Concentrations of chlorophyll a were measured in offshore surface waters of the lake from June through to September in 1967 by the Fisheries Research Board. An *in vivo* fluorometric method was used (Lorenzen, 1966) standardized by comparison with the method of Parsons and Strickland (1963). The results are given in Table 2.4.4 in terms of lake-wide means. It is evident that the high concentrations of early spring were only partly sampled. Chlorophyll a values for the open surface waters of Lake Ontario in 1967 were in general agreement with the results reported for 1965 by FWPCA, and in no way indicative of eutrophy.

These results show that mean annual phytoplankton levels at eight municipalities along Lake Ontario and the St. Lawrence River were relatively low, except for the 1966 average for Cobourg. The yearly means at each of the locations (430 to 1,100 asu/ml) were found to be lower than corresponding averages at Kingsville on the north shore of the western basin of Lake Erie (1966, 2,100 asu/ml; 1967, 5,200 asu/ml). With the exception of the 1966 mean at Cobourg, the yearly inshore averages for Lake Ontario compared favourably with corresponding values at Cedar Springs, (1966, 420 asu/ml; 1967, 670 asu/ml) in the mid-central basin and at Port Dover (1966, 520 asu/ml; 1967, 360 asu/ml) in the eastern basin.

With regard to the seasonal pattern of phytoplankton development, Davis (1964) reported an increase in the intensity and duration of the spring and fall maxima, as well as a failure of the summer and winter minima to materialize, over the period 1920 to 1963 in Lake Erie. Extended durations of the spring and fall maxima did not occur at any of the Lake Ontario municipalities in either of the two years covered by this study.

Table 2.4.4 Mean concentration of surface chlorophyll a (mg/m^3) in Lake Ontario during 1967 (unpublished data of H.F. Nicholson, Fisheries Research Board of Canada).

Cruise	Dates	No. of stations	Chlorophyll a (mg/m^3)
67-0-01	14-16/6	20	20.3
67-0-03	25-28/6	61	19.9
67-0-05	10-13/7	62	3.7
67-0-07	25-27/7	62	6.1
67-0-09	05-08/8	61	3.8
67-0-11	21-24/8	61	5.2
67-0-13	05-08/9	62	6.2
67-0-15	16-19/9	61	8.4
67-0-17	01-05/10	62	5.1
67-0-19	17-21/10	50	7.6
67-0-21	28/10-1/11	62	3.9

The persistence of the diatom *Stephanodiscus* (mainly *Stephanodiscus tenuis Hust.*) at all inshore locations during all seasons of the year may be indicative of a eutrophic condition in the nearshore waters of Lake Ontario (Foged, 1954; Nalewajko, 1966). Nalewajko (1967) described the rapid increase of *Stephanodiscus tenuis* in the spring, and related this increase to the confinement of nutrients in the inshore waters of Lake Ontario by the thermal bar phenomenon.

In Hamilton Bay and the Bay of Quinte, large quantities of Chlorophyceae and Myxophyceae, respectively, reflected the eutrophic condition of these waters. Phytoplankton populations in Hamilton Bay were similar to those recorded from numerous sewage oxidation ponds throughout Ontario.

Results indicated that phytoplankton levels throughout Lake Ontario were moderate to low. Generally, inshore populations declined from the western to the eastern end of the lake. With minor exceptions, the classical bimodal pattern of phytoplankton development was evident throughout the lake, unlike portions of Lake Erie where a breakdown of this pattern was reported to indicate its increasingly eutrophic condition. Phytoplankton concentrations in the main body of the lake suggest a condition between oligotrophy and mesotrophy. The waters of Hamilton Harbour and the Bay of Quinte, on the other hand, are eutrophic in character. The only site for which long-term data are available is the Island Filtration Plant of Metropolitan Toronto. Algal abundance there increased at a rate of 5.6 asu/ml/year from 1923 to 1954, and 42 asu/ml/year from 1956 to 1964.

2.4.3 Zooplankton

There is very little published information on the crustacean zooplankton in Lake Ontario. One of the earliest reports was that of Bigelow (1922) who examined the stomach contents of 7 ciscoes from the western end of the lake. Three species of *Daphnia* were found, of which *Daphnia longispina* was the most abundant. Tressler and Austin (1940) studied plankton samples collected from the open lake on July 20, 1939. Copepods, including *Cyclops* and *Diaptomus* averaged 25 per litre. *Daphnia*, the only recorded cladoceran, averaged 5 per litre. In 1958, Anderson and Clayton (1959) found *Cyclops* to be "very abundant" while *Bosmina* was "abundant" at one location in the middle of the lake.

Little is known about the rotifers of Lake Ontario. According to Tressler and Austin (1940) the most common rotifers in a summer collection from the open lake were *Asplanchna spp.*

and *Keratella spp.*, totalling 104 organisms per litre. In the zooplankton of Sodus Bay the most abundant genera were *Polyarthra* and *Synchaeta*; and in Irondequoit Bay, *Keratella*, *Asplanchna*, and *Kellicotia longispina*. Anderson and Clayton (1959) reported the occurrence in October, 1958 of *Asplanchna sp.*, *Notholca sp.*, *Synchaeta sp.* and *Keratella sp.*

Sampling of the zooplankton in Lake Ontario was carried out recently for this report. At 12 nearshore stations (Fig. 2.4.4) OWRC collected samples regularly between May and September, 1967. Thirty-two to 62 deep-water stations were sampled on cruises during July, August and September of 1967 by the Fisheries Research Board.

The two dominant groups of Crustacea sampled were the Copepoda and Cladocera. Although other crustaceans were identified including the Ostracoda and Amphipoda, their numbers were extremely low and the collections were not considered representative.

Two suborders of limnetic copepods were found in offshore areas of the lake. The Cyclopoida were represented by *Cyclops bicuspidatus thomasi*, *Cyclops vernalis*, *Mesocyclops edax*, and *Tropocyclops prasinus mexicanus*. The Calanoida included *Diaptomus oregonensis*, *Diaptomis sicilis* and *Diaptomus minutus*; *Eurytemora affinis*; *Epischura lacustris* and *Limnocalanus macrurus*. The most abundant cladocerans were *Bosmina longirostris*, *Bosmina coregoni coregoni*; *Daphnia retrocurva*, *Daphnia galeata mendotae*, and *Daphnia longiremis*. Other cladocerans included *Chydorus sphaericus*, *Ceriodaphnia lacustris*, *Leptodora kindtii*, *Diaphanonsoma leuchtenbergianum*, and *Holopedium gibberum*.

Tables 2.4.5 and 2.4.6 outline the locations and dates for the maximum number of Copepoda and Cladocera at the 12 nearshore stations. Low numbers of cyclopoids were found from May until the middle of June when higher numbers were detected. A maximum count of 35,000/m^3 (dominated mainly by *Cyclops bicuspidatus thomasi*) was recorded on June 18 at station 12 (Table 2.4.6). The copepods then decreased until mid-August when levels at all stations, except station 12, increased enormously, reaching the yearly high near the end of August. A late August maximum of 115,000/m^3 for *Cyclops spp.* (almost entirely *Cyclops bicuspidatus thomasi*) was reported from station 200 (Table 2.4.5).

The calanoid copepods were represented by three species of *Diaptomus* including *Diaptomus oregonensis*, *Diaptomus sicilis* and *Diaptomus minutus*; *Epischura lacustris*; *Limnocalanus*

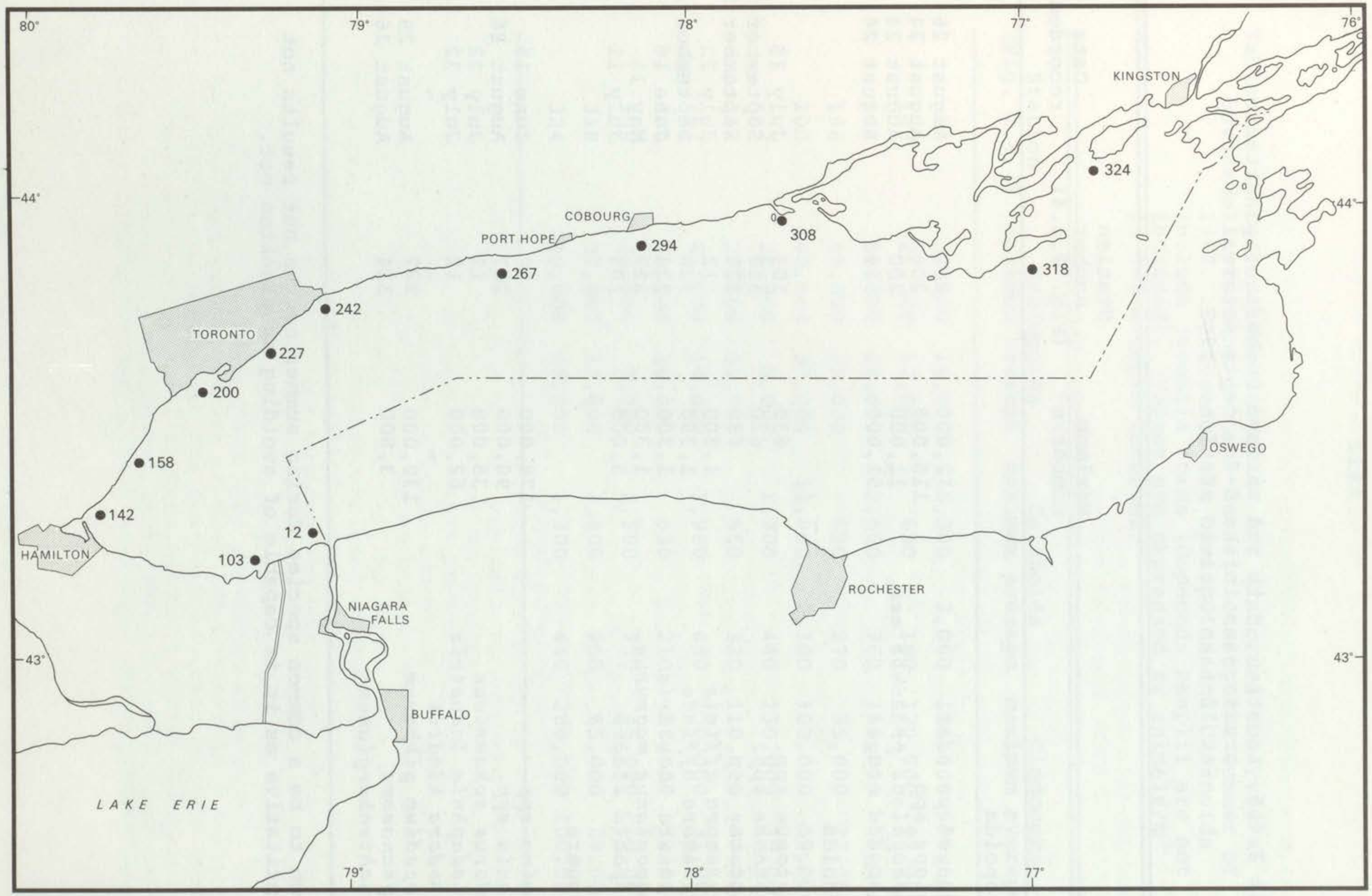


Fig. 2.4.4 Location of nearshore zooplankton sampling stations (1967).

Table 2.4.5 Location, date and maximum numbers of planktonic crustaceans in the 0-7 m depth interval observed at 12 Lake Ontario stations, 1967.

	Maximum number/m^3	Station number (Fig. 2.4.4)	Date recorded
Cyclopoida			
Mesocyclops edax	12,000	267	August 26
Cyclops spp.	115,000	200	August 24
Tropocyclops prasinus mex.	11,000	200	August 24
Copepodid stages	51,000	324	August 24
Calanoida			
Diaptomus spp.	630	103	July 15
Diaptomus spp.	630	318	September 1
Diaptomus spp.	630	324	September 1
Eurytemora affinis	1,300	12	July 22
Eurytemora affinis	1,300	318	September 1
Epischura lacustris	1,300	324	June 16
Limnocalanus macrurus	1,300	227	May 15
Copepodid stages	5,000	103	July 15
Cladocera			
Bosmina spp.	178,000	12	June 15
Daphnia spp.	90,000	267	August 26
Chydorus sphaericus	35,000	12	July 22
Ceriodaphnia lacustris	62,000	12	July 22
**Leptodora kindtii*	-	-	-
Holopedium gibberum	130,000	227	August 29
Diaphanosoma leuchtenbergianum	3,800	324	August 26

*Known to be a common species during summer months but results not quantitative as it is capable of avoiding zooplankton net.

Table 2.4.6 Cyclopoida, Calanoida and Cladocera observed at 12 stations in Lake Ontario during the summer of 1967. Values for the Cyclopoida and Calanoida include juvenile forms (Copepoda nauplii are not included). Values are expressed as animals/m^3 in 0-7 m depth interval.

Station	Cyclopoida		Calanoida		Cladocera	
(Fig. 2.4.4)	maximum	average	maximum	average	maximum	average
12	35,000	16,000	6,300	2,000	191,000	94,000
103	25,000	12,000	630	160	120,000	49,000
142	58,000	24,000	2,500	760	130,000	59,000
158	69,000	22,000	630	270	95,000	27,000
200	140,000	37,000	11,000	2,700	100,000	59,000
227	20,000	8,000	1,300	440	130,000	35,000
242	27,000	11,000	950	320	110,000	34,000
267	41,000	14,000	1,900	650	130,000	31,000
294	38,000	16,000	630	210	57,000	32,000
308	29,000	7,700	2,500	750	46,000	15,000
318	37,000	15,000	3,800	960	65,000	29,000
324	110,000	28,000	1,300	440	280,000	100,000

macrurus and the brackish-water form *Eurytemora affinis*. Generally, the calanoid populations were very low, attaining a maximum of 6,300/m^3 on July 22 at station 12. Maximum numbers of diaptomids occurred in mid-July at station 103 and at stations 318 and 324 on September 1. *Eurytemora affinis* predominated at stations at extreme ends of the lake. *Epischura lacustris* was found infrequently between June and August at a few inshore stations while *Limnocalanus macrurus* occurred only in May at most sampling locations.

Generally, the maximum numbers of Cladocera were considerably higher than corresponding cyclopoid and/or calanoid values. The cladocerans were represented mainly by *Bosmina spp.* (with *Bosmina longirostris* more abundant than *Bosmina coregoni coregoni*) and *Daphnia spp.* (mainly *Daphnia retrocurva*). Two periods of cladoceran development were apparent. The first and largest pulse occurred during mid-June. On June 15, a maximum of 191,000/m^3 was recorded at station 12 where the cladoceran population consisted of *Bosmina spp.* (17,800/m^3), *Daphnia spp.* (9,400/m^3), *Diaphanosoma leuchtenbergianum* (1,200/m^3) and *Ceriodaphnia lacustris* (2,500/m^3). During the mid-August peak when a maximum for cladocerans of 130,000/m^3 was recorded at station 267, the daphnids were proportionately more abundant than during the late spring pulse (Table 2.4.6). Between May and September, *Chydorus sphaericus* was found at stations near the mouths of the Niagara River and the Bay of Quinte. This form reached a maximum of 35,000/m^3 at station 12 at the end of July. A few specimens of *Diaphanosoma leuchtenbergianum* and *Leptodora kindtii* were detected at extreme ends of the lake. In August *Diaphanosoma leuchtenbergianum* reached a high of 3,800/m^3 at station 324. *Leptodora kindtii* is known to be a common species in Lake Ontario during the summer months. However, because it is capable of evading the zooplankton net, the results are not quantitative. *Holopedium gibberum* was recorded only in samples collected at station 227, where in late August it reached an exceptionally high level of 130,000/m^3. *Ceriodaphnia lacustris* was found at most nearshore locations and attained a mid-summer maximum of 62,000/m^3 at station 12.

In offshore samples Cyclopoida were represented by *Cyclops bicuspidatus thomasi*, *Cyclops vernalis*, *Tropocyclops prasinus mexicanus* and *Mesocyclops edax* (Patalas, 1969). The Calanoida included *Diaptomus minutus*, *Diaptomus oregonensis*, *Diaptomus siciloides*, *Diaptomus sicilis*, *Eurytemora affinis* and *Limnocalanus macrurus*. The most abundant cladocerans were *Bosmina longirostris* and *Daphnia retrocurva*. Subdominant forms were *Bosmina coregoni coregoni* and *Ceriodaphnia lacustris*. Other cladocerans included *Daphnia longiremis*, *Daphnia galeata mendotae*, *Chydorus sphaericus*, *Holopedium gibberum*, *Diaphonosoma leuchtenbergianum*, *Leptodora kindtii* and *Polyphemus pediculus*.

Although great differences were found in overall abundance and in species composition in particular parts of the lake, a general pattern of plankton distribution was evident. On the average, the eastern part of the lake was 1.7 times richer in planktonic crustaceans than the western and central parts (610 as against 350 animals/m^3). Most species appeared in June and July in relatively high numbers in the eastern part of the lake. The population increased in numbers and expanded toward the west in August. In September, some of the species, *Bosmina longirostris* and *Ceriodaphnia lacustris* were abundant farther west disappearing from the east. Others like *Daphnia retrocurva* and *Cyclops bicuspidatus thomasi* were distributed throughout the lake showing a tendency to concentrate in deep water areas.

2.4.4 Cladophora

One of the major problems in Lake Ontario is that created by the filamentous green alga *Cladophora*. This alga grows extensively along the shorelines of the lower Great Lakes wherever there is a suitable rocky substrate. Problems arise usually in July, at which time the long algal filaments break off during stormy weather, and accumulate on shore. Additional quantities of lesser magnitude may be deposited periodically throughout the remainder of the summer. Recreational and aesthetic values are seriously affected as the algae decompose, causing unsightly beaches and foul odours. Industries and municipalities have reported difficulties owing to *Cladophora* entering their water intakes. Commercial fishing operations have been seriously affected by the fouling of fish nets.

Nearshore Lake Ontario waters are, in general, rich enough in nutrients to support *Cladophora* growths (Fig. 2.4.5). For this reason, the distribution and quantities of algae produced depend primarily on the physical characteristics of the shoreline. Much of the United States shoreline during summer has large amounts of *Cladophora* washed up on the beaches. At Webster Beach, just east of Rochester, bathers have refused to swim in the fouled waters. Similar beach conditions have occurred from the Niagara River east to Stony Point. Investigations in July of 1965 and 1966 indicated that Stony Point experienced particularly heavy accumulations. During both reconnaissances, *Cladophora* accumulations extended from 25 to 50 feet from shore and were two to three feet thick. The mat was sturdy enough to allow birds and rodents to run about on it. Odours emanating from the decaying mats were highly pungent and foul.

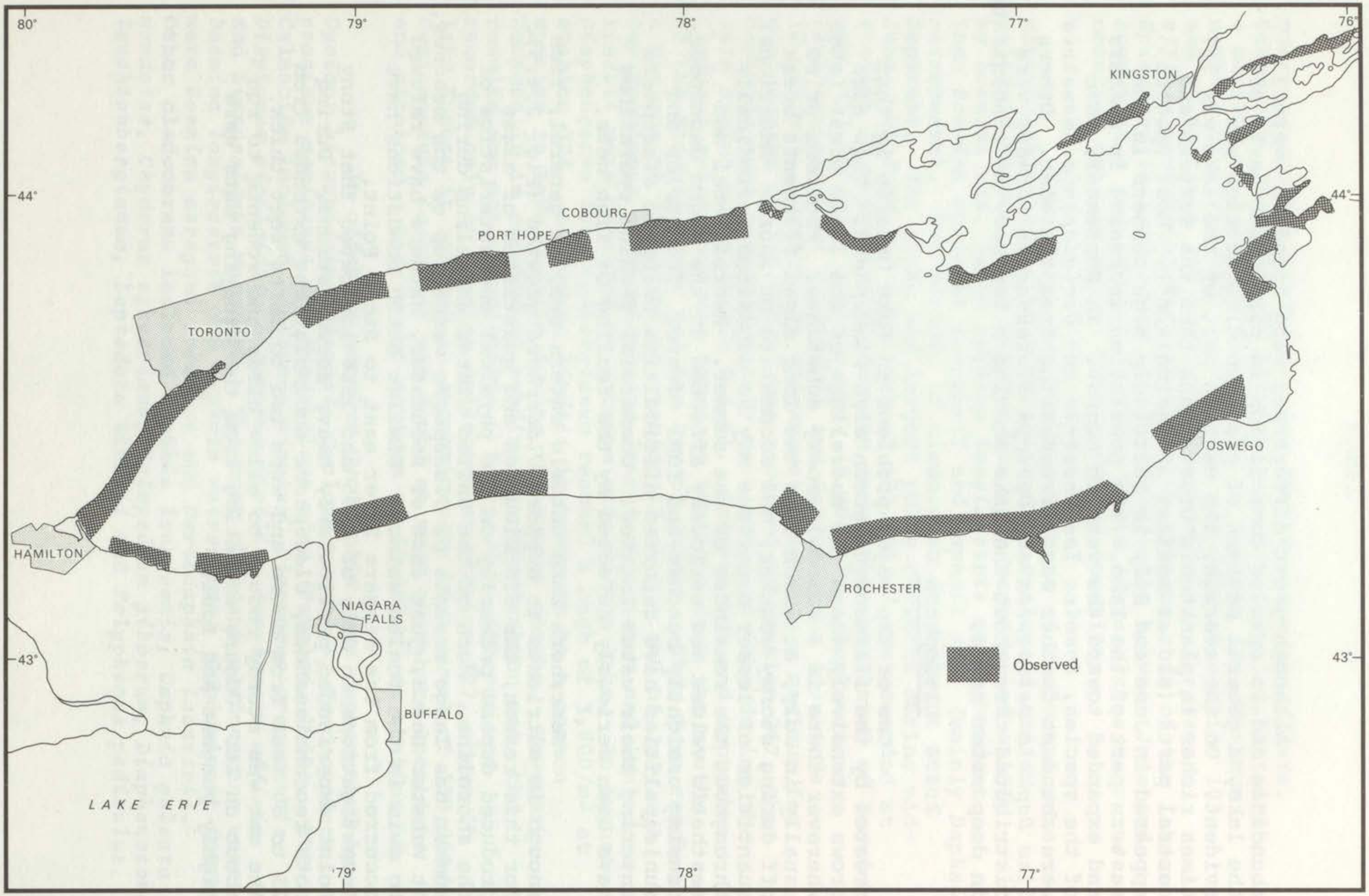


Fig. 2.4.5 Distribution of *Cladophora* in Lake Ontario.

The stretch of shoreline between Toronto and Hamilton has almost a continuous band of growth, and it is along this section of the lake that very heavy accumulations of the algae develop. A rock bottom prevails in this area, with many of the rocky shelves providing depths optimal for growth out to 500 and 1,000 feet from shore. It has been estimated from aerial photographs that growth beds within the three metre depth contour between Toronto and Burlington cover a total of 2,300 acres. Numerous sewer outfalls, together with agricultural drainage entering from several watersheds, undoubtedly promote the excessive growth in this area. The shoreline from Hamilton to the Niagara River has considerable accumulations, but growth in this area is not continuous. East of Toronto, considerable stretches of rocky shoreline have provided ideal conditions for nuisance growths particularly near Presqu'ile Point, Cobourg, Port Hope, Oshawa, and Frenchman Bay. A survey in 1963 (OWRC) showed that 29 miles of the 95-mile shoreline between Toronto and Presqu'ile Point had algal accumulations. This area, similar to eastern Lake Erie, has several beaches that are deserted on many occasions owing to *Cladophora* accumulations. The beach at Presqu'ile is badly affected as it seems to act as a collecting basin for algae washed in from extensive growth beds west of the beach. Growths between Prince Edward County and Prescott on the St. Lawrence River were reported to be "not extensive but prevalent along most of the shore at the waterline" (Neil and Owen, 1964). However, more recent observations and public complaints indicate that *Cladophora* is becoming more extensive in eastern Lake Ontario. While there are considerable lengths of rocky shoreline in the Thousand Islands area of the St. Lawrence River, major problems are not expected to develop because growth beds are limited by the steep depth gradient. For the same reason, algal problems between the Thousand Islands and Cornwall are relatively minor.

The existence of extensive growth beds in the lower Great Lakes obviously shows the presence of sufficient nutrients in the nearshore waters to support *Cladophora* growth. In contrast Neil and Owen (1964) have demonstrated that growths are limited in Lake Huron by low phosphorus concentrations.

The depth contour pattern of the nearshore area is important in determining the size of a growth bed. Studies have indicated that *Cladophora* grows to a depth of eight metres in the Toronto-Hamilton area, but is considerably reduced in depths greater than four metres. In the relatively clear waters along the south shore of Prince Edward County, however, algae were found growing to depths of 15 metres. Growth limitations are undoubtedly a function of depth, turbidity and resulting light penetration, as well as nutrient availability.

Seasonal fluctuations are closely related to water levels and low water levels generally expose a greater area of rock suitable for algal growth. Extensive growths in 1957 and 1958 can be related to low water levels, whereas in 1967, a relatively low degree of production was noted when water levels were high.

Heavy growths of *Cladophora* along the Lake Ontario shoreline seriously impair the water for recreational, industrial and municipal usage. Abundant growths in the Toronto-Hamilton and Rochester areas are stimulated by inputs associated with municipal, industrial and agricultural development. Many chemical and mechanical control measures have been tested, but with little success.

In the St. Lawrence River in 1967, *Cladophora* was found to be common on all rock substrates in the upper littoral throughout most reaches. Along exposed shorelines in the Kingston regions where nuisance conditions are severe, extensive areas supported substantial growths out to a depth of 3 metres. In the more confined waters of the Thousand Islands region and throughout much of the remainder of the river, growth beds were not extensive because of steep shore profiles and sediment accumulations in bays. However, significant areas of growth were observed along the shoreline bordering Elizabethtown and Augusta townships and from Cardinal to upper Lake St. Lawrence. Production was noticeably greater below all sources of municipal wastes and the industrial waste discharges at Maitland than in other parts of the river.

Observations in 1963 in the Kingston and Brockville areas revealed minimal growths occurring only as a shoreline fringe; by 1967 production was significantly greater owing to the increased size of growth beds and an increase in standing crop per unit area. The present extent of growth beds is probably the most extensive observed to date with levels of production dependent largely on the degree of enrichment of the river water.

Observations of rooted aquatic vegetation in upper Lake St. Francis in August, 1966 and the Thousand Islands downstream to Lake St. Lawrence in August, 1967 revealed that growths were abundant in depths less than 6 metres where shallow profiles and minimum flows permitted deposition of organic materials and fine sediments. Growth areas were found to be extensive in the region of the Thousand Islands downstream to Brockville, between Cardinal and Iroquois and below Morrisburg. Flooded land forms much of the littoral zone in the Lake St. Lawrence and appreciable growths of submergent vegetation had not become established by 1967. In areas where growth was most dense principal species included a variety of palmed weed *(Potamogeton spp.)*, Canada Water Weed *(Anacharis canadensis)*, eel grass *(Vallisneria americana)* and water milfoil *(Myriophyllum spp.)*. While there were no earlier observations which would permit an evaluation of trend, reports from the local public emphasize an obvious acceleration of production and related nuisance problems since 1959 in Lake St. Francis and in more recent years in the Thousand Islands region. Affects on river use include: a restriction of commercial fishing operations due to the fouling of gill nets by drifting vegetation and difficulties with the setting, fishing and general efficiency of trap nets; a reduction of open water areas desirable for sport fishing; restriction of small craft navigation in shallow confined waters and an encroachment of mergent and submergent vegetation on swimming beaches.

2.4.5 Bottom Fauna

The bottom-dwelling invertebrates which comprise the benthic macrofauna are those animals which burrow in, cling to or crawl over the lake bottom.

Few investigations of the bottom fauna in Lake Ontario and the St. Lawrence River have been published to date. An analysis by Nicholson (1873) of dredgings taken within a 10-mile radius of Toronto, revealed the presence of mayflies, unionids and amphipods in Toronto Harbour. Beeton (1965) described the distribution of oligotrophic forms in the Great Lakes. More recently, Johnson and Matheson (1968) published the results of a biological survey conducted in 1964 to 1965 on Hamilton Bay and adjacent Lake Ontario. Brinkhurst *et al.* (1968) have summarized the distribution of oligochaetes, chironomids and sphaeriids in Lakes Ontario, Erie, and Georgian Bay.

Investigations of the distribution and abundance of benthic organisms yield valuable information about the environment which they inhabit. A clean-water community typically has a high diversity including pollution-tolerant forms, a well-balanced population not dominated by one major group, and a moderate number of organisms. Organically-enriched environments characteristically have a low diversity dominated by pollution-tolerant organisms. Some insect larvae, notably certain midges (Chironomidae) and certain segmented worms (Tubificidae), often reach their greatest densities in organically-enriched sediments. Wright *et al.* (1955), in his study of western Lake Erie regarded tubificid populations of greater than 5,000 per square metre (5,000/m^2) as indicative of heavy organic enrichment. An environment subjected to a toxic pollutant is characterized by an absence of aquatic life or very low numbers of the most pollution-tolerant organisms.

Numerous attempts have been made to use indicator organisms in the detection and assessment of pollution. King and Ball (1964) proposed the weight ratio of aquatic insects to tubificid worms as a quantitative measure of pollution. Goodnight and Witley (1960) attempted to relate the abundance of these worms to the total bottom fauna as a measure of pollution. Burlington (1962) described the biological populations in an attempt to relate population differences to pollution. Srivastava (1962) and Brinkhurst (1962) described some of the environmental requirements of certain tubificids as related to pollution. Paine and Gaufin (1956) used aquatic Diptera (midges) as indicators of stream pollution. Curry (1962) summarized many of the environmental requirements and tolerance limits of the midges with emphasis on pollution, and Hamilton in Brinkhurst *et al.* (1968) has developed a eutrophication index for the Great Lakes based on midges.

These papers have contributed to our knowledge of the response of the biota to pollution, but as yet no one has described an indicator organism in the strict sense of the word. Brinkhurst (1962) asserts there is no universal indicator species, the mere presence or absence of which will indicate the degree of pollution by any or all effluents. However, through an evaluation of the relative densities of the component benthic forms in a given area of a lake, the general environmental conditions can be outlined on a broad scale. The areas most severely degraded can be readily delineated by the high densities of pollution-tolerant forms and the relative scarcity of other fauna.

The following report provides recent information on the bottom fauna of Lake Ontario, much of which has not yet been published. Stations located throughout the lake were sampled by FWPCA in 1965 (42 stations) and by the Great Lakes Institute between 1964 and 1966 (about 80 stations). In 1966 and 1967, the OWRC studied the benthos along the nearshore Canadian waters of the lake (166 stations), and the international section of the St. Lawrence River. In addition, more detailed studies were conducted in 1966 in the area near the Niagara River mouth (FWPCA) as well as in Toronto Harbour (OWRC).

Methods of collection and sample preparation varied somewhat between the contributing agencies, but qualitative comparisons can be made. Samples were collected using either a Petersen, Ponar or Franklin dredge. The invertebrate samples were separated from the sediment and returned to the laboratories for enumeration and identification.

The benthic fauna at the offshore stations sampled by FWPCA consisted mainly of seven major taxa. The scud, *Pontoporeia affinis* (Amphipoda), and segmented worms (Oligochaeta) were the dominant fauna, constituting an average of 95 percent of all organisms collected during the four sampling cruises. The remaining five percent consisted of fingernail clams (Sphaeriidae), midge larvae and pupae (Diptera: Chironomidae), sowbugs (Isopoda), leeches (Hirudinea) and snails (Gastropoda).

A scud, *P. affinis*, generally indicative of oligotrophic conditions, had a lakewide distribution and was the dominant benthic form in all areas of the lake except near Toronto, and near the mouths of the Niagara, Genesee and Oswego Rivers, where heavy organic loadings occurred. In these areas the Oligochaeta were dominant, sometimes reaching densities in excess of 10,000/m^2 (Fig. 2.4.6, 2.4.7). Fingernail clams, prosobranch snails and pulmonate snails were also abundant near these river mouths. More than 85 percent of the fingernail clams collected were found at depths less than 40 metres, but a few individuals were recorded from as deep as 160 metres. Snails were confined entirely to water less than 36 metres deep.

During 1965, the benthic population remained fairly constant from May through September. Scuds comprised 63.6 percent by number of the standing crop in July as compared to a high of 79.9 percent in September. During May, they accounted for 75.4 percent of the total fauna collected. Oligochaetes constituted 22.4 (May), 28.2 (July) and 17.2 (September) percent respectively of the total fauna collected. The mean percentage density composition of the total fauna for the three sampling cruises was as follows: Scuds, 72.97; oligochaetes, 22.6; midges, 1.04; fingernail clams, 3.28; all others 0.11. The mean total density per square metre of substrate was 631 organisms, with a range of 16 to 6,100.

The October 1967 samples yielded much higher percentages of oligochaetes than did the 1965 collections, but this cannot be interpreted as an indication of environmental changes in the lake bottom since different stations were sampled in the two years. During October, 1967, oligochaetes dominated the bottom fauna, comprising a mean of 72.5 percent of the total numbers of organisms collected from all stations sampled. Scuds accounted for only about 20 percent of the total fauna, with fingernail clams, midges and other forms comprising 5.40, 0.16 and 1.80 percent, respectively. Although fewer stations were sampled in 1967, a relatively higher number were in shallower water

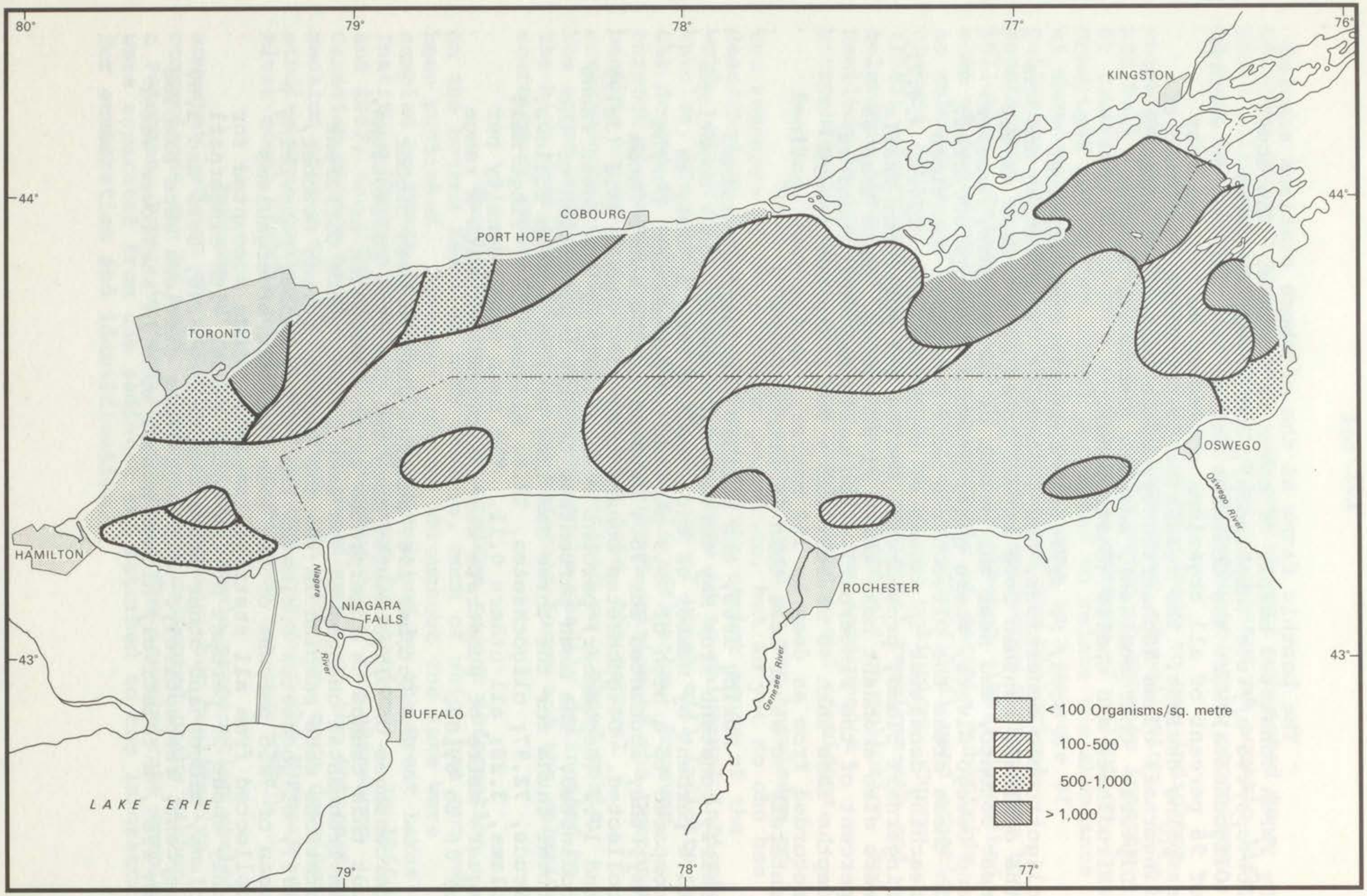


Fig. 2.4.6 Distribution of *Pontoporeia affinis* (1965).

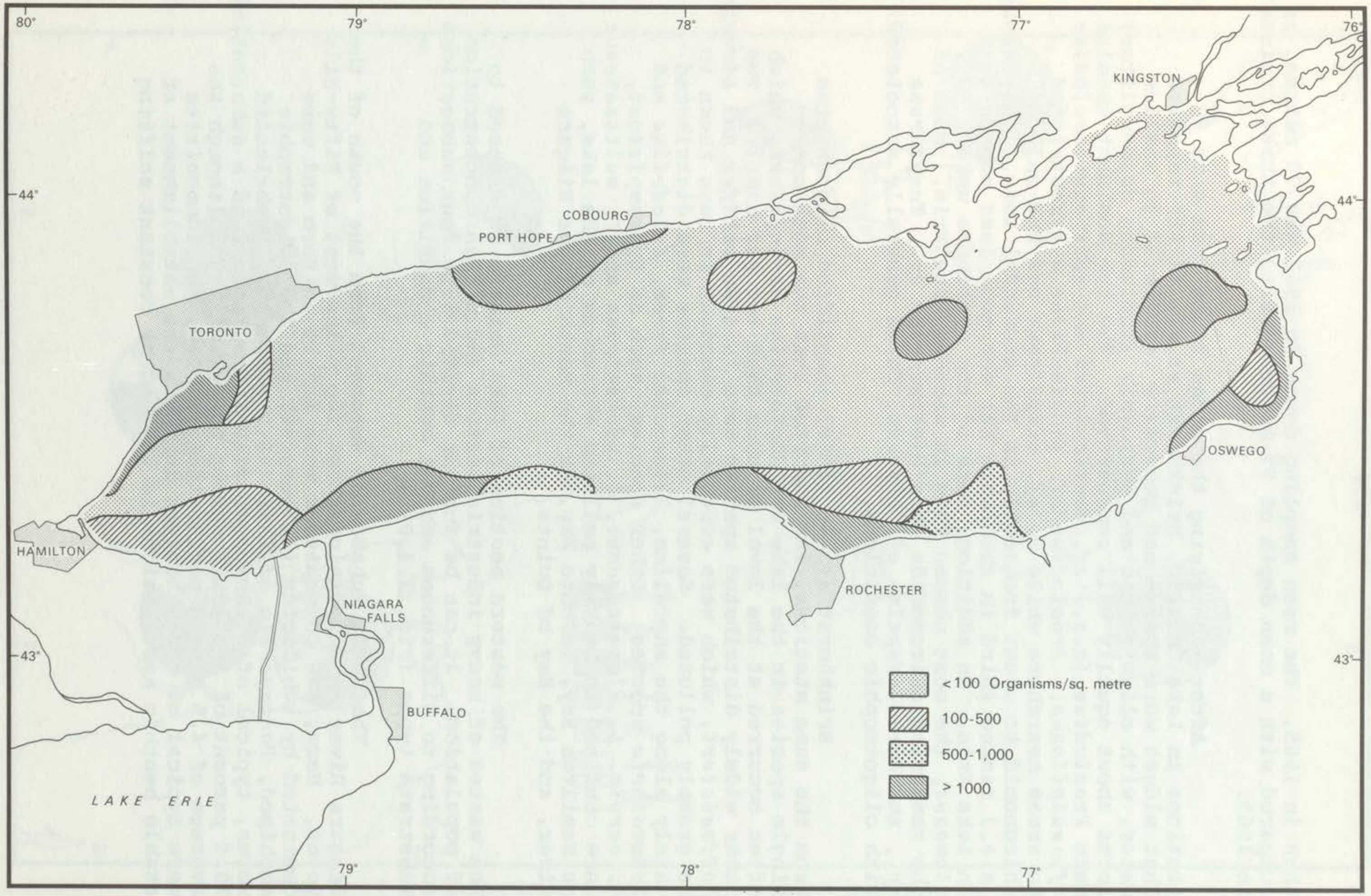


Fig. 2.4.7 Distribution of Oligochaeta (1965).

than in 1965. The mean sampling depth in 1967 was 70 metres, as compared with a mean depth of 99 metres during the three cruises in 1965.

After identifying the midge fauna from some 80 stations in Lake Ontario, Brinkhurst *et al.* (1968) reported that midges were sparse and generally restricted to shallow water, with oligotrophic and eutrophic (including cosmopolitan) forms about equally well represented. The two dominant species were *Procladius (s.s.) cf. denticulatus* and *Heterotrissocladius cf. sulpilosus*. *Procladius cf. denticulatus* was restricted to areas nearshore while *H. cf. sulpilosus* was the only chironomid to occur frequently in the profundal zone. *Chironomus (s.s.)* ranked third in abundance but was much less common than in Lake Erie. In addition, none of the specimens were *C. cf. plumosus*, the most common form in western Lake Erie. Most of the remaining chironomids were *Micropsectra sp.*, *Tanytarsus sp.*, and *Paracladopelma cf. obscura*, forms generally associated with oligotrophic conditions.

Brinkhurst *et al.* (1968) identified oligochaetes from the same stations, and reported that the most common single species in the lake was *Stylodrilus heringianus*, which often occurred at the level of more than ten per sample. Two other widely distributed species were *Tubifex tubifex* and *Limnodrilus hoffmeisteri*, which were especially abundant in bays known to be grossly polluted. Several other species were distributed mainly along the shoreline, *Peloscolex ferox*, *Aulodrilus* and *Potamothrix* species. Other species, such as *L. templetoni*, *L. cervix*, *L. claparedeanus*, *L. udekemianas* and *P. multisetosus* were confined to heavily polluted stretches of the lake, such as Hamilton Bay, Toronto Bay, at the mouth of the Niagara River, and the Bay of Quinte.

The western section of Lake Ontario is exposed to the wastes of heavy industrialization and a high concentration of population. It can be further divided into four subsections according to differences amongst benthic communities and substrate types (Fig. 2.4.8).

The first subsection extended from the mouth of the Niagara River to a location about two miles west of Fifty-Mile Point. Here, the communities were fairly uniform and were dominated by tubificids (33 percent) and the oligotrophic amphipod, *Pontoporeia affinis* (28.5 percent). Lumbriculid worms, typical of clean-water situations, comprised a substantial 10.8 percent of the total number of organisms. Although the average of 4.5 genera per station was low, the communities were typical of sandy bottoms in which the establishment of stable benthic associations is limited by constant shifting

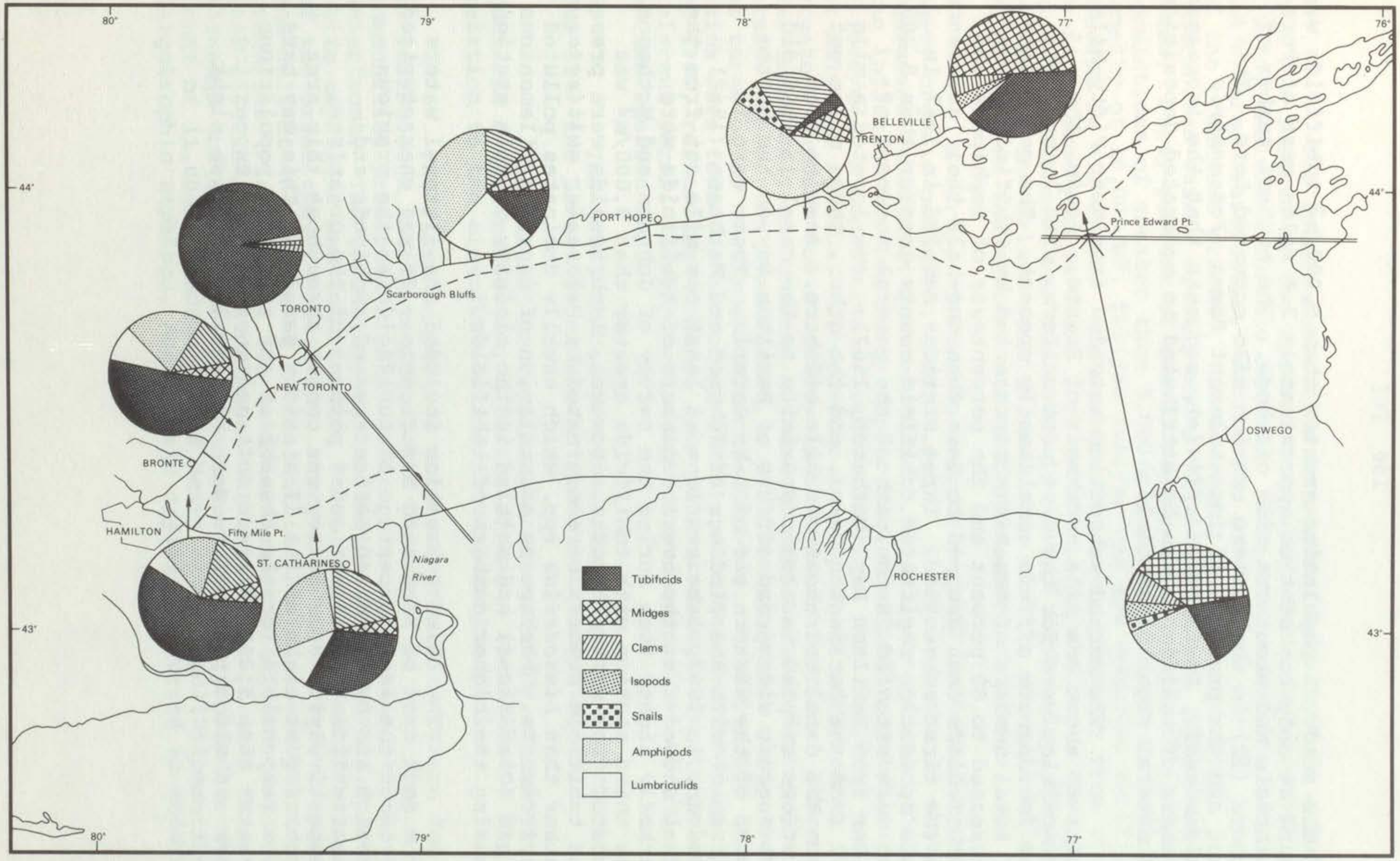


Fig. 2.4.8 Composition of bottom faunal communities in Lake Ontario, 1966-1967.

of the sand. A population greater than 5,000/m^2 tubificids was found at only one station approximately 2.4 miles west of Port Dalhousie and about one mile offshore. The highest number of genera (12) in the western section also occurred here. This fact and the presence of less-tolerant forms (*Potamothrix moldaviensis*, *Pontoporeia affinis*), suggests that the increased numbers of tubificids can be attributed to moderated deposition of natural organic material.

The second subsection extended from near Fifty-Mile Point to about one mile northeast of Bronte. Again, the communities were for the most part uniform, with lumbriculids and *Pontoporeia affinis* consistently present. The percentage of total numbers of organisms represented by tubificid worms increased to 60 percent and the percentages of amphipods and lumbriculids each dropped to less than one-half their abundance in the first subsection. Three stations sampled in 1967 in this subsection registered tubificid counts greater than 5,000/m^2. Two were situated in the path of the general movement of water from Hamilton Bay (Matheson, 1962): one located a mile out from the Burlington Canal, and the other, three miles out from the canal and about one mile offshore. Results from stations sampled in closer proximity to the canal in 1966 did not suggest widespread effects of Hamilton Bay on the bottom fauna of the western end of Lake Ontario. These were in agreement with the findings of Johnson and Matheson (1968). However, in 1967, lake stations at least one mile out from the canal showed that the average numbers of tubificids were markedly higher than during the survey of Johnson and Matheson. The third station with tubificids greater than 5,000/m^2 was located just east of Bronte. However, lumbriculids were present and tubificid numbers were dominated by *Peloscolex multisetosus*, rather than *Limnodrilus spp.* which usually dominates polluted environments. Perhaps an accumulation of decaying filamentous algae (*Cladophora*) had settled in the vicinity of this station causing the higher numbers of tubificids.

The third subsection included the littoral waters from just east of Bronte to New Toronto. It was characterized by about the same percentage of tubificids as the previous section and by increased percentages of amphipods and lumbriculids (21 percent and 9 percent of the organisms, respectively). Rock bottom was common throughout this area, occurring at eight of the 17 stations sampled. This may have been responsible for the absence of any tubificid populations greater than 5,000/m^2 since soft sediment pockets supporting worm and midge populations were not sampled at these eight stations.

The fourth subsection in western Lake Ontario extended from New Toronto to the western extension of the Scarborough Bluffs, excluding Toronto Harbour. Here, the community composition had altered drastically. Tubificids constituted over 96 percent of the organisms present, the remaining four percent being distributed fairly equally among the lumbriculids, amphipods and clams. Forty percent of the 23 stations possessed tubificid populations of greater than 5,000/m^2, seven of these exceeding a density of 10,000/m^2. *Tubifex tubifex* was the dominant tubificid species in all cases. Low numbers of genera, ranging from three to five, accompanied these high tubificid populations. Heavy organic enrichment was indicated in most of Humber Bay, in pockets encircling the island complex, and at a station one-half mile offshore from the western end of the Scarborough Bluffs.

A survey of Toronto Harbour in 1966 indicated extremely heavy organic pollution (Fig. 2.4.9). Fifteen of the 16 stations possessed tubificids greater than 10,000/m^2. One station near the influx of the Don River supported a tubificid population of 97,000/m^2. A population of tubificids less than 5,000/m^2 was found at only one station. *Limnodrilus cervix*, which occurred in its greatest numbers and frequency in the western basin of Lake Erie, was found only in Hamilton Bay and Toronto Harbour during this study. *Sphaerium transversum*, a pollution-tolerant clam, occurred at three of 16 stations in Toronto Harbour. Mayflies and unionids, which were found by Nicholson (1873), were not recovered in 1966 or 1967, reflecting a change from pollution-sensitive to pollution-tolerant forms. Amphipods were found at one station at the mouth of the Eastern Gap.

The total number of genera found in the western section was 22 - the lowest total of the three sections studied.

The central section is characterized by extensive rock and sandstone bottom, a factor of major significance in relation to the distribution and abundance of organisms.

The first subsection extended from the western end of Scarborough Bluffs to Otty Point just west of Port Hope. The communities presented a sharp contrast to those along the Toronto waterfront. The percentage of tubificids dropped to 12.8 percent, while amphipods and lumbriculids increased to 39 and 24 percent of the organisms, respectively. Midges and clams each composed one-half of the remaining 24 percent of the total numbers of organisms (Fig. 2.4.9). No tubificid concentrations greater than 1,600/m^2 were found at open-water stations in this area, although one sample collected in Oshawa Harbour yielded a tubificid count of 11,000/m^2 indicative of heavy organic pollution. The oligotrophic amphipod, *Pontoporeia affinis*, occurred in moderate

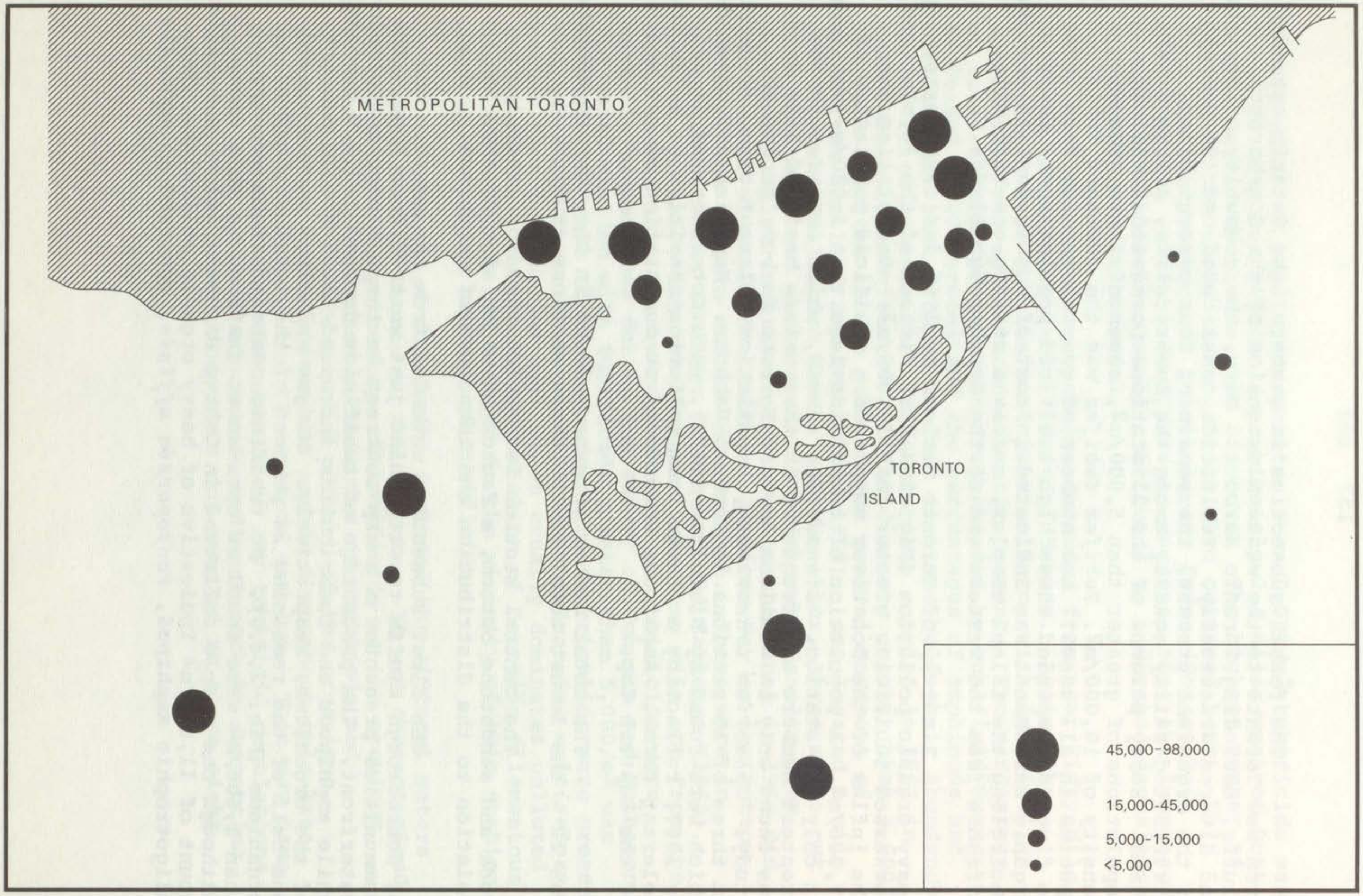


Fig. 2.4.9 Distribution of tubificid animal/m^2 in Toronto Harbour and vicinity (1966).

numbers at 70 percent of the stations. *Mysis relicta*, a small planktonic crustacean which is common in the oligotrophic upper Great Lakes, was collected quite by chance at five of 26 stations.

The remaining area in the central section extended from just west of Port Hope to Prince Edward Point. Samples from this subsection were numerically dominated by amphipods (45 percent), clams (22.5 percent), midges (11 percent) and lumbriculids (10.5 percent). Tubificids and snails made up the remaining 11 percent of organisms (Fig. 2.4.9). Tubificid counts were low, of a magnitude similar to populations in the upper Great Lakes. The highest tubificid density was 1,100/m^2. *Pontoporeia affinis* was abundant at 84 percent of the stations. *Mysis relicta* was incidentally recovered at six of 27 stations. The bottom fauna of the central section of Lake Ontario was typical of the oligotrophic upper Great Lakes. As was the case in Lake Huron (Teter, 1960; Schuytema and Powers, 1966), the amphipod, *Pontoporeia affinis* dominated the populations of nearshore waters in the central region of Lake Ontario and the oligochaetes were the next most prominent group. Heavy organic pollution was indicated only in Oshawa Harbour. The total number of genera identified in this section was 28.

The eastern section is divided into two subsections; the first from Prince Edward Point to Amherst Island, and the second from Amherst Island to the innermost reaches of the Bay of Quinte (Fig. 2.4.8).

The first subsection was characterized by midges (35 percent by number), amphipods (25 percent) and tubificids (22.5 percent), with the remaining 17.5 percent consisting of clams, isopods and snails (Fig. 2.4.8). The highest average number of genera per station in the entire study area (10.3) occurred in this subsection. High generic diversity was most obvious in the midge group which attained its greatest abundance in this area. The relatively shallow mud bottom and the sheltered location of Prince Edward Bay is likely responsible for the increased diversity. No organic enrichment was suggested by the tubificid counts, which never exceeded 1,800/m^2. The abundance of *Pontoporeia affinis* decreased and another amphipod, *Gammarus fasciatus*, which is usually found in shallow and warm water, appeared.

Communities in the Bay of Quinte were characterized by high numbers and percentages of tubificids and midges (40 and 49 percent of the total number of organisms, respectively) and markedly low numbers and percentages of amphipods (2 percent). The number of genera per station averaged 5.5 as compared with higher values in Prince Edward Bay. As a result of the warm, shallow water in the Bay of Quinte, *Pontoporeia affinis* occurred at only 2 stations which were located in Adolphus Reach. *Gammarus fasciatus* was found at five of 13 stations throughout the Bay. The midge larva, *Coelotanypus*, which in Lake Erie was found only in the western basin, was recovered in Lake Ontario only in the Bay of Quinte, occurring at 50 percent of the stations. Again, the determining factor is the warm, shallow water. Although benthic communities in the bay indicate heavy organic enrichment, the highest tubificid count was a moderate 3,100/m^2. Dense populations of predacious midges, plus the unstable sediments in the upper bay, may be keeping oligochaete populations at this low level. Communities in this section were diverse; a total of 33 genera identified was the highest in the lake.

Within Kingston Harbour, located at the mouth of the Cataraqui River, bottom faunal communities were sampled at five stations within 500 feet of the shoreline, covering approximately one mile of the harbour waterfront. Benthic communities consisted of an average of fewer than 2 taxa per station and were comprised solely of tubificid worms *(Limnodrilus sp.)* and midge larvae *(Procladius* and *Chironomus)*. At most stations greater than 1,000 feet offshore along the Kingston waterfront and the shoreline of Pittsburg Township, communities consisted chiefly of pollution-sensitive organisms and showed greater diversity. Within the Cataraqui River near Kingston, communities were similar to those observed at inshore stations of the harbour area. Sampling in the Cataraqui River upstream of Kingston revealed a balanced, diverse fauna.

These data reveal moderate to gross impairment of water quality and adverse effects on aquatic biota within the immediate area of Kingston Harbour, undoubtedly related to pollution sources from the city.

Local pollution of the St. Lawrence River at Brockville was evident from benthic communities at the mouth of Butler Creek and approximately 500 feet downstream. A survey of municipal pollution sources in 1964 revealed gross pollution of Butler Creek from industrial waste discharges and overflows from combined storm and sanitary sewers in Brockville. At the mouth of the creek, within the area of initial dilution, the bottom fauna consisted only of the midge larvae, *Procladius spp.* and *Pentaneura spp.*, and the worms, *Limnodrilus spp.*, all occurring in low densities. At a site 500 feet downstream and within 30 feet of shore, only a few specimens each of *Procladius spp.* and *Limnodrilus hoffmeisteri* were obtained. However, samples taken at 100 feet downstream but further offshore yielded a more diversified fauna typical of unpolluted waters at control stations in this portion of the river.

The Canada Starch Company at Cardinal discharges waste direct to the St. Lawrence River. No benthic animals were found immediately below this discharge. Downstream 200 feet, low numbers of the tubificid, *L. hoffmeisteri*, occurred and downstream 1,000 feet midge larvae *(Chironomus spp.)* and worms were abundant. Re-establishment of normal communities occurred about one-half mile downstream. These results are indicative of heavy organic pollution.

Primary treated effluent from the City of Cornwall and a variety of industrial wastes are discharged to the north channel of the Cornwall Narrows. Of major importance are the large volumes of Kraft process wastes discharged by the Howard Smith Paper Mill (Division of Dominion Tar and Chemical Company) and highly contaminated wastes from Courtaulds (Canada) Limited and related industries. Due to separation of the river at this point, flow in the north channel discharges to Lake St. Francis and wastes from Cornwall do not cross the international boundary.

The bottom fauna was sampled at 11 stations extending along the northern shore (Cornwall waterfront) and southern shore of the north channel from above Cornwall downstream to the eastern extremity of Cornwall Island. No benthic animals were found in samples taken within 500 feet of the Cornwall shoreline at stations 0.6, 2.2 and 3.1 miles downstream of the Howard Smith mill. At these sites, the bottom was blanketed with bark and wood chips. A community dominated by midge larvae and tubificid worms occurred approximately one mile below the mill where a greater current velocity precluded the deposition of solids. On the other hand, an average of 13 taxa consisting predominantly of pollution-sensitive worms was found at stations along the southern shore of the channel. From a comparison of these results, it was evident that nearshore waters along most of the Cornwall waterfront were grossly impaired. On the basis of the few stations sampled, it was not possible to fully assess the effects of specific waste sources.

From an examination of bottom faunal communities at the 24 stations located throughout the general study area, no adverse changes in water quality or downstream variations could be detected. For the most part, these stations exhibited balanced, diversified faunas with low to moderate densities. Pollution-sensitive caddisflies, mayflies, amphipods, clams and snails were common to most reaches of the river. The average number of taxa at all stations was 9.8, ranging from a high of 13.2 in areas of appreciable flow to a low of 4.4 in Lake St. Lawrence, where substrate types were relatively homogeneous and where populations were not yet stabilized in areas of recent flooding. Differences in diversity of fauna in different reaches of the river and between stations at each transect were attributed in all cases to natural variations in the physical environment.

In summary, the bottom fauna of Lake Ontario is quite uniform qualitatively throughout the lake. The predominance of *Pontoporeia affinis* in the offshore waters indicates that the benthos is more like the upper Great Lakes than Lake Erie. However, organic enrichment was evident at several inshore locations including the area near Toronto and the mouths of the Niagara, Genesee and Oswego Rivers where the combination of existing natural conditions plus cultural enrichment has lent itself to eutrophication.

The bottom faunal communities of nearshore environments in western Lake Ontario indicated heavy organic pollution in the Toronto area, from Humber Bay to Scarborough Bluffs. On the basis of somewhat limited sampling, the polluted waters of the Niagara River and Hamilton Bay did not seem to seriously affect the benthic populations of the lake, although tubificids dominated populations in nearshore waters off the Hamilton-Burlington area. Possibly, gradual enrichment is occurring near Hamilton Bay where tubificid counts are high relative to most other areas.

The deep-water area and the central section of nearshore Canadian waters have a bottom faunal association similar to those from the upper Great Lakes but these are limited along the shoreline by extensive rock substrates. Heavy organic enrichment occurs in Oshawa Harbour and at the mouth of the Genesee River.

In the eastern part of the lake, organic enrichment occurs near the mouth of the Oswego River, and in the Bay of Quinte.

Within the international section of the St. Lawrence River, bottom faunal communities generally indicated water of good quality. Local surveys below major waste discharges from Ontario municipalities demonstrated contamination of the river at Kingston, Brockville, Cardinal and Cornwall. The extent of the river affected in each case was limited to nearshore waters. Significant impairment of river water from treated sanitary and industrial wastes and periodic overflows of untreated municipal wastes at other specific locations could not be detected.

2.4.6 Fish Populations

Striking changes in the fish fauna in Lake Ontario have occurred in the past three decades and the belief is widely held that these are related, at least in part, to pollution and eutrophication. The precise relationship, however, remains to be defined. It is of interest that Atlantic salmon once lived in Lake Ontario and reproduced in streams entering the lake. The last specimen was caught at the close of the 19th century.

A major difficulty in any analysis of fish populations is the lack of adequate documentation of water quality and other changes affecting populations, such as predation. A measure of these is therefore essential for a proper interpretation of events. Smith (1968) has recently reviewed the question of species succession in relation to fishery exploitation in the Great Lakes.

Catch records (Baldwin and Saalfeld, 1962), which commercial fishermen have been required to submit provide a useful measure of population changes for nearly one-third of the 92 species of fish found in the lake. These statistics point to declines in eight fishes or groups of fishes (Table 2.4.7). Native lake trout which in the past occurred throughout the lake have virtually disappeared although some survivors of recent trout plantings remain. Populations of whitefish and cisco (lake herring) are no longer detectable in the western half of Lake Ontario, and in the eastern basin both of these species are relatively sparse compared with their former abundance. The deepwater ciscoes or chubs likewise have declined and it is now questionable whether all of the three recorded forms, the bloater, kiyi and shortnose cisco, remain. The blue pike which earlier was found in western Lake Ontario seems to have disappeared, and the closely related walleye which was common in the Bay of Quinte and eastern Lake Ontario region has declined. Catches suggest that bullheads, too, are less abundant. Generally speaking, important species have declined in abundance throughout the lake and in the western end the number of species has decreased.

These changes have had considerable impact on the commercial fishing industry in Lake Ontario, much of which is now on the verge of collapse.

Some of the factors in the declines are recognized. The downward trend in the whitefish stock in eastern Lake Ontario has been attributed by Christie (1963) to overfishing; however, on this basis alone it is difficult to reconcile the

Table 2.4.7 Canadian commercial catch statistics (thousands of pounds) demonstrating the declines of fish species in Lake Ontario.

Year	Cisco*	Chub*	Whitefish	Lake trout	Bullhead	Walleye	Blue pike
1935	836	–	657	245	–	28	38
1936	1,332	–	576	227	–	26	14
1937	1,544	–	552	205	–	22	26
1938	1,222	–	602	276	–	15	60
1939	1,593	–	665	269	–	10	101
1940	1,618	–	404	187	–	4	96
1941	1,922	–	442	126	–	7	58
1942	1,087	–	442	90	–	11	28
1943	857	–	329	76	–	43	38
1944	1,018	–	461	74	–	48	23
1945	761	–	359	105	–	34	19
1946	413	–	398	102	–	45	63
1947	573	–	358	64	–	40	107
1948	480	–	237	42	–	30	42
1949	324	–	219	22	–	28	47
1950	225	–	419	15	–	34	54
1951	197	–	385	40	–	90	189
1952	111	24	417	32	450	103	180
1953	73	18	207	14	397	75	66
1954	70	10	228	7	344	114	59
1955	29	4	340	4	357	124	33
1956	38	7	593	2	418	121	18
1957	84	2	301	1	373	118	9
1958	53	–	340	1	326	166	10
1959	52	–	335	1	273	151	3
1960	74	1	347	1	249	126	1
1961	51	–	572	–	185	125	1
1962	27	–	355	–	181	106	–
1963	38	–	354	–	209	68	–
1964	38	–	125	–	147	66	–
1965	23	1	107	–	122	46	–
1966	36	–	57	–	97	44	–
1967	59	–	50	–	140	27	–
1968	40	–	77	–	196	23	–

*Combined prior to 1952.

fact that at the western end of the lake the decline came sooner and was more complete. About 1950, commercial fishing for whitefish west of Port Hope terminated for lack of fish and since then there has been no return of that species. In the eastern basin, fishing for whitefish remained economical until the early 1960's.

There is no evidence to indicate that fishing was a major factor in the decline of offshore ciscoes, or the decline of walleyes. Lamprey predation is seen as a factor in some declines although its significance is not entirely known. The fact that lamprey have been present in Lake Ontario for over a century suggests that predation by this species is not the only cause of the recent declines. A realistic approach is to consider lamprey predation in combination with fishing mortality.

Climatic conditions, water temperature for example, have been found to influence year-class strength in fishes, but fluctuations so caused seldom take the pattern of the steady decline recently exhibited by many Lake Ontario species. A failure to produce sufficient progeny is known to have caused the reduction of walleyes in the Bay of Quinte. Since 1959, reproduction has been negligible throughout much of the bay even though a sizeable spawning stock was present. It would appear on the surface that the river spawning populations are being sustained but that the shoal spawning populations are disappearing.

The destruction of spawning grounds could account for such spawning failures. Investigations have not been carried out to determine this in the case of walleye in the Bay of Quinte, but elsewhere in the lake there is evidence that rocky shoreline areas have been altered in such a manner to make them either unsuitable or less suitable as spawning sites for shoal spawning fishes. Extensive *Cladophora* growths have been found along most of the shoreline from Toronto to Hamilton and along one-third of the shoreline from Toronto to Presqu'isle. Lesser growths of *Cladophora* have been observed along portions of the south shore of Prince Edward County and along much of the shoreline from there east of Prescott (Neil and Owen, 1964). Whitefish and cisco spawning grounds are thought to have been affected.

2.5 BACTERIOLOGY

2.5.1 Bacteriological Parameters

Coliforms

The group of bacteria most indicative of pollution, encountered in the bacteriological analysis of water, is the coliform group. 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 the coliform group is not normally regarded as pathogenic, the presence of members of this group in water serves as an indication of the potential presence of the scarcer and much more difficult to isolate pathogenic enteric organisms, such as those causing typhoid fever, dysentry and cholera. Standards for water quality are based to a large extent on coliform numbers.

It is generally agreed that waters with coliform counts above 20,000/100 ml are unacceptable for drinking water supplies with conventional treatment. However, waters with counts of 5,000/100 ml or less are acceptable for drinking water supplies with conventional treatment. Waters with counts of 1,000/100 ml or less are acceptable for bathing (McKee and Wolfe, 1963).

Two procedures are commonly used to determine the density of coliforms in water. The oldest and probably the most widely practiced technique for enumerating coliforms is the most probable number (MPN) test. This statistically-oriented technique is based on the ability of coliform organisms to grow in lactose broth with the production of acid and gas within 48 hours at 35°C. A newer and more practical technique, especially for field and shipboard studies, is the membrane filtration (MF) technique. This procedure is based on the filtration of an aliquot of water through a membrane filter with subsequent incubation of the filter on a media soaked pad at 35°C for 24 hours. Coliform colonies are counted and calculated in terms of coliforms per 100 millilitres (ml) of water sample. Data obtained by either technique, (MF) or (MPN), are equally valid even though they are not completely compatible in biotype selection. The work load and lack of space on board the survey vessels used in recent studies led to the adoption of the membrane filtration technique for the estimation of coliform densities.

Fecal Coliforms

Many bacteriologists have suggested that the incidence of *E. coli* Type I in water is a more accurate indication of fecal contamination than the more-inclusive "coliform group". These suggestions are based on the fact that *E. coli* Type I is the predominant coliform organism found in the feces of warm-blooded animals. However, there is little justification for applying the "non-fecal" label to the other coliform biotypes, as they are all usually found in small numbers in the feces of most animals and man.

Fecal Streptococci

Sewage contains fecal streptococci in appreciable numbers but not generally exceeding about one-tenth the number of *E. coli*. Therefore, fecal streptococci are used as an indication of pollution on the same grounds as *Escherichia coli*, namely that they are present in feces and sewage and found in known polluted waters. They are not found in pure waters, virgin soil and sites out of contact with human and animal life, and they do not usually multiply outside the animal body. The test for fecal streptococci is of greatest value when coliform organisms are present in the absence of *E. coli* strains and there is some doubt as to the fecal origin of the bacterial contamination.

Standard Plate Count

The standard plate count test is a means of measuring the number of viable bacteria which are able to grow and multiply in a specific culture media at a specified temperature.

The 20°C standard plate count provides information on the amount of decomposing organic matter available in the water for bacterial nutrition. The majority of colonies that develop at 20°C are non-pathogenic to humans; however, they do provide an indication of the amount of extraneous organic matter available for bacterial nutrition that has gained access to the water from various sources. Generally, the greater the amount of organic matter present, the more likely is the water to be contaminated with potentially pathogenic organisms.

The 35°C standard plate count is a more important index of pollution. The majority of organisms which develop at this temperature are chiefly of soil, sewage or intestinal origin. Thus, the greater the 35°C count the more likely it is that pathogenic organisms will be found.

It has generally been found that in pure water, about 10 times as many organisms develop at 20°C than at 35°C; in polluted water this ratio is less, and in chlorinated waters the 20°C and 35°C counts may be almost equal.

Coliform Classification

Pure culture studies enable the bacteriologist to relate coliform biotype incidence to the possible nature and source of bacteriological pollution. Coliform colonies selected for pure culture study are identified by use of biochemical tests and in some instances by means of serological techniques.

2.5.2 Distribution

Lake Ontario

Data, compiled from an intensive study of Lake Ontario indicate that the main body of Lake Ontario is not bacteriologically polluted, (Dutka *et al.*, 1967a; Van Otterloo *et al.*, 1967; and Federal Water Pollution Control Administration, 1966). The majority of monitor stations recorded median coliform densities of less than 1 coliform per 100 ml (Fig. 2.5.1); only six stations, all located in the Toronto and Niagara River areas, recorded median coliform densities greater than 6 coliforms per 100 ml.

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 were recorded at stations in the Niagara River area, (Van Otterloo *et al.*, 1967). Comparison of 35°C and 20°C standard plate count data from this area indicates that 35°C medians were double the 20°C medians. A further indication that sewage pollution is a contributing factor to the degradation of waters in this area is shown in Fig. 2.5.2.

The inshore waters along the southern shore of Lake Ontario have been extensively sampled. Coliform data (Federal Water Pollution Control Administration, 1966) indicate that the majority of waters along this shore are subject to minimal pollution except in the vicinity of towns and tributary streams where varying degrees of pollution were found. Stations on the majority of tributaries east of the Niagara River recorded median coliform densities greater than 240 coliforms per 100 ml with six tributaries recording median coliform densities greater than 1,000 coliforms per 100 ml. Only four tributary stream stations, Johnson Creek, Salmon Creek, Genesee River and Black River recorded median coliform densities in excess of 2,400 coliforms per 100 ml.

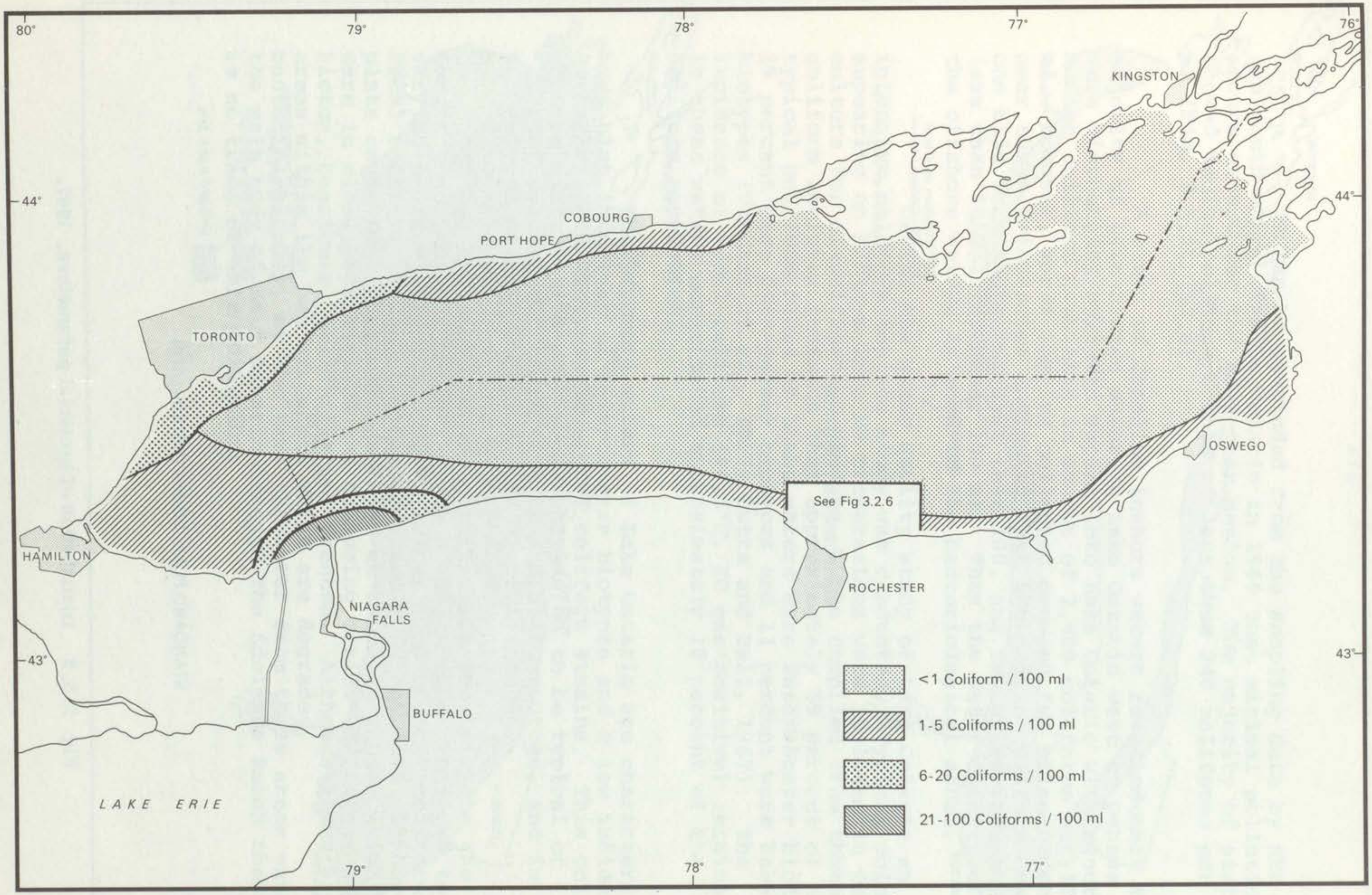
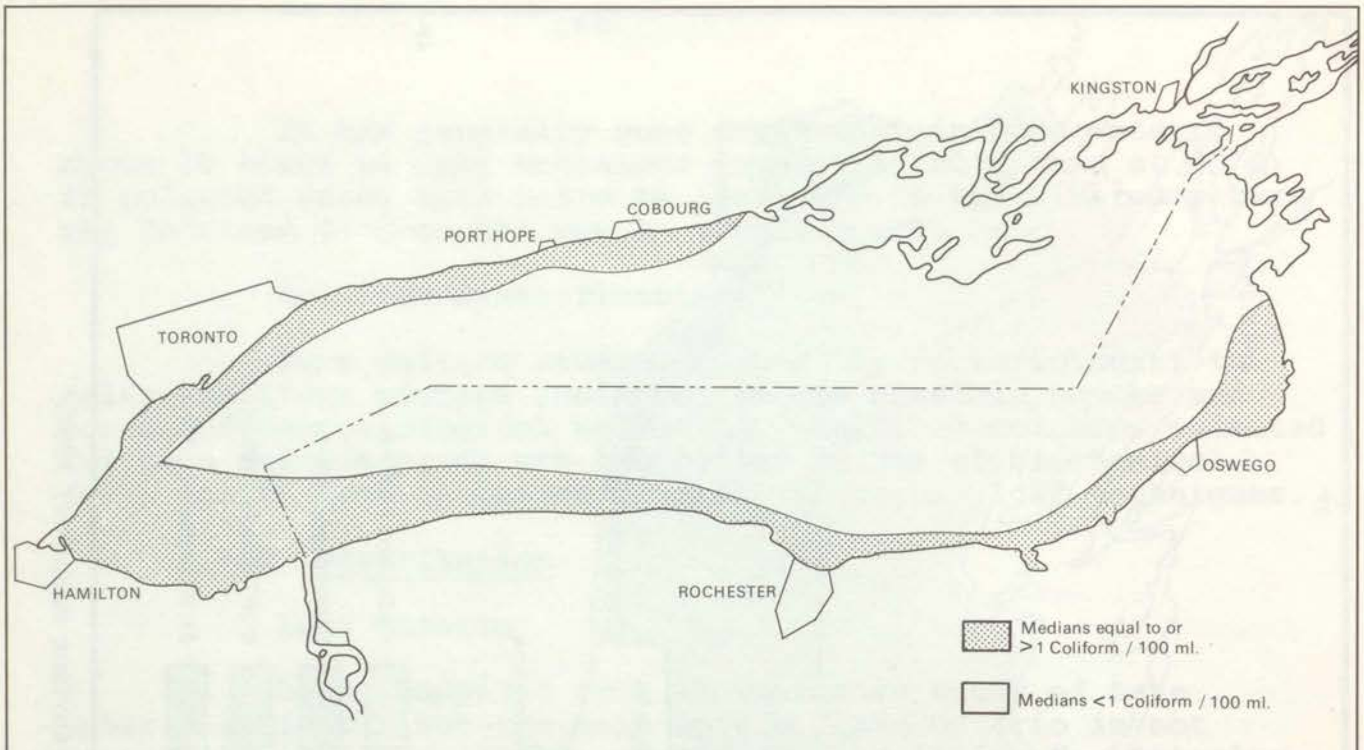
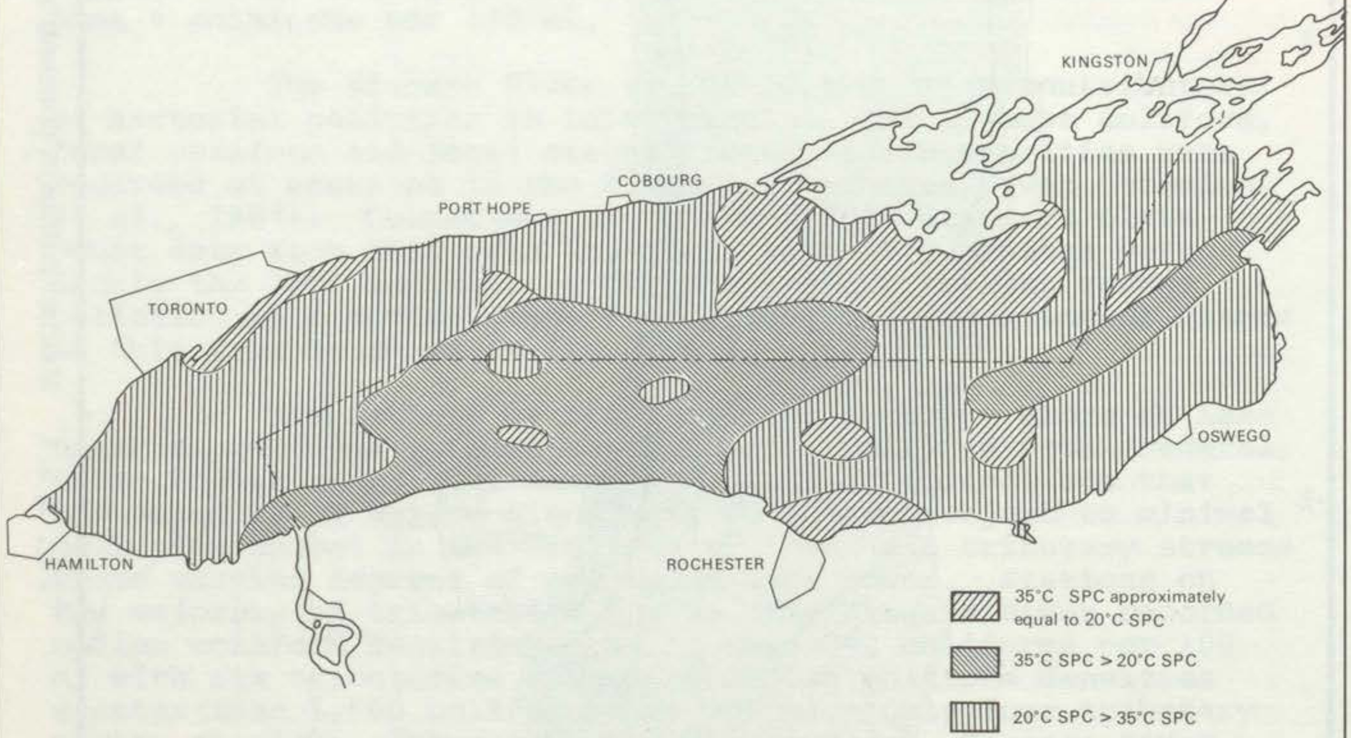


Fig. 2.5.1 Median coliform concentration (MF) in surface samples, 1967.



COLIFORM DISTRIBUTION



STANDARD PLATE COUNT DISTRIBUTION

Fig. 2.5.2 Distribution of bacterial parameters, 1967.

It can be concluded from the sampling data by NHW on the south shore of Lake Ontario in 1966 that minimal pollution occurs except for the Rochester region. The majority of stations showed median coliform counts of less than 240 coliforms per 100 ml (Fig. 2.5.1, 3.2.6).

A study of Canadian inshore waters revealed that the majority of tributaries entering Lake Ontario 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, water samples collected one and two miles offshore near these tributaries indicated that the median coliform count one mile from shore was less than 100, and two miles from shore less than 10 coliforms per 100 ml. Thus the water quality of the offshore waters is good in the bacteriological sense.

During the water quality study of Lake Ontario an intensive coliform isolate study was conducted. Typical colonies appearing on Bacto-m Endo MF preparations were isolated in pure culture for classification studies. Data compiled from these coliform isolates indicate that approximately 59 percent of the typical coliform flora of these waters were *Enterobacter* biotypes, 19 percent were *Citrobacter* biotypes and 11 percent were *Escherichia* biotypes (Tennant *et al.*, 1967; Dutka and Bell, 1967). The incidence of fecal coliform (44.5°C, EC gas-positive) strains in these waters constituted approximately 18 percent of the coliform population.

The offshore waters of Lake Ontario are characterized by a high incidence of *Enterobacter* biotypes and a low incidence of *Escherichia* biotypes and fecal coliform strains. This coliform biotype distribution pattern is considered to be typical of "remote" pollution, originating from distant sources, and is probably of minimal public health significance.

Several areas which are in close proximity to the larger towns and cities in the Bay of Quinte are subjected to varying degrees of bacterial pollution. The highest coliform, fecal coliform, fecal streptococcus and 20°C and 35°C standard plate count densities were reported at sampling ranges which were in close proximity to the following cities and towns: Picton, Deseronto, Belleville and Trenton. Although there are areas within the Bay of Quinte which are degraded bacteriologically, by the time the water from these areas enters the main body of Lake Ontario through the Adolphus Reach there is no trace of this pollution.

St. Lawrence River

Data compiled during the three year study of the international section of the St. Lawrence River by NHW indicate two general trends: cross-sectional coliform density variation; and a progressive downstream increase in coliform densities.

With few exceptions the most northerly stations in the St. Lawrence River between Brockville and the St. Regis River were observed to have the highest median coliform densities while the most southerly sampling stations recorded the lowest coliform densities (Fig. 2.5.3 to 2.5.6). In the section between Alexandria Bay and Cape Vincent a reverse distribution was observed with higher concentrations at the most southerly stations.

The second trend indicated by the data is a progressive downstream increase in coliform densities. Ranges from Clayton to Alexandria Bay were observed to have very low coliform densities in comparison with those recorded at the downstream ranges from Brockville to the St. Regis River. During the three year study of the St. Lawrence River the majority of sampling stations had median coliform densities of less than 240 coliforms per 100 ml; only one station at Cornwall consistently recorded a median coliform density greater than 1,000 coliforms per 100 ml (Bruce *et al.*, 1967; Dutka *et al.*, 1967d). No station was observed to have a median coliform density greater than 1,500 coliforms per 100 ml during this study.

A study of *Salmonella* incidence was undertaken at selected stations in the St. Lawrence River. *Salmonellae* were isolated from the St. Regis River and from waters adjacent to the city of Kingston (Dutka *et al.*, 1967b). Data compiled from coliform isolates collected and classified during this study indicate that *Enterobacter* biotypes constituted approximately 50 percent of the typical coliforms in these waters; *Citrobacter* and *Escherichia* biotypes both constituted approximately 20 percent of the coliform population (Dutka *et al.*, 1967c; Van Otterloo *et al.*, 1967). The incidence of fecal coliform (44.5°C, EC gas-positive) strains among these coliform isolates varied from 15 percent (1965) to 30 percent (1967).

Biotypes, *Enterobacter* and *Citrobacter*, constituted the major portion of the coliform flora. Fecal coliform strains were in the minority. Thus there is strong evidence to indicate that the presence of these organisms may be the result of remote fecal pollution, inadequately-chlorinated effluent and rainfall-induced land wash.

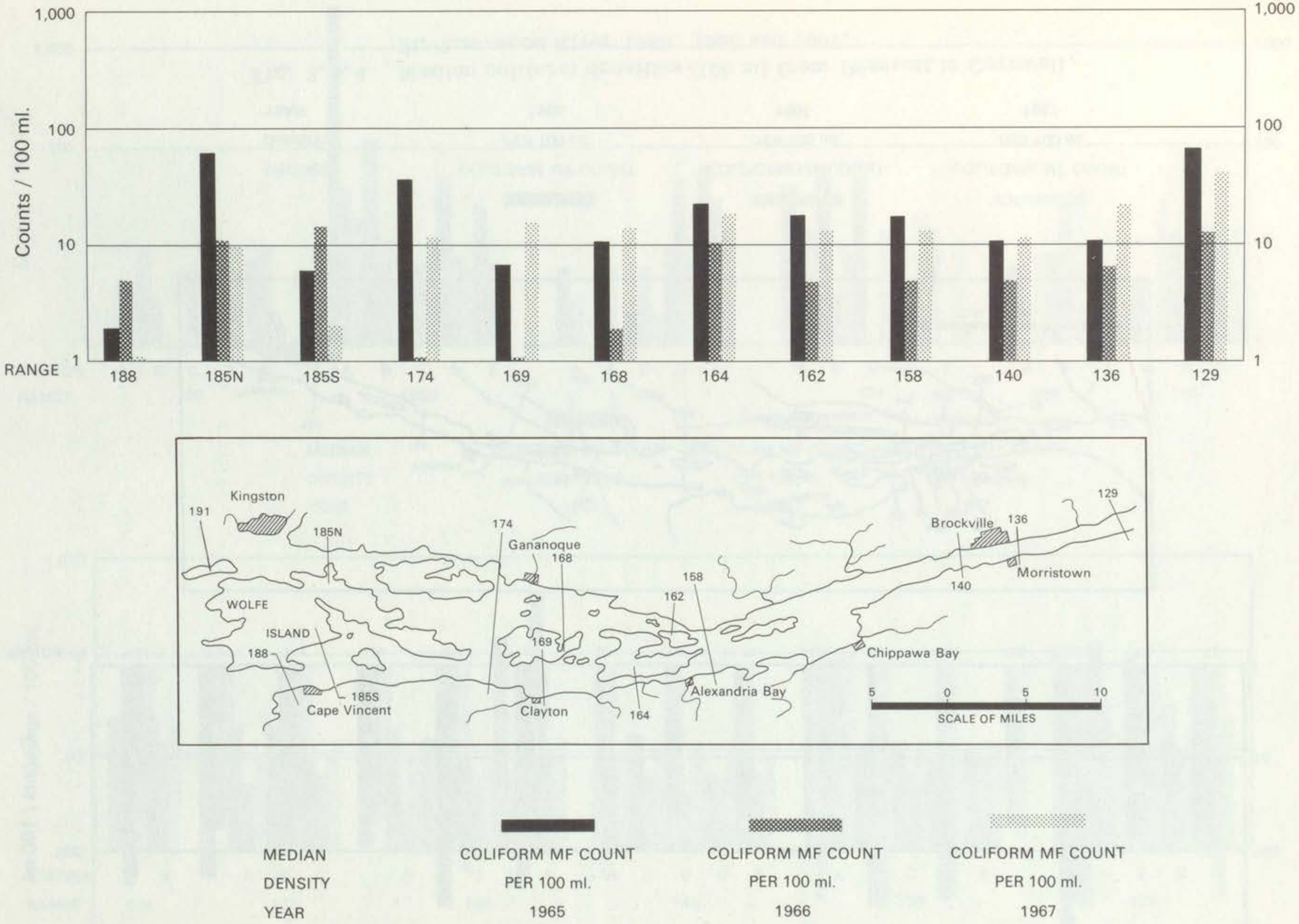


Fig. 2. 5. 3 Median coliform densities/100 ml from Kingston to Prescott, St. Lawrence River, 1965, 1966 and 1967.

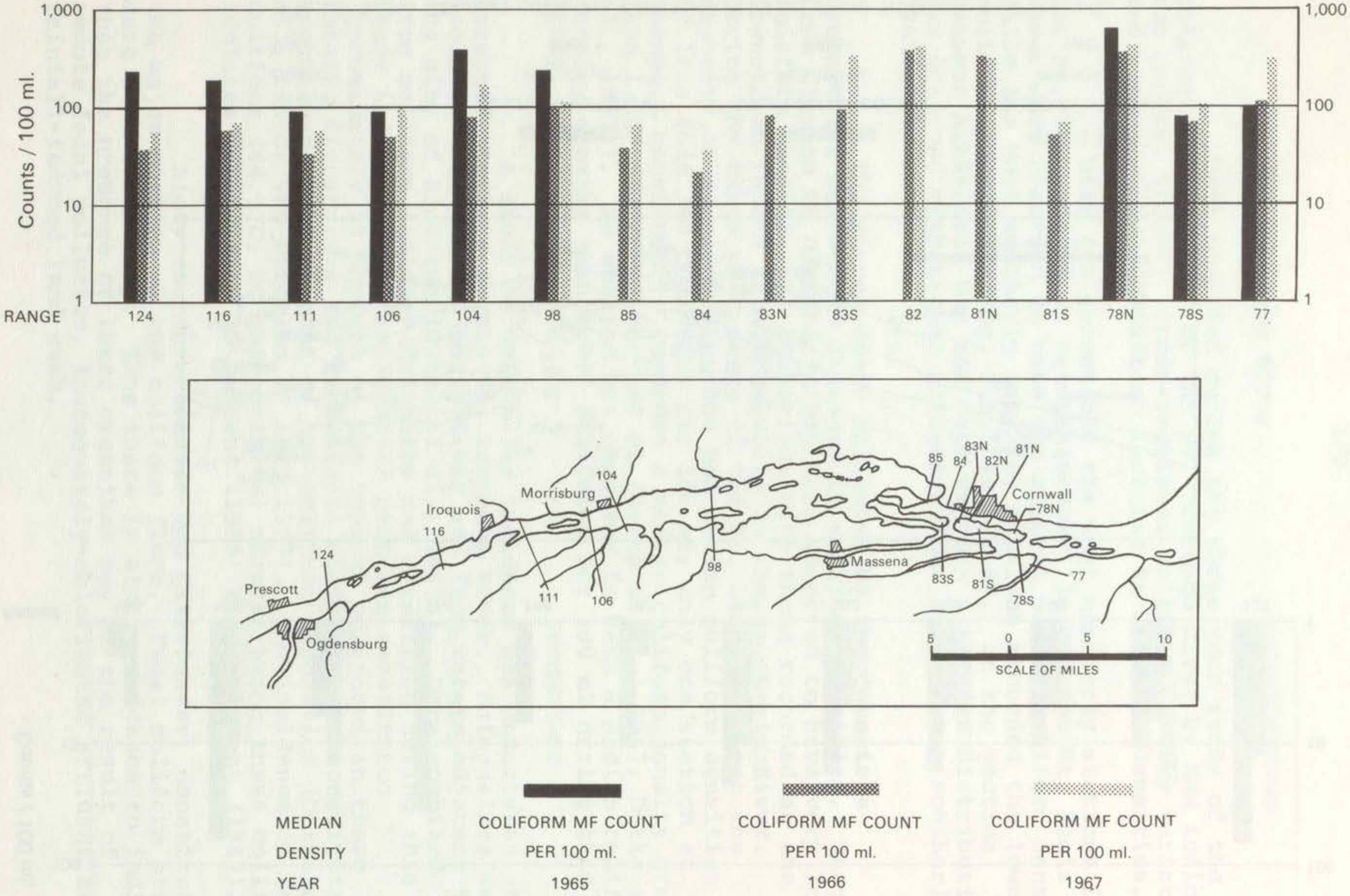


Fig. 2.5.4 Median coliform densities/100 ml from Prescott to Cornwall, St. Lawrence River 1965, 1966 and 1967.

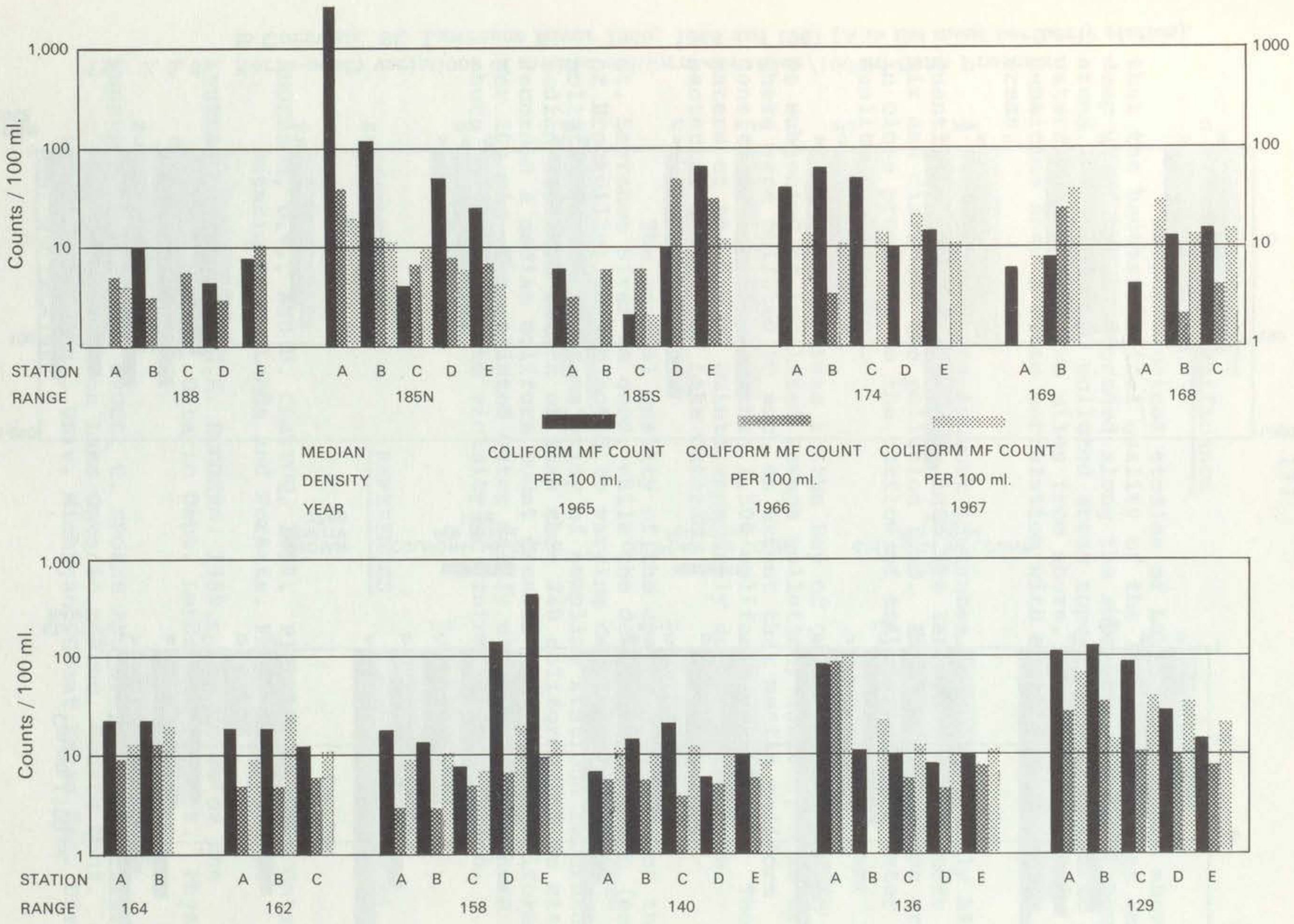


Fig. 2. 5. 5 North-south variation of median coliform densities/100 ml, St. Lawrence River 1965, 1966 and 1967 (A is the most northerly station).

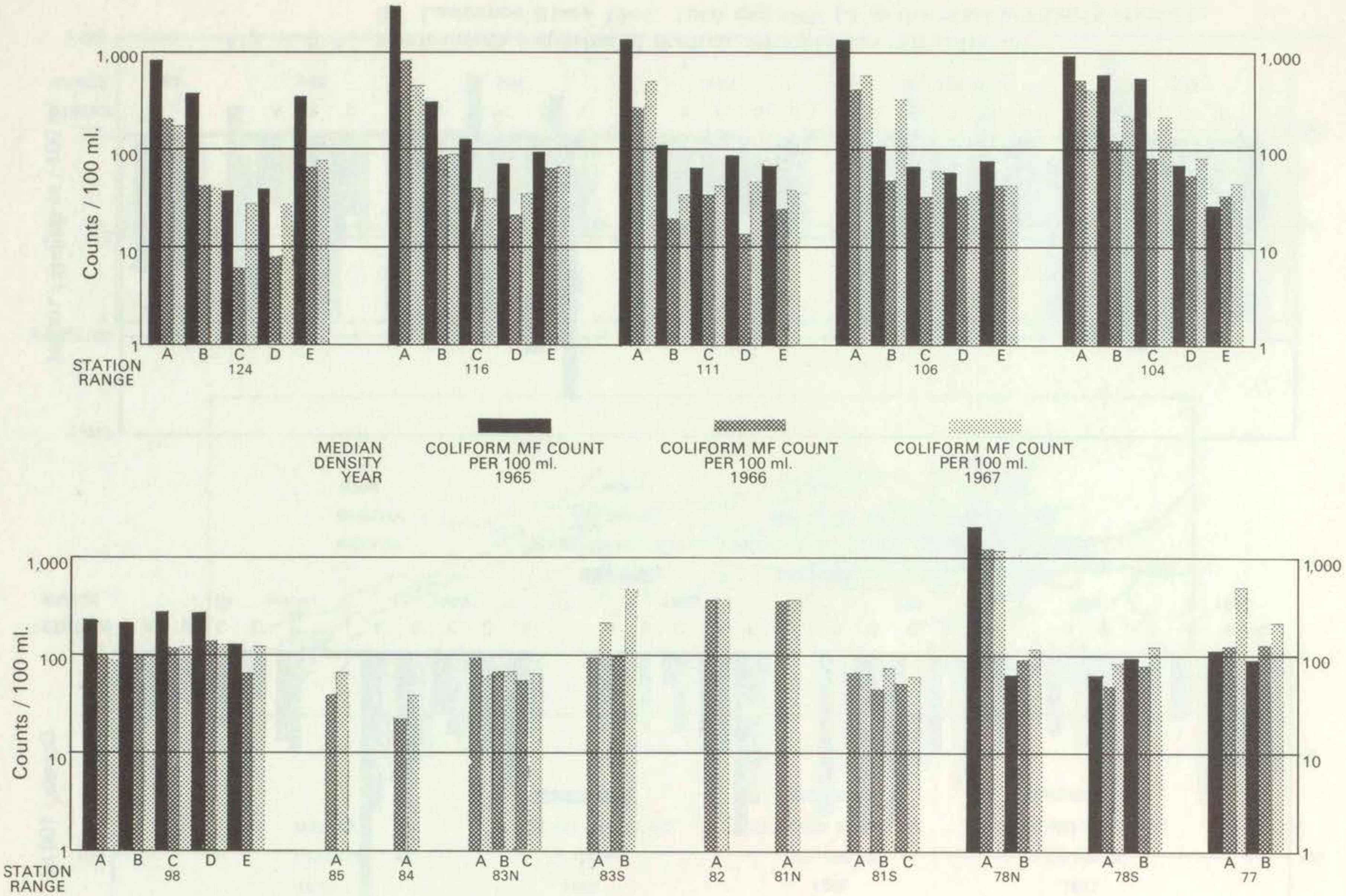


Fig. 2.5.6 North-south variations of median coliform densities/100 ml from Prescott to Cornwall, St. Lawrence River 1965, 1966 and 1967 (A is the most northerly station).

2.5.3 Significance

Bacteriological studies of Lake Ontario have shown that the bacteriological quality of the lake is excellent in deep water but is degraded along the shoreline and in harbour areas. The coliform polluted areas appear to be limited to waters well within two miles from shore. High bacterial densities show a close correlation with heavily populated areas.

Tributaries in most instances introduce fairly high quantities of polluted water into the lake where the waters mix and dissipate the pollution load. Except for inshore areas in close proximity to the outflow of tributaries, the water quality remains good.

Several areas in the Bay of Quinte were found to be subjected to localized sewage pollution; however, none of these were polluted to such an extent that median coliform densities were greater than 1,500 coliforms per 100 ml. The waters of the Bay of Quinte apparently do not affect the bacterial quality of Lake Ontario.

The general quality of the upstream section of the St. Lawrence River is good, while the downstream section (east of Brockville) is subjected to varying degrees of sewage pollution: the great majority of sampling stations recorded median coliform counts of less than 240 coliforms and no station recorded a median coliform count greater than 1,500 coliforms per 100 ml. The polluted water mainly affects the northern shore in the immediate vicinity of centres of population.

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3. SOURCES, CHARACTERISTICS AND EFFECTS OF MATERIAL INPUTS

This chapter describes the cause and effect relationships between the sources of wastes and other materials being discharged into Lake Ontario and the St. Lawrence River, and the impact they are having on the quality of water and its uses.

In the first section examination is made of the sources and loading characteristics of materials discharged or conveyed directly into the lake and river by municipalities, industries and the tributary rivers. The influence of wastes from shipping, dredging operations, sediment accumulations and contributions of nutrient materials from atmospheric sources is also considered. The second section of the chapter relates the materials loading information to the effects on water quality in the immediate offshore areas where water use is the most intensive. An accounting of the material loadings input to Lake Ontario and the output through the St. Lawrence River is followed by a discussion of transboundary movement of pollution. The chapter concludes with a commentary on the state of eutrophication of Lake Ontario.

3.1 SOURCES AND CHARACTERISTICS

Municipal and industrial waste sources include not only continuous discharges of both treated and untreated wastes but also overflows from municipal combined sewer systems and land drainage from urban areas. Sources of pollution from land drainage especially from rural localities are difficult to define, however, in areas of intensive crop and livestock production, significant impairment of water quality has been observed. Similarly, soil erosion is usually a major problem where intensive land use and development occurs.

The pollution loads from municipalities, industries and tributaries introduced directly into Lake Ontario and the St. Lawrence River were determined by waste and stream sampling and related discharge measurements. The relative portions of municipal and other material loadings including industrial wastes carried by the tributaries at their points of discharge to the lake and river have been evaluated.

As a relatively crude but useful approximation, it was assumed that materials added to the tributaries would eventually reach Lake Ontario and the St. Lawrence River. Accordingly, the difference between the measured material loads discharged by the tributaries and the incremental input of upstream municipal loads within each sub-basin was reported as coming from "Other Sources". This assumption is valid for stable substances like chlorides. It does lead to underestimates of the amounts of unstable nutrients such as nitrogen and phosphorus contributed by tributaries from land drainage and soil erosion.

The characteristics of wastes discharged from municipal, industrial and tributary sources are varied. Those measured most commonly include biochemical oxygen demand (BOD5), total and suspended solids, total nitrogen (N), total phosphorus (P), and chlorides, while other important parameters peculiar to specific industries may include acids, alkalis, oil, phenols, cyanide and iron. Pesticides and herbicides and other synthetic organic chemicals, have also become problems of increasing concern as components of land drainage and industrial wastes. The nutrient loadings reported here are based on determinations of total-N and total-P using unfiltered samples of water. The specific forms in which the elements occur (organic, inorganic, particulate or dissolved) can be of major importance in determining the effects on water quality; however, due to biological interconversions and lack of knowledge of the rates involved, the pollution loadings are best evaluated in terms of total element loads.

The five largest source areas or regions that together account for more than 80 percent of the phosphorus, nitrogen and chloride loads to Lake Ontario are shown in Table 3.1.1.

The figures given as percentages of the total loadings discharged to Lake Ontario combine the waste materials from municipal, industrial and tributary sources for each region or drainage area. The three largest sources are the municipalities, industries and land drainage regions of the Niagara River basin, and the Metropolitan Toronto and Rochester areas. The Niagara River alone accounts for over one-half of the total nutrients and about three-quarters of the chlorides added to Lake Ontario.

Waste water treatment plants in the lower Great Lakes drainage basin have been designed to remove organics and solids in waste materials. While some of the nutrients in municipal wastes can be removed by most sewage treatment plants, there are few treatment systems operating in the basin designed to achieve substantial removal of nutrients. In addition, overflows from inadequate municipal sewage collection systems contribute nutrients to the lake.

Table 3.1.1 The five largest waste sources discharging to Lake Ontario.

Source	Percent of total pollution load from all sources discharged to Lake Ontario in 1966-67. Phosphorus	 Nitrogen	 Chlorides
Niagara River including municipal and industrial sources from the Buffalo - Niagara Falls area.	56	54	76
Metro Toronto Region including all local municipal, industrial and tributary discharges directed to Lake Ontario.	13	5	2
Metro Rochester area including all municipal, industrial waste sources and the Genesee River.	9	5.4	1.4
St. Catharines area including municipal, industrial waste sources and Twelve Mile Creek.	5.2	4.8	2.6
Hamilton area including municipal, industrial and tributary discharges to Hamilton Harbour.	2.3	10	0.2

Fig. 3.1.1 shows the location of the major municipal and industrial waste and tributary loadings from Ontario and New York and outlines the drainage basins or regions referred to in this report.

3.1.1 Municipal Wastes

The urban centres around Lake Ontario discharge a total waste flow of about 277 mgd (Imp) and 85 mgd (U.S.) from Ontario and New York, respectively, while for the St. Lawrence River the corresponding wastewater discharges are 22 mgd (Imp) and 2.5 mgd (U.S.). Almost 100 percent of the combined Canadian and American municipal waste discharges receive either primary sedimentation or secondary biological treatment. Sixty-two percent of the total waste volume discharged directly to the lake receives biological treatment.

The four largest municipal waste loads discharging directly to Lake Ontario and the St. Lawrence River are ranked by size in Table 3.1.2. Using phosphorus, nitrogen, biochemical oxygen demand and chlorides as pollutants characteristic of municipal wastes, it is readily apparent that Metropolitan Toronto and the urban centres of Rochester and Hamilton collectively discharge to Lake Ontario 90 percent of the total waste loadings from municipal sources. The cities of Kingston and Cornwall, Ontario introduce the largest input of municipal wastes to the St. Lawrence River.

In Ontario, 24 sewage treatment facilities serving 15 municipalities, two military bases and one institution discharge wastes directly to Lake Ontario or its embayments, while nine municipalities contribute treated wastes directly to the St. Lawrence River. The towns of Deseronto and Prescott discharge untreated wastes to the Bay of Quinte and the St. Lawrence River, respectively. In New York five municipalities discharge treated wastes directly to the lake, but the city of Oswego discharges untreated wastes. Six New York municipalities contribute wastes to the St. Lawrence River. Four of these, Cape Vincent, Clayton, Alexandria Bay and Morristown do not provide treatment.

The municipal loadings described in this section include waste waters from both domestic populations and the industries connected to municipal sewerage systems (Table 3.1.3).

The North Niagara Peninsula region of Ontario is a highly productive agricultural area of approximately 250 square miles with drainage to Lake Ontario. The Welland Ship Canal

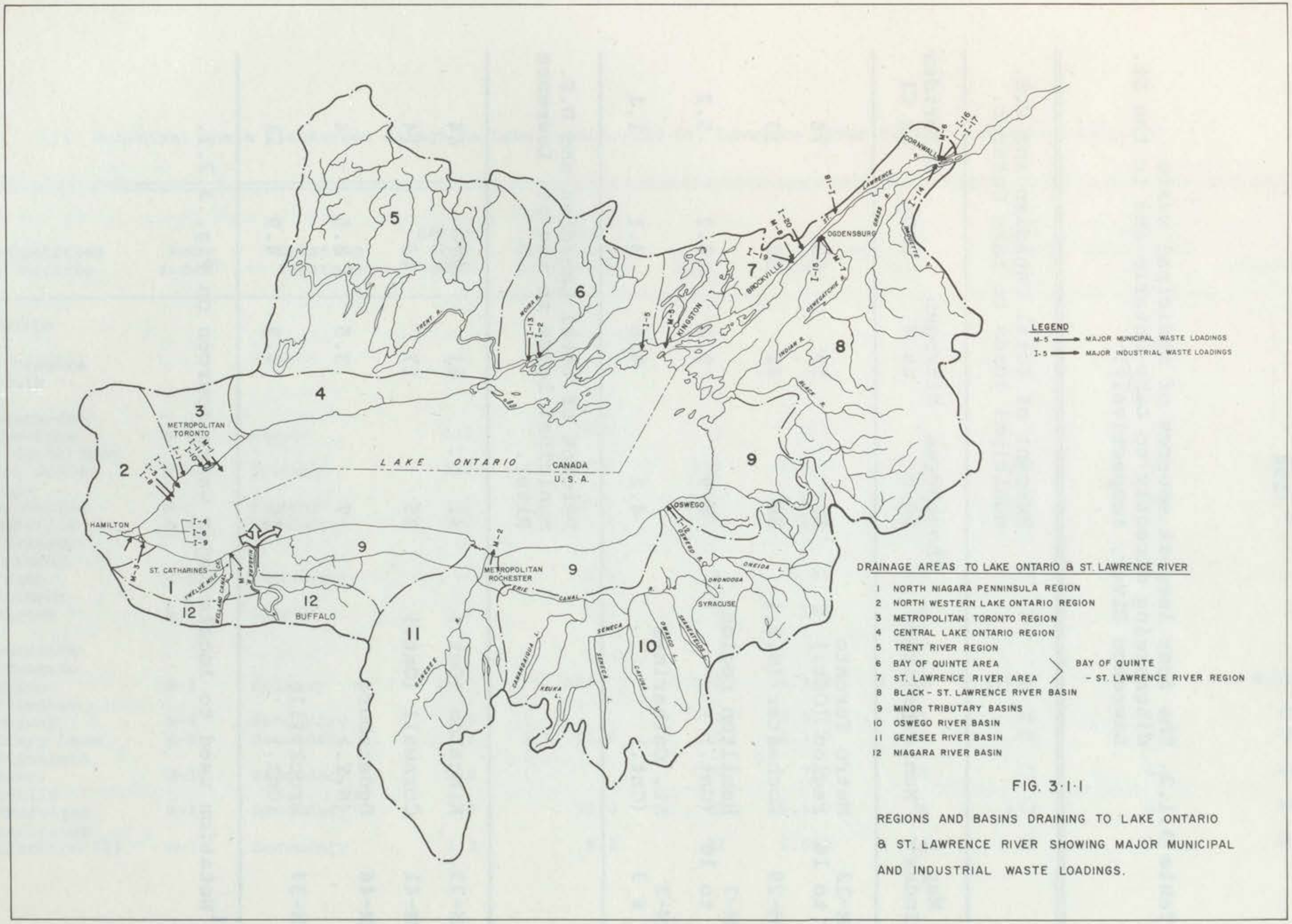

FIG. 3·1·1

REGIONS AND BASINS DRAINING TO LAKE ONTARIO & ST. LAWRENCE RIVER SHOWING MAJOR MUNICIPAL AND INDUSTRIAL WASTE LOADINGS.

Fig. 3. 1. 1 Sources and location of major municipal, industrial and tributary waste loadings to Lake Ontario and the St. Lawrence River.

Table 3.1.2 The four largest sources of municipal waste discharging directly to Lake Ontario and to the St. Lawrence River, respectively.

Map Index[1]	Municipalities	Phosphorus as P	Nitrogen as N	BOD_5	Chlorides as Cl
		Percent of total Canadian and U.S. municipal loads to Lake Ontario.			
M-13 to 16	Metro Toronto region (Ont.)	50	59	33	78
M-28	Rochester (N.Y.)	30	21	52	13
M-7 to 10	Hamilton region (Ont.)	8.9	9.2	8.2	5.2
M-2 & 3	St. Catharines (Ont.)	4.2	4.5	3.1	1.1
		Percent of total Canadian and U.S. municipal loads to the St. Lawrence River.			
M-33	Kingston (Ont.)	41	61	27	64
M-41	Cornwall (Ont.)	25	17	43	14
M-46	Ogdensburg (N.Y.)	7	3.5	8.6	4
M-34	Brockville (Ont.)	10	8.9	4.9	11

[1] Notation used to locate major waste sources on Fig. 3.2.1.

Table 3.1.3 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 (thousands)	BOD_5	Solids		Total nitrogen (N)	Total phosphorus (P)	Chlorides
						Total	Susp.			
Ontario										
North Niagara Peninsula Region										
Niagara-on-the-lake	M-1	Lagoon	0.2	2.9	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	372	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

Table 3.1.3 (cont'd)

Municipalities Lake Ontario	Map index[1]	Existing treatment	Sewage[2] flow (mgd)	Population served with sewers (thousands)	BOD_5	Solids		Total nitrogen (N)	Total phosphorus (P)	Chlorides
						Total	Susp.			
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	(1,690	58	928	133	50	13	200
- Humber	M-15	Secondary	50.5		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

Table 3.1.3 (cont'd)

Municipalities Lake Ontario	Map index[1]	Existing treatment	Sewage[2] flow (mgd)	Population served with sewers (thousands)	BOD_5	Solids		Total nitrogen (N)	Total phosphorus (P)	Chlorides
						Total	Susp.			
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	383,661	31,590	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 UNITED STATES LAKE ONTARIO LOADING			84.52	415.5	22,588	109,664	45,118	2,995	952	21,103

Table 3.1.3 (cont'd)

Municipalities St. Lawrence River	Map index[1]	Existing treatment	Sewage[2] flow (mgd)	Population served with sewers (thousands)	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*
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 UNITED STATES ST. LAWRENCE RIVER LOADING			2.42	24.42	549			68*	23*	272*
TOTAL CANADA				169.92	3,802			1,189	212	4,432

*Estimated

[1] Notation used to locate waste sources in Fig. 3.2.1 to 3.2.7.

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

is supplied principally from Lake Erie and receives treated wastes from a number of municipalities and industries. The population of 170,000 is distributed in one city, three towns, one village, and 10 townships. Approximately 76 percent (129,000 persons) of the population in the region is serviced with sewerage facilities, of these 60 percent or 103,000 persons are serviced by systems that discharge directly to the lake. The principal municipal source of waste water in this area is the City of St. Catharines which employs two primary sewage treatment plants located at Port Weller and Port Dalhousie, respectively.

The northwestern Lake Ontario region covers a 934 square mile area, extending westward from the east boundary of the Credit River watershed to and including the Stoney Creek basin. The region is drained by seven rivers and several small drainage systems. The lakeshore vicinity is highly urbanized with about 56 percent of the population (283,000 persons) resident in the City of Hamilton. The remainder of the population (224,000) lives in nine towns, two villages, and 14 townships. In addition to Hamilton, the towns of Burlington, Oakville and Mississauga are the principal urban centres of the region. About 88 percent (446,000 persons) of the region's total population has municipal sewer services. Four of the six major sewage treatment facilities discharge treated waste water directly to Lake Ontario while two plants discharge effluents to Hamilton Harbour. One of the latter includes the City of Hamilton treatment facilities serving a total population of 324,000 persons.

The Metropolitan Toronto region extends from the east boundary of the Credit River drainage basin to the east boundary of the Highland Creek basin. The principal urban development consists of the City of Toronto and the boroughs of Etobicoke, Scarborough, York, East York and North York. About one-half of the total Ontario population in the Lake Ontario drainage basin is concentrated in the region's 300 square miles with over 90 percent (1,954,000) living in Metropolitan Toronto. The urban population in the region is almost entirely served with municipal sewerage systems. The wastes from about 86 percent of this population are treated before direct discharge to Lake Ontario from four plants. The remainder of the urban population is served by 13 waste treatment plants that discharge to tributaries.

The central Lake Ontario region covers an 865 square mile area of south-central Ontario and extends from the west boundary of the Rouge River basin to the west boundary of the Trent River system. Some 215,000 persons reside in one city

(Oshawa), four towns, seven villages and 17 townships. The region is drained by several river systems. Approximately 65 percent (139,000 persons) of the region's population is urban and served by sewage treatment facilities. The wastes from about 15 percent of the serviced population enter three treatment plants that discharge directly to Lake Ontario with the remaining urban population serviced by sewage treatment plants discharging to tributary streams.

The Trent River region, comprising 4,962 square miles, is drained by the Trent River to Lake Ontario. The region is primarily rural in character and extensive recreational use is made of the many inland lakes. Peterborough and Trenton are the two principal municipalities in the region. About 174,000 persons reside in the basin with approximately 50 percent of the population provided with municipal sewerage facilities. Two sewage treatment plants, one municipal and one military, serving 10 percent of the region's population discharge treated wastes directly to Lake Ontario. The remaining 40 percent of the urban population employs sewerage systems discharging to the Trent River system.

The Bay of Quinte - St. Lawrence River region covers a 3,382 square mile area and is basically rural with about 76 percent of the total population of 246,000 persons residing in urban centres along the shoreline. The Bay of Quinte extends from the eastern boundary of the Trent River watershed to the western boundary of the Little Cataraqui River watershed. The St. Lawrence River section draining to the St. Lawrence River extends from Little Cataraqui River to the eastern boundary of the City of Cornwall. About 78,000 people live in the Bay of Quinte region while 168,000 persons live in the St. Lawrence River area. The principal urban centres are the cities of Kingston and Cornwall along the St. Lawrence River. Sixty-one percent of the population is served by sewerage systems in the Bay of Quinte region. Three plants, treating waste waters from 51 percent of the population, discharge directly to the Bay, while the wastes from another 10 percent are discharged after treatment to tributary streams. Untreated wastes from Deseronto are discharged to the bay. About 91 percent of the population residing along the Ontario side of the St. Lawrence River is serviced by sewage treatment facilities with nine plants discharging directly to the river. Wastes from a further eight percent of the population are discharged, after treatment, to tributaries.

The Black - St. Lawrence River basin comprises an area of approximately 7,000 square miles. The area includes the entire Black River basin, all waters tributary to the lake north of Black River Bay, and the St. Lawrence River from Lake Ontario to its confluence with the Raquette River. About 127,000 of the total 201,000 persons in the region live in the St. Lawrence River area with 58,000 persons served by sewers. There are no municipal facilities discharging directly to Lake Ontario from the region. Six municipalities with a total population of 24,000 persons discharge wastes directly to the St. Lawrence River. The City of Ogdensburg and the Village of Waddington are served with primary treatment facilities while the remaining four municipalities (6,500 persons) have no sewage treatment.

Minor tributaries drain an area of some 2,600 square miles in New York State. The municipalities of Irondequoit, Rochester, Webster, Wilson and Youngstown comprising a total population of 416,000 persons introduce treated wastes directly to Lake Ontario. Oswego discharges about one-third of its untreated waste load to the lake. Part of the sewage flow receives primary treatment before discharge to the Oswego River. The remainder is discharged untreated to the river.

The Oswego River basin has a drainage area of approximately 5,100 square miles and is divided into two major tributary sub-basins, the Seneca and the Oneida. The basin has a population of 872,000 persons with a total of 513,000 people being served by sewers. The estimated stream loading from existing municipal treatment plants and untreated sources in the basin has a population equivalent of about 475,000 persons. There are no municipalities discharging directly to Lake Ontario.

Land use in the Genesee River basin is predominantly agricultural with three-quarters of its 2,400 square miles used for this purpose. In its last 10 miles, the Genesee River passes through Metropolitan Rochester, one of the fastest growing manufacturing districts in the New York area of the Lake Ontario basin. The basin population including the entire population of Metropolitan Rochester was approximately 700,000 in 1960. Waste discharges from Rochester enter Lake Ontario either directly or via the Genesee River. The river receives oxygen-consuming wastes from Rochester equivalent to a population of 350,000 persons.

A number of the larger and older municipalities have combined sewer systems which discharge to municipal treatment plants in dry weather. During periods of heavy rainfall, wastes which are a combination of domestic and industrial waste water and storm runoff, are by-passed directly into the shore waters of the lake. The more important pollutants contributed through these overflows are BOD, bacteria and nutrients. Combined sewer overflows are a serious problem in Rochester, Toronto and Hamilton while at St. Catharines, Kingston and Cornwall they contribute lesser total loads but cause local pollution problems.

3.1.2 Industrial Wastes

Industrial wastes are varied in nature and may contain, aside from oxygen-consuming and nutrient materials, many other polluting substances. The industrial wastes discharged to Lake Ontario and the St. Lawrence River originate from the automotive, chemical, food processing, petroleum, pulp and paper, steel and other industries. Typical waste constituents include oxygen-demanding materials, acids, alkalis, iron, phenols and oils, solids and toxic substances. Oxygen-consuming wastes are readily assimilated in the lake while nutrients and conservative pollutants can exert a lingering affect on the waters of the lake. Power generation contributes large quantities of waste heat. About one-third of the industries in the Lake Ontario basin are connected to municipal sewerage systems. Emphasis in this section will be given to industries discharging directly to the lake and the St. Lawrence River.

Industries in Ontario and New York discharge waste water at a combined rate of 532 mgd (Imp.) or 640 mgd (U.S.). The proportion of the industrial input of nitrogen, phosphorus and chlorides to Lake Ontario and the St. Lawrence River for the 20 major industrial contributors is given in Table 3.1.4. With the exception of the one paper mill at Oswego, New York, the industrial waste load discharged directly to the lake comes from sources in Ontario. The 12 major Ontario sources account for 89 percent of the phosphorus, 96 percent of the nitrogen and 87 percent of the chlorides of the total direct industrial input to the lake.

Industries in Ontario contribute 56 percent of the industrial phosphorus discharged to the St. Lawrence River with the balance being attributed to New York sources. Five Ontario industries account for 98 percent of the industrial nitrogen input to the river.

Data for the individual industries including waste discharge volumes, treatment, and the loading rates for the major waste constituents are presented in Tables 3.1.5 and 3.1.6. Two coal burning generating stations (Lakeview and R.L. Hearn) return cooling water to the lake in the Metropolitan Toronto region.

Table 3.1.4 Major sources of phosphorus, nitrogen and chlorides from industries discharging wastes directly to Lake Ontario and the St. Lawrence River.

		Percent of total Canadian & U.S. industrial loads to Lake Ontario.		
Map Index[1]		Phosphorus as P	Nitrogen as N	Chlorides as Cl
	Lake Ontario			
I-22	St. Lawrence Starch Co. Ltd. Port Credit (Ont.)	25	2	11
I-41	Canada Cement Co. Ltd. Sidney Twp. (Ont.)	13	0	2
I-20	British American Oil Co. Mississauga (Ont.)	10	1	24
I-10	Canadian Industries Ltd. Hamilton (Ont.)	9	0	8
I-42	Canadian Industries Ltd. Millhaven (Ont.)	9	0	0
I-3,4 & 11	Steel Co. of Canada Ltd. Hamilton (Ont.)	8	28	17
I-21	Texaco Canada Ltd. Port Credit (Ont.)	6	1	16
I-18	Ford Motor Co. Canada Ltd. Oakville (Ont.)	4	0	0
I-9	Dominion Foundries & Steel Hamilton (Ont.)	2	62	4
I-27	Continental Can Co. #1 Metro Toronto (Ont.)	2	0	2
I-28	Continental Can Co. #2 Metro Toronto (Ont.)	2	0	2
I-45	Hammermill Paper Co. Oswego (N.Y.)	1	0	1
I-40	Union Carbide Can. Ltd. Belleville (Ont.)	0	2	1
	St. Lawrence River			
I-55	Diamond National Corp. Ogdensburg (N.Y.)	29	0	1
I-53	Courtaulds (Can.) Ltd. Cornwall (Ont.)	22	4	60
I-54	Domtar Pulp and Paper Cornwall (Ont.)	16	1	33
I-51	Canada Starch Co. Ltd. Cardinal (Ont.)	14	1	3
I-56	Reynolds Metal Co. Massena (N.Y.)	14	0	1
I-48	Brockville Chemical Ind. Ltd. Brockville (Ont.)	4	38	-
I-49	Dupont of Canada Ltd. Augusta Twp. (Ont.)	0	55	2

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[1] Notation used to locate major waste sources on Fig. 3.2.1, 3.2.7.

Table 3.1.5 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 nitrogen (N)	Total phosphorus (P)	Chlorides
					Total	Susp.			
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	-

Table 3.1.5 (cont'd)

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*	-

Table 3.1.5 (cont'd)

Industries Lake Ontario	Map index[1]	Existing treatment	Flow[2] (mgd)	BOD_5	Solids Total	Solids Susp.	Total nitrogen (N)	Total phosphorus (P)	Chlorides
- 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	-	-

Table 3.1.5 (cont'd)

Industries Lake Ontario	Map index[1]	Existing treatment	Flow[2] (mgd)	BOD_5	Solids		Total nitrogen (N)	Total phosphorus (P)	Chlorides
					Total	Susp.			
- 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	1.0	-	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	-

Table 3.1.5 (cont'd)

Industries Lake Ontario	Map index[1]	Existing treatment	Flow[2] (mgd)	BOD5	Solids		Total nitrogen (N)	Total phosphorus (P)	Chlorides
					Total	Susp.			
- 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

Table 3.1.5 (cont'd)

Industries Lake Ontario	Map index[1]	Existing treatment	Flow[2] (mgd)	BOD_5	Solids		Total nitrogen (N)	Total phosphorus (P)	Chlorides
					Total	Susp.			
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

Table 3.1.5 (cont'd)

Industries Lake Ontario	Map index^1	Existing treatment	Flow^2 (mgd)	BOD$_5$	Solids		Total nitrogen (N)	Total phosphorus (P)	Chlorides
					Total	Susp.			
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	0.1	3	13	3	0	-	-
TOTAL CANADIAN LOADING TO LAKE ONTARIO			405.4	23,199	395,423	68,520	17,751	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

Table 3.1.5 (cont'd)

Industries St. Lawrence River	Map index[1]	Existing treatment	Flow[2] (mgd)	BOD_5	Solids		Total nitrogen (N)	Total phosphorus (P)	Chlorides
					Total	Susp.			
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

Table 3.1.5 (cont'd)

Industries St. Lawrence River	Map index[1]	Existing treatment	Flow[2] (mgd)	BOD_5	Solids		Total nitrogen (N)	Total phosphorus (P)	Chlorides
					Total	Susp.			
- 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 in Fig. 3.2.1 to 3.2.7.

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

Table 3.1.6 Other industrial waste discharges direct to Lake Ontario and St. Lawrence River 1966-67* (short tons/year).

Industries	Total 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 Alk. 42 ($CaCO_3$)
Steel Co. Canada Ltd. (#2 Rod Mill)	150	1	314		16	3,000			
Firestone Tire & Rubber	1								
Domtar Chemicals Ltd.					1	27		2	Alk. 4 ($CaCO_3$)
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	Alk. 17,337 ($CaCO_3$)
Canadian Industries Ltd.	35	26	1,409			507			Fluoride 400 Zinc 12 Alk. 1,270 ($CaCO_3$)
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

Table 3.1.6 (cont'd)

Industries	Total iron	Dissolved iron	Sulphate	Sulphite	Ether solubles	COD	Cyanide	Phenols	Others
St. Lawrence Cement Co.			183		18				Lead 4 Alk. 196 ($CaCO_3$)
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

Table 3.1.6 (cont'd)

Industries	Total 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 Alk. 8 ($CaCO_3$)
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

Table 3.1.6 (cont'd)

Industries	Total 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.

3.1.3 Major Tributaries

The major tributaries of Lake Ontario and the St. Lawrence River transport residual wastes and materials from upstream municipal, industrial and land drainage sources. Oxygen-consuming wastes carried by the tributaries are often degraded before the streams empty into the lake or have been assimilated in its waters. However, the nutrient components have a broad and long term influence on the water quality of the lake. Pesticide residues and other synthetic chemical compounds are also contributed by the tributaries. In some tributaries the silt loading is a serious problem. Examples of these are the Don River in Ontario, and the Genesee River in New York which carry heavy loads of sediment into Toronto and Rochester harbours, respectively. Dredging is required in these harbours to maintain sufficient water depth for shipping.

When compared with all other tributaries to Lake Ontario, the Niagara River introduces the greatest single material input to the lake. The relative influence of the materials carried in the Lake Erie outflow and the wastes imparted from activities in the immediate Niagara River drainage area is apparent in Table 3.1.7. The material load from local sources in the Niagara River basin is contributed mainly by the municipal and industrial development along the upper river extending from Buffalo and Fort Erie at Lake Erie to Niagara Falls. Because of the large population and industrialization on the American side, most of the wastes introduced directly to the river originate in the United States. The Niagara River receives municipal wastes which are treated, usually by sedimentation and chlorination. The industries responsible for most of the industrial wastes entering the river from the Buffalo-Niagara Falls area include chemical, steel, abrasives, paper and oil refining. Dye manufacturing and alkali-chlorine production comprise a significant portion of the chemical industry in this area. In Ontario, the tailrace of the Hydro Electric Power Commission power plant, Sir Adam Beck No. 1, carries residual waste waters from the cities of Niagara Falls and Welland and several steel and chemical industries. The nitrogen and phosphorus contents of the Niagara River increase about 20 and 71 percent, respectively, as it flows from Lake Erie to Lake Ontario.

Excluding the Niagara River, the proportion of the inputs of phosphorus, nitrogen, chlorides and suspended solids from all other major tributaries to Lake Ontario and the St. Lawrence River are given in Table 3.1.8. The quantities carried by individual tributaries are given in Table 3.1.9. The Oswego

Table 3.1.7 Material loadings (short tons/year) for the Niagara River.

Waste sources	Waste or stream discharge rate	BOD_5 tons/yr.	Total nitrogen as N tons/yr.	Total phosphorus as P tons/yr.	Chlorides (thousands) tons/yr.
Lake Erie to Niagara R.	194,000 cfs		79,400	4,500	5,000
Niagara River Basin					
State of New York					
Municipal	250 mgd (U.S.)	30,500	5,700	2,000	95
Industrial	230 mgd (U.S.)	17,300	3,600	150	52
Land Drainage	-		400	50	25
Province of Ontario					
Municipal	14.3 mgd (Imp)	4,600	600	330	4
Industrial	15 mgd (Imp)		3,500	80	1
Land drainage (Welland River basin via Sir Adam Beck No. 1)	500 cfs	1,800	400	50	3
Unaccountable	-		1,700	540	20
Niagara River to Lake Ontario	195,000 cfs		95,300	7,700	5,200

Table 3.1.8 Major Canadian and U.S. tributary inputs direct to Lake Ontario and the St. Lawrence River.

Source		Total phosphorus as P	Total nitrogen as N	Total chlorides as Cl	Suspended solids
		Percent of total Canadian and U.S. tributary inputs to Lake Ontario excluding the Niagara River.			
Oswego R.	(U.S.)	22	17	72	28
Genesee R.	(U.S.)	11	19	5	27
Black R.	(U.S.)	7	8	1	8
Salmon R.	(U.S.)	1	2	-	1
Twelve Mile Cr.	(Can.)	21	25	12	19
Trent R.	(Can.)	5	9	2	3
Don R.	(Can.)	5	2	-	<1
Welland Canal	(Can.)	4	3	3	5
Harmony Cr.	(Can.)	4	1	-	<1
Credit R.	(Can.)	2	2	-	<1
Moira R.	(Can.)	1	2	-	2
		Percent of total Canadian and U.S. tributary inputs to the St. Lawrence River.			
Raquette R.	(U.S.)	31	36	32	39
Oswegatchie R.	(U.S.)	30	41	34	35
Grass R.	(U.S.)	30	16	16	22
Cataraqui R.	(Can.)	4	3	9	2
Gananoque R.	(Can.)	4	3	7	2
Little Cataraqui	(Can.)	1	1	2	-

Table 3.1.9 Tributary discharges direct to Lake Ontario and St. Lawrence River 1966-67 (short tons/year).

Tributaries Lake Ontario	Flow (cfs)	Population served with sewers (thousands)	BOD_5	Solids		Total nitrogen (N)	Total phosphorus (P)	Chlorides
				Total	Susp.			
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

Table 3.1.9 (cont'd)

Tributaries Lake Ontario	Flow (cfs)	Population served with sewers (thousands)	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

Table 3.1.9 (cont'd)

Tributaries Lake Ontario	Flow (cfs)	Population served with sewers (thousands)	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
CANADIAN TOTALS 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								
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
UNITED STATES TOTALS INTO LAKE ONTARIO	15,163	1,197.4	63,053	5,440,000	799,000	19,000	1,390	1,207,000

Table 3.1.9 (cont'd)

Tributaries Lake Ontario	Flow (cfs)	Population served with sewers (thousands)	BOD_5	Solids		Total nitrogen (N)	Total phosphorus (P)	Chlorides
				Total	Susp.			
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

River, Twelve Mile Creek, Genesee River and Black River together carry in excess of 60 percent of the total nutrient loads, 90 percent of the chloride and 83 percent of the suspended material inputs. The Raquette, Oswegatchie and Grass rivers introduce more than 90 percent of the loads carried by tributaries of the St. Lawrence River. For the most part, the individual tributaries excluding the Niagara River, convey a relatively small part of the total nutrient load imposed on Lake Ontario. When taken together, however, the minor tributaries account for a total load equivalent to about one-quarter of that carried by the Niagara River. Estimates of the municipal portion of the tributary drainage using per capita contributions of three and nine pounds per year for phosphorus and nitrogen, respectively, indicate a sizeable contribution from other sources.

The industrial and other waste components of the tributary loads represent a nitrogen and phosphorus contribution of 2,100 and 120 pounds per square mile, respectively, if applied to the entire Lake Ontario drainage basin including the Niagara River. The industrial component of the tributary loading can be regarded as relatively small, in the order of 10 percent. On this basis, land drainage alone would probably account for 1,800 and 100 pounds per square mile for nitrogen and phosphorus contributions measured at the mouths of the tributaries. In this estimate no attempt is made to differentiate between the yields from agricultural, urban or other land use. It should be recognized, however, that the yields of nitrogen and phosphorus from rural lands will reflect the use of the land and may be high in areas where agriculture is intensive.

3.1.4 Other Sources

Vessel Wastes

Commercial vessels and recreational craft plying the waters of Lake Ontario and the St. Lawrence River contribute untreated or inadequately treated wastes to the open waters and harbour areas.

Approximately 7,000 commercial ship passages are made through the St. Lawrence Seaway and across Lake Ontario each year. Some of these vessels provide treatment for sanitary wastes, but many discharge their wastes without treatment. In addition, garbage, bilge and ballast waters, and bunker oil are disposed of to the lake waters either wilfully or accidentally. Harbour waters are often seriously degraded by discharges from commercial ships.

Among the cargoes which could cause hazardous conditions in the event of a major spill or release are crude petroleum, fuel oil, gasoline and lubricating oils. Petroleum and its products accounted for about 3.3 million tons of the commodities handled at Canadian ports on Lake Ontario in 1966. During the same period, approximately 0.08 million tons of petroleum products were handled at Rochester and Oswego, New York. The only vessel traffic in crude petroleum is Canadian and represents less than two percent of the total crude petroleum imported by pipeline to the Canadian Great Lakes region from western Canada. In addition 0.38 million tons of chemicals, including salts, organic and inorganic chemicals, sulphuric acid, glycol, fertilizers and dyestuffs were handled in the ports. Similarly, 0.09 million tons of these products were handled at Rochester and Oswego. These materials could also pose even greater problems if accidentally spilled.

The tremendous increase in pleasure craft over the past few years has given rise to concern for their effect on water quality. The problem is most severe in harbour and marina areas, where waste disposal facilities are usually not available. Many large and small boat harbours are found along the Ontario shore. Approximately 3,100 boats can be accommodated at nine federal recreational harbours in the State of New York. It is estimated that private moorings exceed this figure. Many of these boats are equipped with toilets which discharge untreated sanitary wastes. The custom of using pleasure boats as "weekend apartments" without moving them out of the marina, results in heavy waste loadings to the confined waters of harbours. Collectively, pleasure craft are significant because of their large number and mobility.

Dredging

In the Canadian waters of Lake Ontario, dredging is carried out under contract by the Canada Department of Public Works with major harbour dredging maintained by local harbour commissions. The quantities of materials dredged in recent years are shown in Table 3.1.10. The usual requirement is that spoils be placed in water no shallower than 16 metres, nor in waters within three miles of the dredging site. In certain instances spoils are used to reclaim land and are deposited behind retaining walls. The OWRC and the Canada Department of Public Works have initiated studies of the character of dredged material and its effect on water quality in disposal areas.

Year round maintenance dredging is carried out by The Toronto Harbour Commission at the mouth of the Don River

Table 3.1.10 Sediment loads in cubic yards from dredging operations for Lake Ontario.

Harbour	Quantities of materials dredged cubic yards 1967	 Estimated 1968
Ontario		
Hamilton	25,000	564,000*
Oakville	Nil	Nil
Toronto	152,000	91,000
Port Hope	20,000	Nil
Cobourg	19,000	Nil
Belleville	Nil	Nil
Kingston	Nil	Nil
New York		
Rochester	517,000	360,000
Great Sodus Bay	71,000	30,000
Oswego	93,200	80,000

*Dredging at Canada Centre for Inland Waters at Burlington, Ontario, accounts for 450,000 cubic yards.

in Toronto Harbour. In 1967, about 112,000 cubic yards were dredged and the spoil incorporated in a headland structure under construction as part of the Metropolitan Toronto Waterfront Plan. Prior to 1966, the spoil was dumped in Lake Ontario approximately two miles offshore from the harbour.

The National Harbours Board maintains a small harbour at Prescott on the St. Lawrence River which requires periodic dredging. With the exception of work carried out in 1963, little dredging has been done in the area in the past 15 years. Spoils were deposited in waters deeper than 16 metres, in an area designated by the St. Lawrence Ship Channel Branch, Department of Transport.

Maintenance of navigation channels in federal harbour projects on the United States shore of Lake Ontario is the responsibility of the Corps of Engineers, U.S. Army. Dredging is done either with government-owned equipment or by contract. Three deep-draft harbours, Rochester, Great Sodus Bay, and Oswego accommodate about 1,000 ships each year, and require annual maintenance dredging. Disposal of material from these harbours occurs at locations designated by the Corps of Engineers, usually a few miles offshore.

The Great Sodus Bay dredging operation involves some 6,000 feet of approach channel. The material in the channel is mostly from the lake, is clean and does not pose a pollution problem when it is redeposited over a designated spoil area in the lake.

Bottom sediments in some harbours, notably Rochester and Oswego, consist of a combination of silt and municipal and industrial wastes. Some of these sediments contain high concentrations of pollutants such as iron and other metals, oil and grease, nutrients and oxygen-consuming materials. The transfer of these materials to the open lake constitutes a source of pollution.

Dredging in Rochester Harbour involves about five miles of channel and two turning basins. Soil erosion upstream on the Genesee River causes silting of the harbour area. Industrial wastes, combined sewer overflows and municipal wastes combine with the silt to produce a significant organic fraction in the bottom material. Tubificid worm populations in the dredged area range from 6,500 to 29,000/m^2. Chemical oxygen demand values of 1,330 to 4,200 mg/l have been found in the dredged material. The overflow from the hydraulic dredge is high in organic matter and the fine suspended material settles with difficulty. The redistribution of these organic materials in the confines of the river has an oxygen-demanding effect. When spoil is placed in the designated open area of the embayment aerial photographs have shown the fine material to be carried about the embayment by currents.

A similar dredging operation in 1967 at Oswego Harbour of an area not usually dredged produced COD values ranging from 9,200 to 24,000 mg/l in the dredged material. The spoil was redeposited over a designated spoil area in Lake Ontario.

Private slips and docking facilities outside the federally dredged areas are maintained by the property owners under permits issued by the Corps of Engineers. Disposal of materials is usually in designated lake disposal areas.

Oil and Gas Well Drilling

There is no production of oil and gas from submerged lands underlying Lake Ontario or the St. Lawrence River, and there are no known plans for exploration activities.

Sediments

Stream bank erosion is the major contributing source of sediment to Lake Ontario. A measure of the large sediment loads carried by many of the tributaries is given in the suspended solids data presented in Section 3.1.3 of this chapter. The problem is sufficiently acute in the streams entering harbours that annual maintenance dredging is essential. The significance of the sediment loads carried by the Don and Genesee rivers in the Toronto and Rochester harbours, respectively, is discussed in the previous section on dredging. While the Don River contributes less than one percent of the suspended solids load introduced to Lake Ontario, dredging of approximately 112,000 cubic yards was required in 1967 to maintain the channel opening.

Because of its great discharge volume, the Niagara River introduces about 81 percent of the suspended materials load to Lake Ontario. Other major sediment carrying rivers are the Black, Oswego and Genesee rivers in New York and Twelve Mile Creek in Ontario.

Sediments, both organic and inorganic, accumulate in the vicinity of waste outfalls where inadequate waste treatment is provided. While this will be less of a problem with the completion of needed municipal waste treatment facilities, there are locations where industrial solids have been allowed to accumulate in water and smother bottom life.

While not as obvious as the physical damage, the chemical and biological effects of sedimentation are also important. Phosphate compounds, unlike the other typical constituents of fertilizer, are not easily leached out of soil, but rather tend to cling to soil particles. When stream bank or other forms of soil erosion occur these materials are transported into the streams and lake and provide an additional supply of nutrients. Many types of pesticides, notably DDT and dieldrin, adhere to soil particles in a similar fashion. These accumulate in stream sediments, are taken up by the bottom-dwelling worms that ingest the mud, and subsequently reach other life forms in the food chain of aquatic life.

Atmosphere

Atmospheric sources of nutrients are the contribution of nitrogen compounds from rainfall, dustfall and fixation of nitrogen by algae. According to Hutchinson (1954), the greater part of the nitrate contained in rain is not derived from direct oxidation of N_2 in the atmosphere. Photochemical oxidation of ammonia is apparently the more reasonable explanation for the source of nitrate in rainwater (Feth, 1966). Junge and Manson (1961) emphasized the abundance of ammonium-bearing particles in atmospheric aerosols, based on studies of samples near the earth's surface. Studies of particulate matter of the stratosphere revealed that the aerosols consist largely of ammonium sulphate and ammonium persulphate. It is suggested that a constant fallout of these particles occurs from the stratosphere to lower layers of the atmosphere, where they are incorporated into rain and snow.

Some of the nitrogen found in rainwater could be attributed to industrial activity, and in certain areas to smog. Other workers (Gambell and Fisher, 1964) have studied individual rainfalls in the United States and have concluded that NH_4 and NO_3 ions in rain resulted mostly from gaseous constituents of the atmosphere. Industrial air pollutants contain ammonia and other gaseous nitrogen compounds.

The nitrogen content of rain and snow was studied at Ottawa from 1907 to 1924 (Shutt and Hedley, 1925). In these studies nitrogen was determined as free ammonia, as albuminoid nitrogen and as nitrate plus nitrite. On the average, nitrogen as nitrate plus nitrite made up about 30 percent of the total nitrogen in rain and about 35 percent of the total nitrogen in snow. Rain contributed about 83 percent and snow 17 percent of the precipitated nitrogen during the 17 year observation period. The total nitrogen contributed to the land averaged about 7 lbs/acre/year.

Studies on inorganic nitrogen in precipitation and atmospheric sediments were carried out at Hamilton, Ontario, over a period of 18 months. The results were reported by Matheson (1951). The nitrogen fall for the whole period averaged 5.8 lbs/acre/year. Sixty-one percent of the total nitrogen was collected on 25 percent of the days, when precipitation occurred. The balance, occurring on days without precipitation, was attributed to the sedimentation of dust. Ammonia nitrogen averaged 56 percent of the total. In comparison, McKee (1962), reported a rate of 2 to 10 kilograms per hectare per year (1.8 to 8.9 lbs/acre/year) from European studies on atmospheric nitrogen, precipitation and dustfall.

Using a value of 5 lbs/acre/year, the total nitrogen precipitated by rain and dry fallout onto the surface of Lake Ontario is estimated to be 12,000 tons per year. This is estimated to account for less than 10 percent of the total input or supply of this nutrient to Lake Ontario.

Molecular nitrogen (N_2) is present in lake waters near the concentrations corresponding to equilibrium with air. The ability of certain species of algae (especially blue-greens) and bacteria to utilize molecular nitrogen as a nutrient source has been well documented (Dugdale *et al.*, 1959; Fogg, 1956; Williams and Burris, 1952) and is referred to as nitrogen fixation. The actual quantity of nitrogen input into Lake Ontario via nitrogen fixation cannot be estimated because of the lack of data.

An indication of the relative importance of nitrogen fixation can be obtained from some quantitative work done on Sanctuary Lake in Pennsylvania (Dugdale and Dugdale, 1962) and Lake Mendota in Wisconsin (Goering and Neess, 1964). During the period of maximum nitrogen fixation rates, from about June to August, nitrogen fixation accounted for one to three percent of the total organic nitrogen present in the surface waters of Sanctuary Lake and 0.1 to 0.6 percent in the case of Lake Mendota. Both lakes have large blooms of blue-green algae, regularly, and probably represent more extreme cases of nitrogen fixation than either Lake Erie or Lake Ontario. In all probability, nitrogen fixation can be discounted as a significant source of nitrogen in the lower Great Lakes.

3.2 IMMEDIATE EFFECTS

The material loads or wastes introduced into Lake Ontario and the St. Lawrence River have their greatest impact on the intensively used shore waters where many varied water uses are common. This section describes the disposition and effects of pollution in these waters emphasizing the immediate effects on water quality and the implications for the various uses. The observations are based on data collected by the FWPCA in 1965 and by the OWRC in 1966 and 1967.

3.2.1 Effects on Water Quality

Several indicators characteristic of water-borne pollutants are presented in the accompanying figures (Fig. 3.2.1 through 3.2.6) in concentration contour form. These depict typical water quality variations in the immediate offshore waters of Lake Ontario. Particular attention is given to the nearshore waters at the Niagara River outlet and the waters adjacent to the cities of St. Catharines, Hamilton, Metropolitan Toronto, Rochester and other locations where water use is extensive. Unless otherwise stated, average values are referred to in the text.

The immediate zones of influence of the material and pollution load carried by the river are evident by the distribution of isopleths of total phosphorus, soluble orthophosphate, ammonia, chlorides, conductivity and coliforms (Fig. 3.2.1 to 3.2.6). The general trend of these contours shows the highest levels of impaired water quality within a ten-mile radius of the Niagara River mouth. High total phosphorus values were found in two zones, one at the mouth of the Niagara River and the other at the mouth of the Welland Ship Canal (Fig. 3.2.1). Concentrations ranged from 40 µg P/l at the river mouth to 30 µg P/l eight miles offshore as the river plume dispersed in the lake. Values of total phosphorus of 95 µg P/l at the ship canal outlet dissipate rapidly to 30 µg P/l at a distance of one mile offshore. The distribution of soluble orthophosphate was similar to that of total phosphorus.

Ammonia-nitrogen values immediately off the river mouth and ship canal outlet ranged as high as 130 µg NH_3-N/l and 160 µg NH_3-N/l, respectively. Values of total nitrogen of 600 µg N/l found as far as two miles offshore were reduced to 440 µg N/l eight miles from the Niagara River outlet.

The highest coliform counts adjacent to the Canadian shoreline were found within a four mile wide zone extending from Niagara-on-the-Lake to Port Dalhousie (Fig. 3.2.6).

The shore waters from Twelve Mile Creek to Hamilton are relatively free of the effects of pollution. Waste sources discharging directly to the lake in this area are of localized significance.

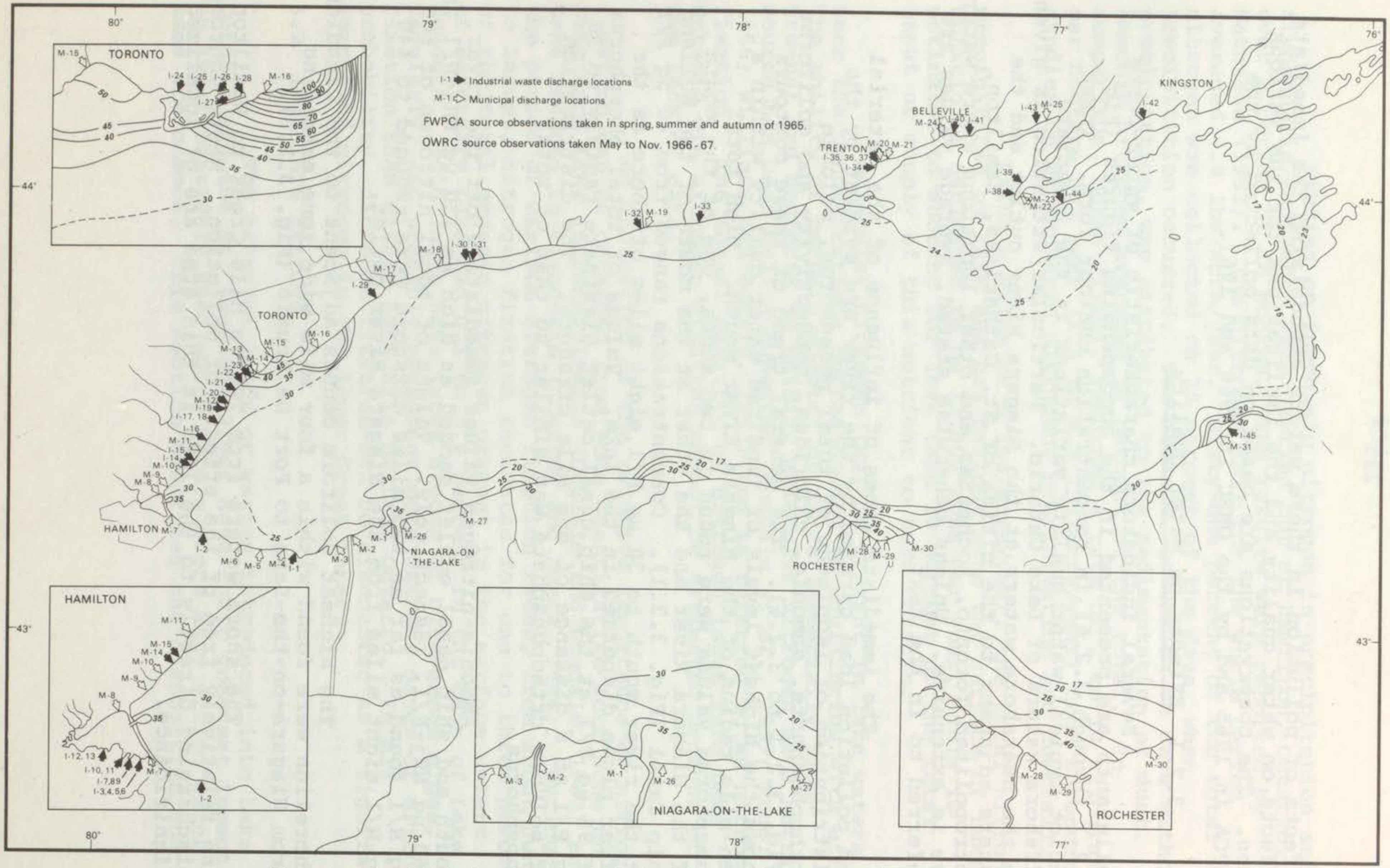


Fig. 3. 2. 1 Distribution of total phosphorus (μg total-P/1) in nearshore waters.

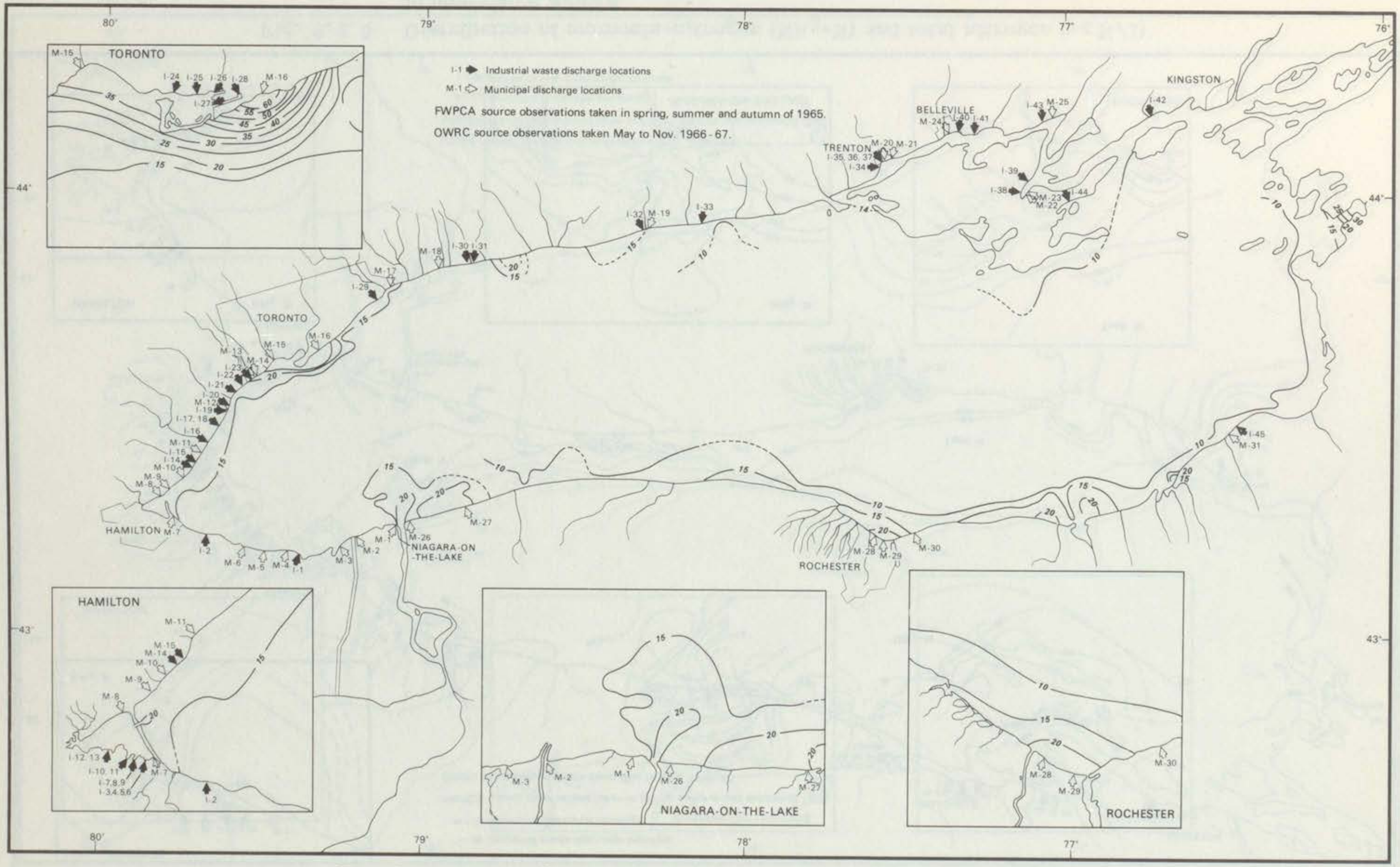


Fig. 3.2.2 Distribution of orthophosphate-phosphorus (μg PO_4-P/1)

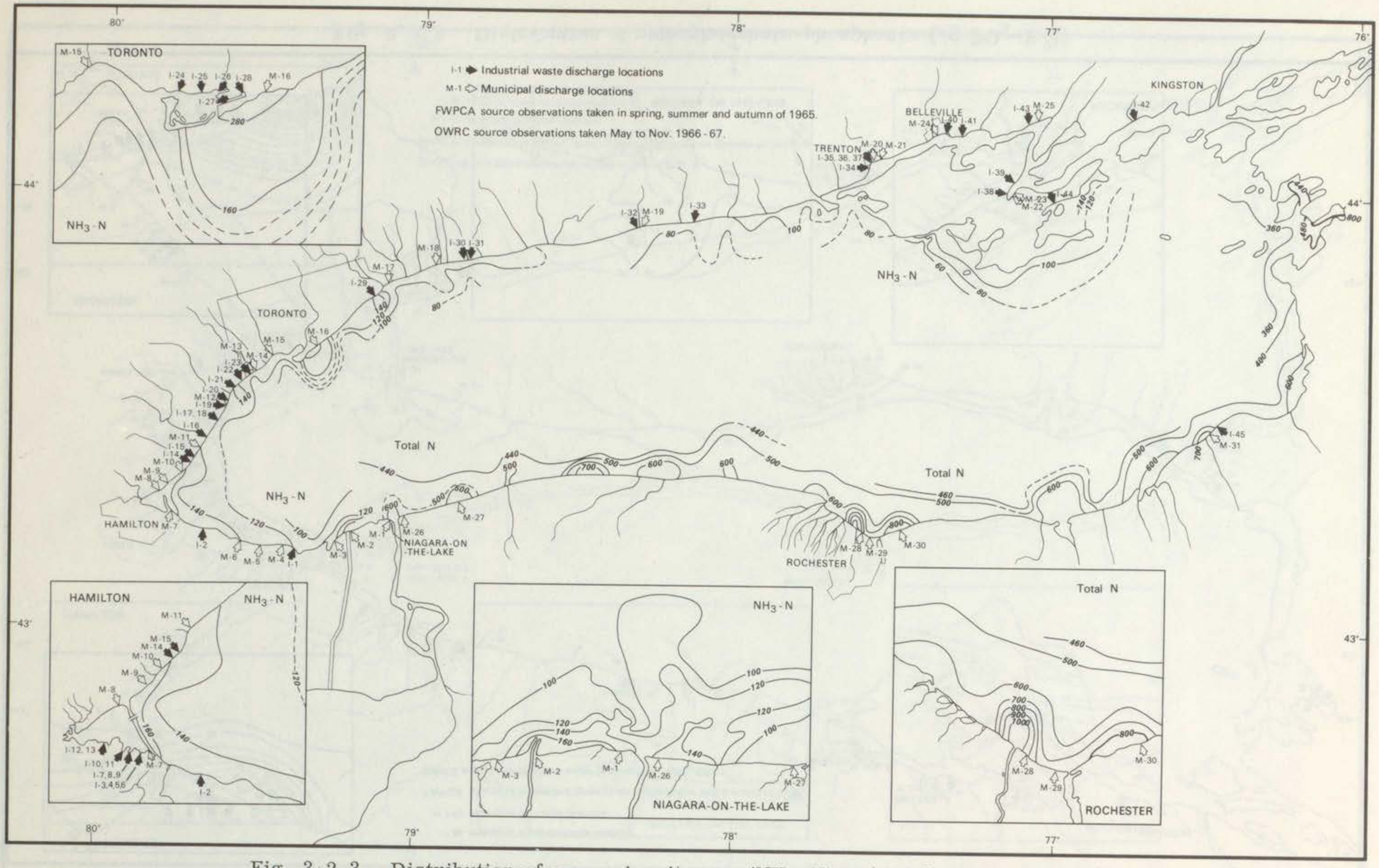


Fig. 3.2.3 Distribution of ammonia-nitrogen (NH_3-N) and total nitrogen (μg N/1) in nearshore waters.

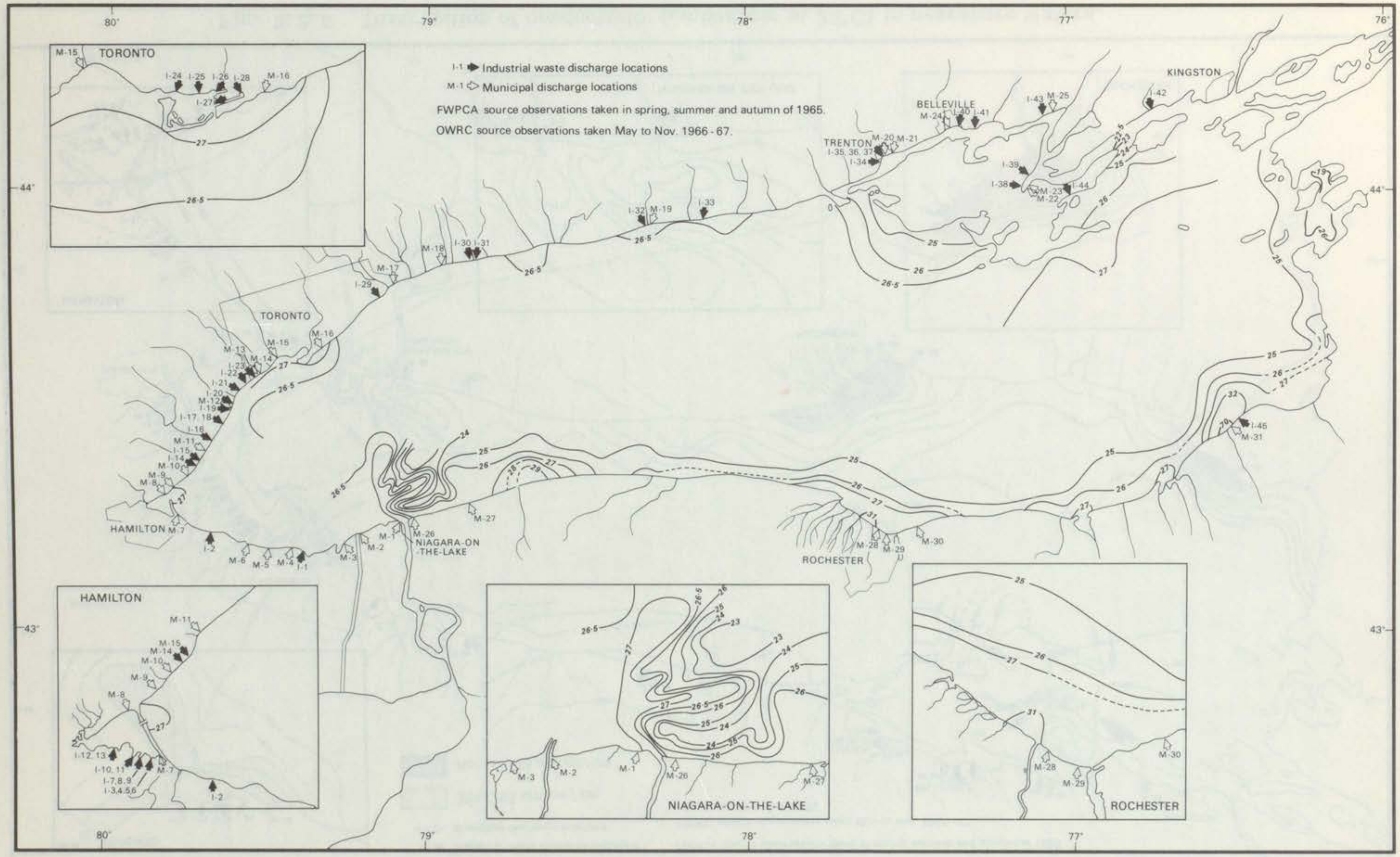
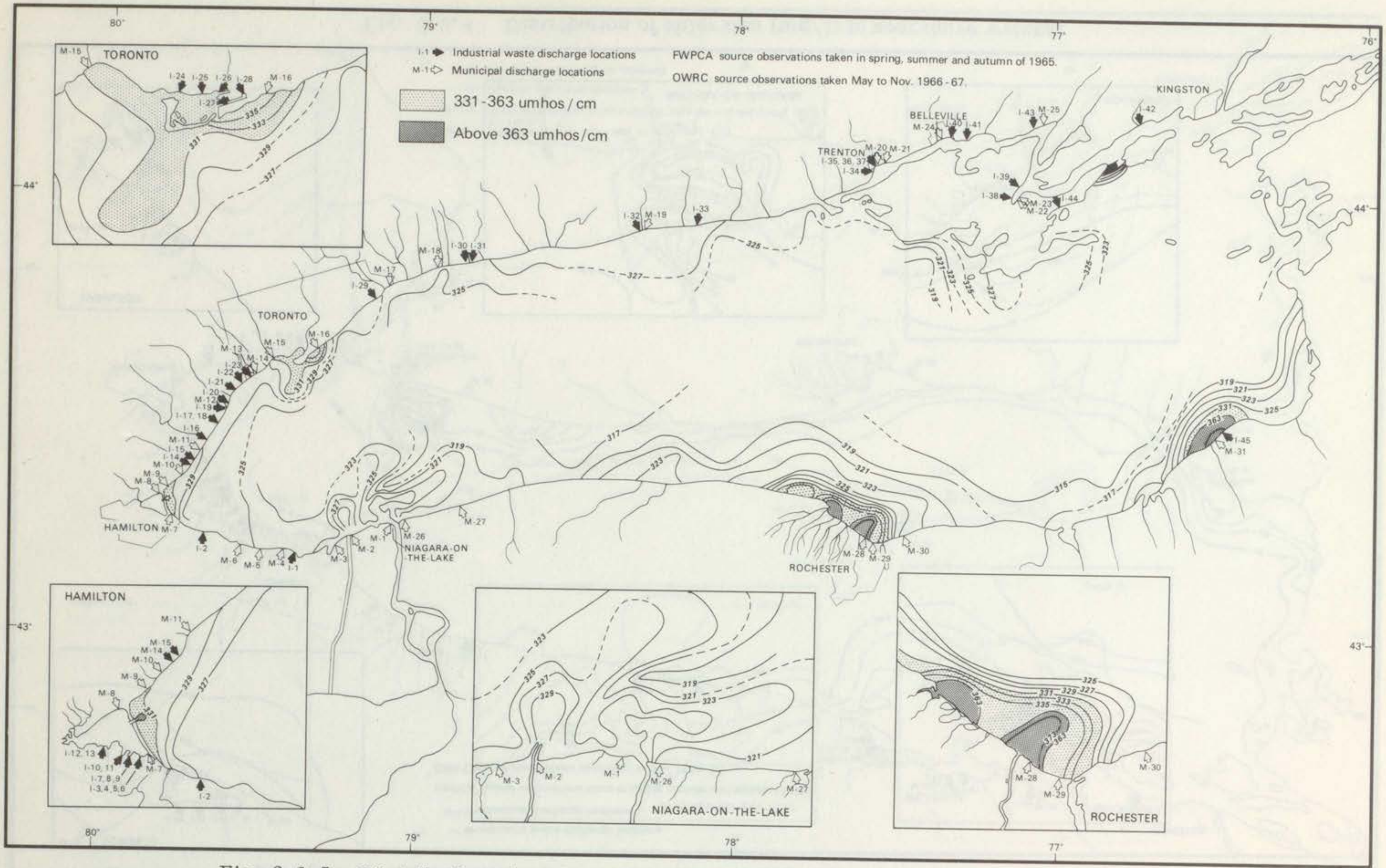


Fig. 3.2.4 Distribution of chlorides (mg/1) in nearshore waters.



FWPCA source observations taken in spring, summer and autumn of 1965.

OWRC source observations taken May to Nov. 1966 - 67.

Fig. 3. 2. 5 Distribution of conductivity (μmhos/cm at 25°C) in nearshore waters.

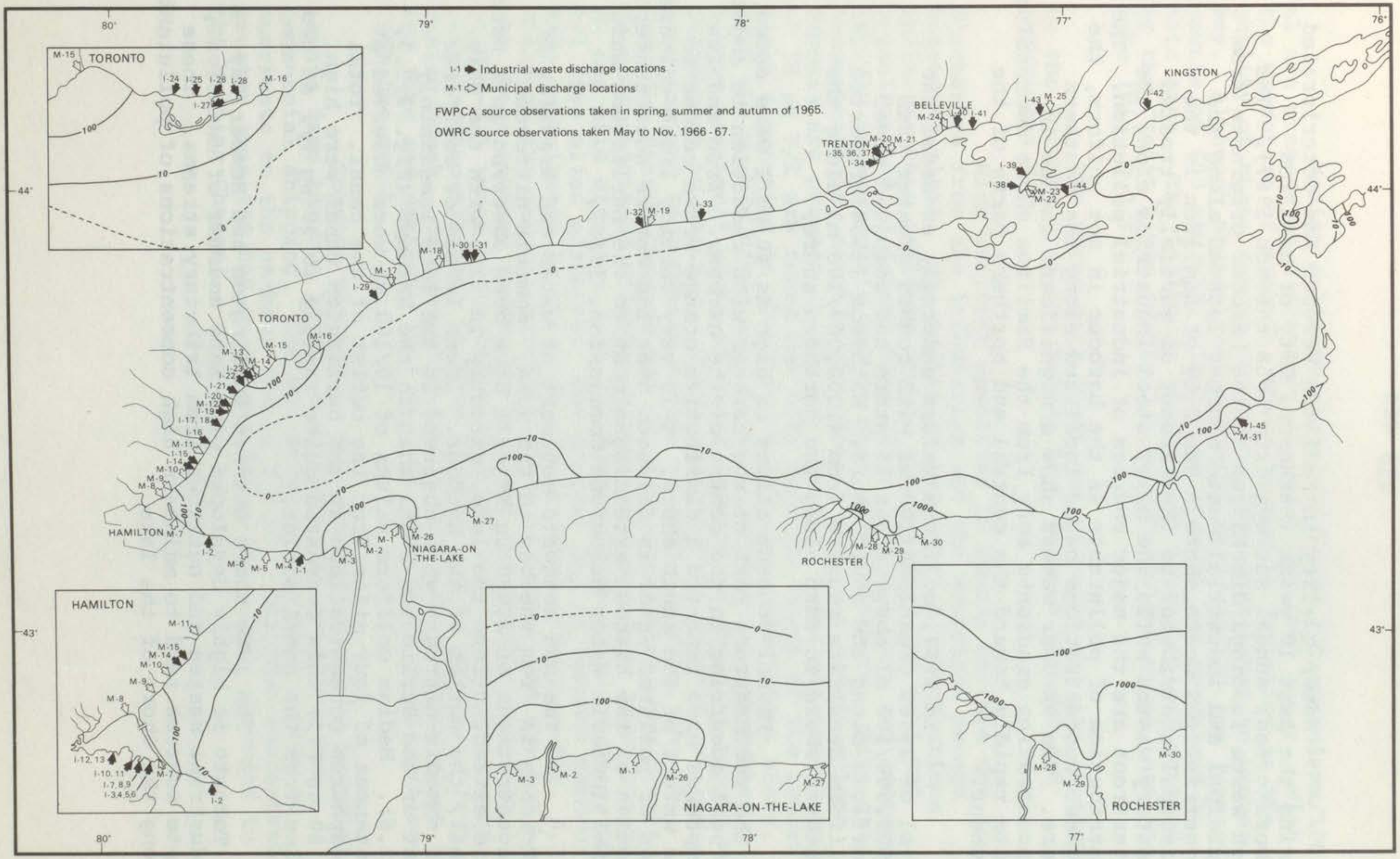


Fig. 3.2.6 Distribution of median total coliforms (MF count/100 ml) in nearshore waters.

Water quality in Hamilton Harbour has deteriorated during the past 10 years (Matheson, City of Hamilton Laboratories, annual surveys from 1958 through 1967). The high waste loadings discharged to the harbour originate from municipal and industrial waste sources located along the industrialized south shore. The City of Hamilton is the principal contributor to the harbour of partially treated sanitary wastes while the heavy steel industries along the waterfront are the major sources of industrial pollution. The distribution of pollutants in the harbour is not uniform, the highest concentrations being localized along the southern shore. The harbour waters show a significant change in concentration gradients away from the Hamilton shore decreasing quite rapidly toward the central and northern parts of the harbour.

In 1967, coliform values generally exceeded the level of 2,400 organisms/100 ml with counts greater than 5,000,000/100 ml observed at 15 storm and combined sewer overflows along the south shore. Matheson (1958) reported coliform densities ranging from 4,000,000/100 ml along the southern shore to zero along the northern shore.

Phenol concentrations as high as 40 µg/l were noted in the southeastern part of the harbour with reduction to about 16 µg/l occurring in the centre of the harbour. Iron and its compounds have imparted a distinctive orange-brown colour to the waters of the south shore. This very turbid, light-coloured mass of polluted water is diffused over the entire southeastern section of the harbour extending almost to the Burlington Ship Canal (Ontario Water Resources Commission, 1968).

The net eastward movement of water and transfer of nutrients is from the bay to the lake. Ammonia-nitrogen concentrations of 2,000 µg NH_3-N/l have been observed in a narrow zone extending into the lake, directly in line with the ship canal, the outlet of the harbour. Lower levels of coliforms and ammonia-nitrogen were observed in the lake immediately east of the Burlington Canal than in the harbour (Fig. 3.2.3, 3.2.6). Median coliform values of 10/100 ml were observed at distances of four miles from the outlet of the canal. Total phosphorus concentrations at the Burlington Canal were high at 50 µg P/l; this decreased quite rapidly to 30 µg P/l at two miles from the canal outlet.

The lake shore between Burlington and Humber Bay at Toronto is highly developed with many sources of municipal, industrial wastes and outflows from tributary streams. These waste sources tend to maintain high concentrations of pollutants along the shore of the lake.

Median coliform counts of 10 to 100 organisms/100 ml are present at a distance of two miles from shore. With the exception of ammonia, there is little variation in the quality of these waters extending from Burlington to Humber Bay. Although phytoplankton crops are generally low (average counts of 600 asu/ml), *Cladophora* growths are prevalent in this area. The influence of the high nitrogen load carried by the Credit River (Table 3.1.9) extends two miles into the lake (Fig. 3.2.3).

The three main locations of water quality impairment in the Toronto area are Humber Bay, Toronto Harbour and Ashbridges Bay.

High coliform densities in Humber Bay are due to discharges from the tributaries and the municipal sewage treatment plant. The median of two years of observations indicates that coliform counts ranging from 100 to 1,000 organisms/100 ml extend four miles into the lake and decrease rapidly to negligible values nine miles offshore. High nutrient concentrations, notably phosphorus, and to a lesser extent ammonia are present in the bay waters. Total phosphorus values of 50 μg P/l are found one mile from the mouth of the Humber River decreasing to about 30 μg P/l seven miles from shore. Both the Humber River and the Metropolitan Toronto-Humber sewage treatment plant effluent provide an abundant supply of phosphorus to the bay. Other contributing sources are the Lakeview and Long Branch sewage treatment plants, the St. Lawrence Starch Company and the Mimico and Etobicoke Creeks. Concentrations of soluble phosphorus range from 35 μg PO_4-P/l at one mile offshore from the Humber River mouth of 15 μg PO_4-P/l five miles offshore. The Western Gap of Toronto Harbour also contributes to the high values found offshore (Fig. 3.2.2). Although the ammonia concentrations in Humber Bay are not high, the above sources appear to maintain the ammonia level at 12 μg NH_3-N/l three miles offshore (Fig. 3.2.3). High average phenol concentrations in this area appear to originate from Mimico Creek. Concentrations of 3 μg/l extend three miles into the lake and decrease to 1 μg/l at a distance of five miles from the creek.

Toronto Harbour is seriously polluted by material inputs from the Don River, combined sewer overflows and commercial shipping. The Don River is the main source of nutrients to the harbour (Table 3.1.9). Coliform concentrations greater than 250,000 organisms/100 ml have been recorded in the Keating Channel.

The average concentration near the Metropolitan Toronto treatment plant outfall to Ashbridges Bay is 100 µg P/l, which dissipates quite rapidly to 30 µg P/l four miles offshore (Fig. 3.2.1). Soluble orthophosphate concentrations show a a very similar pattern with values of 60 µg PO4-P/l at the outfall decreasing to 30 µg PO4-P/l three miles from shore (Fig. 3.2.2). Ammonia-nitrogen also showed the same radial pattern of dispersion as did total phosphorus and soluble orthophosphate with concentrations of 280 µg NH3-N/l near the outfall attenuating to 100 µg NH3-N/l six miles from shore (Fig. 3.2.3).

Chlorides and conductivity also reflect the large input of treated municipal wastes (Fig. 3.2.4 and 3.2.5). Median coliform counts ranged from 10 to 100 organisms/100 ml. The water in this area is gray in colour as distinct from the characteristic green coloured waters of the lake. Solids originating from the Ashbridges plant have been observed along the adjacent shoreline. Average phenol concentrations of 2 µg/l occur along the lakefront, notably at Bronte Creek and Port Credit.

Ammonia concentrations were elevated slightly at the mouth of Highland Creek and in the vicinity of Amherst Island (Figure 3.2.3). Soluble orthophosphate concentrations remained relatively low in the immediate offshore waters except for local increases adjacent to Highland Creek, Bowmanville, Port Hope and the entrance to Presqu'ile Bay (Figure 3.2.2). Algal blooms are infrequent in this area, however, average counts as high as 696 and 894 asu/ml have been noted at Oshawa and Cobourg, respectively. Decreases in chloride concentrations were observed in the Presqu'ile Bay area and at the entrance to the Bay of Quinte at Amherst Island. Conductivity readings in this section of the lake are relatively constant except at the mouth of Adolphus Reach at Amherst Island, where a rapid shoreward decrease similar to that for chlorides was noted. Median coliform counts were in the range of 0 to 10 organisms/100 ml along the entire shoreline.

Total phosphorus concentrations are in the range of 60 and 70 µg P/l while ammonia-nitrogen concentrations are generally greater than 15 µg NH3-N/l. The transition from bay to lake water quality is gradual over the section from Picton to the Upper Gap. As noted previously, large gradients in chlorides and conductivity occur across the Upper Gap (Fig. 3.2.4 and 3.2.5).

Currents in the bay are almost negligible. Consequently, waste materials from land drainage, municipal and industrial discharges accumulate. High nutrient concentrations give rise to excessive algal blooms (Section 2.4).

Immediately east of the Niagara River the villages of Youngstown and Wilson discharge primary treatment plant effluents directly to Lake Ontario. The problems arising from these sources are confined to a small area of the lake, since these municipalities do not represent a major waste input.

Eighteen Mile Creek, one of several minor tributaries, enters Lake Ontario laden with high concentrations of nutrients from industrial wastes and domestic sewage. Algae and plankton blooms occur near the creek mouth. Total phosphorus and total nitrogen values of 550 µg P/l and 3,220 µg N/l have been measured at the mouth of Eighteen Mile Creek and above 30 µg P/l total phosphorus, and 500 µg N/l total nitrogen to a distance of one mile from the creek mouth (Fig. 3.2.1 and 3.2.3). Similarly, high ammonia, chlorides, conductivity and coliform values were found at these locations and reflect municipal and industrial development at Lockport some eight miles upstream from the mouth of the creek.

Several small streams discharge to the lake between Eighteen Mile Creek and the Genesee River at Rochester. These streams have little influence on the lake but do contain high nutrient levels and organic wastes from seasonal canning operations.

In the summer of 1964, an algae bloom *(Ankistrodesmus* and *Scenedesmus)* of 84,000 cells per ml was recorded adjacent to Johnson Creek. Concentrations of sulphate as high as 220 mg/l originate from gypsum mining in the Oak Orchard Creek watershed each spring.

One of the major water quality problems, along the New York shoreline, is centered around the Rochester embayment. Wastes are transported to the embayment by a few small creeks, the Genesee River and three direct inputs from the City of Rochester, the Town of Irondequoit and the Village of Webster.

The lower reach of the Genesee River is badly polluted by discharges from combined sewer overflows from the City of Rochester and domestic and industrial waste discharges from surrounding suburbs. During the summer and fall of 1965, serious oxygen depletions were noted in the last one mile stretch of the Genesee River. In the spring considerable amounts of silt are transported from upstream erosion to Lake Ontario. The average concentrations of total phosphorus (270 µg P/l), total nitrogen (2,530 µg N/l) and chlorides (39 mg/l) in the river at its mouth maintain the concentrations in the waters of the embayment above 40 µg/l, 1,000 µg/l and 31 mg/l, respectively.

Mainly as the result of waste discharges from the Genesee River and the City of Rochester's sewage treatment plant, extremely high total coliform counts are encountered in this area. Counts at the mouth of the Genesee River ranged from 8,000 to 67,000/100 ml during the summer bathing season of 1967. During 1968, counts in the range of 11,000 to 2,300,000/100 ml were recorded. Since 1966, bacterial contamination of the embayment has required the closing of public beaches. Unattractive decomposing algae *(Cladophora)* also accumulate along the beach areas. The excessive growth of algae is promoted by the high nutrient content of the inshore waters.

Irondequoit Bay retains much of the nutrients discharged to it and appears to be aging rapidly. This is evident by the prolific crops of algae and aquatic plants noted each summer. Total phosphorus concentrations in the bay averaged 580 µg P/l, whereas total nitrogen averaged 2,820 µg N/l. Chloride levels at the bay outlet were high at 84 mg/l compared to 28 mg/l in nearby Lake Ontario. While conditions are most unsatisfactory in the bay, its effect on Lake Ontario is hardly measurable beyond the immediate outlet from the bay.

Between Rochester and Oswego, there are several minor tributaries which have a minimal effect on Lake Ontario. Most of these streams are highly enriched and carry organic wastes during the canning season.

The City of Oswego, the outlet of the Oswego River and the Hammermill Paper Company combined represent one of the major waste inputs to Lake Ontario.

The Oswego River discharge is characterized by high chlorides (354 mg/l), conductivity (1,433 µmhos/cm), sulphates (104 mg/l) and dissolved solids (857 mg/l). High nutrient loads maintain the total phosphorus and total nitrogen concentrations above 30 µg P/l and 700 µg N/l, respectively, within a one mile radius from the river outlet. The nutrient loadings of phosphorus and nitrogen combine to produce phytoplankton blooms at the river mouth.

Numerous untreated waste discharges from pulp and paper mills are responsible for the seriously polluted condition of the Black River. Total phosphorus concentrations at the mouth of the river were 90 µg P/l compared to 34 µg P/l in the Black River Bay area and 24 µg P/l in the lake. Total nitrogen at the river mouth was 1,300 µg N/l reducing to 800 µg N/l in Black River Bay. The inshore water of the lake had a total nitrogen concentration of 600 µg N/l.

A number of major industrial and municipal water users discharge waste water directly to the St. Lawrence River. The locations of these discharges are shown in Fig. 3.2.7. As a result of its large flow, waste discharges disperse rapidly in the river within a short distance, and water quality except in the immediate vicinity of the waste discharges, is satisfactory. Chemical companies at Brockville and Maitland and industrial and municipal inputs at Cardinal discharge heavy loads of BOD and nutrients. The nutrients in the river support algal growth along the shoreline. Generally, the waste inputs are dissipated rapidly in the river, however, the influence of the nitrogenous wastes from two chemical industries at Brockville and Maitland, doubles both the nitrate and nitrite content of the entire river cross-section between Brockville and Cornwall.

At Cornwall, the influence of waste waters from the Domtar Pulp and Paper mill extends from Cornwall to Lake St. Francis (Ontario Water Resources Commission, 1960). These wastes have been held responsible for taste problems that developed in several species of fish caught in the river and in Lake St. Francis. Odour tests of the river water showed traces of the Domtar discharge as far as 19 miles downstream.

There are two locations along the 115 miles of river in the State of New York where waste discharges cause degradation in water quality. At Massena, wastes from the General Motors Corporation aluminum casting plant and Reynolds Aluminum give a milky, oily appearance to the river. At Ogdensburg, the Diamond National paper plant discharges raw wastes, including nearly 1,300 tons/year of BOD_5, floating fibres, wood chips and rafts of white foam. Unsightly discoloration is caused along the United States shoreline despite the paper mill's efforts to trap and remove the larger suspended material with a floating barrier.

The major United States tributaries to the St. Lawrence River, the Raquette, Grass and Oswegatchie rivers all have localized areas of pollution. The organic wastes discharged to the tributaries are for the most part assimilated by the streams before reaching the St. Lawrence River. These tributaries contribute significant amounts of nutrients to the main stream (Table 3.1.9).

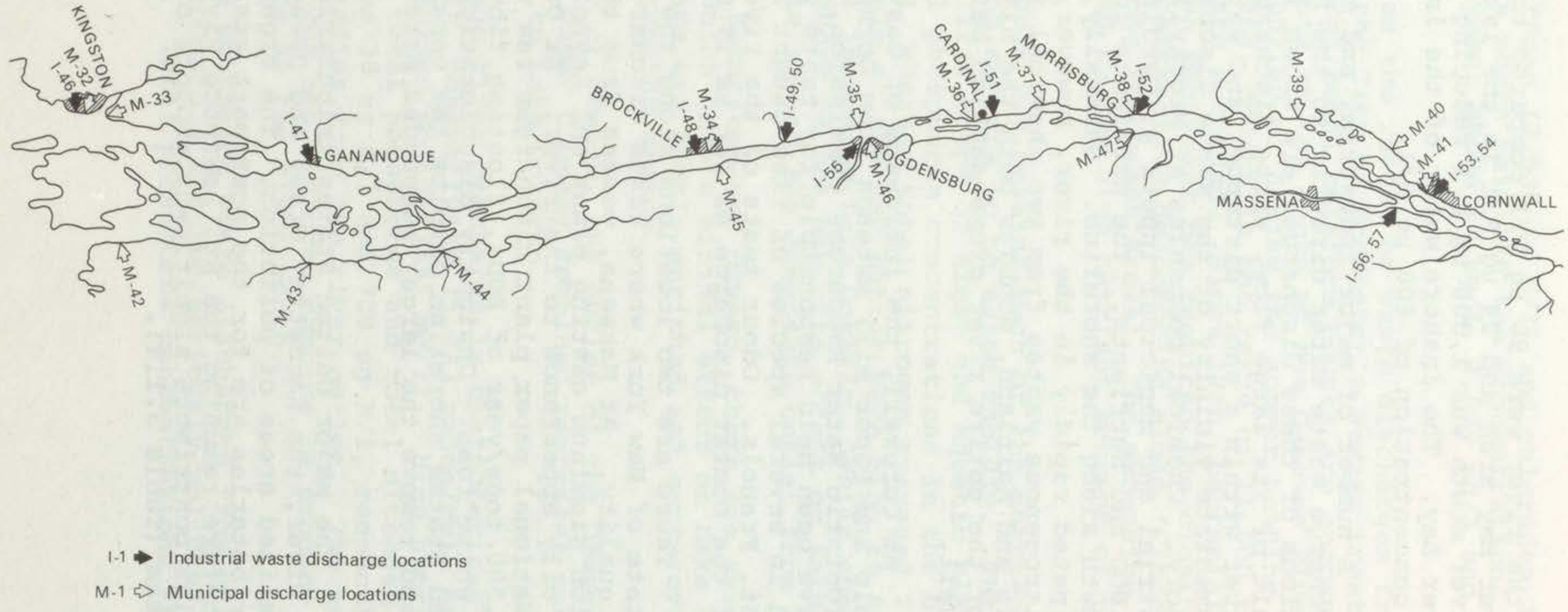


Fig. 3.2.7 Sources and locations of industrial and municipal wastes – International Section of the St. Lawrence River.

3.2.2 Effects on Water Uses

Over-enrichment and associated impairment of the nearshore waters of Lake Ontario comprise the principal problems of pollution. Other polluting substances, such as debris, silt, oil, toxic materials, phenols and complex organic chemicals interfere with many water uses and while their effects are usually local they pose an increasing potential threat to water quality and water use. Waste heat may reduce the amount of oxygen in solution and exert adverse local impairment of water quality. Generally, water quality problems are manifested by increasing costs of water treatment, reduced catches of fish and restricted bathing areas.

Public Water Supply

The municipalities along the Canadian shoreline of Lake Ontario and the St. Lawrence River withdraw 349 mgd to serve a population of 2,700,000 persons. Municipal water supply systems in the State of New York supplied from Lake Ontario and the St. Lawrence River serve 350,000 persons and withdraw 76 mgd from the lake. The cities of Rochester and Syracuse which use the greatest portion of this amount supplement their supplies from other sources.

Water treatment usually comprises coagulation, filtration and disinfection. In addition, microscreening is provided in some cases during seasons when algae are abundant. The presence of decaying algal cells produce unique taste and odour problems for water treatment plant operators. Other problems related to high algal populations are clogging of water intakes and reduced filter runs. In some cases wastes bearing trace amounts of phenolic compounds require careful treatment to avoid offensive tastes in water supplies. Water treatment processes in normal use cannot cope with sudden adverse changes in raw water quality without a sacrifice in treated water quality or a reduction in the quantity of water produced.

Continued development pressure in urban areas and use of agricultural resources without regard for effects on water quality will lead to increases in nutrient loadings and associated quality problems for water supplies drawn from the lake. Unless the additions of nutrients to the lake are reduced substantially, considerable expenditures will probably be required for new water purification plants or modifications and additions to existing plants.

Industrial Water Supply

The locations of intakes and the relative amounts of water used by industry for cooling and processing have been given in Section 1.4. Water use for cooling outpaces process water needs by a factor of 10.

Because the use of water for thermal power and industrial cooling is rapidly increasing, the quality requirements of raw water for these purposes are increasing. Generally, it is desirable that water for any type of cooling should have a low initial temperature, be non-corrosive, and non-scale forming. Further, it should be low in suspended solids, dissolved gases, and free from oil and other organic compounds and materials.

In general, the water presently withdrawn from the lake for industrial uses meets the various industrial quality requirements. Although treatment to the desired water quality is entirely a problem for the water user, water quality objectives or standards should be maintained to keep treatment costs to a minimum. Adequate control of expected increases in municipal and industrial waste discharges will be required to avoid additional expenditures on water treatment for industrial needs.

Agricultural Water Supply

Irrigation in Ontario using Lake Ontario water is carried out in the western part of the Niagara peninsula and in the eastern section of Prince Edward County. Some minor supplemental irrigation is carried out along the lake plain areas of the United States. The quality of the water places no restriction on irrigation use.

Recreation, Aesthetics and Boating

The natural resources of the Lake Ontario basin and the St. Lawrence River are excellent for recreational use and development. Cool summers, beautiful sandy beaches, bays and inlets make the lake and river popular for outdoor recreation. The St. Lawrence River, especially the Thousand Islands area, is famous for its muskelunge and northern pike fishing.

At the eastern end of the lake there are large recreation areas with beaches located on the southern side of the Prince Edward County in Ontario. The beaches are generally clear of algae and water quality is satisfactory for recreational use. Exceptions do occur when high coliform counts at times endanger the use of beaches, and heavy algal accumulations render certain areas unsightly.

The recreation areas in the western end of the lake are influenced by the effects of extensive municipal and industrial development. Beaches at Hamilton have experienced coliform contamination believed to be due to polluted land runoff. Oil and tar deposits thought to originate from shipping have occasionally been observed on the beach. In the Niagara region surveys have shown that beaches from Grimsby to Jordan Station are generally unaffected by pollution while others in the Twelve Mile Creek and Port Weller areas sometimes show high bacterial levels due to the influence of the waters of Twelve Mile Creek.

In the Toronto area, the western beaches are seriously affected by high coliform counts resulting from the overflows from combined sewers. The beaches on the northern and southern sides of Toronto Island are relatively free from contamination. The eastern beaches are affected by algal accumulations and the effluent discharged from the nearby sewage treatment plant.

Three of the four beaches located near the City of Rochester were closed during 1966 and 1967 due to localized pollution. These beaches had an average yearly attendance of 1,700,000 persons in previous years. High coliform counts from direct municipal waste discharges along with other wastes transported to the embayment by the Genesee River were primarily responsible for creating this health hazard.

Along the New York shoreline periodic accumulations of *Cladophora* have been experienced. Conditions have been worse at Stoney Point, with *Cladophora* extending offshore 25 to 50 feet and to depths of one metre. Odours emanating from the decaying mats were highly pungent and foul.

Pleasure boating is a rapidly expanding activity and there are many marinas and docking facilities available along the lake shore. There have been occasions when releases of oil from commercial vessels have polluted harbour waters and coated the hulls of pleasure craft. While water quality is generally satisfactory for pleasure boating, wastes from pleasure craft have adversely affected the aesthetics of parts of the lake and its harbours and do create a health hazard for other recreational activities.

Propagation of Fish and Wildlife

The commercial fish catch in Lake Ontario has not only declined drastically in poundage but also in the quality of the catch composition. There have been declines in the six most commercially attractive species over the years and a shift to harvesting less valuable fish such as perch and smelt. Commercial fishing has been absent from the western end of the lake for some time with most fishing confined to the eastern basin and the Bay of Quinte. Many factors bear on this situation including overfishing, lamprey predation, pollution and the alteration of spawning grounds by algal growth.

The gradual enrichment of the lake waters is probably causing the destruction of spawning grounds. Increased nutrient levels contribute to excessive growths of algae and accumulations of organic material on the lake bottom. The walleye has been affected in the eastern end of the lake, where rocky shoreline areas have been altered by growths of *Cladophora* to make them less desirable for spawning sites. While commercial fishing is limited in the St. Lawrence River, sport fishing is fairly extensive.

Waste Assimilation

The Metropolitan Toronto, St. Catharines and Hamilton areas contribute the bulk of the direct municipal and industrial waste loadings from Ontario. In New York State the Metropolitan Rochester area produces the largest source of treated municipal waste water discharged directly to the lake. The Niagara River conveys a heavy municipal and industrial load and a large residual loading component from the outlet of Lake Erie. The tributaries to Lake Ontario are used extensively to transport treated wastes.

Water quality has been adversely affected in many sections of Lake Ontario. With increasing waste water loadings, outfalls must be carefully placed to avoid undesirable effects on existing possible water uses. As the major nutrient loadings introduced to Lake Ontario exert heavy pressures on water quality, reductions in the magnitude of these loads will be essential to avoid continued deterioration of water quality. Careful design of thermal power generation facilities will be required to avoid adverse local effects.

3.3 LONG TERM EFFECTS

3.3.1 Materials Balance

An accounting of the input of materials from municipal, industrial, land drainage and natural sources provides a measure of the origin and fate of the pollutants and a rational basis upon which measures can be taken for the control of water quality.

A materials balance of four constituents, chlorides, total dissolved solids, total nitrogen and total phosphorus, is summarized in Tables 3.3.1 and 3.3.2 for Lake Ontario and the St. Lawrence River, respectively. These summaries relate all inputs to the lake and river to the quantities observed at the head of the St. Lawrence River. Estimates include the differences between the quantities in the inflows and outflow of Lake Ontario or the amount retained in the lake. The input of phosphorus contributed by municipal, industrial and land drainage sources is shown in the second part of the Table.

While the input of chlorides to Lake Ontario are in reasonable balance with the quantities carried in the inflow to the St. Lawrence River, the imbalance of nitrogen and phosphorus indicates either retention or alteration of these constituents in the lake. Seventy-seven percent of the phosphorus and 35 percent of the nitrogen are retained in Lake Ontario.

Fifty-seven percent of the phosphorus discharged into Lake Ontario is attributed to municipal and industrial sources in the Lake Ontario basin, while 33 percent of the total phosphorus introduced to the lake originates in the inflow from Lake Erie. Thirty percent of the nitrogen added to the lake comes from municipal and industrial sources. Knowledge of these basic relationships may be used to plan overall water quality control programs and specific requirements for the various sources of pollution.

3.3.2 Transboundary Movement of Pollutants

The essential question asked by the International Joint Commission is whether the waters of Lake Ontario and the St. Lawrence River are 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. Information contained in earlier sections of this volume on circulation of lake waters, water chemistry and sources of material inputs, provide some understanding of the movement of pollution across the boundary.

The section on circulation and water movement in Lake Ontario (Section 2.1.2) describes the variability of currents, especially near the water surface, and the role that winds play. During the summer, a large gyre appears to persist in the main lake waters. It produces westerly flows along the northern shore of the lake and easterly currents along the southern side (Fig. 2.1.10). This pattern suggests that water masses originating at Rochester may move to the Prince Edward

Table 3.3.1 Materials balance for Lake Ontario 1966-67 (thousands of short tons/year).

	Chlorides	Total dissolved solids	Total nitrogen	Total phosphorus
Niagara River 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

Quantities of phosphorus contributed to Lake Ontario by source (short tons/year)

Source	U.S.	Canada	Total	1967
Lake Erie to Niagara River				4,500
Niagara River				
Municipal	2,000	330	2,330	
Industrial	150	80	230	
Land drainage	50	50	100	
Unaccounted				540
Sub-Total				7,700

Table 3.3.1 (cont'd)

Source	1967			
	U.S.		Canada	Total
Point Sources				
Municipal	950		2,010	2,960
Industrial	Nil		180	180
Sub-Total		3,140		
Other Major Tributaries				
Municipal	920		1,200	2,120
Industrial				
Land drainage	470		250	720
Sub-Total		2,840		
Total-Municipal & Industrial		7,820		
Total-Other Sources		5,860		
TOTAL		13,680		

Table 3.3.2 Materials input to the St. Lawrence River 1966-67 (thousands of short tons/year).

	Chlorides	Total dissolved solids	Total nitrogen	Total phosphorus
Lake Ontario to St. Lawrence River	6,100	37,370	113	3.1
St. Lawrence River				
Point sources	47	270	6	.3
Tributaries	24	480	4	.2
Total input	6,171	38,120	123	3.6

Quantities of phosphorus contributed to the St. Lawrence River by source (short tons/year)

Source	1967		
Lake Ontario to St. Lawrence River	3,100		
	U.S.	Canada	Total
Point Sources			
Municipal	23	190	213
Industrial	21	28	49
Sub-Total	262		

Table 3.3.2 (cont'd)

Source	1967		
	U.S.	Canada	Total
Major Tributaries			
Municipal	176	2	
Industrial		-	
Land drainage		14	
Sub-Total			192
Total input			3,554

County area of Ontario and in combination with waters from the northern shore may be returned to the New York shoreline.

There is no doubt that material inputs from the Niagara River affect Lake Ontario waters on both sides of the boundary. The Niagara River outflow which can be distinguished for up to 30 miles has been shown to turn mostly along the New York shoreline in westerly winds. Under easterly winds, the outflow from the river has a major component which moves directly across the lake almost to the Oakville-Port Credit area.

With winds from north to southeast a surface gyre develops in the western basin; this tends to trap materials from the Niagara River and the Toronto-Hamilton-St. Catharines region within that basin. Under a condition of westerly winds, materials in the western basin are dissipated along the New York shoreline.

It should be emphasized that many changes take place to the materials once they are in the lake. Biological changes and chemical reactions occur within the water as the substances age. It is difficult to directly establish the effects of a pollution load on one side of the lake on water quality on the other side. However, it is clear from the studies of the water movements, that material inputs from the Niagara River and from both sides of the lake do contribute to increasing changes in the quality of the western basin of Lake Ontario.

3.3.3 State of Eutrophication

The state of eutrophication of Lake Ontario can only be evaluated by comparison with other lakes of the world. Diverse criteria have been proposed for the classification of lakes as oligotrophic, mesotrophic and eutrophic by phytoplankton abundance, phytoplankton production, species associations of planktonic and benthic communities, nutrient concentrations, nutrient loads, sediment types and fish production. Although none of these provides a reliable overall characterization, they do collectively yield a framework within which it is possible to classify lakes broadly according to their trophic states.

Table 3.3.3 gives an overall evaluation of the current trophic state of Lake Ontario based on information from diverse sources, together with comparable information for Lake Erie. As a large and deep body of water, Lake Ontario is morphometrically predisposed toward oligotrophy. Because of the great mean depth (86 metres as compared to a mean depth

Table 3.3.3 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.

of 18 metres for Lake Erie) and large volume of hypolimnetic water, only a slight oxygen deficiency is observed in the bottom waters. High oxygen concentrations in turn permit the existence of certain deep water species such as the scud, *Pontoporeia affinis*, the midge, *Heterotrissocladius cf. subpilosus*, and deep water salmonid and coregonid fish, all of which are characteristic of oligotrophic lakes. Lake Ontario as a whole is mesotrophic in character, though decidedly lying more towards the side of oligotrophy than eutrophy. The concentrations of total phosphorus and nitrogen given in Section 2.3 (lake means of 14 µg P/l and 400 to 600 µg N/l, excluding dissolved N_2 gas) are also in accordance with this interpretation.

In nearshore environments, where shallow areas are to some extent isolated from the main body of the lake either by features of bottom topography or transitory phenomenon such as the thermal bar, there is evidence of a higher trophic level than that existing in offshore areas. Thus, as outlined in Section 2.4, planktonic algae are more abundant in the Bay of Quinte and Hamilton Harbour than in the open lake. Dense populations of oligochaetes in Toronto Harbour also indicate heavy organic pollution. The extensive growths of *Cladophora* at many points along the northern and southern shorelines also attest to this condition. The nearshore areas exhibit total phosphorus concentrations in excess of 15 µg PO_4-P/l which for practical purposes is considered at the lower limit for conditions promoting excessive algae growths, provided that other growth factors are favourable.

Vollenweider (1968) has proposed criteria to evaluate the state of eutrophication of lakes based on a knowledge of the loadings of total-P and total-N delivered from both natural and cultural sources. In order to permit a comparison of lakes with different areas and volumes, the annual loadings are expressed as grams of total-P or total-N per square metre of lake surface. Predicted effects are then evaluated as a function of mean depth of the lakes in question, thus bringing all comparisons to a standard volume of lake water.

Table 3.3.4 lists the admissible and dangerous loading limits proposed by Vollenweider (1968). From data presented in Section 3.1 of this Volume, the annual loadings of total-P and total-N for Lake Ontario are 14,000 and 173,000 short tons, respectively. Converted to a unit area of lake surface these correspond to 0.7 g total-P/m^2.yr and 8.0 g total-N/m^2.yr. The admissible and dangerous loading limits for a lake of 100 metres mean depth (*versus* 84 metres for Lake Ontario) from Fig. 3.3.1 are 0.4 and 0.8 g/m^2.yr, respectively, for total-P. The corresponding limits for total-N are 6 and

Table 3.3.4 Estimates of admissible and dangerous loading limits for total-N and biologically active total-P as a function of mean lake depth (After Vollenweider, 1968)*.

Mean depth (metres)	Admissible loading $g/m^2.yr.$ total-N	Admissible loading $g/m^2.yr.$ total-P	Dangerous loading $g/m^2.yr.$ total-N	Dangerous loading $g/m^2.yr.$ total-P
5	1.0	0.07	2.0	0.13
10	1.5	0.1	3.0	0.2
50	4.0	0.25	8.0	0.5
100	6.0	0.4	12.0	0.8
150	7.5	0.5	15.0	1.0
200	9.0	0.6	18.0	1.2

*Vollenweider (1968) gives these values only as preliminary and tentative estimates.

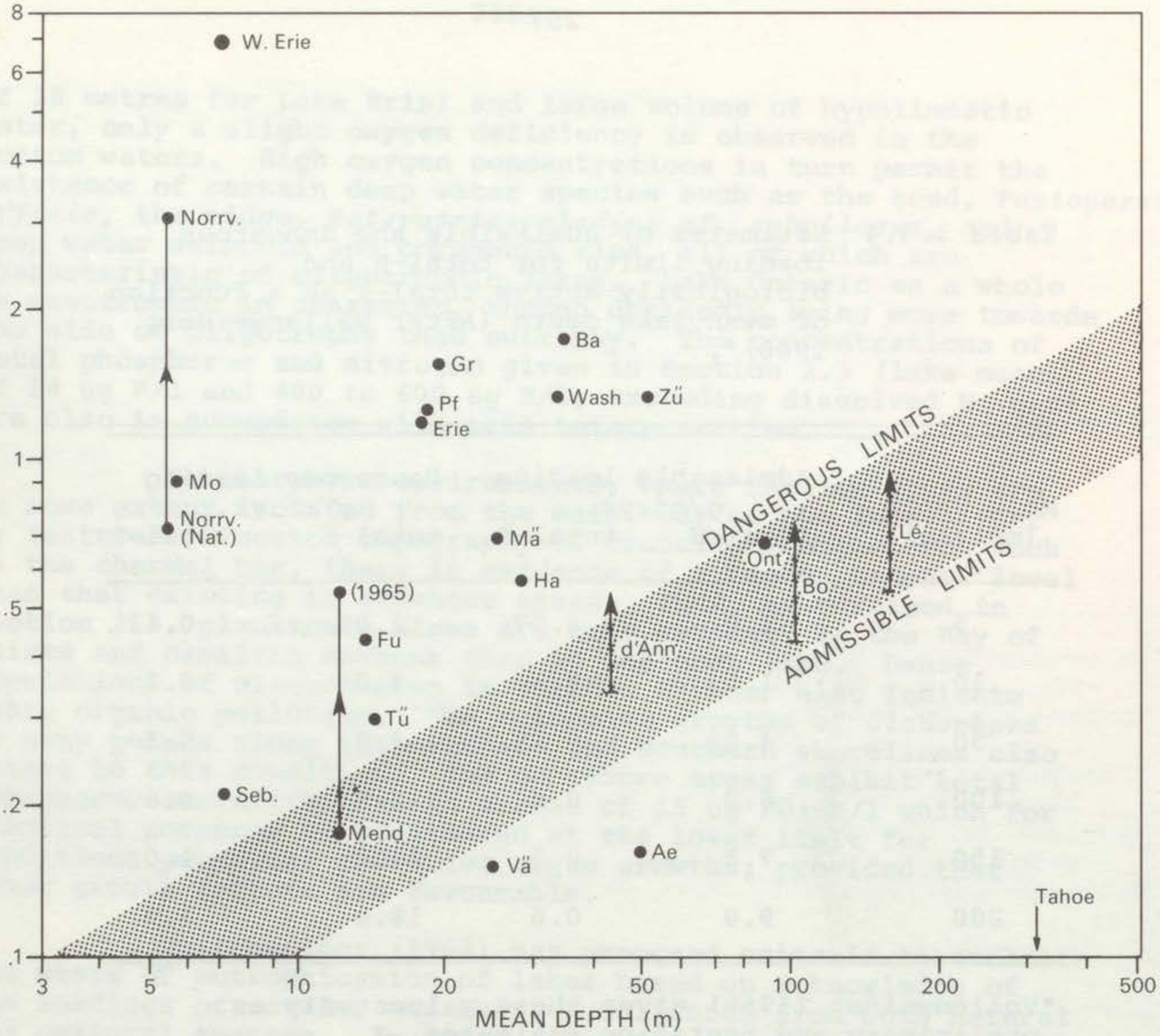


Fig. 3. 3. 1 Phosphorus loading *versus* mean depth for various lakes.

Abbreviations: Ae (Aegerisee), Ba (Baldeggersee), Bo (Bodensee, Obersee), d'Ann (Annecy), Fu (Furesø), Gr (Greifensee), Ha (Hallwilersee), Lé (Léman), Mä (Mälaren), Mend (Mendota), Mo (Monona), Norrv (Norrviken), Ont (Ontario), Pf (Pfäffikersee), Seb (Sebasticook), Tü (Türlersee), W. Erie (western basin, Lake Erie), Wash (Washington), Vä (Vänern), Zü (Zürichsee). The value for Bodensee is twice the value for orthophosphate-P (After Vollenweider, 1968).

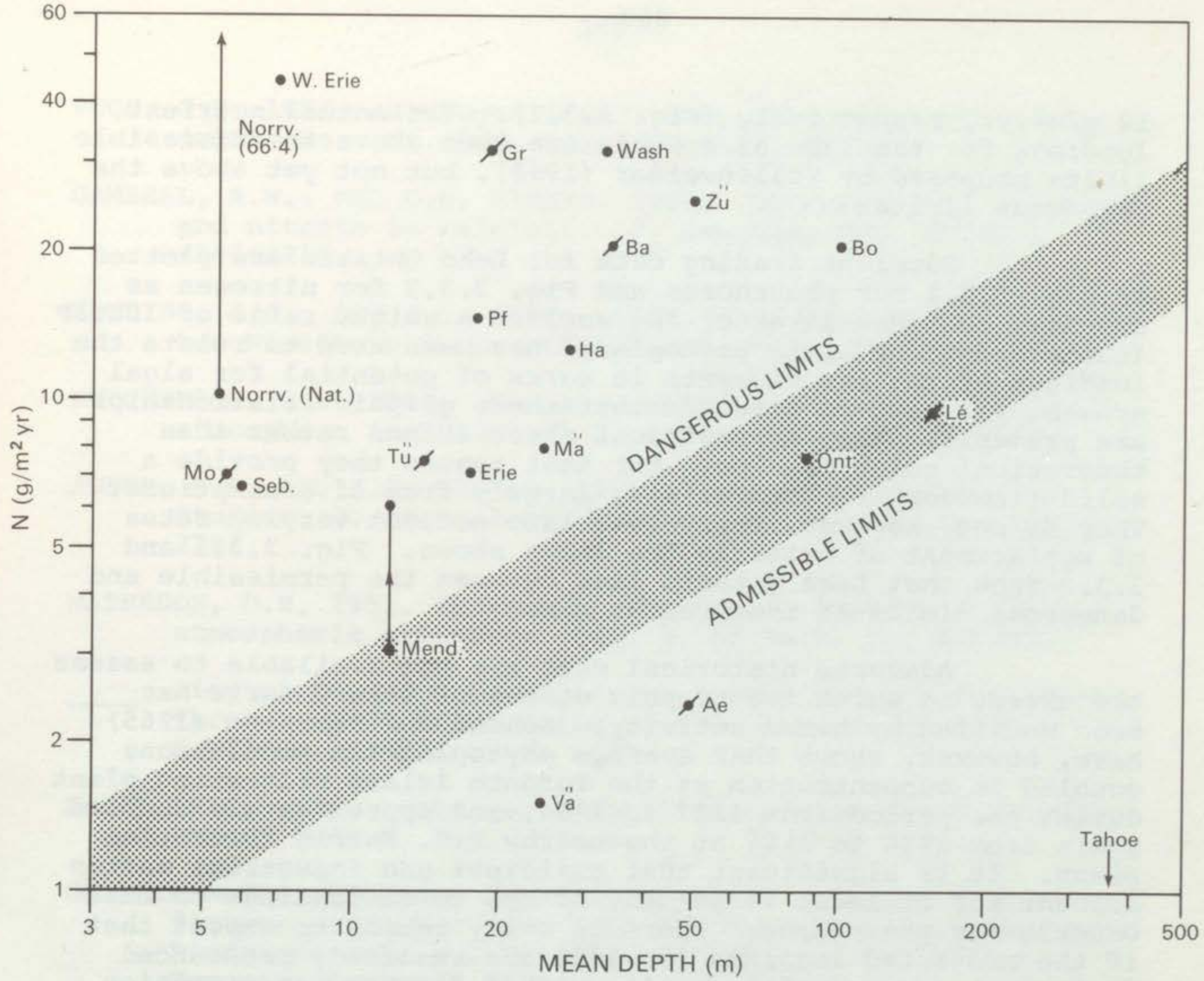


Fig. 3. 3. 2 Nitrogen loading *versus* mean depth for various lakes.

Abbreviations: Ae (Aegerisee), Ba (Baldeggersee), Bo (Bodensee, Obersee), Gr (Greifensee), Ha (Hallwilersee), Lé (Léman), Mä (Mälaren), Mend (Mendota), Mo (Monona), Norrv (Norrviken), Ont (Ontario), Pf (Pfäffikersee), Seb (Sebasticook), Tü (Türlersee), W. Erie (western basin, Lake Erie), Wash (Washington), Vä (Vänern), Zü (Zürichsee). The dots with slanted lines refer only to inorganic-N (After Vollenweider, 1968).

12 g/m^2.yr, respectively (Fig. 3.3.2). The actual nutrient loadings for the lake as a whole are thus above the admissible limits proposed by Vollenweider (1968), but not yet above the dangerous limits.

Nutrient loading data for Lake Ontario are plotted in Fig. 3.3.1 for phosphorus and Fig. 3.3.2 for nitrogen as compared to other lakes of the world. A weight ratio of 15N:1P (the average for algal protoplasm) has been used to relate the loadings of the two elements in terms of potential for algal growth. It must be stressed that these graphic relationships are primarily based on empirical observations rather than theoretical relationships. For that reason they provide a solid framework for comparison, largely free of assumptions. They do not, however, fully take into account varying rates of replacement of water in the lakes shown. Fig. 3.3.1 and 3.3.2 show that Lake Ontario lies between the permissible and dangerous limits at the present time.

Adequate historical data are not available to assess the extent to which the trophic status of Lake Ontario has been modified by human activity. Schenk and Thompson (1965) have, however, shown that average phytoplankton populations doubled in concentration at the Toronto Island Filtration plant during the period from 1923 to 1954, and approximately doubled again from 1956 to 1966 at the nearby R.C. Harris Filtration plant. It is significant that municipal and industrial wastes account for at least 76 percent of the total loadings on Lake Ontario for phosphorus. There is every reason to expect that if the projected loadings for 1986 are realized, pronounced biological changes will result, with a further deterioration of water quality particularly in nearshore areas around population centres.

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4. DEVELOPING PROBLEMS

Protection of the uses of water such as public, agricultural and industrial water supplies, fish and wildlife conservation, recreation and aesthetic enjoyment requires the successful control of all pollution sources. Where high quality water exists the necessary steps should be taken to prevent a deterioration of the existing quality and thus preserve the water for future use.

Water quality investigations have shown that existing measures to control water pollution have not advanced sufficiently to satisfy the needs of all water uses. Unsatisfactory conditions occur in harbours and in the local waters of Lake Ontario where offensive accumulations of debris and growths of aquatic plants are often found near waste water discharges. In view of the large population and industrial growth anticipated within the Lake Ontario drainage basin over the next twenty years, restrictions on development will become necessary unless adequate provision can be made to restore and maintain water quality. The main problem that has emerged in the study of Lake Ontario is the need to control sources of nutrient materials emanating from waste discharges and land drainage.

4.1 MUNICIPAL AND INDUSTRIAL WASTES

Estimates of the total phosphorus expected from the urban population and industrial development projected to 1986 for the Lake Ontario basin are presented in Table 4.1.1. The contributions from the forecasted populations are based on an expected phosphorus wastage ratio of 3.5 pounds per capita per year of which 2.5 pounds per person will originate from detergent phosphorus. At present it is estimated that 50 to 70 percent of the total input of phosphorus from all municipal and industrial wastes in the lower Great Lakes basin comes from detergents. The increases in phosphorus sources will account for a doubling of the quantities now supplied to the lake to a level of 27,000 tons per year by 1986.

Reference to Fig. 5.1.1 and Table 5.1.2 illustrates the significance of this total phosphorus loading on Lake Ontario. When expressed as an annual loading rate, per unit of surface area, the 1986 input of phosphorus indicates that a considerable advance in the degree of eutrophication in the lake can be expected.

In the past few years the economic growth rate in the Lake Ontario basin has been of the order of four percent

Table 4.1.1 Annual input of total phosphorus projected (short tons/year) to 1986.

Source	Projected for 1986 without control measures			
	U.S.		Canada	Total
Lake Erie to Niagara River		6,700*		
Niagara River				
Municipal	5,860		400	6,260
Industrial			210	210
Land drainage			50	50
Unaccounted		600		
Sub-Total		13,820		
Point Sources				
Municipal	1,740		5,700	7,440
Industrial	20		460	480
Sub-Total		7,920		
Other Major Tributaries				
Municipal)	2,500		2,000	4,500
Industrial)				
Land drainage	510		270	780
Sub-Total		5,280		
Total-Municipal & Industrial		18,890**		
Total-Other Sources		8,130		
TOTAL		27,020		

*Increased in proportion to projected 1986 loading to Lake Erie.

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

annually. If this rate of growth continues industrial production and industrial waste loadings should almost double by 1986.

Several important factors will affect future output of industrial wastes such as changes in manufacturing processes, advances in treatment methods, improved efficiency of materials handling at existing manufacturing plants, and improved treatment facilities.

The present variety of waste materials ranging from acids and alkalis, phenolic and organic substances, oils, metals, phosphorus and nitrogen containing wastes will expand as new types of manufacturing processes are employed in the future.

Organic contaminants include the persistent or biochemically resistant compounds which increasingly occur in municipal and industrial wastes from new product formulations, insecticides, herbicides, and other agricultural chemicals. In view of their persistent and toxic nature, even in low concentrations, they pose a growing threat to water quality and the aquatic environment.

Radioactive wastes from nuclear reactors, waste processing plants, industrial, medical and research uses are either discharged to the lakes directly or through municipal sewers. While the amount of radioactivity that can be discharged to surface waters by nuclear operations is controlled by government regulations, the release of these substances to the environment is increasing with the development of nuclear power generation facilities. It should be noted that all values of radionuclides are well below maximum permissible concentrations recommended by the International Commission for Radiological Protection (ICRP) and are within the allowable limits of the public drinking water standards in the United States and Canada.

Finally, water must 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 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 other viruses of animal origin may also 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 would certainly contain viruses.

The number of viable viruses present at any given point 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, since it is these very regions that are used for recreation and water supplies.

4.2 LAND DRAINAGE

Nutrients and other materials in land drainage reflect local and regional land use practices and are contributed in varying amounts by the tributaries to Lake Ontario (Section 3.1.3). Replacement of forest cover by farm crops and urban development has resulted in increased soil erosion and greater fluctuations in natural streamflow. Favourable conditions have been created for the leaching and transport of soluble and suspended materials from the land surface. Techniques for the application of pesticides, methods of livestock waste disposal and practices of soil fertilization and land tilling will continue to have a direct bearing on stream quality. By 1986 the amount of phosphorus contributed from land drainage is expected to increase by about 10 percent.

Although the quantities of pesticides and herbicides applied each year do not vary appreciably, there is a trend towards the use of more potent chemicals. This has been the case since the introduction in 1945 of hydrocarbon compounds and since 1950 when a range of organic pesticides was brought onto the market. Since most of the compounds presently in use resist biological breakdown, their use has resulted in increasing residual concentrations in surface waters and aquatic fauna. Water quality problems can be reduced by more discriminate application of pesticides and the use of chemicals which are readily degradable. Another possible approach is the substitution of biological control of pests instead of chemical control.

The intensive production of livestock in feed lots will require improved provision for the handling and disposal of animal wastes to avoid pollution of water. The practice of fertilizing farm lands in the winter with animal wastes requires attention since it results in large pollutional runoff loads in the spring. Streambank erosion, resulting from overgrazing along river banks and re-channelling, is another contributing factor.

In Ontario an estimated 5,000 tons of phosphorus and 25,000 tons of nitrogen are produced annually by the beef and dairy cattle, hens and chicken broilers and the hog population (Ontario Department of Agricultural and Food, 1966). It is estimated that 9,000 tons of phosphorus and 45,000 tons of nitrogen are produced by the cattle, chicken and hog population in the United States section of the basin.

A total of 4,800 tons of phosphorus and 8,100 tons of nitrogen were applied as chemical fertilizers in the Ontario section of the basin. This represents an increase in application of 60 and 190 percent for phosphorus and nitrogen, respectively, from 1960 to 1967. In 1964, 12,100 tons of phosphorus and 21,000 tons of nitrogen were applied to the drainage basin in New York state (U.S. Department of Agriculture, 1966).

4.3 THERMAL INPUTS

Lake Ontario is a desirable source of supply for cooling purposes since it is a large deep lake with relatively low summer water temperatures. While large cooling water discharges from power generation facilities are not expected to have a perceptable effect on the lake as a whole, the effects of waste heat may be of considerable importance locally depending on conditions near the point of waste discharge. The use of water for thermal cooling will increase greatly in the future since power requirements are expected to double every ten years.

The Lakeview and R.L. Hearn Generating Stations, located on the shores of Lake Ontario in the Metropolitan Toronto region, will ultimately utilize a combined total of 2,300 mgd of cooling water in producing 3,600 Mw of electricity. The Pickering nuclear power generating station with a planned output of 2,160 Mw is presently under construction near Toronto. Additional power generating plants are under consideration near Port Hope and Kingston.

On the American side of the lake there will be two nuclear-fueled power generating stations; one to be located at Rochester and the other at Oswego scheduled for completion in 1969 (Fig. 4.3.1).

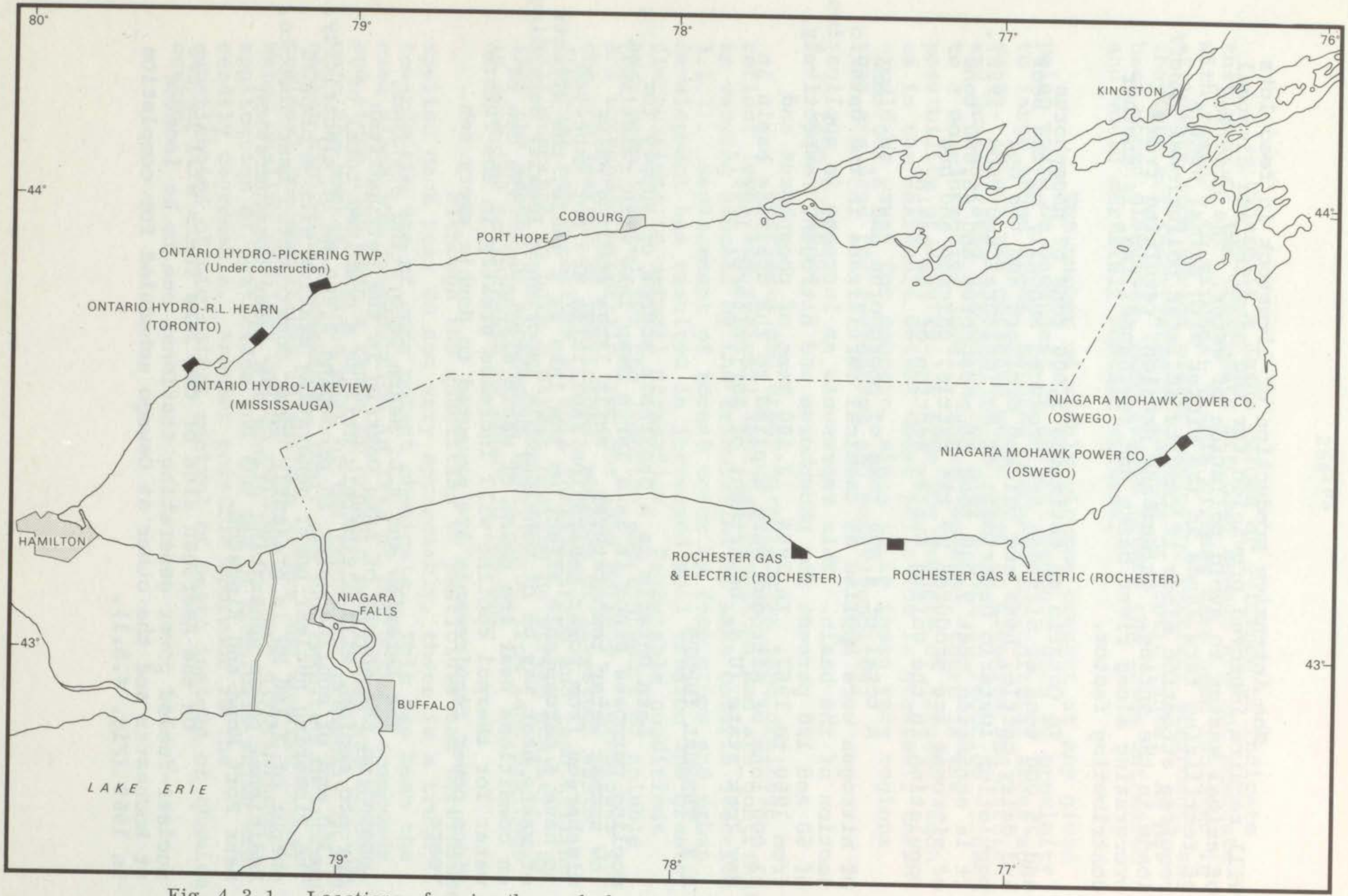

Fig. 4. 3. 1 Locations of major thermal electric power facilities in the Lake Ontario basin, 1968.

Localized effects of thermal pollution near shore include stimulation of algal growth, depletion of dissolved oxygen and possible alteration of the entire local ecology. Pollution of lake water by thermal inputs decreases the value of water for domestic and industrial purposes including cooling.

The effects of thermal pollution on the quality of water and the aquatic environment has been the subject of extensive studies both in the United States and Canada. The studies have not been carried far enough to establish prediction models for the purpose of engineering design as yet. Additional research and observation will be necessary to predict and assess the effects of thermal discharges to the lakes in order that improved guidelines for future installations can be developed and applied. Proper engineering of intake and outfall structures must insure that local warming effects will be kept to a minimum.

4.4 OIL AND MATERIAL SPILLS

The effects of accidental spills and releases of oil may interfere seriously with most water uses. Oil may be lost during manufacturing operations, production, storage and transferring activities involving terminal and dockside facilities, tank farms, freighters, pipelines, tank cars and trucks.

Apart from major oil spills, severe cases of local pollution have occurred as the result of improper handling or 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 incidences occur at the rate of several a month during the shipping season on the Great Lakes. A number of sunken ships in Lake Erie and Lake Ontario also pose a threat from oil pollution. 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.

In Lake Ontario and the St. Lawrence River, a number of large industries may accidently release oil and other hazardous materials. The steel industry in Hamilton, the oil refineries along the northern shore of western Lake Ontario and the industries on the St. Lawrence River are all potential sources of accidental chemical spills.

The movement and persistence of oil in lakes or along their shores are influenced by the properties of the oil, wind, sunlight, temperature, presence of solids, shore conditions, bacteria and other factors. In general, emulsified materials, oils adsorbed on solids, and thin films of oil are much more susceptible to decomposition than are thick layers or lenses of oil. Certain oil fractions evaporate, some undergo autoxidation, some sink to the lake bottom or are carried on shore by wind and water movements.

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5. CONCLUSIONS AND SUMMARY

5.1 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, although, their role is 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 less 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 (57 percent of the total phosphorus contributed to Lake Ontario is attributable to municipal and industrial sources, *versus* 30 percent for nitrogen; comparable figures for Lake Erie are 70 percent for phosphorus and 30-40 percent for 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 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).

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 5.1.1, for Lake Erie, and 5.1.2, 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 a basis of evaluating the probable effect on the lake if a program of phosphorus reduction was 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. 5.1.1 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 - Léman, 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 Türler are slightly eutrophic, Vänern 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.

The 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

Table 5.1.1 Lake Erie: Annual input of total phosphorus (short tons/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 percent removed from all municipal and industrial sources				11,160 (0.39 $g/m^2.yr$)		

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

Table 5.1.2 Lake Ontario: Annual input of total phosphorus (short tons/year).

Source	1967			Projected for 1986 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	6,260
Industrial	150	80	230		210	210
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	1 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 percent 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 percent of this will be from detergents.

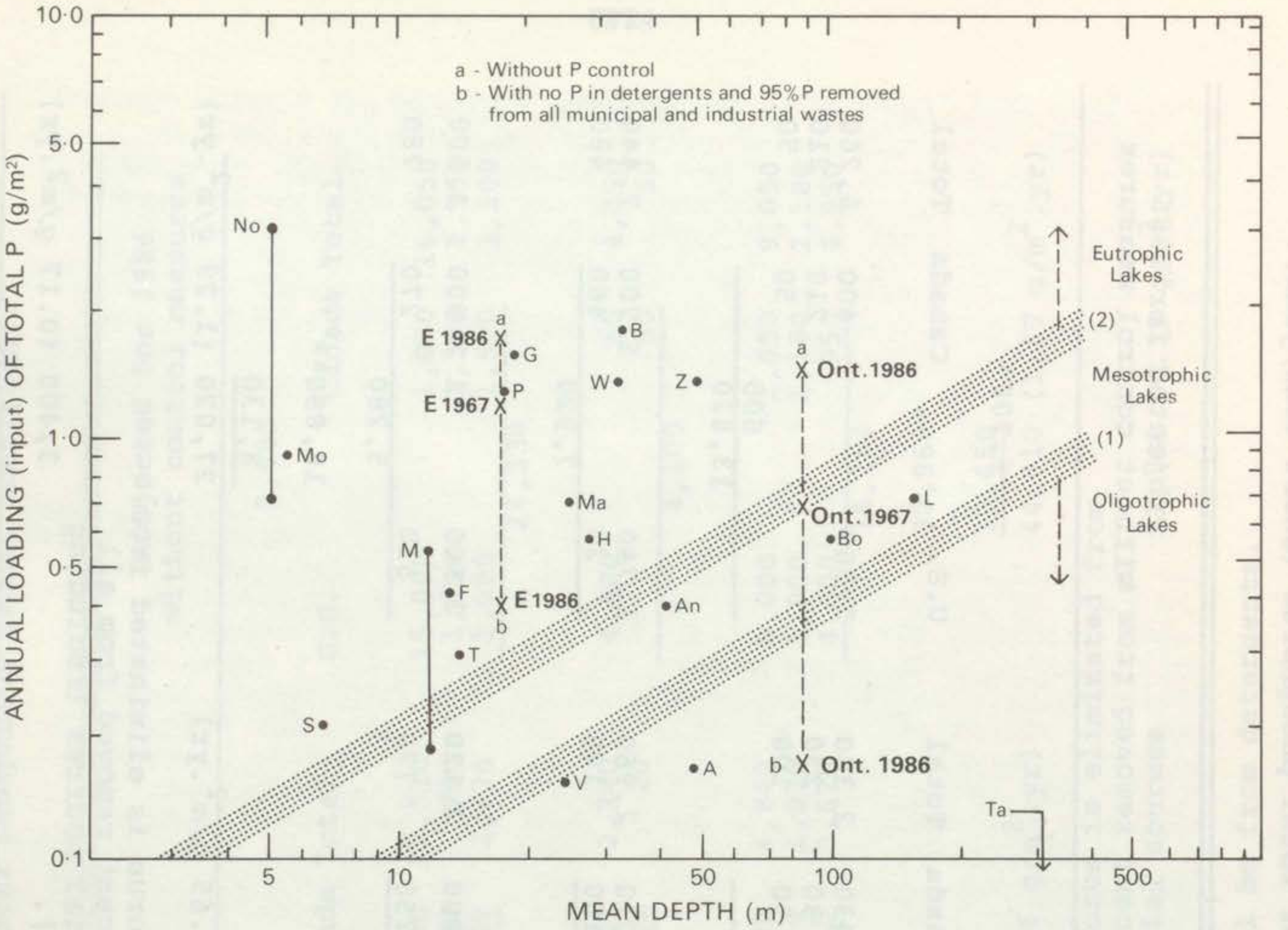

Fig. 5. 1. 1 State of eutrophication for a number of lakes in Europe and North America.

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

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. 5.1.1 might be different for other lakes.

The relative position of points for some of the lakes in Fig. 5.1.1 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 Zürichsee 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. 5.1.1, 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 implemented.

Fig. 5.1.1 suggests that Lake Ontario is presently mesotrophic, in the upper range nearer to eutrophy. However, based on the various criteria examined earlier (Table 3.3.3, Lake Ontario Volume or Table 3.3.2, Lake Erie Volume) Lake Ontario actually seems to be more oligotrophic or 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. 5.1.1). 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. 5.1.1. 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 found for Lake Ontario, the earlier examination of various criteria indicated that Lake Erie is considerably less eutrophic than Fig. 5.1.1 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.

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 input 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 the sediments of enriched lakes after the nutrient supply from controllable sources is cut off. Once a lake has become so productive 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 mud.

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. 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, Zürichsee, where 55 percent of the phosphorus loading comes from controllable sources (Fig. 5.1.1). 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. 5.1.1) 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 a year ago.

In the recommendations to the International Joint Commission with respect to phosphorus reduction in municipal wastes it should be understood that two concurrent steps are proposed to control cultural eutrophication in the lakes: firstly, that phosphates must be replaced in detergents with an environmentally acceptable substitute and secondly, that the load remaining in municipal wastes after phosphate removal from detergents must be reduced by 80 percent. This will amount to an overall reduction in present municipal waste loads of 95 percent, and that by 1986, municipal waste reduction of phosphates is to be further increased from 80 to 95 percent at the treatment plants.

5.2 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 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 on 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 (Volume 1) 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 remedial measures should be thought of as complementary since detergents and human wastes are the principal sources of phosphorus to the lakes. For the above 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 is needed (Table 3.1.3). 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 principal industries contributing direct discharges of wastes to the lakes are listed in Tables 3.1.5 and 3.1.6. 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.

5.3 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, respectively. Water pollution control agencies should ensure that appropriate action is taken to reduce the input of phosphorus from these sources by encouraging government 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.

5.4 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 their 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.

5.5 OTHER SOURCES

5.5.1 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 that 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.

5.5.2 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.

5.5.3 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.

5.5.4 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.

5.5.5 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.

5.6 SUMMARY

The foregoing chapters describe the intensification of the pressures responsible for water pollution in the Lake Ontario basin. The projections of population growth and industrial developments indicate a probable doubling by 1986 of the raw waste loadings produced by municipalities and industries. Land drainage has been cited as causing significant pollution problems but practical control measures are not yet readily available. Waste heat and losses of oil and industrial materials are not new problems, however, their magnitude has grown. It is clear that future requirements for cooling water and the discharge of large quantities of waste heat will pose serious questions on how to protect or preserve the ecological environments of nearshore waters. Industrial growth and increasing vessel traffic in the Great Lakes will create further potential hazards for spills of oil and hazardous materials unless precautions are taken to prevent such occurrences.

Improvement in the quality of water can be expected with phosphorus reduction in the drainage basin provided that the recommended implementation programs are developed and carried through by municipalities and industry. To be effective these programs must cope not only with existing sources of nutrients but the increasing amounts that will be wasted in the waters of the drainage basin. Waste treatment facilities must be designed to satisfy needs for the next fifteen to twenty years to meet the waste loading projections for the mid 1980's.

The principles that have evolved in dealing with the complexity of water use and quality control of river systems are applicable to the Great Lakes. At one time, the general rule was that the downstream owner had the right to enjoy the flow of water in its natural state (Gross, 1965). It was subsequently recognized that the public interest might best be served by yielding the private rights of the downstream proprietor. Lyon (1968) drew attention to the case where the downstream use was in the public interest, often involving public water supply. In this case, the public use deserved precedence over the upstream waste discharge. In recent years, water pollution control laws have been enacted to protect a variety of public interests involving many water uses.

At one time abatement plans were relatively simple involving merely simple pollution sources, whereas, in many cases today, multiple sources of pollution having a cumulative effect on water quality are common. Thus, the effect of any one discharge is not readily discernible, and minimum degrees of treatment (primary and secondary) may not be adequate to protect water uses. In these situations, comprehensive systems analysis should be used to deal with the complexities of the problem and waste load allocations made among the water users. The latter approach is required to deal with both existing and developing water quality problems of the Great Lakes especially in those areas of intensive water use.

In order to protect water uses that may interfere increasingly with one another improved water quality criteria have been needed. These criteria are set forth to determine the desired quality for future uses of water as the standards and objectives for Lake Erie and Lake Ontario.

5.6.1 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 and industrial growth and technological changes in industry and waste treatment processes.

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.

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 sensitive 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 - Neither less than 6.0 mg/l at any time in epilimnetic (upper) waters nor in concentrations which would 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.

5.6.2 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.

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NIGERIA

APPENDIX

METHODS OF MEASUREMENT

INTRODUCTION

Chemical, bacteriological, biological, physical and sedimentological methods are reported and referenced in this Appendix. This is followed by a description of the methodology for materials balance and annual input of total-phosphorus projected to 1986.

Chemical methods have changed significantly over the years, so that comparisons in the report between recent and earlier chemical determinations although accurate enough to indicate general trends, are not highly precise. In any one year reported on in this study, data from only one, or at most two, laboratories were used, so that spatial and time comparisons during the year are valid.

Some of the chemical analyses may have been affected by changes occurring in storage of the samples, and interference in the colorimetric methods arising from sample turbidity. Reliable and well established methods exist for many constituents but for most, new techniques are evolving rapidly. Colorimetric methods, for example, are being automated to permit high sampling rates, and new techniques such as atomic absorption spectrophotometry are becoming available.

PARTICIPATING AGENCIES

EMR	Dept. of Energy, Mines and Resources
FRB	Fisheries Research Board
FWPCA	Federal Water Pollution Control Administration
LEBO	Lake Erie Basin Office (Cleveland)
LOBO	Lake Ontario Basin Office (Rochester)
GLI	Great Lakes Institute - University of Toronto
NHW	Dept. of National Health and Welfare
OWRC	Ontario Water Resources Commission

CHEMICAL METHODS FOR LAKE WATER AND RIVER WATER

ALKALINITY

The unit for alkalinity used in this report is reported as mg $CaCO_3$/l. The constituents reacting with hydrogen ion during the alkalinity measurement were assumed to be CO_3^{-2}, and an equivalent amount of Ca^{++} was arbitrarily assumed to be present. Actually most of the alkalinity in Great Lakes waters is HCO_3^-. The conversion factor for alkalinity is 1 mg $CaCO_3$/l = 1.219 mg HCO_3^-/l.

FWPCA, 1965, 1967 and 1968 and EMR, 1966 and 1967

An indicator solution of bromcresol green + methyl red was added, then the sample was titrated with 0.02 normal sulphuric acid until the colour changed from blue to pink at a pH of 4.6 (American Public Health Association, 1965).

NHW, 1966

Samples were mixed with a buffered acidic methyl orange indicator solution and the final colour was measured at 550 millimicrons, in an Auto-Analyzer. Standard solutions contained sodium bicarbonate (Ad Hoc Working Committee on Methodology, 1968).

AMMONIA

FWPCA (LOBO) 1965 to 1967

The technicon Auto-Analyzer was used for most NH_3-N and organic N tests. Both of the following methods were used simultaneously.

a) Samples with adjusted pH to 9.5 with buffer were distilled into 2 percent boric acid. An aliquot was Nesslerized and colour development in samples compared with a blank and standards (American Public Health Association, 1965).

b) Filtered samples were mixed with sodium hydroxide + phenol + sodium hypochlorite + sodium nitroprusside. The mixture was passed through a 38°C heating bath and the resulting colour measured at 630 millimicrons in an Auto-Analyzer. A trap containing sulphuric acid isolated the reagents from ammonia in the laboratory air (Ad Hoc Working Committee on Methodology, 1968).

NHW, 1967 and FWPCA (LEBO) 1965, 1967 and 1968

Unfiltered samples were mixed with sodium hydroxide + phenol + sodium hypochlorite + sodium nitroprusside. The mixture was passed through a 38°C heating bath and the resulting colour measured at 630 millimicrons in an Auto-Analyzer. A trap containing sulphuric acid isolated the reagents from ammonia in the laboratory air (Ad Hoc Working Committee on Methodology, 1968).

OWRC, 1964 to 1967

The direct Nesslerization method was used. Zinc sulphate was added to the sample, then sodium hydroxide was added to give a pH of 10.5, then Nessler reagent (potassium iodide + mercuric chloride + potassium hydroxide) was added, and the resulting colour measured at 410 millimicrons (American Public Health Association, 1955).

BIOCHEMICAL OXYGEN DEMAND

NHW and EMR, 1966

Samples were stored for a few hours to attain laboratory temperature. Air was then bubbled through each sample to produce oxygen concentrations near equilibrium values. Two 300 ml BOD bottles were filled from each sample through a siphon. Dissolved oxygen in one of the BOD bottles was measured immediately. The other bottle was stored in the dark at 20°C for five days, and its final oxygen concentration measured. A water seal was maintained around the top of the bottle during incubation. Dilution and seeding procedures were not required (American Public Health Association, 1965).

OWRC and FWPCA 1965, 1967 and 1968

In the period 1964 to 1966, initial and final oxygen values were determined by the azide modification of the Winkler method (American Public Health Association, 1960). From 1967 on, oxygen values were determined by polarography (American Public Health Association, 1960).

CHLORIDE

FWPCA, 1965, 1967 and 1968 and EMR, 1966

An indicator reagent, containing s-diphenyl-carbazone + enough nitric acid to give a pH of 2.5 ± 0.1, + xylene cyanol FF + ethyl alcohol, were added to the sample. The mixture was titrated with mercuric nitrate to a purple endpoint, Standard Methods, Twelfth Edition (American Public Health Association, 1965).

NHW, 1966 and EMR, 1967

Unfiltered samples were mixed with ferric ammonium sulphate + nitric acid + mercuric thiocyanate. The resulting colour was measured at 505 millimicrons in an Auto-Analyzer (Ad Hoc Working Committee on Methodology, 1968).

OWRC, 1964 to 1967

Initially, the Mohr titration method was used (American Public Health Association, 1955) but later, samples were simply titrated with silver nitrate using a Fisher automatic titration unit and a chloride-sensing electrode.

CONDUCTIVITY

OWRC, 1964 and FWPCA 1965, 1967 and 1968

The electrical conductivity and temperature of the sample were measured at room temperature (20 to 30°C) and the conductivity at 25.0°C calculated using the temperature-conductivity relationship of 0.01 normal potassium chloride (American Public Health Association, 1965).

HARDNESS (CALCIUM + MAGNESIUM)

FWPCA (LOBO) and EMR, 1966

The sample was titrated with a magnesium salt of EDTA using eriochrome black T indicator, the solution turning from wine red to blue when all the magnesium and calcium ions are complexed (American Public Health Association, 1965).

NHW, 1966 and FWPCA (LEBO) 1965, 1967 and 1968

The sample was mixed with disodium magnesium EDTA and disodium EDTA, then with pH 10.3 buffer (ammonium chloride + ammonium hydroxide) and Eriochrome Black T. The resulting colour was measured at 520 millimicrons (Ad Hoc Working Committee on Methodology, 1966).

EMR, 1967

Total hardness was computed from the results of calcium and magnesium obtained by atomic absorbtion spectrophotometry.

NHW, 1967

The sample was mixed with disodium magnesium EDTA + disodium EDTA + pH 10.3 buffer + Calmagite. The resulting colour was measured at 520 millimicrons (Ad Hoc Working Committee on Methodology, 1968).

IRON

FWPCA, 1965

The sample was boiled in the presence of hydrochloric acid + hydroxylamine. A buffer solution of ammonium acetate + acetic acid was added to give a pH of 3.2, then phenanthroline was added. The resulting colour was measured at 510 millimicrons (American Public Health Association, 1965).

TOTAL BIOLOGICALLY AVAILABLE IRON

NHW, 1967 and EMR, 1967

An unfiltered sample was mixed with hydrochloric acid, hydroxylamine hydrochloride, 2, 4, 6-tripyridyl-s-triazine, and (sodium acetate + acetic acid) buffer. The mixture was then passed through a 37°C heating bath. The resulting colour was measured at 600 millimicrons in an Auto-Analyzer (Ad Hoc Working Committee on Methodology, 1968).

NITRATE

FWPCA (LOBO)

The Brucine method was used (American Public Health Association, 1965).

OWRC, 1964 to 1967

A phenoldisulphonic acid method was used, without correction for chloride concentration (American Public Health Association, 1955).

NITRITE

OWRC, 1964 to 1967

Sulphanilic acid + hydrochloric acid were added; then α-naphthylamine hydrochloride + hydrochloric acid, and sodium acetate. The resulting colour was measured at 520 millimicrons (American Public Health Association, 1955).

NHW, 1966

Nitrite in unfiltered samples was measured after adding sodium hydroxide + ortho-phosphoric acid + sulphanilamide + N-(1-naphthyl) ethylenediamine dihydrochloride. The resulting colour was measured at 520 millimicrons in an Auto-Analyzer (Ad Hoc Working Committee on Methodology, 1966).

NHW, 1967

Nitrite in unfiltered samples was measured using an Auto-Analyzer. Sulphanilamide, hydrochloric acid, and N-(1-naphthyl) ethylenediamine dihydrochloride were mixed with the sample and the resulting colour measured at 550 millimicrons (Ad Hoc Working Committee on Methodology, 1968).

NITRATE + NITRITE

FWPCA, 1967 to 1968
(Sum of Nitrate + Nitrite reported as Nitrate)

Nitrate was reduced to nitrite in a zinc column buffered with sodium acetate and hydrochloric acid. The diazonium salt was produced by reacting nitrite with sulphuric acid. The diazonium salt formed an azo dye when reacted with 1 - naphthylamine hydrochloride. An Auto-Analyzer was used to measure the absorbance at 520 millimicrons.

NHW, 1966

Samples were not filtered. Nitrate was reduced to nitrite by adding sodium hydroxide, hydrazine sulphate, and copper sulphate. The mixture was passed through a 38°C heating bath. Total-nitrite was measured by adding orthophosphoric acid + sulphanilamide + N-(1-naphthyl) ethylenediamine dihydrochloride, and measuring the resulting colour at 520 millimicrons in an Auto-Analyzer (Ad Hoc Working Committee on Methodology, 1966).

NHW, 1967 and EMR, 1967

Unfiltered samples were analyzed using an Auto-Analyzer. Nitrate was reduced to nitrite by adding EDTA and passing the mixture over cadmium filings. Total nitrite was then measured by adding sulphanilamide and N-(1-naphthyl) ethylenediamine dihydrochloride, and measuring the resulting colour at 550 millimicrons (Ad Hoc Working Committee on Methodology, 1968).

TOTAL-KJELDAHL NITROGEN (AMMONIA + ORGANIC NITROGEN)

FWPCA (LOBO), 1965 to 1967

Unfiltered samples were digested using potassium persulphate digestion. The ammonia liberated was Nesslerized and measured at 425 millimicrons. An alternate method utilized an automated alkali phenol nitro-pruisside procedure on an Auto-Analyzer preceeded by digestion with sulphuric acid and potassium persulphate.

OWRC, 1964 to 1967 and FWPCA (LEBO) 1964, 1967 and 1968

Sulphuric acid and copper sulphate were added, and the organic nitrogen digested by boiling. The solution was made alkaline with sodium hydroxide. The solution was then distilled and Nessler reagent (potassium iodide + mercuric chloride + potassium hydroxide) added. The colour was compared with Tintometer glass disc standards.

NHW, 1967

Unfiltered samples were digested and then analyzed for total ammonia, using an Auto-Analyzer for both steps. Selenium dioxide + sulphuric acid + perchloric acid were added. The mixture was heated to 380°C. After digestion, the mixture was neutralized with sodium hydroxide. Ammonia was measured by adding alkaline phenol + sodium hypochloride + sodium nitroprusside, and measuring the resulting colour at 630 millimicrons (Ad Hoc Working Committee on Methodology, 1968).

DISSOLVED OXYGEN

FWPCA and NHW, 1965 and M/V "Theron" on Lake Ontario, 1967

The Winkler iodometric method was used. Two millilitres of each reagent were added to each sample. The alkaline iodide reagent contained 150 grams of potassium iodide and 10 grams of sodium azide per litre (American Public Health Association, 1965).

EMR, M/V "Brandal" 1966; M/V "Theron" 1968

The Winkler iodometric method was used. One millilitre of each reagent was added to each sample. In 1966 the alkaline iodide solution contained 700 grams potassium hydroxide and 150 grams potassium iodide per litre. From 1967 the Pomeroy-Kirschman reagent, containing 400 grams sodium hydroxide and 900 grams sodium iodide per litre, was used (Ad Hoc Working Committee on Methodology, 1968).

pH AT LABORATORY TEMPERATURE

EMR (M/V "Brandal") 1966 and 1967

Samples were analyzed about 10 to 20 hours after sampling. Changes in pH during the storage interval limited the accuracy of the data to about ± 0.1 to 0.3 pH units. The pH was measured using a Corning Model 10 meter, and glass and reference electrodes, calibrated with pH 7.4 (phosphate) and pH 9.2 (borax) standard solutions (Ad Hoc Working Committee on Methodology, 1966).

FWPCA (LOBO) 1965

Beckman zeromatic pH meter with temperature adjustment.

PHENOL AND RELATED SUBSTANCES

NHW and FWPCA from 1966

The pH of the sample was adjusted to 4.0 by adding ortho-phosphoric acid. Copper sulphate was added and the sample distilled. Phenol in the distillate was measured by adding ammonium chloride, ammonium hydroxide to produce a pH of 10.0 ± 0.2, and finally 4-aminoantipyrine and potassium ferricyanide. The resulting colour was extracted into chloroform and measured at 460 millimicrons (American Public Health Association, 1965).

OWRC, 1964 to 1967

A preliminary distillation step was omitted for most samples. A buffer solution with pH 9.3, and containing sodium arsenite was added, then Gibbs reagent (2, 6 - dibromoquinonechlorimide and ethyl alcohol) were added, and finally n-butyl alcohol. The colour in the butanol layer was compared visually with a series containing known amounts of phenol.

ORTHOPHOSPHATE-PHOSPHORUS

FWPCA (LOBO)

Stannous chloride method was used on an unfiltered sample and colour was measured photometrically at 690 millimicrons (American Public Health Association, 1965).

NHW, 1966

Phosphate in unfiltered samples was measured by adding ammonium molybdate + hydrochloric acid + stannous chloride. The resulting colour at 660 millimicrons in an Auto-Analyzer (Ad Hoc Working Committee on Methodology, 1966).

SOLUBLE ORTHOPHOSPHATE-PHOSPHORUS

EMR, 1967

The method utilized an ammonium molybdate-antimonyltartarate/ascorbic acid reduction with an isopropyl alcohol extraction. Determinations were made spectrophotometrically.

NHW, 1967

Samples were filtered through a 5 micron membrane filter that had been previously washed with hydrochloric acid. Phosphate was measured by adding sulphuric acid + ammonium molybdate + potassium antimonyl tartrate + ascorbic acid, passing the mixture through a 70°C heating bath, and measuring the resulting colour at 660 millimicrons in an Auto-Analyzer (Ad Hoc Working Committe on Methodology, 1968).

OWRC, 1964 to 1967 and FWPCA

Samples were filtered, then ammonium molybdate + sulphuric acid, and stannous chloride + hydrochloric acid were added. The colour that developed was measured at 690 millimicrons (American Public Health Association, 1955).

TOTAL-PHOSPHORUS

FWPCA (LOBO)

Unfiltered samples were digested with sulphuric acid and potassium persulphate and the analyzed using the stannous chloride method used for orthophosphate-phosphorus (American Public Health Association, 1965).

NHW, 1967 and FWPCA (LEBO) 1965, 1967 and 1968

Samples were digested with sulphuric acid + potassium persulphate + heat, then neutralized with sodium hydroxide. Sulphuric acid + ammonia molybdate + potassium antimonyl tartrate + ascorbic acid were added passing the mixture through a 70°C heating bath. The resulting colour was measured at 660 millimicrons in an Auto-Analyzer (Ad Hoc Working Committee on Methodology, 1966, 1968).

OWRC, 1964 to 1967

Samples were treated with perchloric acid + heat. Phosphate was measured by adding ammonium molybdate + sulphuric acid, and stannous chloride + hydrochloric acid. The resulting colour was measured at 690 millimicrons (Ad Hoc Working Committee on Methodology, 1966; American Public Health Association, 1955).

SOLUBLE PHOSPHORUS

FWPCA, 1965, 1967 and 1968

The sample was filtered through Whatman filter paper #9 and treated as in total-phosphorus in the FWPCA analysis.

REACTIVE SILICATE

NHW, 1967 and FWPCA

Silicate in unfiltered samples was measured using an Auto-Analyzer, by adding ammonium molybdate + sulphuric acid + oxalic acid + sodium bisulphite + sodium sulphite + 1-amino-2-naphthol-4-sulphonic acid. The resulting colour was measured at 660 millimicrons (Ad Hoc Working Committee on Methodology, 1968).

OWRC, 1964 to 1967

Samples were dried at 103°C, and the residue cooled and weighed (American Public Health Association, 1960).

NONFILTERABLE RESIDUE (TOTAL SUSPENDED MATTER)

OWRC, 1964; NHW, 1966 and FWPCA, 1965, 1967 and 1968

The sample was filtered through a preweighed glass fibre filter. The filter was then dried at 103°C and weighed (American Public Health Association, 1960).

TURBIDITY

EMR and NHW, 1966 and FWPCA, 1965, 1967 and 1968

Turbidity was measured with a Hellige turbidimeter.

EMR and NHW, 1967

Turbidity was measured with a Hach Model 1860 turbidimeter.

BACTERIOLOGICAL METHODS FOR LAKE AND RIVER WATER

UNITS FOR BACTERIOLOGICAL DATA

Colonies per 100 millilitres is the unit used for reporting the bacteriological data. The Standard Plate Count unit is given as colonies per millilitre.

BACTERIOLOGICAL SAMPLING

NHW, M/V "Brandal" and "Theron", 1966

Sterilized deflated rubber bulbs were fastened to the side of Knudsen water-sampling bottles. These opened at the same time as the Knudsen bottles were triggered (Ad Hoc Working Committee on Methodology, 1966).

TOTAL COLIFORM BACTERIA

NHW and OWRC, 1965 and FWPCA, 1965, 1967 and 1968

Membrane filtration followed by incubation of the filter with M-Endo MF broth at 35°C for 20 hours (American Public Health Association, 1965).

FECAL COLIFORM BACTERIA

NHW, 1965 and FWPCA, 1965, 1967 and 1968

Membrane filtration followed by incubation of the filter with fecal coliform medium at 44.5°C for 24 hours (Geldreich *et al.*, 1965).

FECAL STREPTOCOCCAL BACTERIA

NHW, 1965

Membrane filtration followed by incubation of the filter with M-enterococcus agar medium at 35°C for 48 hours (American Public Health Association, 1965).

FWPCA, 1965, 1967 and 1968

Membrane filteration, and incubation of the filter with KF-streptococcus agar at 35°C for 48 hours (Federal Water Pollution Control Administration, 1966, 1967).

STANDARD PLATE COUNT AT 20 and 35°C

NHW, 1965

Part of the sample was mixed with tryptone glucose yeast agar, then incubated at 20°C for 48 hours, or at 35°C for 24 hours (American Public Health Association, 1965).

FWPCA, 1965

Membrane filtration followed by incubation of the filter with tryptone glucose yeast agar at 20°C for 48 hours, or at 35°C for 24 hours (Federal Water Pollution Control Administration, 1966, 1967).

PHYSICAL OBSERVATIONS

CURRENT VELOCITY

EMR

Method A - moored current meters. Instruments were moored on a taut vertical wire, between a submerged buoy and an anchor. A floating buoy and another anchor were located 600 to 1,200 feet away. The two anchors were connected by a ground line. This U-shaped mooring facilitated placement and retrieval of the instruments, and kept the instruments stationary during use. The instruments were Plessey Model MO21 and Geodyne Model A920. Precision and accuracy limitations were such that the true reading was given within ±1 or 2 cm/sec for speeds in the range 5 to 80 cm/sec, and ±010° for all directions. The instruments were recovered every two to six weeks, to replace magnetic tapes and batteries.

Method B - drogues. Various objects with large submerged areas, and with radar reflectors above the water, were tracked by radar from ships or boats.

Method C - drift objects. Slightly buoyant objects were released, and carried along by surface currents. Initial and final locations and times were noted.

FWPCA, 1963 to 1965

Current meters (Geodyne Model 100) were moored similar to EMR method A. They were recovered every 3 to 6 months. Bottom drifters were released and carried along by bottom currents. Initial and final locations and times were noted.

TEMPERATURE

EMR, M/V "Brandal" and "Theron"

Method A - oceanographic reversing thermometers. Oceanographic reversing thermometers (two on each sampling bottle) were lowered to the required depth, and turned over after five minutes. Each thermometer was read twice. Scale corrections and thermal expansion corrections were applied to the readings. A single mean value for each depth was reported in the final data record (U.S.N. Hydrographic Office, 1955).

Method B - bathythermograph. A bathythermograph was lowered to produce a graph of temperature versus depth (U.S.N. Hydrographic Office, 1955).

Method C - thermistor. A thermistor was towed at a depth near one metre and the water temperature recorded continuously while the ship was underway.

FWPCA, 1964 and 1965

Self recording thermographs were set at several midlake stations at depths of 10, 15, 22 and 30 metres and retrieved at 3 and/or 6 month intervals. Each thermograph was calibrated before and after use.

SEDIMENT ANALYSIS

Surface sediments were collected using a Franklin (Toronto) grab (Franklin and Anderson, 1961) or a Shipek bucket sampler (Kemp and Lewis, 1968). A few Lake Ontario samples collected at the mouth of the Niagara River, in 1966, were taken with a Petersen dredge. The samplers were lowered slowly to curtail disturbance of a loose surface ooze commonly present in muddy areas. The samplers recovered sediment (up to 12 centimetres depth in soft mud) from a single point on the lake bed. On hard clay, rock or sand bottoms, the samplers tended to scrape the lake bed and collect only the looser surface debris. Some sample loss probably occurred by washing through the jaws of the Franklin and Petersen grabs.

The sediment column, was sampled with Kullenberg piston corers fitted with plastic tubes of diameters ranging from 3.5 to 5.7 centimetres (Kullenberg, 1947). Gravity corers, consisting of weighted tubes up to 2 metres long, with a check valve in their upper ends, were used in the extensive reconnaissance of surficial sediment sequences. The Toronto gravity corer (Lewis, 1966) was used primarily in Lake Erie and an Alpine gravity corer (Lewis and McNeely, 1967) in Lake Ontario.

Surface sediment samples and cores were refrigerated during storage. As soon as possible, sub-samples were taken and analysed for organic matter and particle size distribution. For those sediments in which organic carbon and chlorophyll pigments are reported, the samples were refrigerated and freeze-dried almost immediately following collection.

POSTGLACIAL MUD THICKNESS

This feature was mapped acoustically throughout the basins. Thicknesses to the nearest 0.5 metres were read from echograms of a 14.25 KHZ sounder showing reflections from the mud surface and the sub-bottom surface of the underlying glacial deposits. The speed of sound in the mud was assumed to be similar to that in water, about 1.46 km/sec. Acoustically measured mud thicknesses correlated well with observed mud sections in piston core samples.

SEDIMENT PARTICLE SIZE

The distribution of particle diameters ranging from 1 micron to 2 millimetres or more was determined by combining results from different methods. Particles coarser than 63 microns were sieved through a screen nest, having ½ ϕ aperture intervals (diameter in ϕ units = $-\log_2$ (diameter in millimetres)). Weight percentages were calculated as described by Krumbein and Pettijohn (1938). The size distribution of the fine-grained fraction was measured by sedimentation methods, following dispersion of the sediment in 0.5 percent solution of Calgon or sodium hexametaphosphate. The suspension density was monitored with settling time using either the hydrometer method (Lambe, 1951; American Society for Testing and Materials, 1964; Lewis, 1966) or the pipet method (Krumbein and Pettijohn, 1938). Variations of mean particle diameter over each lake as shown in the sedimentology section of this report were largely based on the combined results of sieve and hydrometer analysis. The reported mean diameter of the sediment size distribution was computed from the cumulative frequency curves according to the equation:

$$M = \frac{\phi 84 + \phi 50 + \phi 16}{3.0}$$

where $\phi 84$, $\phi 50$ and $\phi 16$ are phi diameters of the 84th, 50th and 16th percentiles, respectively. A standard deviation of 0.035 was calculated for this parameter, based on replicate measurements of the same sample by the pipet and sieve methods.

MINERALOGY

Mineral identification of fine-grained sediment (clay and fine silt sizes) was accomplished with powder x-ray diffraction techniques using a Philips or similar diffractometer (Brown, 1961). Oriented mounts of the sediment powder were prepared following a procedure similar to that of Mallory and Kerr (1961) involving dispersion in distilled water, and sedimentation onto glass slides.

The constituent termed "clay mineral content" was computed from chemical measurements of some other constituents, using methods adapted from Trostell and Wynne (1940). Quartz was determined independently. The three results were subtracted from the total sediment amount. The clay mineral content determined by this method actually includes all components in the sediment other than quartz, feldspar, zircon, carbonate, and organic matter.

REDOX POTENTIAL AND HYDROGEN ION CONCENTRATION

Redox potential was measured at several levels in the sediment, down to 5 centimetres depth, immediately after recovering the Shipek bucket sample. The bucket was placed in a stand so that the sediment surface was horizontal. Combination glass/Ag Cl and platinum/Ag Cl electrodes were inserted at predetermined depths and clamped securely. Readings of pH were taken between 30 and 60 seconds after insertion with a Metrohm E 208A meter. Eh potentials were read on the same meter after a 10 minute stabilization period. Sample temperatures were recorded at the same time.

ORGANIC MATTER (LAKE ONTARIO)

The organic matter of bottom sediments in western Lake Ontario was determined from sub-samples taken from refrigerated, homogenized Franklin grab samples. Eastern Lake Ontario sediments were taken from the upper centimetre of gravity cores and were similarly analysed. The oxidizable organic content was measured by a wet dichromate oxidation method, the modified Walkley-Black method (Jackson, 1958). It was assumed that 70 percent of the carbon present was oxidized by the chromic acid, and that the total carbon comprised 58 percent of the organic matter. Observed values of oxidized material were increased by these factors and reported as percent organic matter in dry weight of sediment. The coefficient of variation (the ratio of the standard deviation to the mean value) varied from 0.6 percent to 6.7 percent on samples containing 25.0 and 0.5 percent oxidizable organic matter, respectively.

ORGANIC CARBON

Total carbon (carbonate + organic) was measured by heating the freeze-dried sample to about 1,300°C in a Leco induction furnace carbon analyser. Organic carbon was measured in the same furnace after carbonate removal in sulphurous acid at room temperature (Rittenberg *et al.*, 1963; Shaw, 1939). Organic carbon was reported for selected sediment samples along the axes of Lakes Erie and Ontario.

CHLOROPHYLL PIGMENTS

Pigments were extracted from the dried sediments in cold 80 percent acetone under 5 minutes of ultrosonic probe treatment. The absorbance was measured at 536, 645, 655, 662 and 666 millimicrons with a Bausch and Lomb Spectronic spectrophotometer. The method and calculations are based on the procedures of Vernon (1960). The coefficient of variation was 2 percent, except at low chlorophyll or pheophytin concentrations of about 5 ppm, where the coefficient of variation was 20 percent.

NITRATE, PHOSPHATE, AMMONIA

Nitrate, phosphate and ammonia were extracted from freeze-dried sediments by electrodialysis. Nitrate and ammonia were determined by the rapid methods given by Bear (1964). The extracted orthophosphate was measured colorimetrically after ascorbic acid reduction (Fogg and Wilkinson, 1958).

SULPHIDES

FWPCA (LEBO)

Sulphides were separated by distillation into zinc acetate. The resultant zinc sulphide was reacted with N, N-Dimethye, P-phenylenediamine in sulphuric acid and ferric chloride to form methylene blue. The methylene blue was measured spectrophotometrically at 650 millimicrons.

PHYTOPLANKTON METHODS

General

Phytoplankton counts are reported in a variety of ways, as cells, colonies or clumps, in areal units or in volumetric units. Because of the size ranges for different species, only volumetric measurements are directly proportional to biomass. Identification is usually made only to the generic level. Counts are generally reliable to within 5 to 20 percent of stated values.

FWPCA

Samples (usually 2 litres in volume) were collected with a polyvinyl chloride (PVC) sampler from stated depths (surface, thermocline and bottom in the case of Lake Ontario) and analyzed separately. The samples were preserved by the addition of formalin (37 percent formaldehyde) to yield a 3 percent solution of formaldahyde on mixing with the sample. Prior to counting, the water sample was repeatedly shaken by inversion and an aliquot transferred by means of a dropper to a one millilitre Sedgwick-Rafter counting chamber as quickly as possible. The contents were allowed to settle for 15 minutes. Microscopic analyses were made using 10X oculars and a 20X objective, one of the oculars being fitted with a Whipple ocular micrometer. Two strips were normally counted, each one Whipple field wide. When the sample was sparsely populated, 4 to 8 strips were counted and when dense, only one. The clump count method was used for enumeration. Colonies, filaments and isolated cells were counted as single units. Identification was made at 200X magnification. Forms not identifiable at this magnification were simply referred to as unidentified members of a given group. Results were calculated by multiplying by a factor appropriate to the number of strips counted (American Public Health Association, 1965). Permanent slides of diatoms were prepared and the remainder of the sample discarded.

OWRC

Samples from municipal water treatment plants were collected in 40 ounce bottles and concentrated using the Sedgwick-Rafter sand filtration technique (American Public Health Association, 1965). A predetermined volume of the concentrate was examined in a one millilitre Sedgwick-Rafter counting cell as previously described (American Public Health Association, 1965). All algae were identified to the generic level with results expressed as areal standard units (asu). One asu is equivalent to 400 square microns.

Samples from offshore waters were collected by two different methods. Up to August 1, 1967, equal volumes of water (collected by a 40 ounce water bottle) from 1.5 metres and 4X Secchi depth were combined and counted as described above for samples from water treatment plants. After August 1, 1967, all samples were obtained by lowering a 40 ounce bottle provided with a restricted inlet to 4X Secchi depth. The bottle was lowered and raised by prior trial at such a rate that it just filled completely as it reached the water surface on ascent.

Samples were preserved by addition of a 5 percent solution of 5 to 10 percent methanol in formalin (37 percent formaldehyde). All phytoplankton samples were retained for future reference. Permanent slides of diatoms were made by mounting in either Hyrax or Mikrops mounting media.

FRB

Samples were collected with a PVC water sampler from stated depths, and preserved by the addition of 5 percent Lugol's solution.

CHLOROPHYLL METHODS

FWPCA and OWRC

The method of Richards and Thompson (1952) as modified by Creitz and Richards (1955) was used for determination of chlorophyll. Millipore HA filters were used for the filtration of 250 to 1,000 millilitres of water depending on the density of phytoplankton. Filters were refrigerated and stored in a desiccator in the dark until extracted with 15 millilitres of 90 percent acetone in a centrifuge tube. FWPCA used a Vortex Junior Mixer to facilitate initial extraction. After 18 to 24 hours extraction in the dark, the samples were centrifuged and extracts transferred to a cuvette. Optical density was determined at 665, 645, and 630 millimicrons using a Beckman Model B or Model DU spectrophotometer. The formulas used for determination of chlorophylls *a*, *b*, and *c* in the extract were (Creitz and Richards, 1955):

Chlorophyll *a* (mg/l) $15.6\ D_{665} - 2.0\ D_{645} - 0.8\ D_{630}$

Chlorophyll *b* (mg/l) $25.4\ D_{645} - 4.4\ D_{665} - 10.3\ D_{630}$

Chlorophyll *c* (mg/l) $109\ D_{630} - 12.5\ D_{665} - 28.7\ D_{645}$

Chlorophyll values in mg/m^3 of water were then obtained as follows:

$$\frac{\text{ml of extract}}{\text{litres filtered}} \quad \text{X} \quad \frac{1}{\text{light path of cuvette (cm)}}$$

Results were expressed as chlorophyll (*a* + *b*) or as chlorophyll *a*. Chlorophyll *c* values were usually not calculated because of the high error involved.

FRB

The *in vivo* fluorometric method of Lorenzen (1966) was used for chlorophyll determination, with standardization through periodic determinations of chlorophyll a using the method of Creitz and Richards (1955). Modifications of Lorenzen's procedure included the use of a larger recorder, and warming of the inflowing water to avoid condensation of moisture on the surface of the flow-through cell.

ZOOPLANKTON METHODS

General

Zooplankton can be collected with a variety of devices ranging from traps that open at a particular depth enclosing a standard volume of water, to metered or unmetered nets towed through the water either vertically or horizontally. Regardless of the sampling apparatus all measurements are relative only. The efficiency of net sampling varies with the mesh size, the rate at which the net is hauled through the water, and the degree of clogging from concentrations of algae and zooplankton.

FWPCA

Collections were made with a Wisconsin-type plankton net (50 centimetres in diameter, with a 6 foot length of #20 bolting cloth) and preserved in 3 percent formaldehyde. Vertical hauls were made from 3 metres above bottom to the water surface during daylight hours. The samples taken have not yet been analyzed in detail, but are being retained for future reference.

OWRC

Collections were made with a Wisconsin-type plankton net (12 centimetres in diameter, with a 23 inch length of #20 mesh Nylon bolting cloth). The samples were collected by vertical hauls from 7 metres depth to the water surface, raising the net slowly by hand. The collections were made during daylight hours only. The fraction of the sample counted varied from 1/15 to 2/3 depending on the numbers involved. Duplicate counts using a Sedgwick-Rafter counting cell were usually made for about 10 percent of the samples. Species identifications were made at 400X magnification. Samples were preserved in 5 percent formalin and were retained for future reference.

FRB

Collections were made with a Wisconsin-type plankton net (25 centimetres in diameter, 70 centimetres length of nylon bolting cloth with a mesh opening of 70 microns). The net was hauled vertically from 50 metres depth to the surface at a rate of 0.3 to 0.5 m/sec. For stations shallower than 50 metres depth, the net was hauled from just above bottom to the surface. A minimum of 200 specimens per haul was counted using a Sedgwick-Rafter counting cell, representing 1/100 to 1/500 of the total number of specimens per haul. Samples were preserved in 8 percent formalin with representative samples retained permanently on file at the FRB Freshwater Institute. Samples were collected anytime during the day or night that the ship was on station. Tests have shown that an average of 90 percent of the total zooplanktonic populations (by number) occurs in the uppermost 50 metres. *Limnocalanus macrurus* is not adequately sampled by this procedure.

BENTHOS METHODS

General

No single dredge is effective for all substrates in sampling the benthic population. There are also marked differences in sampling efficiency for different types of dredges. Only samples taken with the same dredge in similar types of substrate can be compared on a quantitative basis.

FWPCA

All collections were made with a Petersen dredge concentrated through a 30 mesh/inch sieve and sorted according to the procedures described by the American Public Health Association (1965). The preservative consisted of 40 millilitres of formalin mixed with 60 millilitres of 70 percent ethanol. Phloxine B or Rose Bengal were used as stains. Data were expressed in terms of the number of organisms per square metre. Samples were either retained by FWPCA or sent to the Ohio State Museum for future reference.

OWRC

Collections in 1966 were made with a Petersen dredge, approximately ten inches by ten and a half inches. Collections in 1967 were made with a Ponar dredge, approximately nine inches by nine inches. Samples were sorted through a 24 mesh sieve (0.65 mm aperture) and preserved in 95 percent ethanol. All samples were retained by OWRC. Data were expressed in terms of the number of organisms per square metre.

GLI and FRB

Samples were collected with a Franklin dredge, kept cool until the termination of each cruise and sorted in a laboratory in a column bounded by two sieves through which water was allowed to flow. Subsequent tests revealed that the operation of this sieving device resulted in losses of specimens, probably due to maceration between sediment particles. Further details on the number and times of cruises, and the sampling stations, are given in Brinkhurst *et al.* (1968).

SESTON METHODS

FWPCA

Gravimetric determinations of seston were conducted to provide a gross estimate of standing crop. Samples for organic seston determinations were collected at the same depths as for phytoplankton by the membrane filter technique. A two-litre plastic bottle was filled and 60 millilitres of Lugol's preservative or formalin was added.

Crucibles and covers were washed in a detergent solution, rinsed in tap water, and placed in a 30 to 40 percent nitric acid solution for at least two hours. They were then removed and immersed in distilled water for 5 to 10 minutes and placed in a pan until the excess water evaporated.

The crucibles and covers were then placed in a muffle furnace preheated to 600°C for 30 minutes, removed, allowed to cool at room temperature for several minutes, and placed in a desiccator.

After removal from the desiccator, each crucible and its corresponding numbered cover were weighed together on an analytical balance, the cover being inverted on top of the crucible, and the weight recorded. A dried HA 0.45 micron membrane filter was placed in the inverted cover and the crucible cover and filter weighed. This weight was recorded as the tare weight.

Aliquots were passed through the weighed filters and each filter returned to the crucible from which it was taken and the cover replaced. The crucibles were then dried in the drying oven at 100°C for one hour. They were then removed, placed in a desiccator for at least one hour, weighed again, and the weight recorded as the total dry weight. The difference between the tare weight and dry weight was the sample residue weight.

The crucibles, filters, and covers were then placed in a muffle furnace at a temperature of 600°C for 30 minutes, removed and after several minutes, placed in a desiccator for at least one hour, weighed, and the weight recorded as ashed weight. The difference between the ashed weight and the crucible and cover weight was the weight of the non-organic material in the sample. The difference between the dry residue weight and the non-organic material was the weight of the organic material. This figure was converted to either milligrams of seston per cubic metre or milligrams per litre. The measurement is similar to that for volatile and fixed solids.

METHOD FOR DDE RESIDUES IN FISH

OWRC, 1966 and 1967

The fresh fish were kept on ice until they could be frozen for extended storage. In preparing the fish for analyses, they were thawed and the specific tissued dissected out and homogenized in a food blender. In the case of whole fish composites, the fish were ground in a meat grinder.

In the saponification step of the analyses, a 10 gram homogenized sample was boiled for 30 minutes with 40 millilitres of 20 percent potassium hydroxide. In the saponification step, the tissue was converted to a water-soluble liquid and any DDT present was converted to DDE. Any DDE present remained unchanged. The DDE was extracted from the saponified tissue using 3 x 15 millilitres portions of hexane in a 125 millilitre separatory funnel. The hexane was cleaned by using column chromatography on florosil. An Aerograph 1520 gas chromatograph was used for the analysis. All measurements were calculated in terms of mg/kg DDE per unit fresh weight of tissue.

LAKE ONTARIO MATERIAL BALANCE

NIAGARA RIVER OUTPUT

The calculated loads are based on data of average constituent concentration determined on IJC Range Ni-1.0 and adjusted to an average flow of the lower Niagara River of 195,000 cfs for the period of record 1900-1967. The following concentrations were determined: total-N 500 µg/l, total-P 40 µg/l, Cl 27 mg/l, dissolved solids 198 mg/l.

Constituent	Data Collecting Agency	Data Year
N - total	FWPCA and OWRC	1963 and 1964 1967
P	OWRC	1966 and 1967
Cl	OWRC	1966 and 1967
Dissolved solids	FWPCA	1963 and 1964

LAKE ONTARIO INPUTS

Includes municipal and industrial point sources, municipal, industrial and land drainage tributary sources and natural sources.

Point Sources

Municipal

Municipal sources (Province of Ontario) were sampled on a monthly basis during 1967. Loadings were then calculated using measured concentrations and metered average annual flows. United States loadings were based on a limited number of effluent samples, both grab and composite, obtained during the years 1965-1966 and 1966-1967.

Industrial

Industrial loadings were based, in most cases on four samples and flow measurements during 1967 and supplemented by past data and company records, in the Province of Ontario. United States loadings were estimated from a limited number of composite samples obtained during 1965-1966.

Tributaries

Municipal

Municipal nutrient loads for the Province of Ontario and the United States were based primarily on urban population and per capita annual contributions of 3 lbs. P (MacKenthen, 1968) and 9 lbs. N (Vollenweider, 1968). United States municipal loads were based on data for the period of 1965 to 1967. These estimates were checked against available sampling data.

Industrial

Industrial loads from Canada are based, in most instances, on two annual measurements of concentrations and metered averaged annual flow, in the Province of Ontario. The United States industrial and municipal loading estimates are presented as a combined loading. The total tributary loading minus the municipal and land drainage loads was considered as a rough approximation of the United States industrial load.

Land Drainage

Land drainage for the Canadian side is the total tributary load minus the municipal and industrial loads. For the United States side, land drainage estimates were based on run-off constants developed for specific land uses such as cropland, pasture, woodland, etc. The tributary loads to Lake Ontario were based primarily on samples taken during 1965 and 1966 with a sampling frequency of 8-12 times per year for the Province of Ontario and a frequency of 20-24 times per year for the United States. Loadings were calculated using concentrations and daily flow values at the time of sampling.

Natural sources represent an estimated nitrogen contribution of 5 lbs/acre/year to the lake surface through precipitation. Matheson (1951) measured nitrogen in precipitation as averaging 5.8 lbs/acre/year. McKee (1962) reports values equivalent to 1.8 to 8.9 lbs/acre/year, with an average of about 5 lbs/acre/year. Therefore a value of 5.0 lbs/acre/year was taken as being representative of the Great Lakes region.

LAKE ONTARIO OUTPUT

The calculated loads are based on data of average concentration on the Department of National Health and Welfare St. Lawrence River Ranges 191 and 188S and were adjusted to an average flow of the St. Lawrence River of 232,000 cfs, for the period of 1900-1967. The concentrations were: total-N 500 μg/l, total-P 14 μg/l, Cl 27 mg/l, dissolved solids 162 mg/l.

ANNUAL INPUT OF TOTAL PHOSPHORUS PROJECTED TO 1986

MUNICIPAL INPUTS

Municipal inputs are based on projected urban population and an annual per capita contribution of 3.5 lbs. P - as raw sewage. The population projection is based on population trends and anticipated economic growth. Phosphorus contribution of 3.5 lbs/person/year is based on current United States loadings and anticipated Canadian loadings. This is considered a conservative value in view of past trends in annual per capita consumption of phosphates in detergents.

INDUSTRIAL INPUTS

Industrial growth in the Province of Ontario was estimated in part on past economic performance and on a knowledge of planned and proposed industrial expansion, particularly in development of thermal power. The real economic growth rate has been in the order of 4 percent per year. By 1986 this is expected to compound to a factor of about 2.5 times. Industrial projections for the United States were based on past trends of employment for each water use industry. The resultant water use indexes of growth were developed for Standard Industrial Classification categories and also reflect productivity and water re-use factors.

LAND DRAINAGE

By 1986 the amount of phosphorus contributed by land drainage is expected to increase 10 percent. This is based on such factors as past trends in fertilizer use, replacement of forest cover by farm crops and increased soil erosion.

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