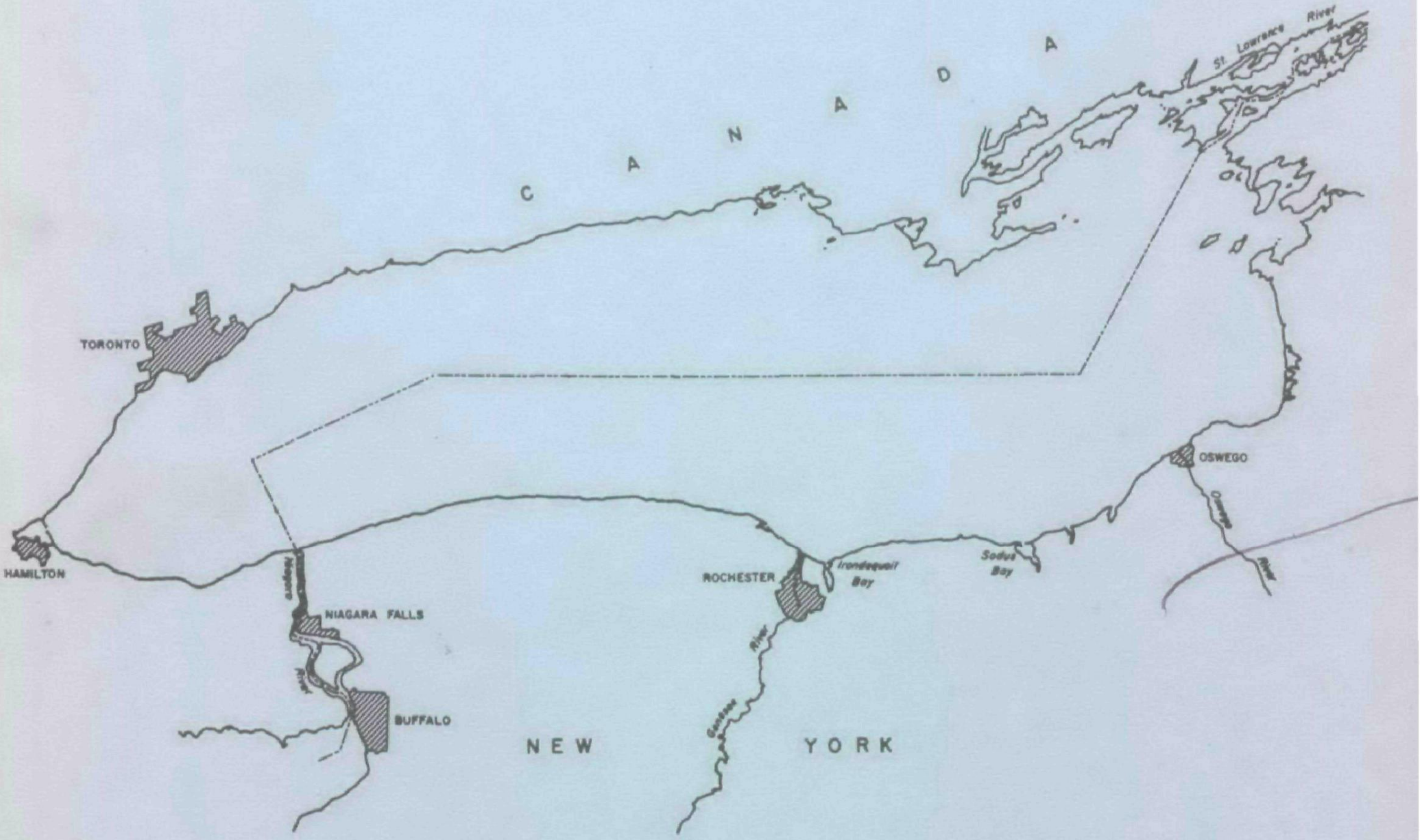
EPA-902/9-73-002

LAKE ONTARIO ENVIRONMENTAL SUMMARY 1965



U.S. ENVIRONMENTAL PROTECTION AGENCY
REGION II
ROCHESTER FIELD OFFICE
ROCHESTER, NEW YORK

LAKE ONTARIO

ENVIRONMENTAL SUMMARY

1965

by

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William Fisher
Conrad O. Kleveno

U. S. Environmental Protection Agency
Region II
Rochester Field Office
Rochester, New York

PREFACE

This report on Lake Ontario water quality was written in 1966. Several scientists involved in the International Field Year for the Great Lakes program, who were aware of the draft report, suggested that the material be made available to document historical data on the water quality of the lake.

The report contains conclusions which are based on the data as originally collected. It is recognized that subsequent investigations may have resulted in information and conclusions which differ from some of the material in this report. However, no effort has been made to update the report. It is published here as it was written in 1966.

At the time this report was prepared, the Federal water pollution control program was being carried out by the Federal Water Pollution Control Administration. The material for the report was assembled by the staff of what was at that time the Lake Ontario Program Office, which was part of FWPCA's Great Lakes Region, under the direction of Lee Townsend. His efforts, as well as those of other members of the staff who made this report possible, are gratefully acknowledged.

In 1970, when the Environmental Protection Agency was formed, the former Lake Ontario Program Office became the Rochester Field Office of Region II of EPA.

K. H. Walker, Director
Rochester Field Office

May 1973

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Chapter 1

INTRODUCTION

Purpose

The purpose of this report is to provide a summary of the results of the chemical, biological, and physical studies of Lake Ontario. These studies were conducted by the Lake Ontario Program Office, Great Lakes Region, Federal Water Pollution Control Administration, U.S. Department of the Interior, in cooperation with the New York State Health Department, Monroe County Health Department, U.S. Corps of Engineers, and U.S. Geological Survey.

Areas of Interest

This report deals with the deep water areas of Lake Ontario. A separate report entitled "Minor Tributaries Area" will deal with the shallower water areas. This report includes biological and chemical data obtained from three sampling cruises conducted by the Lake Ontario Program Office, using the Corps of Engineers vessel T-501. Physical and sedimentary data were obtained from the T-501 cruises and the three separate phases of operation carried out by the physical oceanography section.

Deep Water Sampling

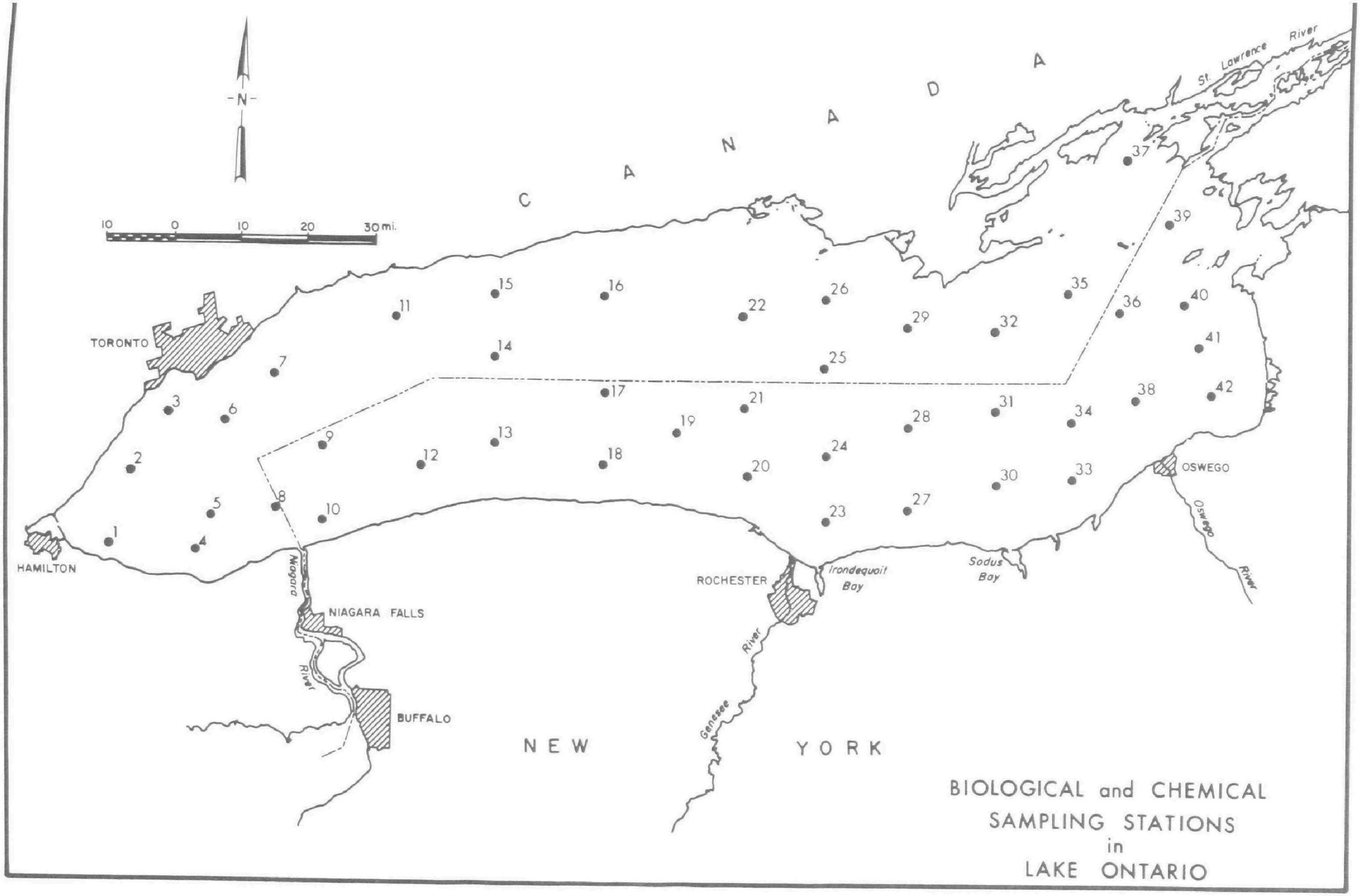
Three major sampling cruises were conducted by the Lake Ontario Program Office during 1965, using the Corps of Engineers 60-foot vessel T-501. This vessel was equipped with laboratory facilities for microbiological, biological, and chemical work. At the time of sampling, physical parameters such as air temperatures, wind velocity, and water temperatures were also recorded.

Forty-two stations (Figure 1-1) were sampled in May, Cruise 102; late July-early August, Cruise 103; and in late September-early October, Cruise 104. Cruise 101 was carried out while setting the first series of current-metering stations in August 1964. The purpose of Cruise 102, 103, and 104 was to gather data on the various chemical, biological, and physical parameters of the lake. Cruise 101 was a reconnaisance sampling cruise to gather background data to help in planning the three major cruises. Data from Cruise 101 have not been included in this report.

Related Work

The lake study was conducted as part of the development of a comprehensive water pollution control program for the Lake Ontario Basin, which is documented in several sub-basin reports. Each of these reports presents a survey of major pollution problems, water uses and trends in water usage, and presents a program for the abatement of water pollution in the Basin.

The reports are titled: "A Water Pollution Control Program for the Black and U.S. St. Lawrence River Basins", "A Water Pollution Control Program for the Genesee River Basin", "A Water Pollution Control Program for the Minor Tributary Basins of Lake Ontario",


C A N A D A
N
10 0 10 20 30 mi.
TORONTO
HAMILTON
NIAGARA FALLS
BUFFALO
ROCHESTER
OSWEGO
Niagara River
Genesee River
Irondequoit Bay
Sodus Bay
Oswego River
St. Lawrence River
NEW YORK
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42
BIOLOGICAL and CHEMICAL
SAMPLING STATIONS
in
LAKE ONTARIO

FIGURE I-1

and "A Water Pollution Control Program for the Oswego River Basin".

Acknowledgments

The assistance of the Lake Ontario Program Office staff is gratefully acknowledged. Especially helpful were: Mr. Lawrence R. Moriarty, assistant director, and Mr. Thomas Kamppinen who drafted most of the illustrations.

Particular thanks go to Mr. Robert Hartley, Mr. Robert Booth, and Mr. Wesley Kinney of EPA; and Dr. Robert Sweeney, SUNY at Buffalo Dr. Fred G. Lee, University of Wisconsin, and Dr. Keith Rodgers, University of Toronto, all of whom reviewed this report and gave continued encouragement to the authors.

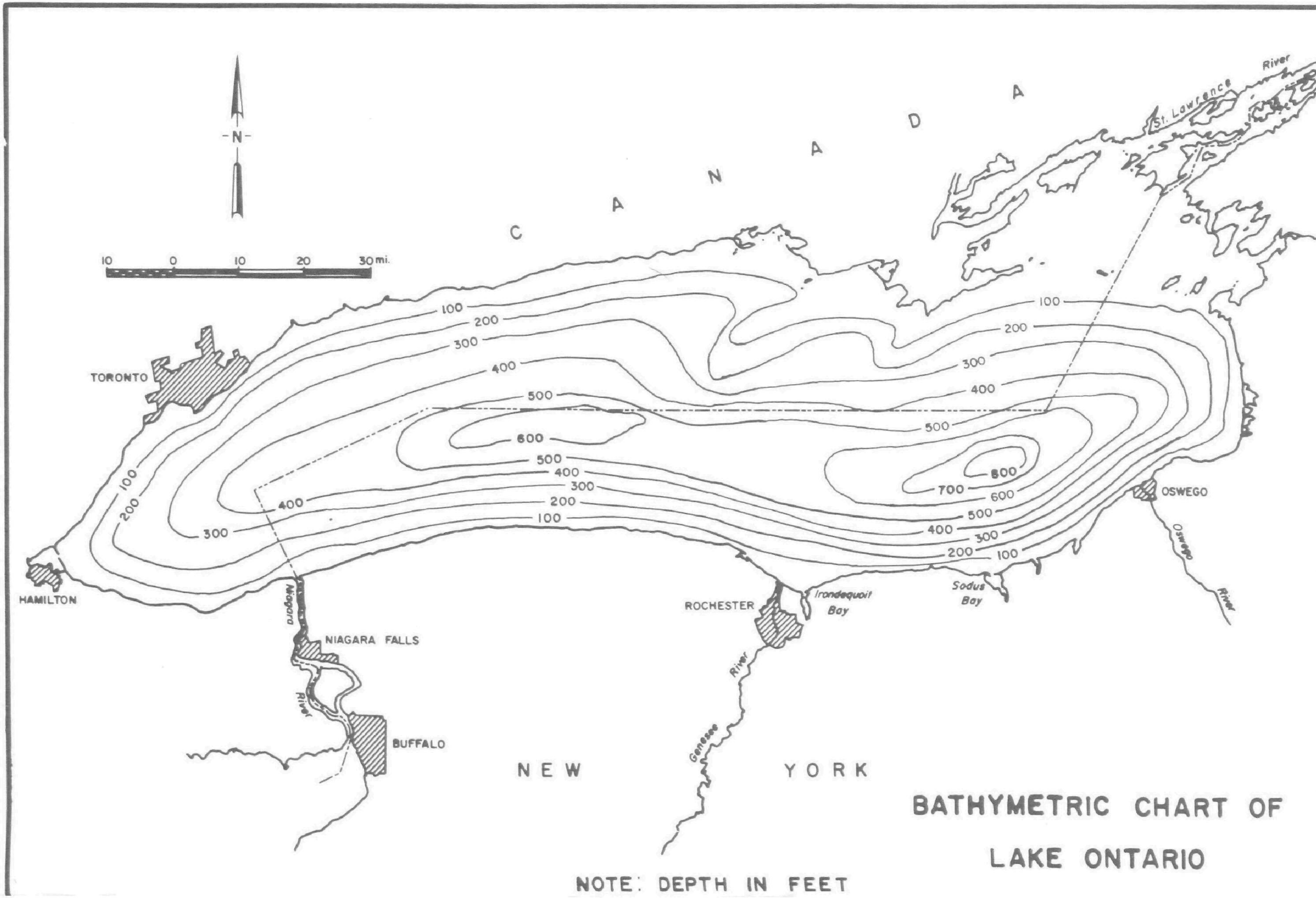
Chapter 2

LAKE ENVIRONMENT

Morphometry

Lake Ontario is a relatively narrow deep lake with its long axis aligned in an east-west direction. The lake, Figure 2-1, is approximately 190 miles (305 km) long and 53 miles (85 km) wide. Its greatest depth is 840 feet (256 meters); the average depth is 300 feet (91 meters). The total volume of the lake is 390 cubic miles (1628 cubic km); 85 percent of this volume is below the thermocline in summer. The surface area of the lake is 7,600 square miles (19,684 sq. km), and its basinal area is 34,800 square miles (90,130 sq. km). The elevation of the lake's surface is 245 feet above sea level, and its deepest part is approximately 600 feet (185 meters) below sea level.

Lake Ontario, Figure 2-1, can be considered to have two longitudinal basins: the western basin comprises almost two-thirds of the lake and has a maximum depth of 630 feet (192 meters), and the other at the eastern end of the lake has a maximum depth of 840 feet (256 meters). The deeper basin, while smaller, is more sharply defined. A ridge, which appears to be geologically controlled, separates the basins with a maximum sill depth of 540 feet (165 meters).



BATHYMETRIC CHART OF LAKE ONTARIO

NOTE: DEPTH IN FEET

FIGURE 2-1

The difference in depth between the two basins can be explained by a difference in sedimentation rates. This would also account for the more gentle bathymetry of the western basin. The southern side of the lake is steeper than the northern side, due to differentiated glacial scour during Pleistocene time.

Figure 2-2 is a hypsometric curve for Lake Ontario proper, excluding the bay-like area northeast of Duck Island. Inasmuch as the curve is almost linear, the percent of surface area can be interpreted as percent of volume. One very important physical characteristic of Lake Ontario is apparent: the large volume of water mass per unit surface area. If we assume that the average depth to the thermocline is 70 feet (21 meters), then 85 percent of the lake's water mass is below the epilimnion. In comparison, the situation is nearly reversed in Lake Erie. This physical characteristic has far-reaching effects on the chemical and biological systems within the lake. For example, a large reserve of oxygen exists in the hypolimnion, so it is unlikely that a serious overall depletion of oxygen will occur; however, this should not be taken to mean that serious local depletion will not occur.

As regards the biota, a relatively small surface growing area exists in comparison to the volume of the water mass; thus, Lake Ontario has a large nutrient reserve in comparison to the growing area.

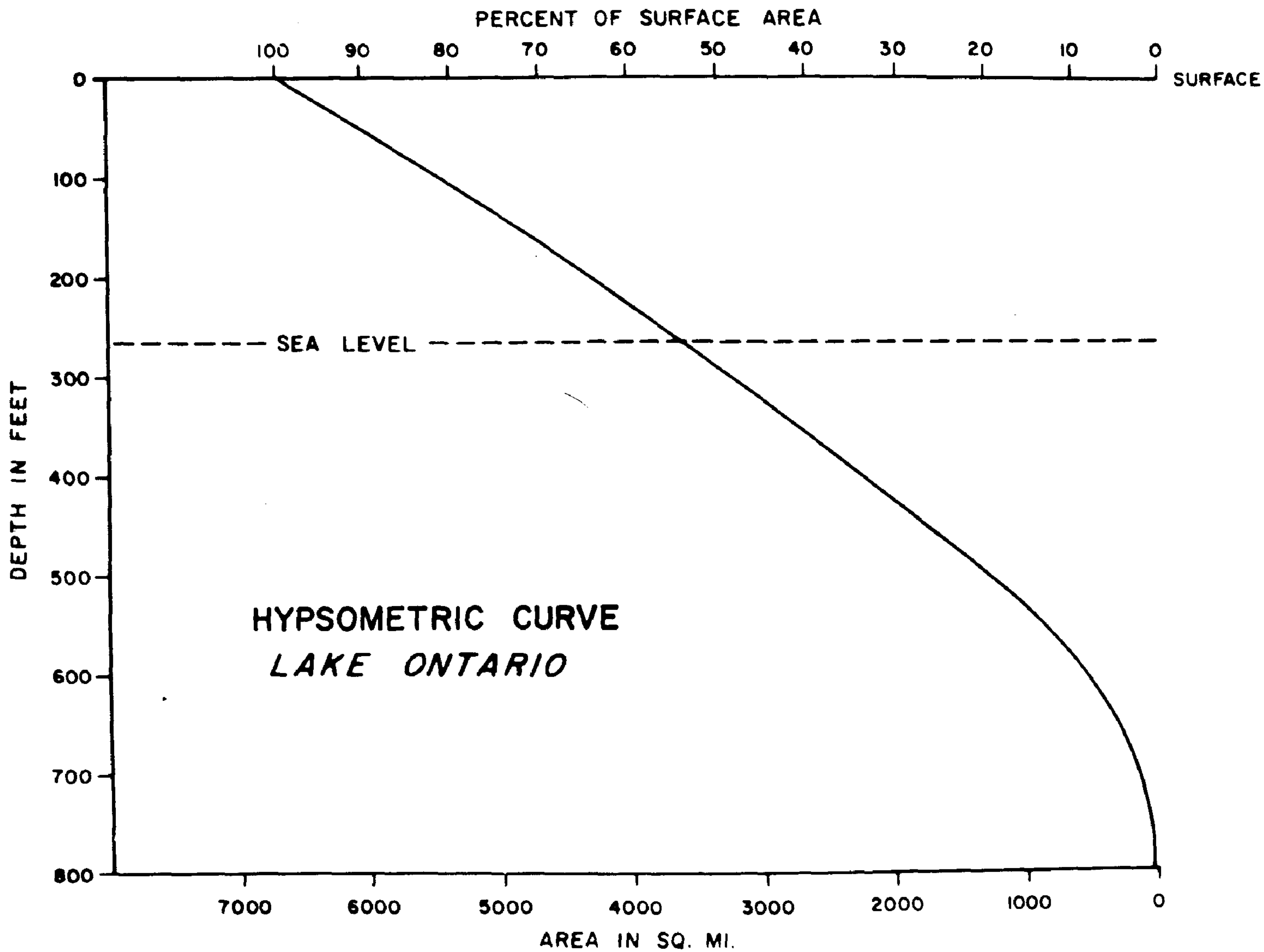

PERCENT OF SURFACE AREA
100
90
80
70
60
50
40
30
20
10
0
SURFACE
0
100
200
300
400
500
600
700
800
DEPTH IN FEET
SEA LEVEL
HYPSOMETRIC CURVE
LAKE ONTARIO
7000
6000
5000
4000
3000
2000
1000
0
AREA IN SQ. MI.

FIGURE 2-2

Also, with the large oxygen reserve available in Lake Ontario, it would require a very large amount of phytoplankton production in the surface waters to cause a generalized depletion of dissolved oxygen in the hypolimnion of Lake Ontario. The effects of the basin's physical shape on the chemical, biological, and physical characteristics of the water mass will be discussed further on in this report.

Hydrology

The Niagara River, Table I, with a mean annual inflow into Lake Ontario of approximately 200,000 cfs, is by far the greatest hydrologic factor influencing the lake environment. The distribution of this flow is quite even because of the dampening influences caused by the upstream lakes and regulation by power plants, and the result is that an essentially steady state gradient flow is constantly imposed on Lake Ontario, extending from the river's mouth to the lake's outlet at the St. Lawrence River.

Other major rivers are few in the Lake Ontario Basin. They are the Oswego River, which drains the Finger Lakes Region; the Genesee River, which drains the Appalachian Front; the Black River, which drains the western Adirondack Mountains; and the Trent River, draining part of Ontario,Canada.

Table I

WATER BUDGET

Niagara River	203,000 cfs
Small rivers	19,500 cfs
Rainfall	18,000 cfs
Oswego River	6,500 cfs
Black River	3,900 cfs
Trent River	3,100 cfs
Genesee River	2,800 cfs
St. Lawrence River	238,000 cfs
Evaporation	18,800 cfs[1]

Volume of Lake Ontario 391 cubic miles

Average Residence Time

$$\frac{391 \text{ miles}^3}{219{,}000 \text{ cfs net}} = 8.4 \text{ years}$$

1 Bruce, J. P. and Rodgers, G. K., 1962

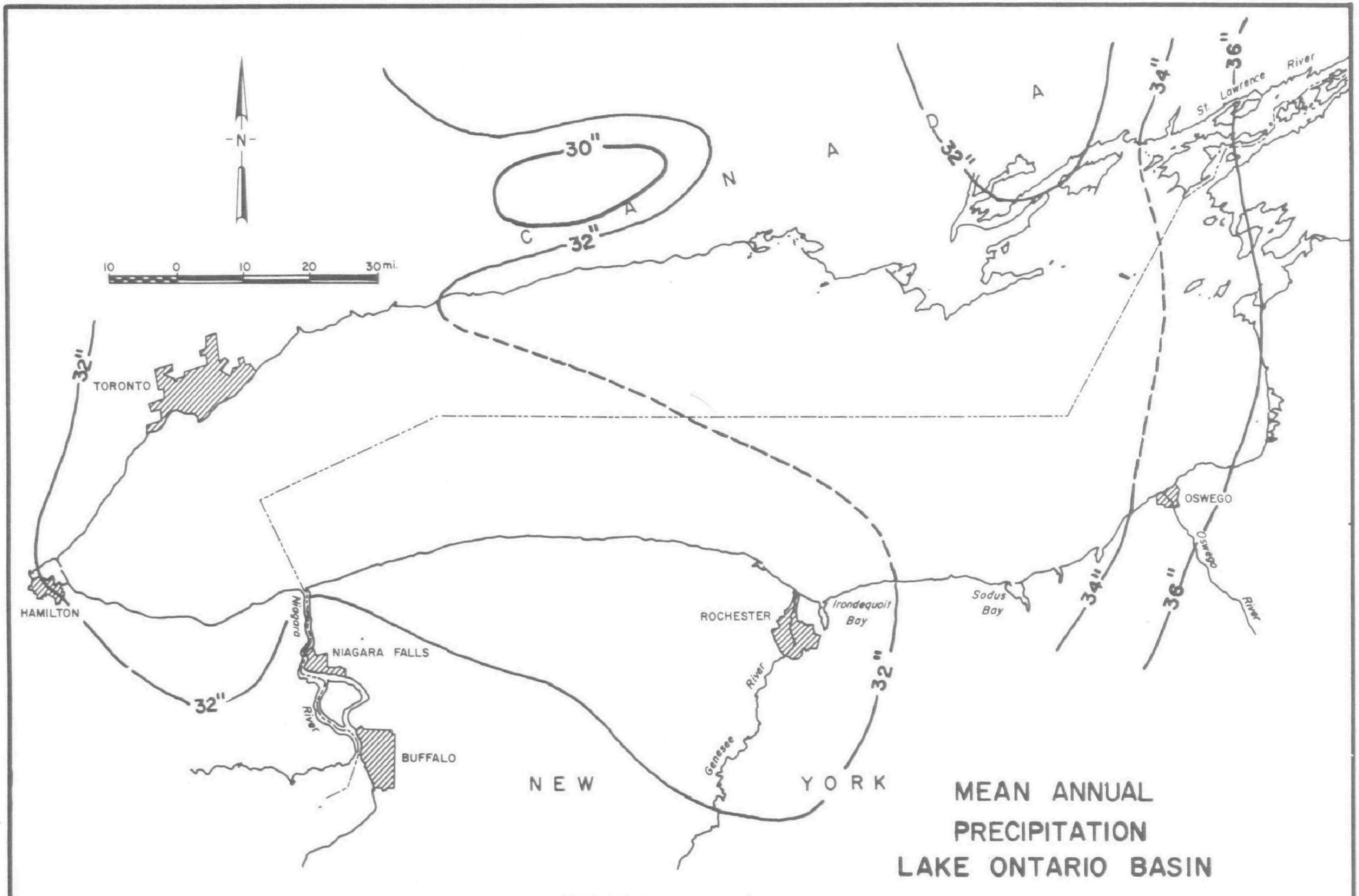
The smaller creeks and rivers draining the sedimentary rocks along Lake Ontario have flows that are characteristic of limestone terrains, with high spring runoff and very low summer flows. In the summer months, almost all of these streams, because of sluggish flow and pollution, develop such prolific growths of algae and duckweed that very little open water can be seen near their mouths.

The mean annual precipitation in the lake basin is approximately 33 inches, Figure 2-3. The lowest values occur in the west-central part of the basin and the highest values in the area of the Adirondack Mountains and the Appalachian Front.

The retention time for water entering the lake (using the refill method) is on the order of eight years. The actual retention time, however, is affected by the effects of stratification and net circulation. Water in the deeper parts of the lake is retained for very long periods. The retention time, considering such factors as circulation, the effects of stratification, and that outflowing waters are a mix of Lake Erie and Lake Ontario waters, etc., is over 15 years.

Climate

Although the Lake Ontario Basin is considered to have a continental climate, the lake has a moderating effect and brings to the area influences of a marine climate that are apparent in such elements as



MEAN ANNUAL PRECIPITATION LAKE ONTARIO BASIN

NOTE: Precipitation in inches.

FIGURE 2-3

temperature and humidity, and the usual effects of land and lake breezes. During the summer months the lake stores up heat (the maximum heat content of the lake occurs after the maximum surface temperatures are reached. See G. K. Rodgers and D. V. Anderson.) which is released to the atmosphere during the late fall and early winter as it cools, thus delaying the onset of cold weather. In the spring the reverse is true; the cold lake waters take up heat by cooling the air masses and delay the onset of warm weather. Upper and lower extremes of temperature are modified by this lake effect so that the daily, as well as the long-term, range of temperature is less than normal at this latitude. The average range is between 70°F. (21°C) in July and 25°F. (-4°C) in February. Summer temperatures rarely reach 100°F. (38°C), and the winter minimum rarely reaches 0°F. (-18°C). The lake effect also increased the cloudiness during cold weather, when air masses that are warmed, and whose moisture content increased in passing over the lake, are cooled upon striking the cooler land mass. Snowfalls, so caused, are frequent and sometimes severe.

Another factor governing the area's climate is the St. Lawrence storm track. Cyclonic systems passing up this track bring in moisture from the Gulf of Mexico and are the principal source of rainfall in the area.

Geology

Lake Ontario lies wholly in Paleozoic rocks of Ordovician Age excavated along the axis of a former valley by glaciers in Pleistocene time. At one time in the past, geologically speaking, the lake basin was actually an arm of the sea.

The axis of the lake is oriented parallel to the strike of the rocks, which dip southward. Along the southern side of the lake, the Niagara dolomite, sharply defined at Niagara Falls, forms a rim that gradually disappears in an easterly direction. The deeper part of the lake, to the south of center, was excavated in the less resistant Queenstown shale. The northern part of the lake basin is underlain by older and more resistant limestone.

The superficial geology of the basin is the result of marine, glacial, and lake deposition and erosion.

Sediments

Physical

During July 1965, sediment samples were collected on a 10-mile (16 km) spacing throughout the lake. Sand mixed with boulders and pebbles was found all along the edge of the lake from the shore line out to depths of 77 feet (22 meters) or more. (So-called shingle beaches are common along the southern shore line.) Most of this material comes from the numerous glacial and bedrock (shale) deposits found along the shore. On the Canadian side, these deposits are much more extensive; in some areas sand is found out to depths of 200 feet (61 meters). Near Scotch Bonnet Shoal there is a large extensive shelf area with numerous boulders and pebbles mixed with reddish sand. This shelf area extends from Colbourne, Ontario, around the eastern rim of the lake to the southwestern end of Mexico Bay.

From the edge of the sand deposits, the sediments grade laterally from sand to silt to clay, with various mixtures in between.

Sand also was found to be present in the samples obtained from the deep basins, along with the clays and silts. The source of the sand in these samples appears to be wind-blown material because of the fresh-looking fractures and angular shapes. Sediments from two sources are being deposited in the deep basins: those derived from stream and shore erosion and a wind-carried fraction.

Chemical

Twenty-five sediment samples from Cruise 103 and 34 samples from Cruise 104 were analyzed for several parameters, two of which were total iron and total phosphate. The results of this study suggest that the amount of phosphate in the sediment is related to the amount of iron in the sediment, since the ratio of phosphate to iron did not vary significantly between the two cruises, while the total amount of iron did. The amount of iron was less for Cruise 104 than for Cruise 103 on a station-to-station comparison. This consistent difference cannot be attributed to a laboratory error inasmuch as three analytical separate runs were made using samples from both cruises for each run.

The mean percent of interstitial water by weight for these sediment samples was 60 and ranged from a high of 68 percent to a low of 20 percent. The amount of interstitial water appears to be related to the depth from which the sample was taken; the greater the depth, the more interstitial water.

Where enough of this interstitial water could be obtained for a valid result, analysis for iron and phosphate was made. The results of this study, when compared to the lake waters, show that phosphate was higher in the interstitial waters, on the average, by a factor of 10. Analysis for iron was not made in the water sampling cruises, so no comparison between lake water and interstitial water can be made for iron. The amount of iron in the interstitial water averaged .037 mg/l.

Chapter 3

BIOLOGY OF LAKE ONTARIO

Introduction

The biota of Lake Ontario are of great importance, for they represent the overall effect on the environment of a series of chemical and physical systems existing in the lake. Changes in the biota can be, and often are, detected before measurable changes occur in, for example, the chemistry. They can often mask any changes that have occurred in the lake chemistry as well.

Benthic Fauna

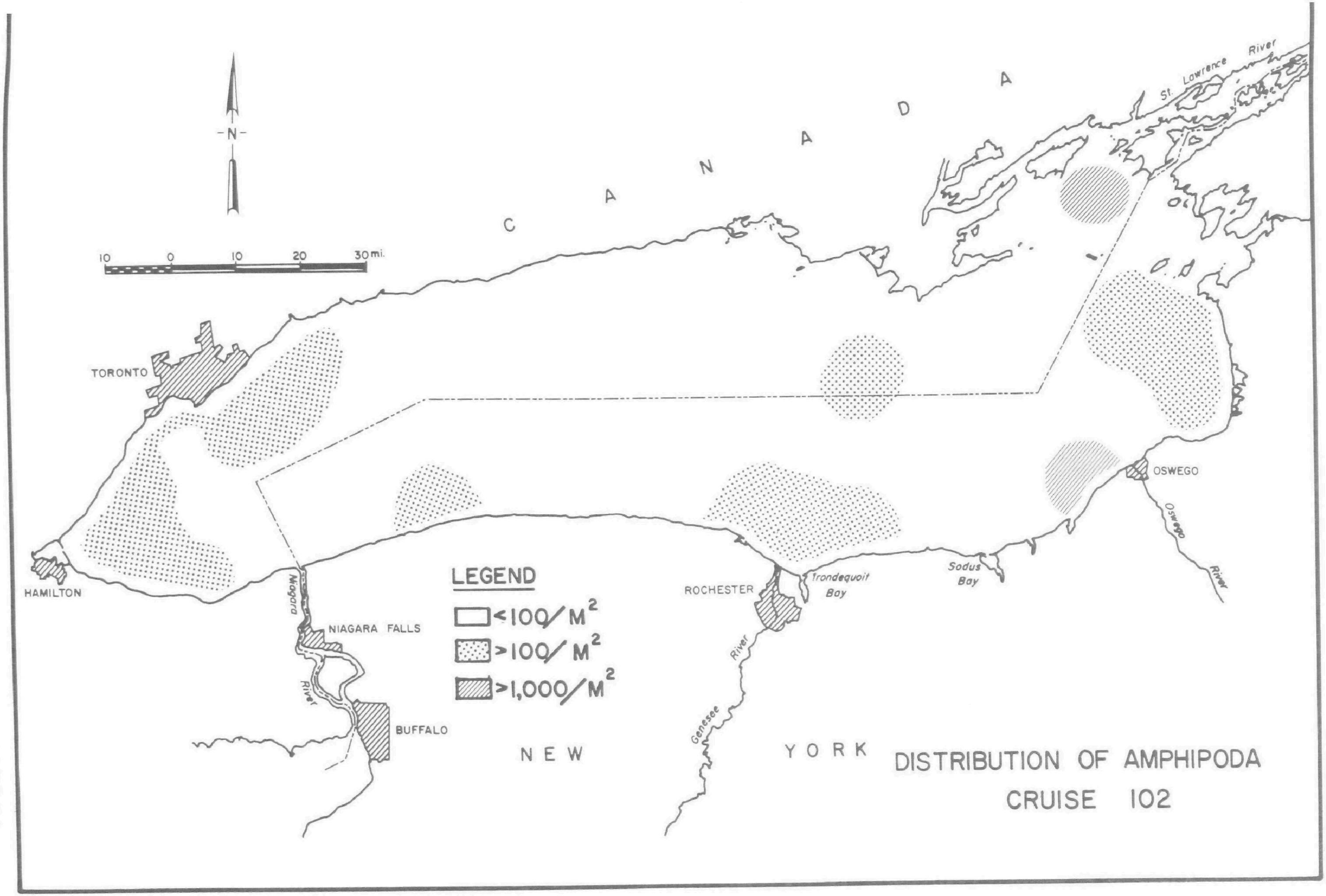
The benthic fauna of Lake Ontario is comprised of six principal organisms. Two types, Amphipoda (scuds) and Oligochaeta (sludgeworms) constituted 95 percent of all organisms collected; the remaining 5 percent consisted of Sphaeriidae (fingernail clams), Chironomidae (bloodworms), Isopoda (aquatic sow bugs), and Hirudinea (leeches), in order of importance. Amphipoda were dominant organisms at all stations except number 10, near the mouth of the Niagara River.

The range in numbers of organisms per square meter varied from 0 to 5,400, of which scuds and sludgeworms comprised approximately 70 percent and 20 percent, respectively, at the deep-water stations. Areas where greater numbers of biota generally existed were the western end of the lake (in the Toronto-Hamilton-Niagara River area) near the mouths of the Genesee, Oswego, and Black Rivers, and Mexico Bay.

Inasmuch as the sampling stations were 10 to 15 miles (16 to 24 apart, these biological data should be considered only of a general nature. Sampling should be done on a much denser scale if the areal extent and gradational distribution of the biota are to be noted. Tl is particularly true of the benthic fauna where significant changes quality and quantity of biota occur in short distances. Sampling phytoplankton can be done on a somewhat wider scale because their distribution is related more to a particular water mass. However, such physical factors as the time of day, the type of weather, and the temperature of the water also govern the type and quantity of th organisms present.

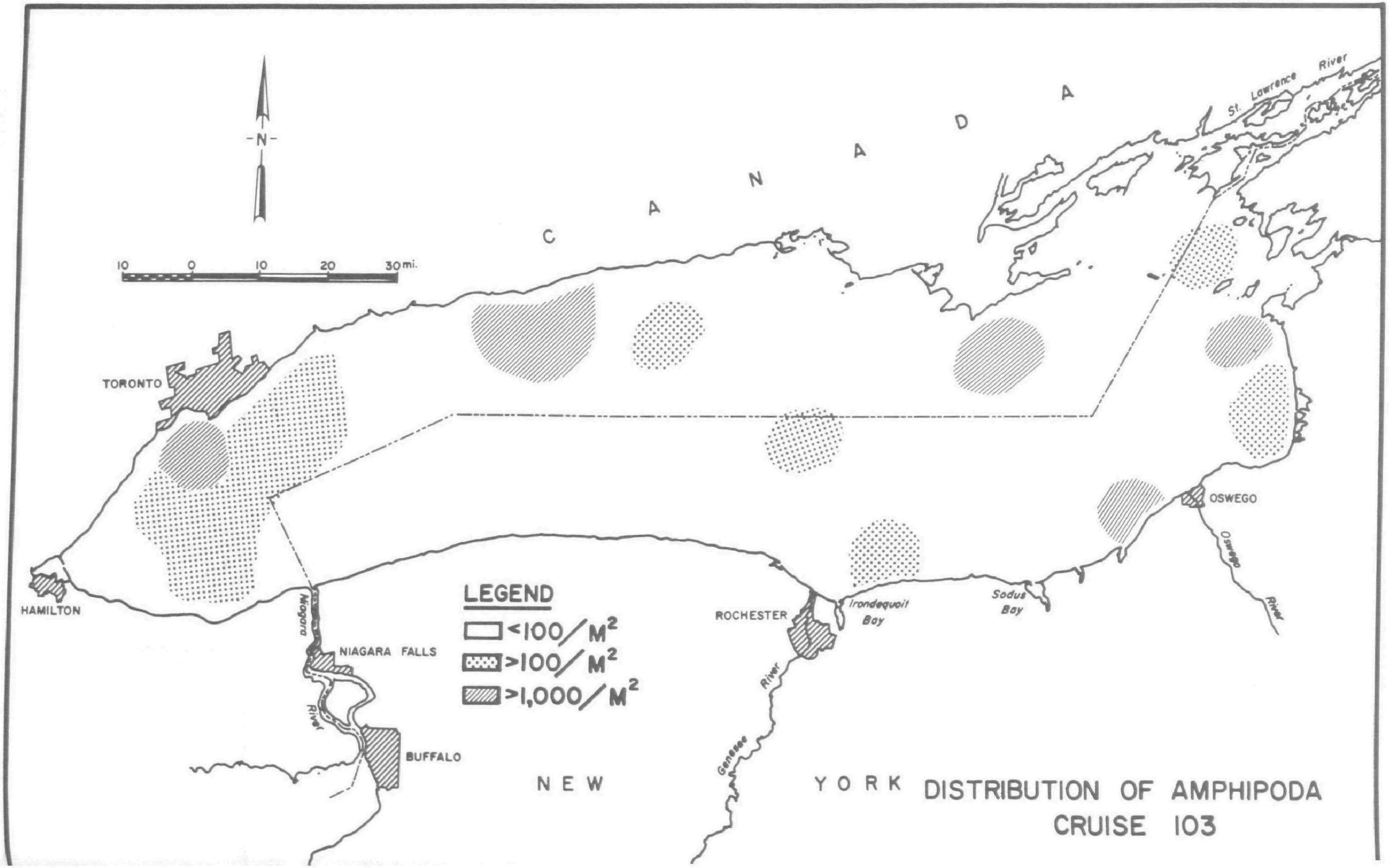
Amphipoda (scuds)

Amphipoda are considered to be of an intermediate type as regar tolerance of pollution. Included also in this category are such organisms as certain midges, fingernail clams, snails, and dragon f nymphs. The areal distribution of Amphipoda for Cruises 102, 103, and 104 is shown in Figures 3-1, 3-2, and 3-3, respectively. The patchlike patterns are partly due to areal distribution and spacing sampling sites. Data from all three cruises show a continuous



DISTRIBUTION OF AMPHIPODA
CRUISE 102

FIGURE 3-1



C A N A D A
St. Lawrence River
10 0 10 20 30 mi.
N
TORONTO
HAMILTON
Niagara
NIAGARA FALLS
River
BUFFALO
OSWEGO
Oswego River
ROCHESTER
Irondequoit Bay
Sodus Bay
Genesee River
NEW YORK
LEGEND
<100/M²
>100/M²
>1,000/M²
DISTRIBUTION OF AMPHIPODA
CRUISE 103

FIGURE 3-2

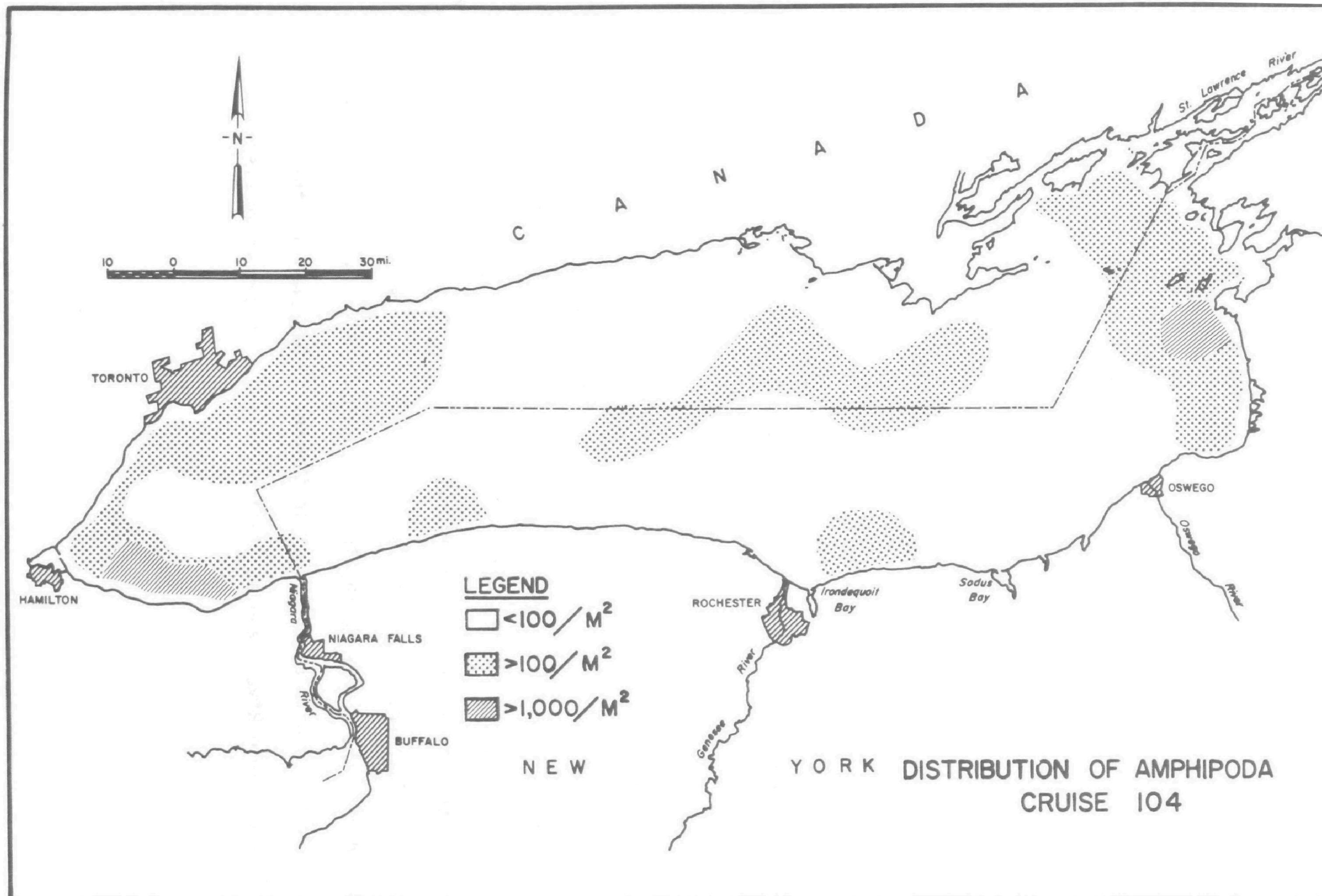

N
10 0 10 20 30 mi.
C A N A D A
St. Lawrence River
TORONTO
HAMILTON
Niagara
NIAGARA FALLS
River
BUFFALO
ROCHESTER
Irondequoit Bay
Sodus Bay
OSWEGO
Oswego River
Genesee River
LEGEND
<100/M²
>100/M²
>1,000/M²
NEW YORK
DISTRIBUTION OF AMPHIPODA
CRUISE 104

FIGURE 3-3

distribution of Amphipoda in the eastern end of the lake. The widest areal distribution was observed during Cruise 104, which also coincided with the greatest number of Amphipoda observed. The fewest number of Amphipoda observed was during Cruise 102, Figure 3-1. The general overall distribution of Amphipoda observed during the three cruises shows that their greatest number and widest areal distribution occur in areas of high pollutional (nutrient) input into the lake.

Oligochaeta (sludgeworms)

The distribution of Oligochaeta, generally considered a pollution-tolerant organism, was not adequate for presentation on charts since they varied greatly in quantity and areal extent. Data from Cruise 102 show that Oligochaeta are found in the eastern end of the basin (count of 200 or less) and in particular off the mouth of the Niagara River (Station 10), where a count of 4,000 organisms was made. Counts as high as 250 organisms/meter^2 were found in the vicinity of the Oswego and Genesee Rivers.

Data from Cruise 103 showed a general increase in Oligochaeta during the summer months in the Toronto-Hamilton area at Station 10 near the mouth of the lake, in the Mexico Bay area off the mouth of the Oswego River, and at Station 29 (1,000 organisms/meter^2) near

Scotch Bonnet Shoal. These increases are probably related to an increase in sediment nutrients and a warming of the muds in the shallower areas. Sediments that contained the high numbers of Oligochaeta in general were in a reduced state. Station 23, off Rochester, showed a marked decrease during the summer for which no explanation is available.

Data from Cruise 104 show the same areal distribution of Oligochaeta as Cruise 103, but the quantity declined.

The greatest areal extent of Oligochaeta was observed in the eastern end of the lake. The highest count was observed near the mouth of the Niagara River. While it appears Oligochaeta prefer shallower areas of the lake, they are most widespread in areas of highest pollutional input (western end) to the lake.

Phytoplankton

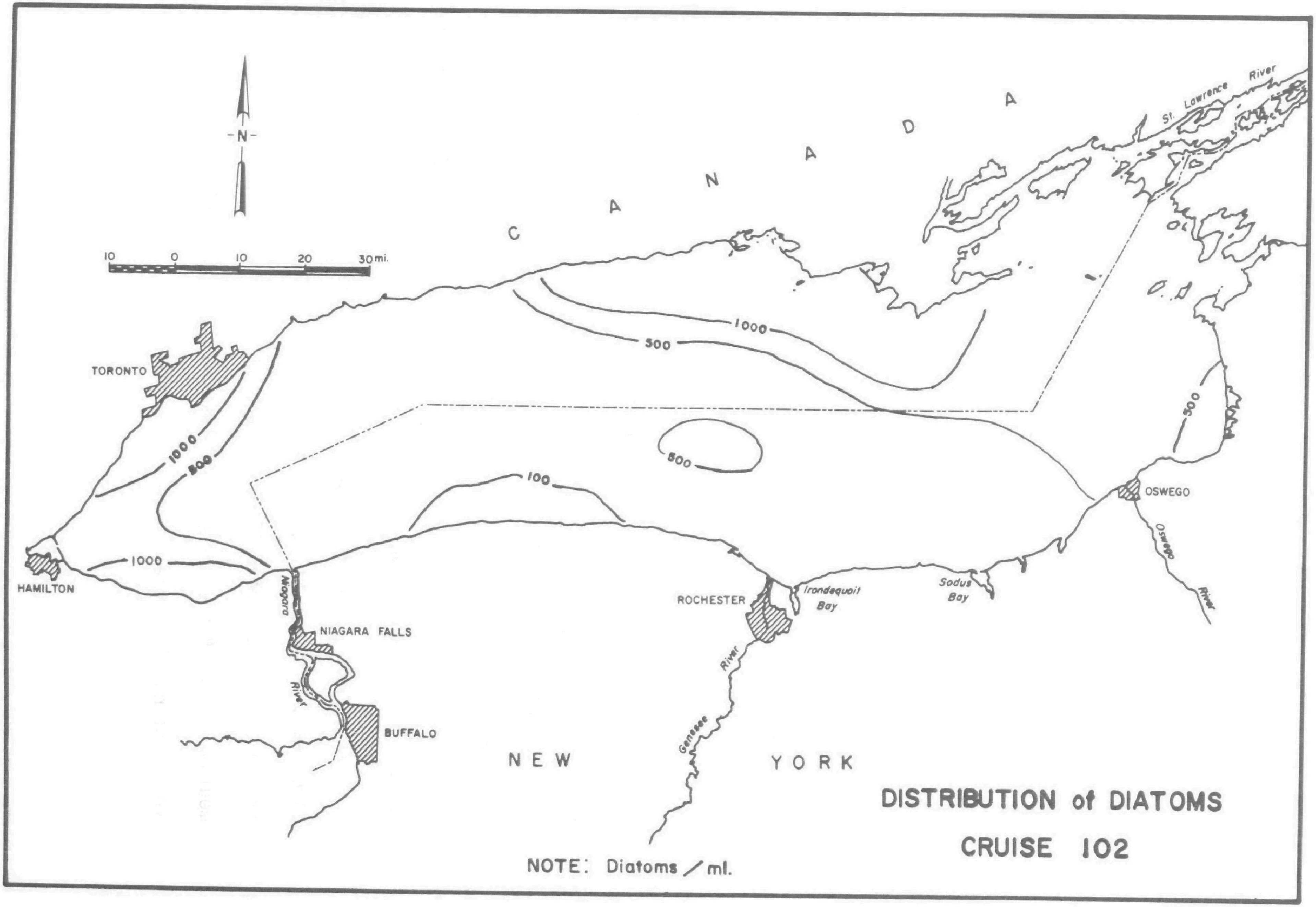
The densities of phytoplankton in Lake Ontario ranged from a minimum of 50 organisms per milliliter to a maximum of 3,600 organisms per milliliter during the three cruises. In May of 1965, the total counts were greater than in July or September. These counts reflected a spring pulse, which consisted predominantly of the green alga Scenedesmus. During Cruises 103 and 104, the predominant form observed was Chlamydomonas, a flagellated green alga. Scenedesmus and Chlamydomonas are not found as the dominant forms in the other Great Lakes, with the exception of Lake Erie. Both forms are considered to be indicative of enriched waters.

Diatoms

The highest densities of diatoms, both centric and pennate undifferentiated, were observed during Cruise 102 (Figure 3-4). High densities were found in the western end of the basin (the Toronto-Hamilton-Niagara River area). The lowest diatom densities were observed along the southern shoreline. The northeastern area of the lake showed the greatest areal extent of high diatom counts.

The distribution of the spring pulse of diatoms was related to the distribution of dissolved silicon dioxide in the water. (See Figure 5-30).

Cruise 103 showed a marked decrease in diatoms which paralleled a decrease in dissolved silicon dioxide in the water. Cruise 104 showed a slight recovery in the number of diatoms, but this recovery was not related to any measured increase in dissolved silicon dioxide. The data from Cruises 103 and 104 are not displayed on charts because the distribution of diatoms was too scattered.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C A N A D A
St. Lawrence River
TORONTO
HAMILTON
1000
500
1000
500
1000
500
500
100
1000
500
Niagara
NIAGARA FALLS
River
BUFFALO
ROCHESTER
Irondequoit Bay
Sodus Bay
OSWEGO
Oswego River
Genesee River
NEW YORK
DISTRIBUTION of DIATOMS
CRUISE 102
NOTE: Diatoms / ml.

FIGURE 3-4

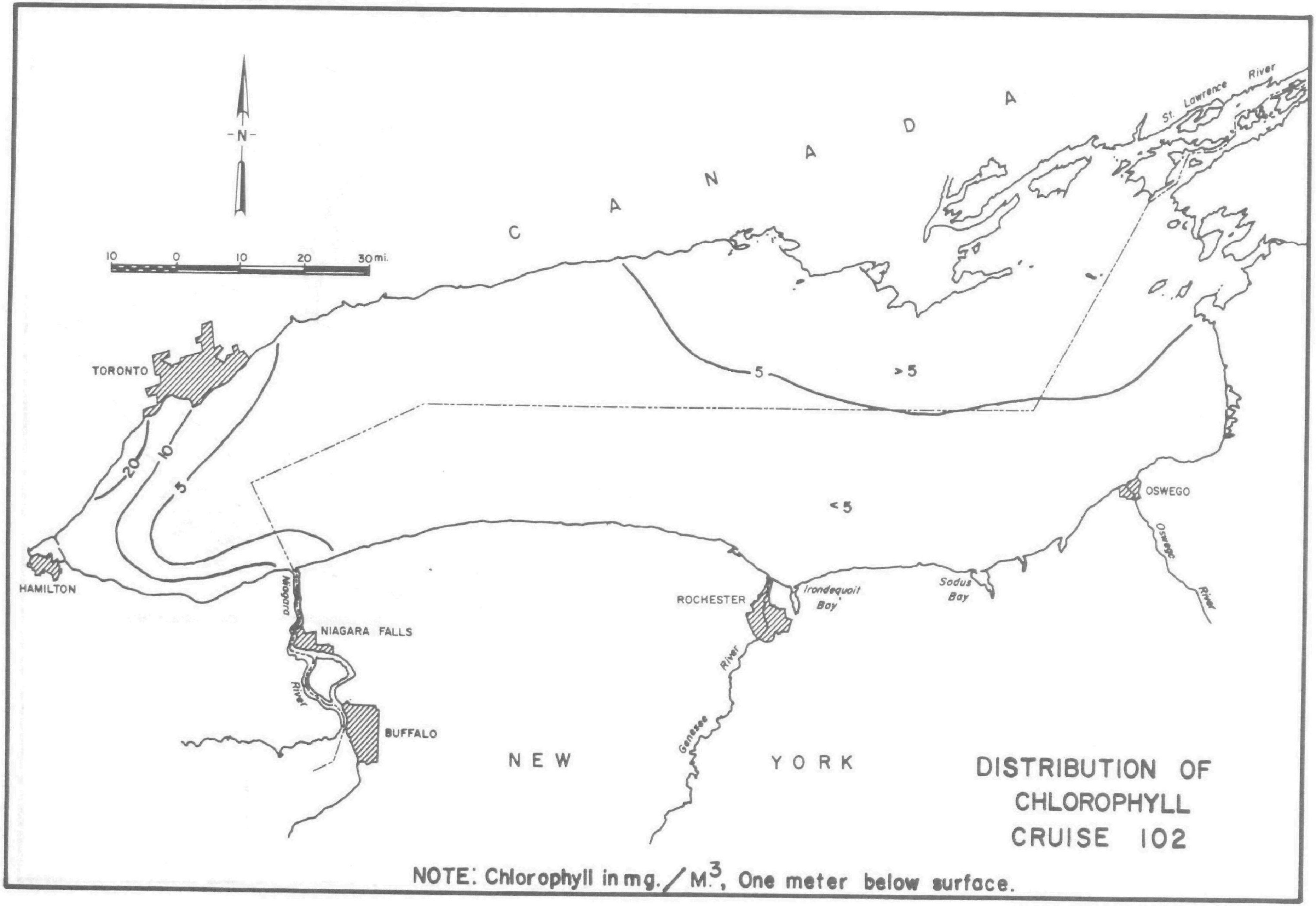
Chlorophyll

Chlorophyll concentrations are indicative of the planktonic concentrations present in the water mass inasmuch as the amount of chlorophyll is related to the photosynthetic process.

Data from Cruise 102 (Figure 3-5) show large amounts of chlorophyll in the western end of the basin. This probably represents a spring pulse which also shows up in the chemistry data (Figure 5-21) as an area where supersaturation values for dissolved oxygen were observed. The lowest chlorophyll values (less than 5 milligrams/meter^3) were observed in the area of Scotch Bonnet Shoal and appear to be in the same area where high diatom densities were reported; however, the diatom population may have been at a different depth than where the chlorophyll sample was taken. This distribution pattern corresponds with the temperature and circulation of the lake observed at the same time.

Data from Cruise 103 (Figure 3-6) show an overall increase in the chlorophyll. Notable were the high chlorophyll concentrations found off the Genesee River; whereas both the Niagara and Oswego Rivers showed no such levels of concentration.

Data from Cruise 104 (Figure 3-7) while incomplete (no samples were taken east of Sodus Bay), show a further increase in chlorophyll concentrations. Values above 10 milligrams/meter^3 are found near the river mouths, Scotch Bonnet Shoal, mid-lake, and in the Toronto-Hamilton area. At no time were concentrations below 5 milligrams/meter^3 observed.



DISTRIBUTION OF CHLOROPHYLL CRUISE 102

NOTE: Chlorophyll in mg./M^3, One meter below surface.

FIGURE 3-5

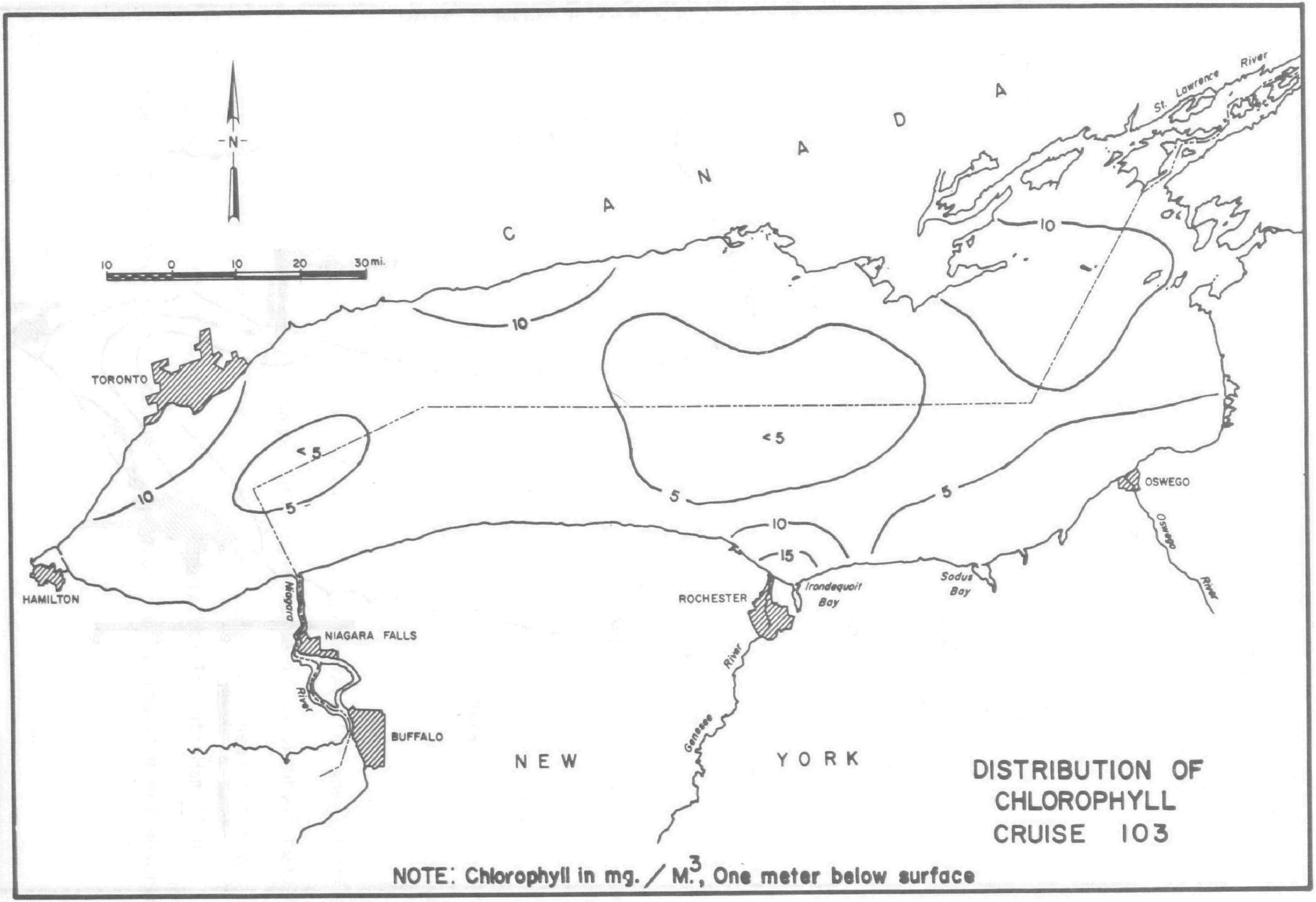

CANADA
St. Lawrence River
N
10 0 10 20 30 mi.
TORONTO
HAMILTON
Niagara
NIAGARA FALLS
River
BUFFALO
ROCHESTER
Irondequoit Bay
Sodus Bay
OSWEGO
Oswego River
Genesee River
NEW YORK
10
10
10
<5
<5
5
5
5
10
15
DISTRIBUTION OF CHLOROPHYLL CRUISE 103
NOTE: Chlorophyll in mg. / M.^{3}, One meter below surface

FIGURE 3-6

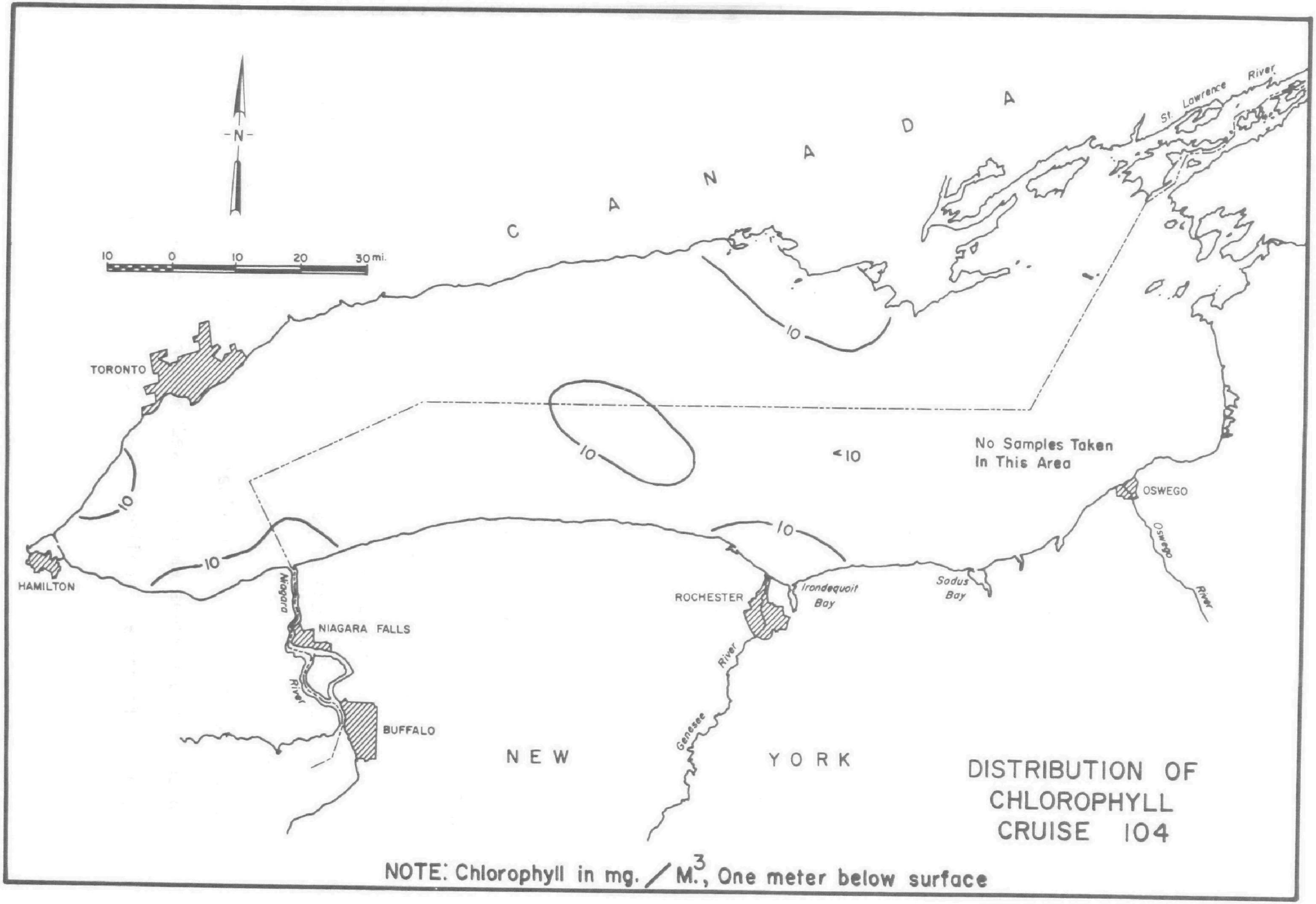

N
10 0 10 20 30 mi.
C A N A D A
St. Lawrence River
TORONTO
HAMILTON
10
<10
No Samples Taken
In This Area
OSWEGO
Oswego River
Niagara River
NIAGARA FALLS
BUFFALO
ROCHESTER
Irondequoit Bay
Sodus Bay
Genesee River
NEW YORK
DISTRIBUTION OF
CHLOROPHYLL
CRUISE 104
NOTE: Chlorophyll in mg. / M.³, One meter below surface

FIGURE 3-7

In general, the distribution of chlorophyll concentrations reflects temperature and circulation patterns at the time of sampling. The results presented here represent the first lake-wide chlorophyll sampling carried out on Lake Ontario. Some of the apparent discrepancies, such as the development of chlorophyll concentrations off the Genesee River and no apparent concentrations at other stream mouths, may represent flow conditions or a difference of density between lake and stream waters, and,because sampling was carried out only at a depth of one meter, a concentration of plankton at a different depth would have been missed.

It is felt, however, that with refinement the chlorophyll concentrations in conjunction with chemical data (nutrient concentrations) will enable one to estimate the plankton crop.

Cladophora

Probably the major and most perplexing biological problem in Lake Ontario is the yearly crop of *Cladophora* . The genus *Cladophora* is an attached branched filamentous green alga, whose distribution is worldwide. Along with a sufficient nutrient level, a suitable bottom, such as rocks or other coarse material, is necessary for the growth of Cladophora. In Lake Ontario, most nutrient-rich waste effluents are discharged into the water float on the surface and drift to accumulate in the inshore areas where the sedimentary material, largely cobblestones, affords an excellent bottom for algal attachment

Prolific growths of *Cladophora* have been reported in Lake Ontario as far back as 1932 (Neil and Owen, 1954). The distribution of *Cladophora* appears to be governed by water movements, for the growths are most prolific where currents keep the supply of nutrients high. Where local conditions tend to hinder water movement, the concentrations are lower. This alga also appears to be quite tolerant of temperature, for it is found growing under a wide range of temperatures. Light penetration governs the depth at which *Cladophora* are found; in Lake Ontario it is found at depths of 30 feet or more. On oceanographic equipment located in mid-lake, growths of *Cladophora* were found on current meters located at the 50-foot level. *Cladophora* also develop best in an environment where pH (Prescott's findings may be misleading, inasmuch as the higher pH values may be the result of, not the cause of, *Cladophora* growths) values are high (Prescott, 1951), such as are found in Lake Ontario. The results of studies by Neil and Owen (1954) to determine the limiting factors suggested that phosphorus, rather than nitrogen, is the limiting nutrient.

Cladophora growth begins in early spring with a fringe-like growth and develops rapidly into strands 15 inches or so in length by late June. These strands at times break away from their substrate, drift up onto the shore, decompose, and cause strong odors and an unsightly condition.

During the early summer months at Lake Ontario bathing beaches, it is a common occurrence to see no swimmers in the water and life- guards raking and shoveling Cladophora mixed with dead fish, (the di off of alewives begins in May and continues until late July), parti- cularly in areas where artificial groins have trapped the algae and dead fish by their interference with the littoral drift, such as occ at Webster Beach near Rochester. To say that it is an unsightly mes that lakeshore property values are affected, and that recreation is impaired, is indeed an understatement.

Fishing

Lake Ontario never has had a good commercial fishery. While ca particularly in the years before 1930, were considered good, with an annual production of approximately 5 million pounds, the annual proc tion has now dropped to less than 2 million pounds. The decline in commercial fishery is related to the decline of the desirable specie such as lake trout and cisco, and is not indicative of the total fis life contained within the lake, inasmuch as the numbers of certain species of fish have increased, particularly the alewife, white perc and smelt.

Sea-lamprey predatism, which threatens the lake trout when it fairly mature (about three years old), is a major factor in the dec of lake trout. Lake Ontario was the first of the Great Lakes to be invaded by the sea lamprey. However, it is difficult to see how the lamprey alone could account for the decline of the lake trout, inasmuch as the lamprey has been present in the lake since before 1900 and the major decline of lake trout began in 1930. (The first heavy growths of *Cladophora* in the lake were first reported in 1932). Also significant is the predatism of the increasing numbers of alewife and smelt, which threatens the trout spawn. Interesting is the increasing number of reports of a spring run of rainbow trout, which, unlike the lake trout, is a stream spawner and thus may escape the early predatism by other lake fish. The fact that Lake Ontario does not have a balanced fish population or a significant commercial harvest, in effect, increases the propagation of algae.

Alewives present a serious problem in Lake Ontario because they apparently have a two-year life cycle, and in late May or June, when the die-off is most severe, numerous windrows of dead fish are visible throughout the lake. These fish eventually drift or are driven into the littoral zone. Decomposition of these fish enriches the inshore waters with large amounts of nutrients, notably phosphorus. This may indirectly stimulate the heavy growths of *Cladophora*.

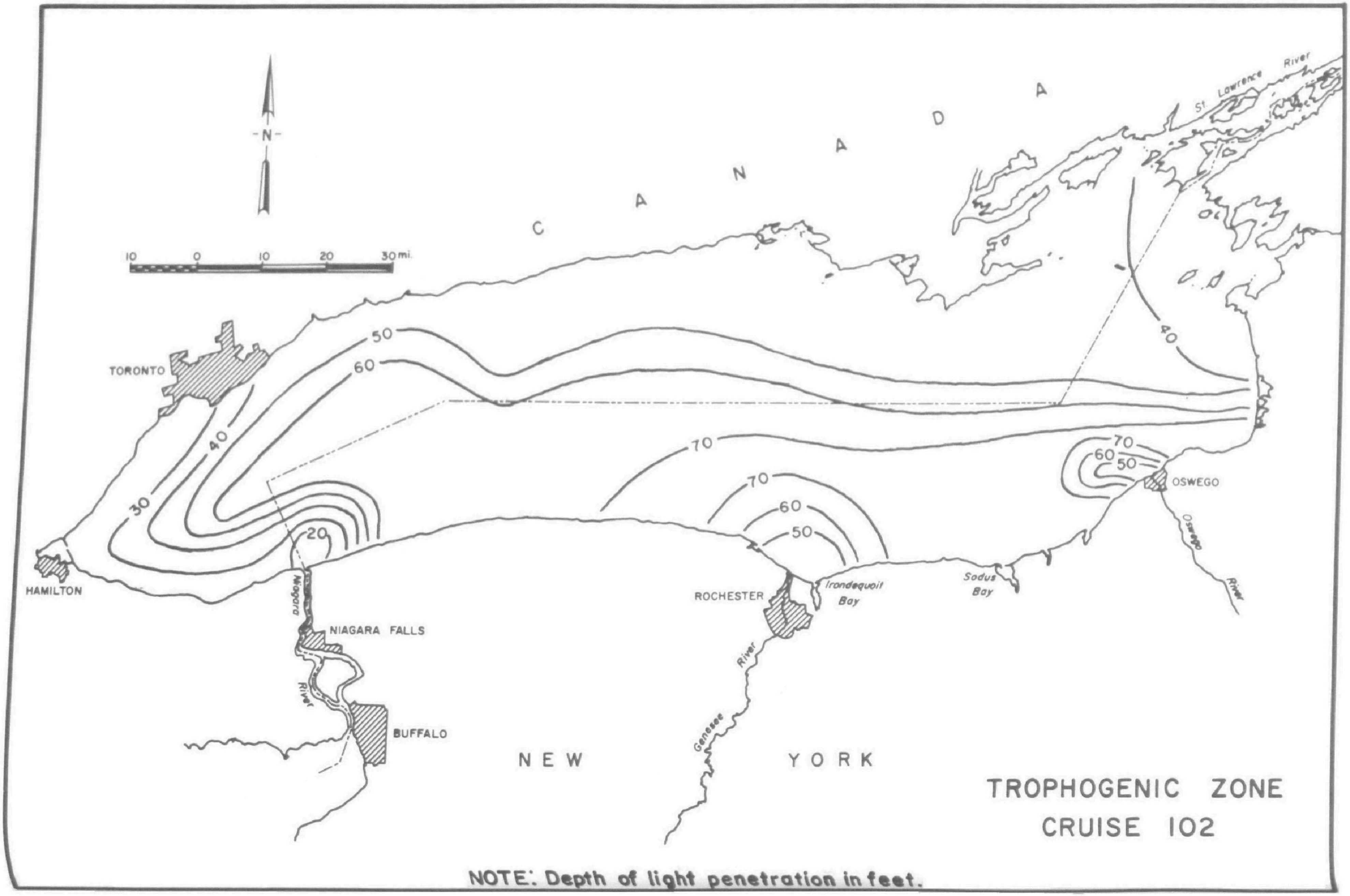
A suggested solution is that a commercial alewife fishery be developed and that efforts be made to promote the growth of desirable species of fish, possibly the rainbow trout or coho salmon. This would help to cut down on the number of alewives and smelt while increasing the number of desirable species and, in effect, would remove phosphat from the water mass by harvesting and by increased retention (storage time in the phosphate cycle. It should be pointed out here that such fish as coho salmon and rainbow trout need unpolluted streams for spawning. If, for example, the number of alewives present in Lake Ontario is proportional to the number in Lake Michigan, as reported by the Bureau of Commercial Fisheries, 150,000 pounds of phosphate could be harvested each year without affecting the alewife population. This would amount to less than a one percent removal of the gross input of phosphate each year, but, if one assumes that during the month of June input to the Ontario phosphate budget is reduced by 150,000 pounds because of a reduction in die-off, the actual effect of this is much greater, perhaps as much as 20 percent, particularly if the harvesting was done in early spring. A thorough study, however, should be made before introducing any new species of fish into Lake Ontario so that the long-term result is not merely the substitution of one problem for another.

Trophogenic Zone

The trophogenic zone is defined by Ruttner as "the superficial layer of a lake in which organic production from mineral substances takes place on the basis of light energy". This zone has been further defined as the layer that encompasses 99 percent of the incident light. The thickness of the trophogenic zone in Lake Ontario was measured by a submarine photometer, which consisted simply of an incident light reference cell and a submergible cell that was lowered until it measured a light value that was one percent of the value recorded by the reference cell. Inasmuch as the length of daylight in the lake depths is inversely proportional to the depth, and sampling was carried out throughout the day, these data should be considered only fair.

Light penetration into lake water is an important physical factor for plant life. If light penetration is low, it affects the whole biology. The principal factors that affect the depth of penetration are suspended plants and animals and suspended particulate material such as clays, silts, and colloids.

Figures 3-8, 3-9, and 3-10 show the depth of the trophogenic zone for the three cruises. In May (Cruise 102), Figure 3-8, the shallowest penetration was recorded near the mouths of the major rivers, as one would expect at this time of year. The shallow penetration (20 feet) shown at the mouth of the Niagara River, as compared to the value found off the Genesee and Oswego Rivers (50 feet), is probably due to sampling locations and not to a significant difference in turbidity



NOTE: Depth of light penetration in feet.

FIGURE 3-8

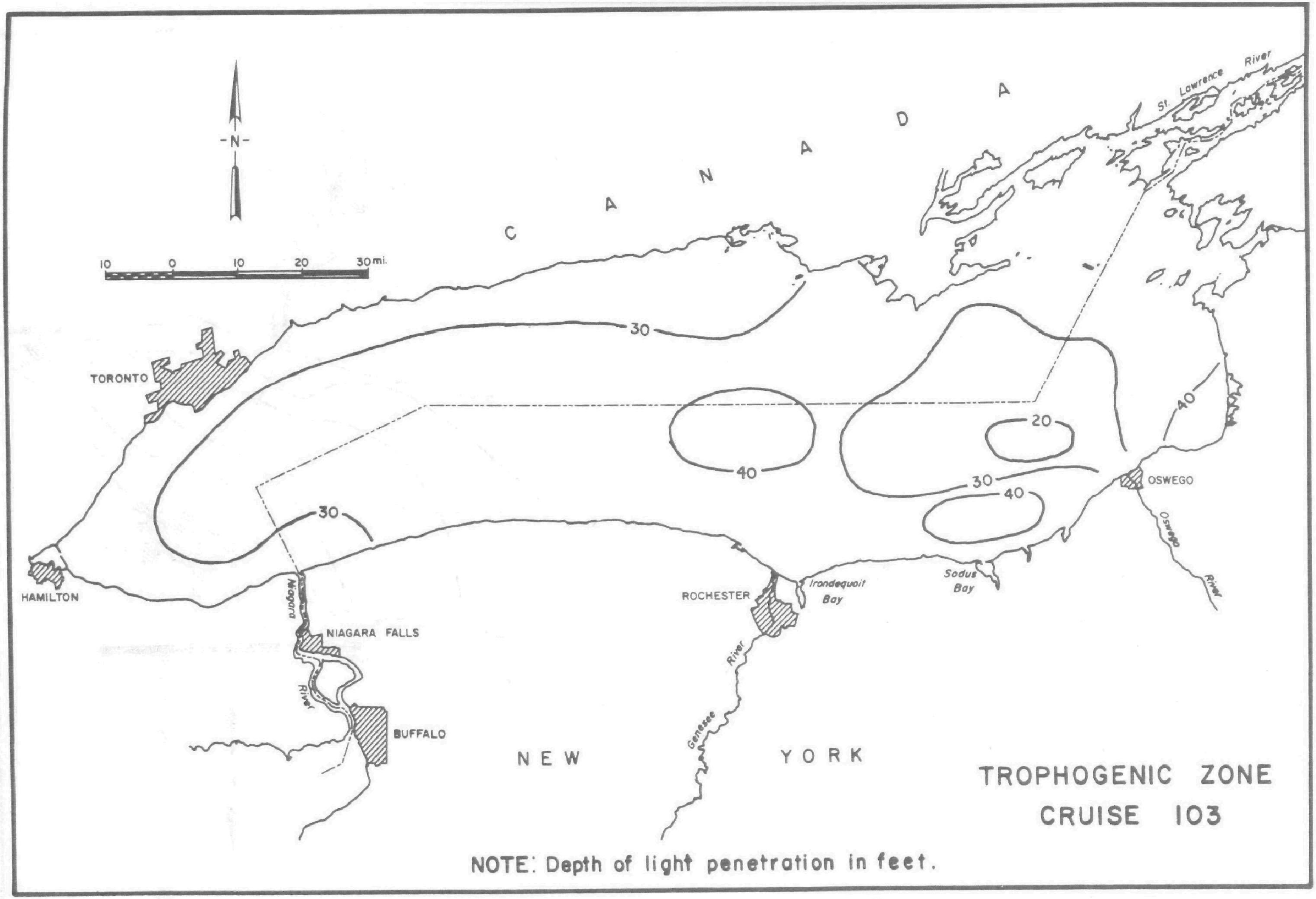
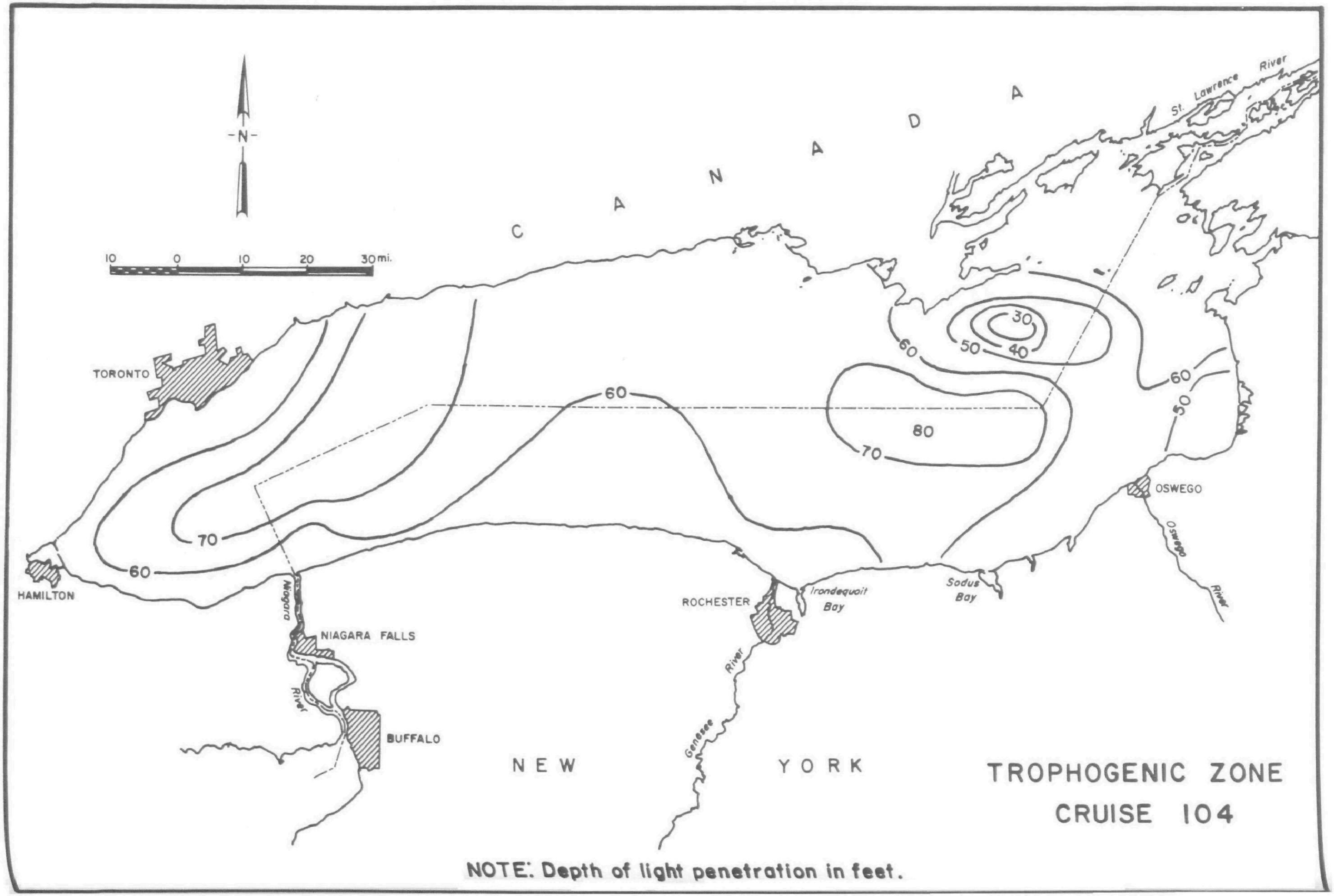

C A N A D A
St. Lawrence River
10 0 10 20 30 mi.
N
TORONTO
HAMILTON
Niagara
NIAGARA FALLS
River
BUFFALO
ROCHESTER
Irondequoit Bay
Sodus Bay
OSWEGO
Oswego River
Genesee River
N E W Y O R K
30
40
20
TROPHOGENIC ZONE
CRUISE 103
NOTE: Depth of light penetration in feet.

FIGURE 3-9



TROPHOGENIC ZONE
CRUISE 104
NOTE: Depth of light penetration in feet.
N
10 0 10 20 30 mi.
C A N A D A
St. Lawrence River
TORONTO
HAMILTON
Niagara River
NIAGARA FALLS
BUFFALO
ROCHESTER
Genesee River
Irondequoit Bay
Sodus Bay
OSWEGO
Oswego River
NEW YORK
30
40
50
60
70
80

FIGURE 3-10

caused by river discharge. In May, the difference in depth of trophogenic zone depends principally on suspended silts and clays.

Figure 3-9 shows that the trophogenic zone during Cruise 103 was generally shallower than during Cruise 102. The reason for this is most likely due to an increase in suspended plankton and not to suspended silts and clays. The area of shallow depths off the Oswego River corresponds to the area in which a plankton bloom was reported during July.

Figure 3-10 shows the trophogenic zone distribution for Cruise 104. Immediately apparent are the greatly increased depths.* At this time of year, the fall storms have not yet affected the lake,and the production of plankton has lessened and/or spread out in depth.**

The difference in the general overall depth of the trophogenic zone noted from one cruise to the next indicates a seasonal change in the makeup of the trophogenic zone. In general, these data also agree with water circulation of the lake during these periods. Implicit is the danger of defining a typical physical characteristic such as this on the basis of a few single season measurements.

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*Comparison of Figures 3-8, 3-9, and 3-10 with Figure 2-1, shows the limited zone where light reaches the bottom.

**During this calm period in the fall, the lake is cooling; thus the density of the epilimnion is changing and increasing in depth.

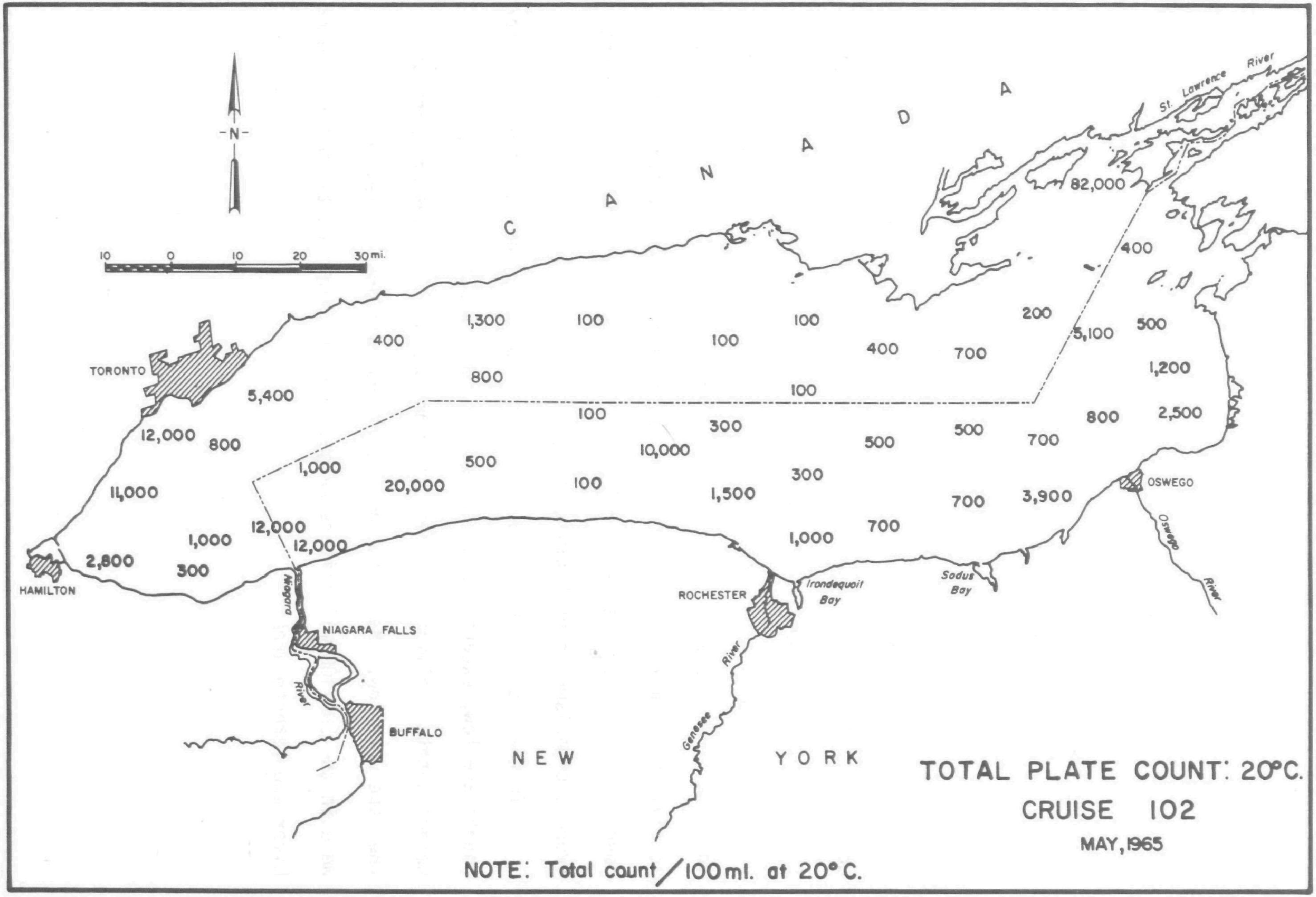
Chapter 4

MICROBIOLOGY OF LAKE ONTARIO

Introduction

The microbiological study in the Lake Ontario Basin investigated the parameters of total coliform and total plate counts. All of these tests were conducted using the membrane filter technique. The total coliform test is used as an index of all coliform organisms present and does not differentiate those of fecal and non-fecal origin. The total plate counts is a supplemental test which uses a nutrient media conducive to the growth of bacteria, including those of natural waters and the intestines. Plate counts at 20°C (Figure 4-1 and 4-2) are considered to give an estimate of heterotrophic bacteria in natural waters. Plate counts at 35°C (Figures 4-3 and 4-4) are considered indicative of heterotrophic organisms of pollutional origin.

In the eastern end of the lake, total plate counts and total coliform counts are low, except during Cruise 103, when a slight increase was noted in total coliform. Total coliform counts in the western part of the lake were low. Many stations showed no coliforms; a few, however, were in the 500/100 milliliters range, with the high counts in the Niagara River and Toronto area.



C A N A D A
St. Lawrence River
10 0 10 20 30 mi.
N
TORONTO
HAMILTON
Niagara River
NIAGARA FALLS
BUFFALO
ROCHESTER
Genesee River
Irondequoit Bay
Sodus Bay
OSWEGO
Oswego River
NEW YORK
82,000
400
200
5,100
500
1,200
2,500
800
1,300
100
100
100
400
700
400
800
5,400
100
12,000
800
100
300
10,000
500
500
700
1,000
20,000
500
100
1,500
300
700
3,900
11,000
12,000
12,000
1,000
1,000
700
2,800
300
TOTAL PLATE COUNT: 20°C.
CRUISE 102
MAY, 1965
NOTE: Total count / 100 ml. at 20° C.

FIGURE 4-1

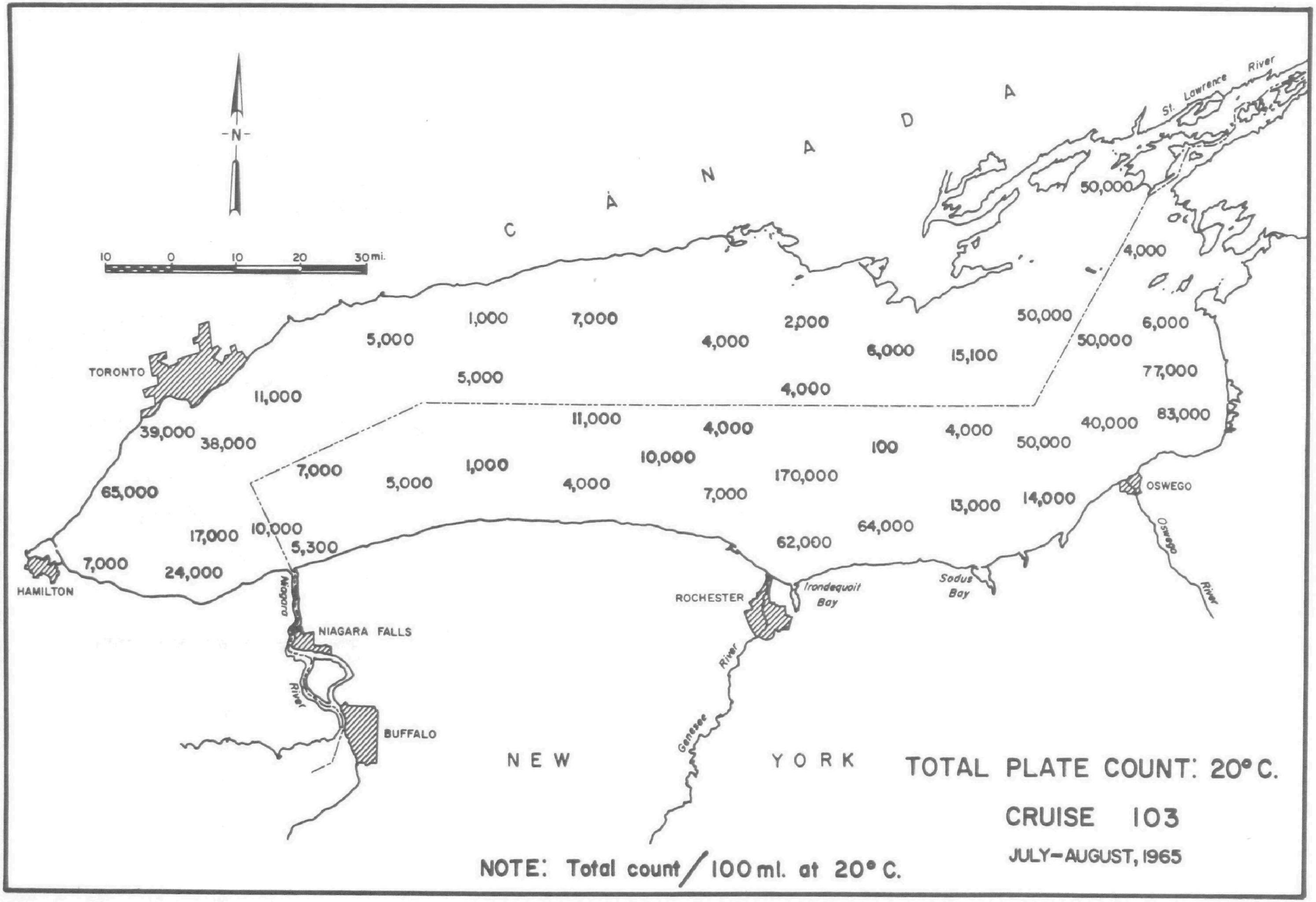

CANADA
St. Lawrence River
N
10 0 10 20 30 mi.
TORONTO
HAMILTON
NIAGARA FALLS
Niagara
River
BUFFALO
ROCHESTER
Genesee River
Irondequoit Bay
Sodus Bay
OSWEGO
Oswego River
NEW YORK
50,000
4,000
1,000
7,000
5,000
2,000
4,000
6,000
15,100
50,000
50,000
6,000
77,000
5,000
4,000
11,000
11,000
4,000
4,000
100
50,000
40,000
83,000
39,000
38,000
7,000
5,000
1,000
10,000
4,000
170,000
7,000
13,000
14,000
65,000
17,000
10,000
5,300
64,000
62,000
7,000
24,000
TOTAL PLATE COUNT: 20° C.
CRUISE 103
JULY—AUGUST, 1965
NOTE: Total count / 100 ml. at 20° C.

FIGURE 4-2

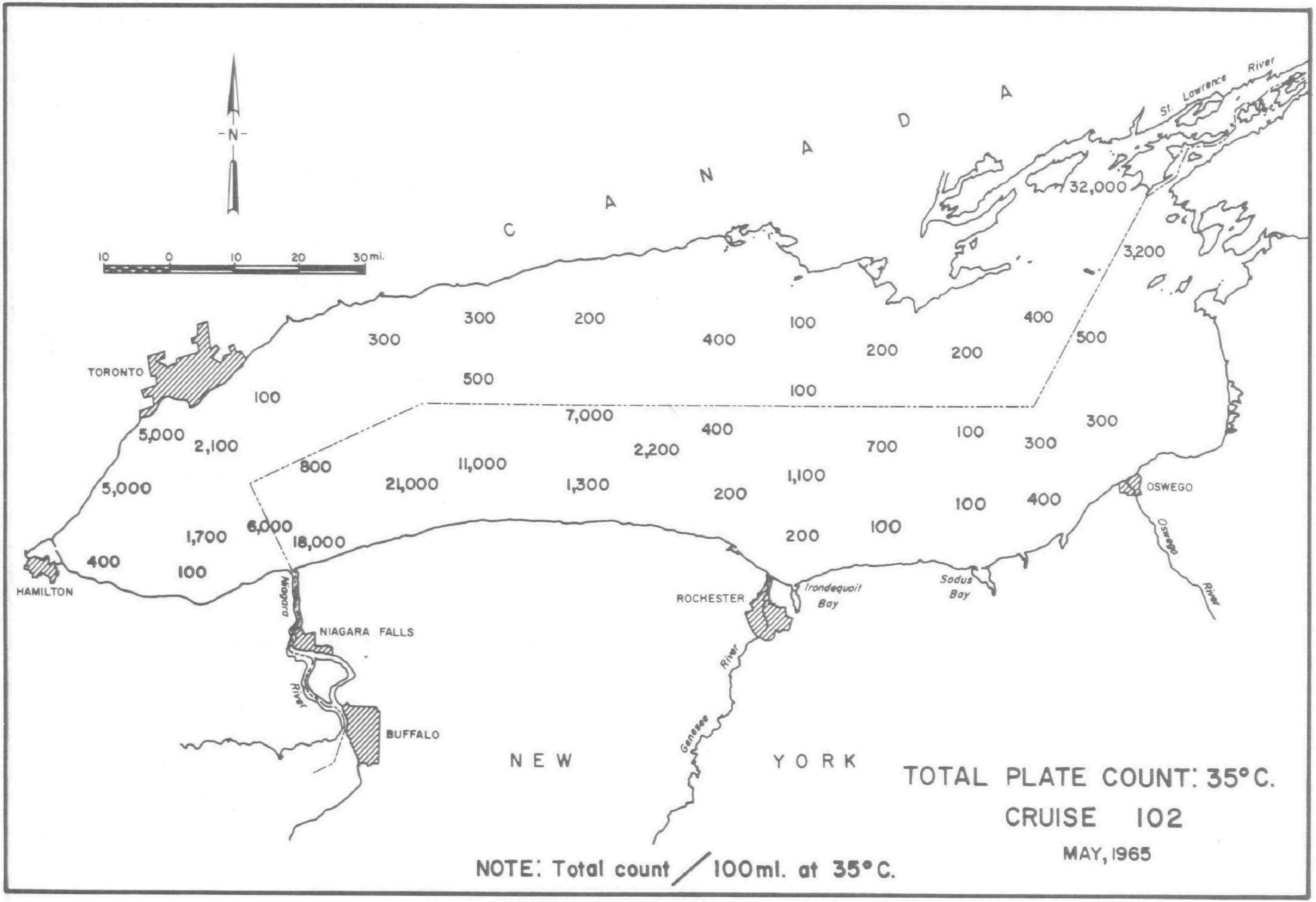

N
10 0 10 20 30 mi.
C A N A D A
St. Lawrence River
TORONTO
HAMILTON
NIAGARA FALLS
Niagara River
BUFFALO
ROCHESTER
Genesee River
Irondequoit Bay
Sodus Bay
OSWEGO
Oswego River
NEW YORK
32,000
3,200
300
300
200
400
100
200
200
400
500
500
100
100
7,000
400
100
300
300
5,000
2,100
2,200
700
800
11,000
21,000
1,300
1,100
5,000
200
100
400
6,000
1,700
18,000
200
100
400
100
TOTAL PLATE COUNT: 35° C.
CRUISE 102
MAY, 1965
NOTE: Total count / 100ml. at 35° C.

FIGURE 4-3

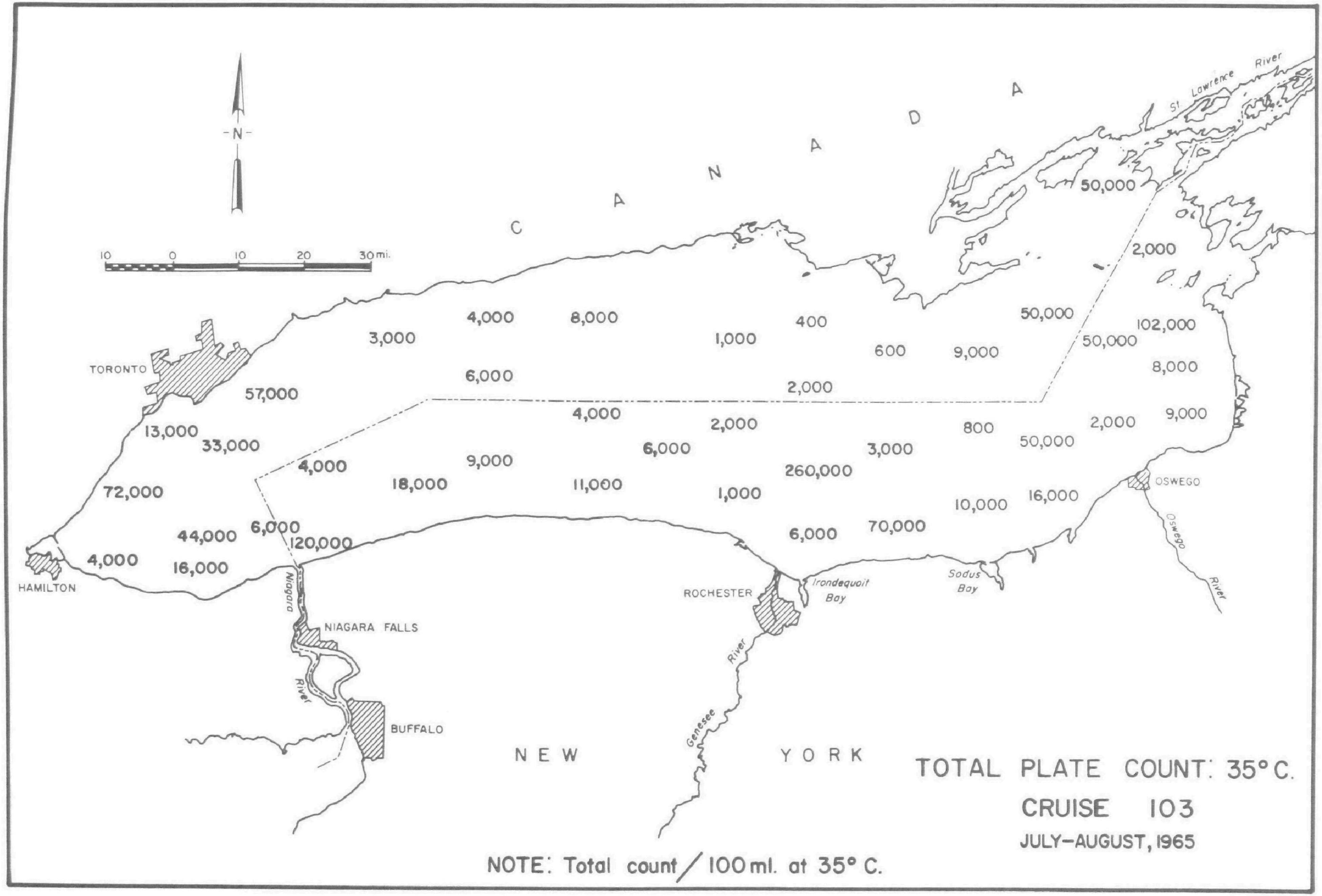

CANADA
St. Lawrence River
TORONTO
HAMILTON
NIAGARA FALLS
Niagara
River
BUFFALO
ROCHESTER
Genesee River
Irondequoit Bay
Sodus Bay
OSWEGO
Oswego River
NEW YORK
N
10 0 10 20 30 mi.
50,000
2,000
3,000
4,000
8,000
1,000
400
600
9,000
50,000
102,000
50,000
8,000
57,000
6,000
2,000
4,000
2,000
800
2,000
9,000
13,000
33,000
6,000
3,000
50,000
4,000
9,000
18,000
11,000
260,000
72,000
1,000
10,000
16,000
44,000
6,000
120,000
6,000
70,000
4,000
16,000
TOTAL PLATE COUNT: 35° C.
CRUISE 103
JULY–AUGUST, 1965
NOTE: Total count / 100 ml. at 35° C.

FIGURE 4-4

The central area of the lake has the lowest bacteria counts of all. Part of the central area did have higher counts of total coliforms and total bacteria. Of these low counts, the non-pollutional plate counts were in the vicinity of Rochester, and a gradational distribution of these higher counts towards the northeast was noted. Total coliform counts were low, with some stations recording zero during Cruise 102. The higher of these low counts was recorded in the southern part. At station 23, the total coliform counts were near 500 coliforms/100 milliliters.

The eastern end of the lake showed higher bacterial values, especially near the Oswego River. Total plate counts indicated a greater amount of 20°C (non-pollutional) organisms than the 35°C (pollutional) organisms. Total coliform counts were low.

The role that bacteria play in the lake environment is important. However, it is an extremely complex subject of which little is known. We do know that certain types of bacteria reduce sulphate and fix nitrogen, and that some secrete such compounds as calcium carbonate and ferric hydroxide, but knowledge of the chemistry of this bacterial action is lacking. Bacteria, in general, through metabolic processes, break down substances into simpler forms which, in effect, make them more acceptable to the algae.

Chapter 5

CHEMISTRY

Introduction

The chemistry of the lake waters and the streams entering the lake is most important, for it is the mineral substances dissolved in these waters that govern the type and quantity of the animal and human communities that establish themselves within the lake basin. How fit these waters are for human consumption, fish life, recreation, industry are all factors that govern the long-term productivity of this region.

The chemistry of the lake waters is constantly changing, adjusting to biological, physical, and chemical demands or changes. Thus, chemical parameters in themselves are not as directly meaningful as we would desire them to be in evaluating a large lake. Many elements and/or compounds are part of a biogeochemical system. Consequently, a measurement of a particular element or compound represents only what is existing in that part or phase of the system; it does not represent the quantity or speed of an element or compound moving through the system. For example, sediments may be able to supply from storage certain substances to the water mass as rapidly as the biota may use them, and, as a consequence, the concentration of that substance in the water mass would remain constant.

In a lake, the concept of availability to a biogeochemical system as opposed to concentration of a dissolved substance per se is important; since the lakes have a stability (long retention time) unlike streams, where the chemical part of these biogeochemical systems can, and in many cases do, reach and remain at equilibrium and may or may not remain in that state.

The most immediate problem, however, is the control of algae. The implication is that any chemical substance used by the algae is part of a system or cycle and that availability or lack, rather than concentrati is the measure of control.

Nitrogen

Nitrogen occurs in Lake Ontario in five major forms: atmospheric nitrogen (N_2), ammonia, (NH_4^{+1}), nitrite (NO_2^{-1}), nitrate (NO_3^{-1}), and as organic nitrogen compounds. Nitrogen is a fundamental element in an organism's metabolism, which is the synthesis and maintenance of protoplasm.

"Nitrogen chemistry is controlled largely by biochemical reactions in natural waters". (Lee & Hoadly, 1967, p. 327). The oxidation and reduction of nitrogen compounds (nitrogen cycle) are principally the result of enzymatic processes.

A graphic comparison of (trilinear diagrams) the relative amounts of nitrate nitrogen, ammonia nitrogen, and organic nitrogen, by percent weight, in Lake Ontario, using data from FWPCA cruises 102 (May 1965), 103 (July 1965), and 104 (September 1965), Figures 5-1, 5-2, and 5-3 respectively, shows that in the spring the surface layer is rich in nitrate[1], but by July an increase in organic nitrogen compounds occurs with a related decrease in nitrate and ammonia. In the fall, the amount of organic nitrogen in the surface layer lessens and a corresponding increase in nitrate and ammonia occurs.

Vertically, during the spring (FWPCA 102), the amount of organic nitrogen and nitrate followed no specific pattern, which probably is a reflection of changing lake conditions. Generally, the relation between organic nitrogen and nitrate nitrogen was an inverse one. Ammonia nitrogen concentrations appeared to be random.

Vertically, during the summer (FWPCA 103), a maximum of organic nitrogen was observed just above the thermocline. Nitrate nitrogen concentrations were observed to increase from the surface downward. The nitrate maximum was usually observed at approximately 150 meters deep.

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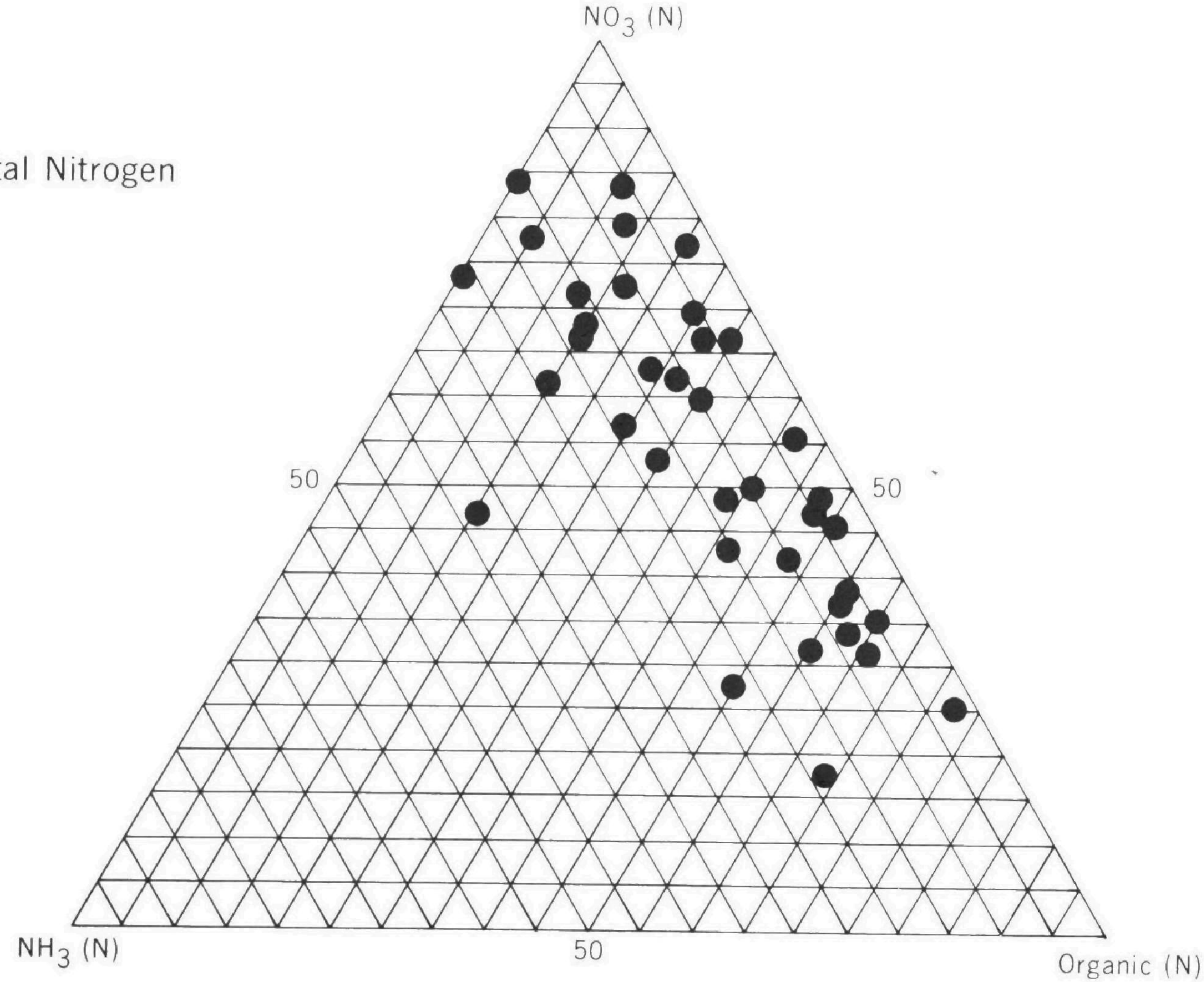
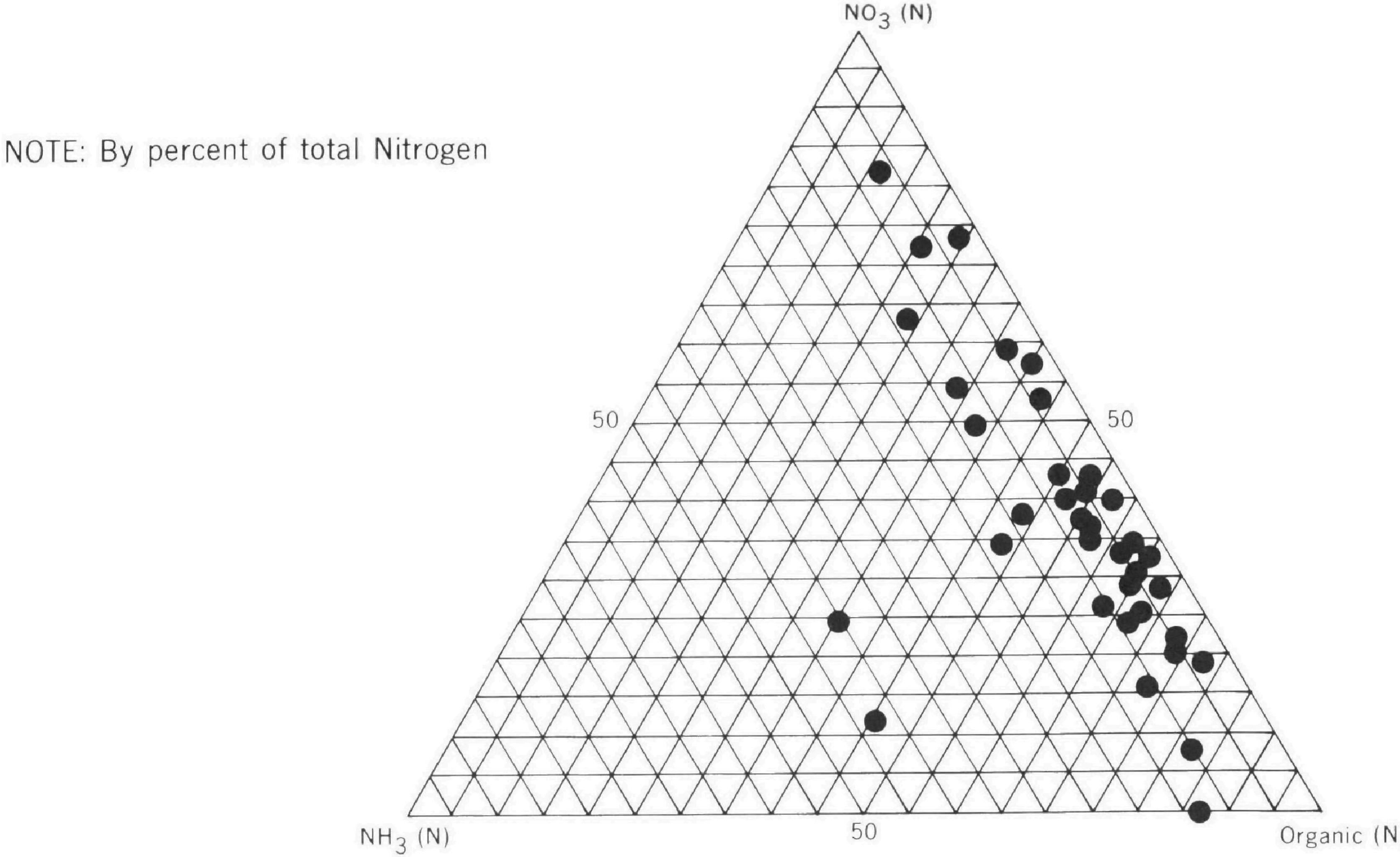
[1] During the spring cruise, photosynthesis was already occurring and is reflected in Figure 5-1. Thus, some nitrate, from supposed higher winter concentrations, has been converted into organic nitrogen.

NOTE: By percent of total Nitrogen



RELATION OF NITRATES, AMMONIA AND ORGANIC NITROGEN
IN
LAKE ONTARIO SURFACE WATER
CRUISE 102
MAY, 1965

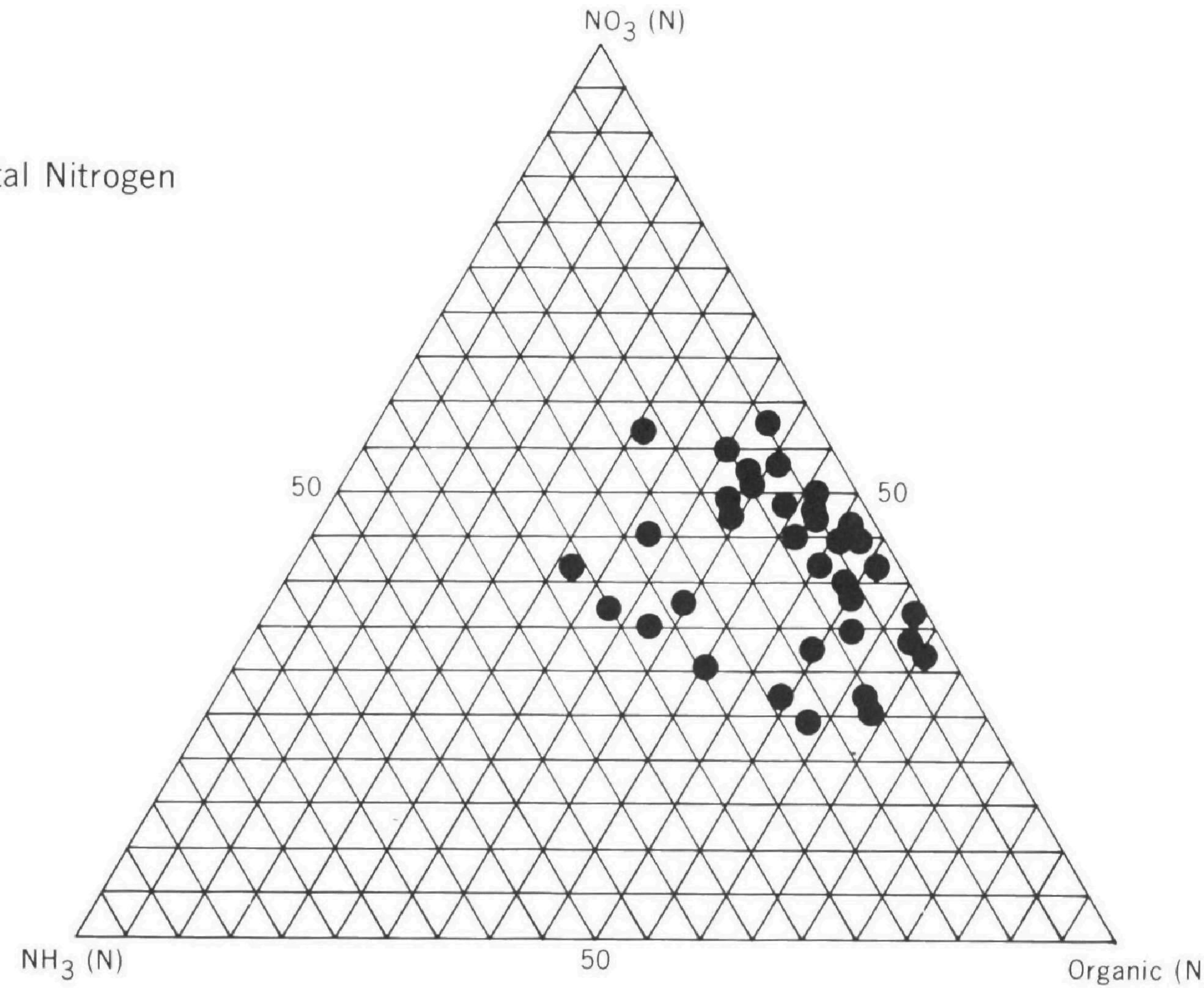
FIGURE 5-1



RELATION OF NITRATES, AMMONIA AND ORGANIC NITROGEN
IN
LAKE ONTARIO SURFACE WATER
CRUISE 103
JULY-AUGUST, 1965

FIGURE 5-2

NOTE: By percent of total Nitrogen



RELATION OF NITRATES, AMMONIA AND ORGANIC NITROGEN
IN
LAKE ONTARIO SURFACE WATER
CRUISE 104

FIGURE 5-3

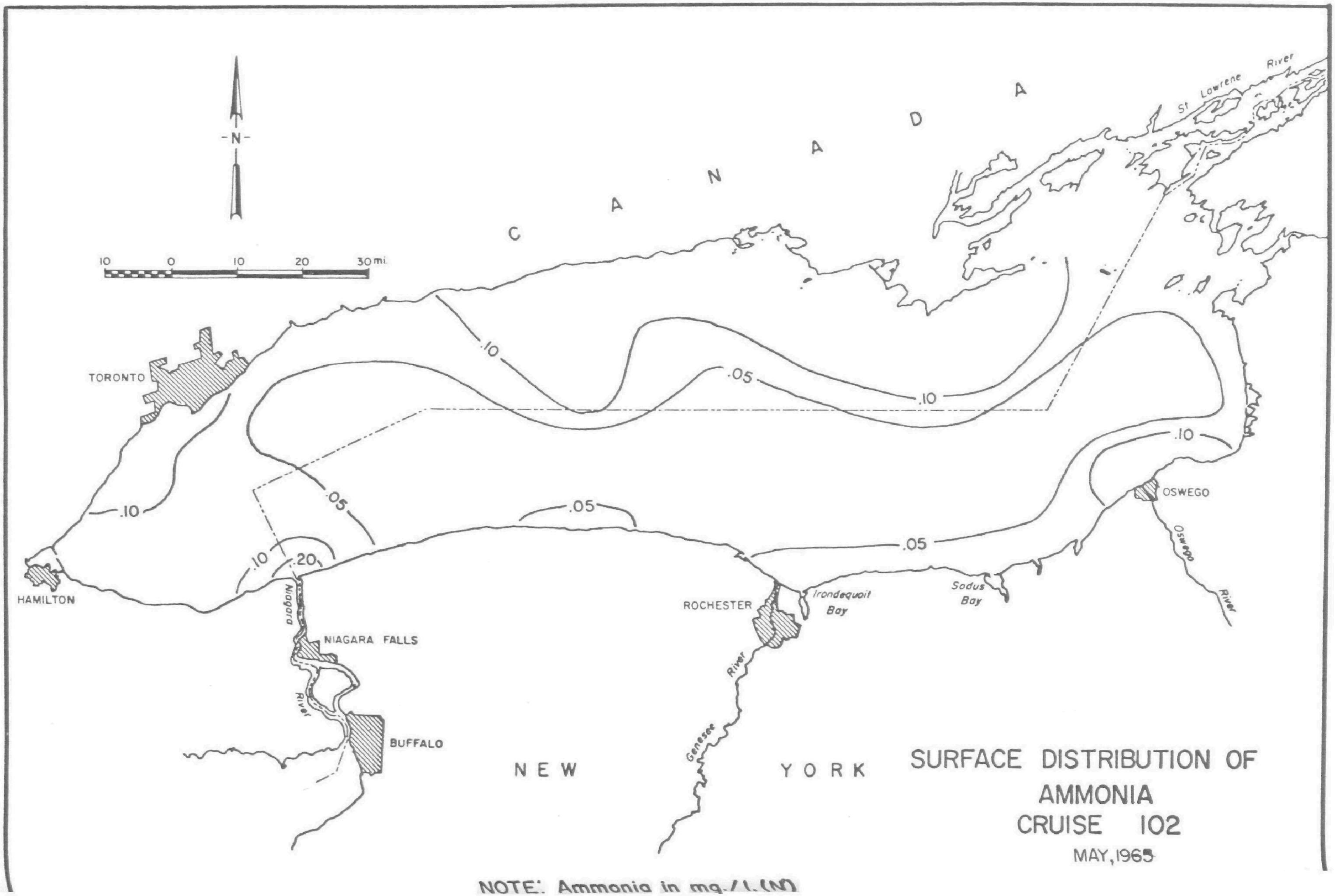
However, this observation could have been affected by sampling procedures. The ammonia nitrogen maximum usually was located just above the thermocline.

Vertically, during the fall (FWPCA 104), an overall increase in nitrate nitrogen concentrations was observed, maximum again occurring at the 150 meter depth. A corresponding decrease in organic nitrogen was observed, maximum again occurring above the thermocline. Ammonia nitrogen varied, but the maximum normally occurring near the thermocline.

Ammonia Nitrogen

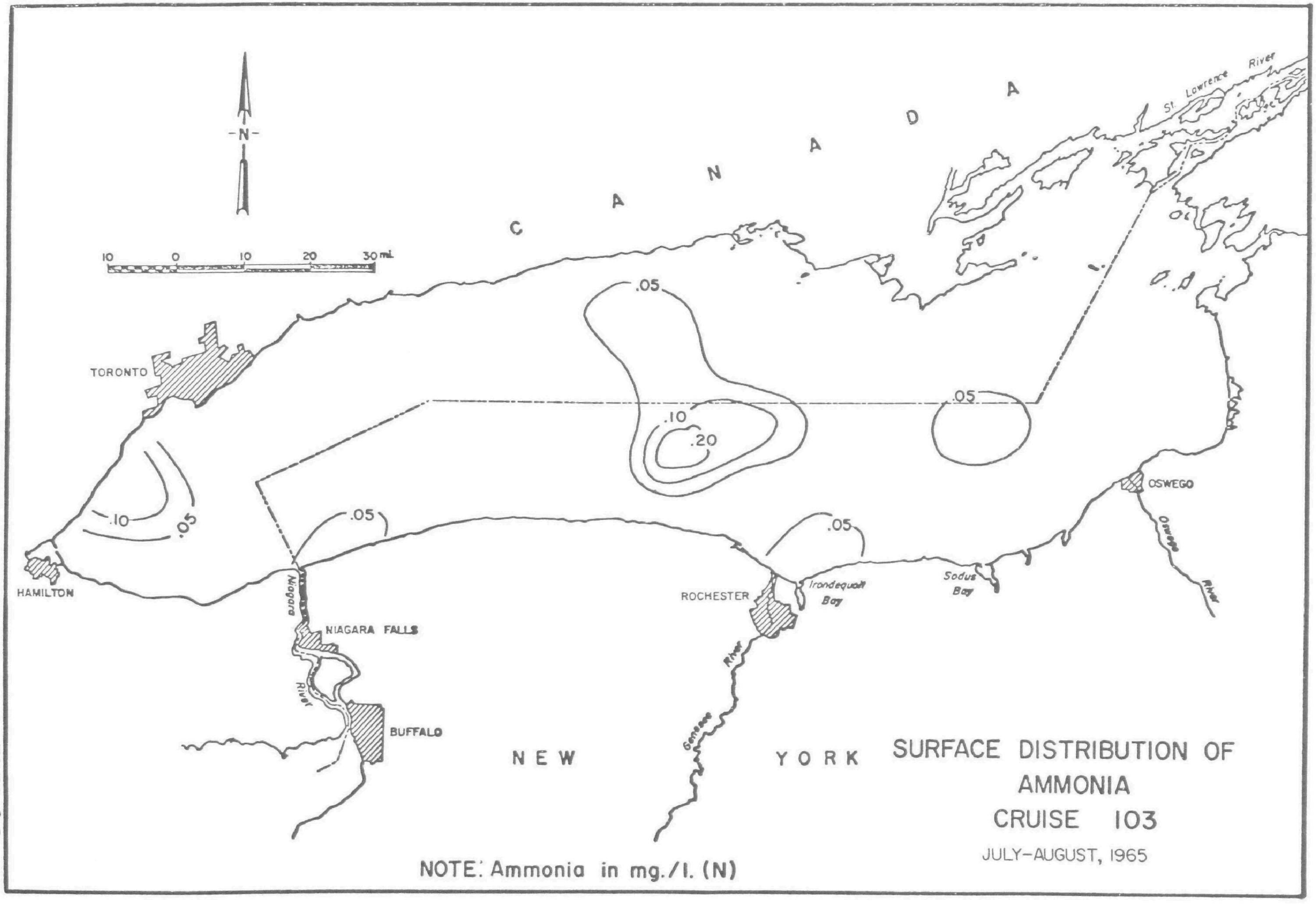
Ammonia nitrogen is formed by the decomposition of plant and animal matter. It is oxidized to nitrate in oxygen-containing waters by microorganisms.

Ammonia is relatively unstable in the water of Lake Ontario. It is first changed to nitrite and then nitrate. Figures 5-4, 5-5, and 5-6 show the distribution of the ammonia in Lake Ontario surface water for FWPCA cruises 102, 103, and 104 respectively. Obviously, the higher concentrations of ammonia observed were in areas of metro-industrial development and stream discharges. The weighted averages (weighted on basis of volume of water mass) for ammonia for FWPCA cruises 102, 103, and 104, were 0.66 mg/l N, 0.04 mg/l N, and 0.07 mg/l N.



NOTE: Ammonia in mg./l. (N)

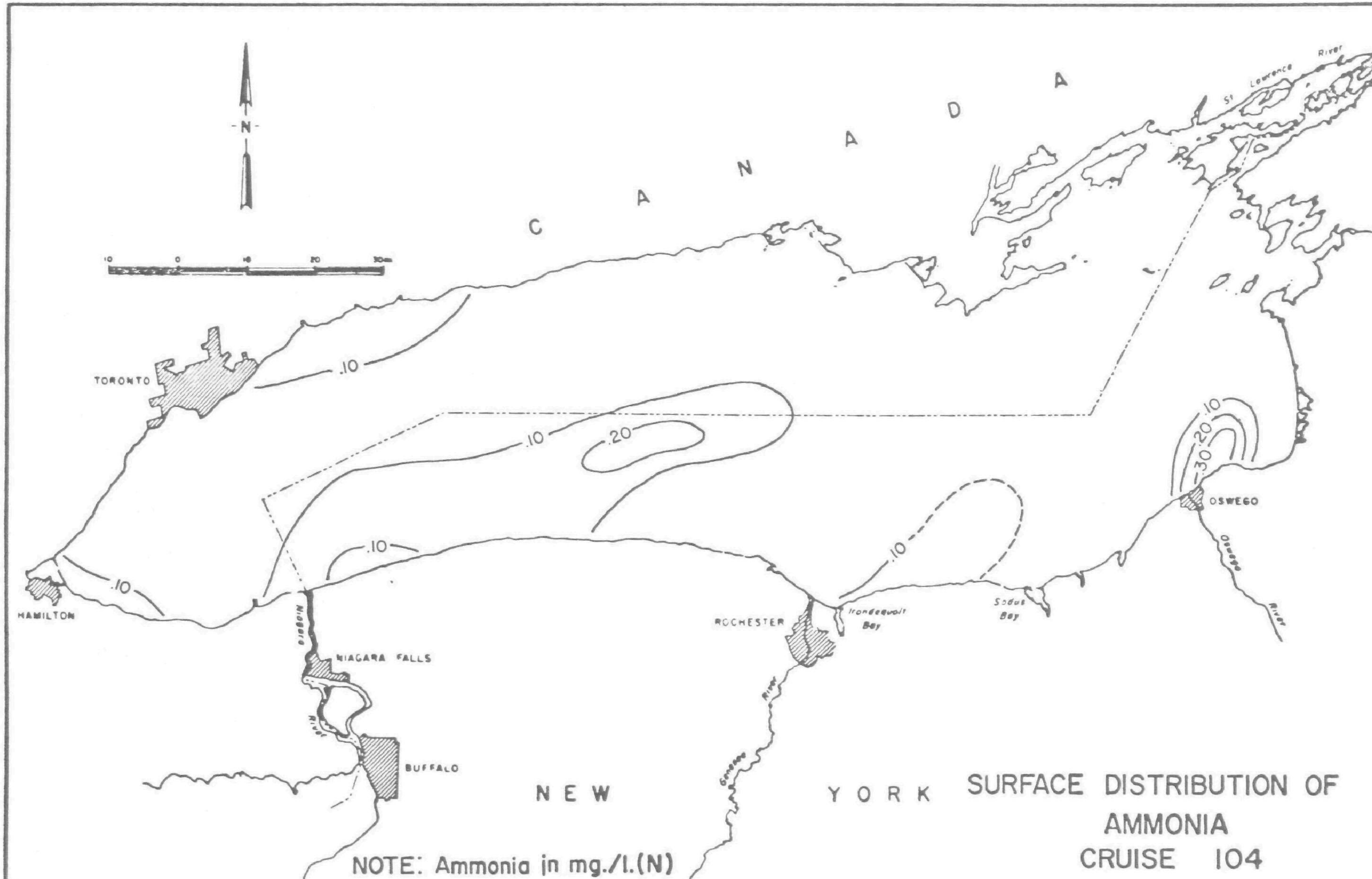
FIGURE 5-4



SURFACE DISTRIBUTION OF AMMONIA
CRUISE 103
JULY-AUGUST, 1965

NOTE: Ammonia in mg./l. (N)

FIGURE 5-5



N
10 0 10 20 30 mi
C A N A D A
St. Lawrence River
TORONTO
HAMILTON
.10
.20
.30
NIAGARA FALLS
Niagara River
BUFFALO
ROCHESTER
Irondequoit Bay
Sodus Bay
OSWEGO
Oswego River
Genesee River
N E W Y O R K
SURFACE DISTRIBUTION OF AMMONIA
CRUISE 104
NOTE: Ammonia in mg./l.(N)

FIGURE 5-6

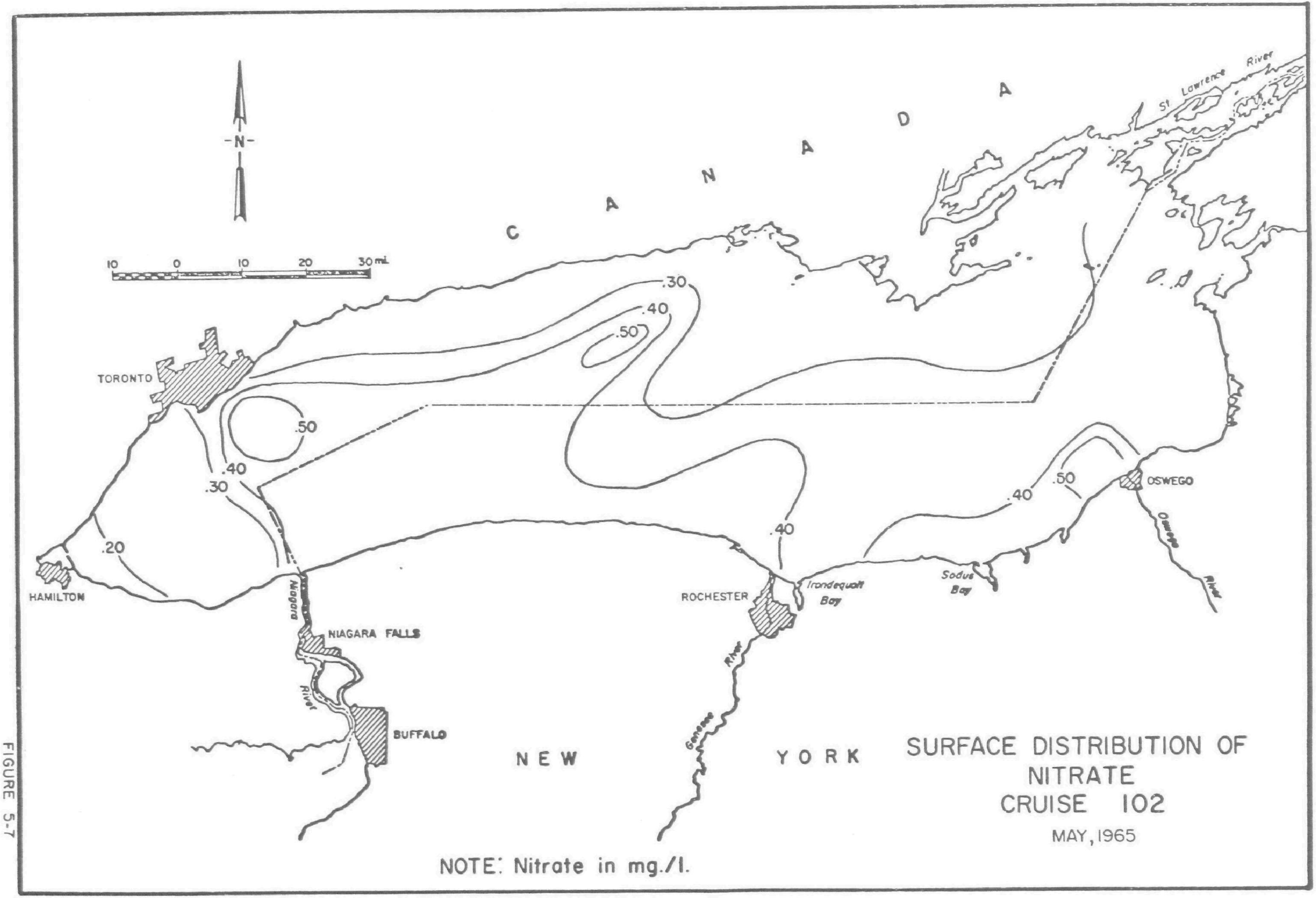
Nitrite

Nitrite, like ammonia, is an intermediate product of the nitrogen cycle and is the result of decomposition; on further oxidation, nitrite is converted to nitrate. In northern fresh water lakes, the regeneration processes of nitrogen apparently run to completion, and inorganic nitrogen is present, principally as nitrate. Consequently, nitrite is transitory in the lake environment. The water samples collected by the FWPCA were not analyzed for nitrite nitrogen.

Nitrate Nitrogen

Nitrate is the most important form of inorganic nitrogen found in natural waters. It is the form of nitrogen which is required by most phytoplankton, and is formed by the oxidation of organic material.

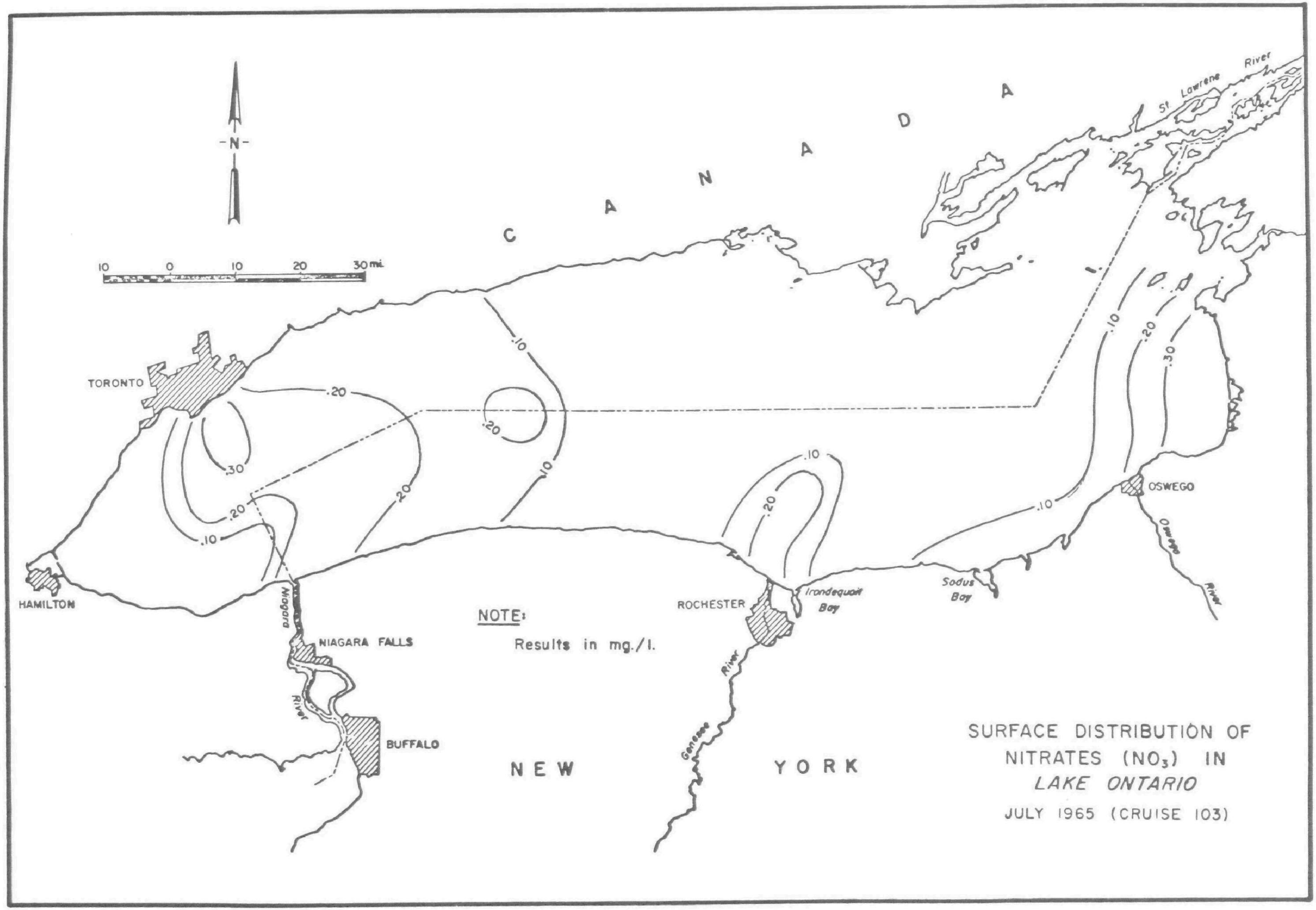
The data collected by the FWPCA in 1965 (Figures 5-7, 5-8, and 5-9, cruises 102, 103, and 104, respectively)show that the highest concentrations of nitrate in the surface water of Lake Ontario were observed in the inshore areas, particularly in areas of influent streams and metro-industrial centers. The weighted averages for nitrate concentrations were 0.34 mg/l N (FWPCA Cruise 102), 0.31 mg/l N (FWPCA Cruise 103), and 0.41 Mg/l N (FWPCA Cruise 104).



SURFACE DISTRIBUTION OF NITRATE
CRUISE 102
MAY, 1965

NOTE: Nitrate in mg./l.

FIGURE 5-7



SURFACE DISTRIBUTION OF NITRATES (NO_3) IN *LAKE ONTARIO*

JULY 1965 (CRUISE 103)

FIGURE 5-8

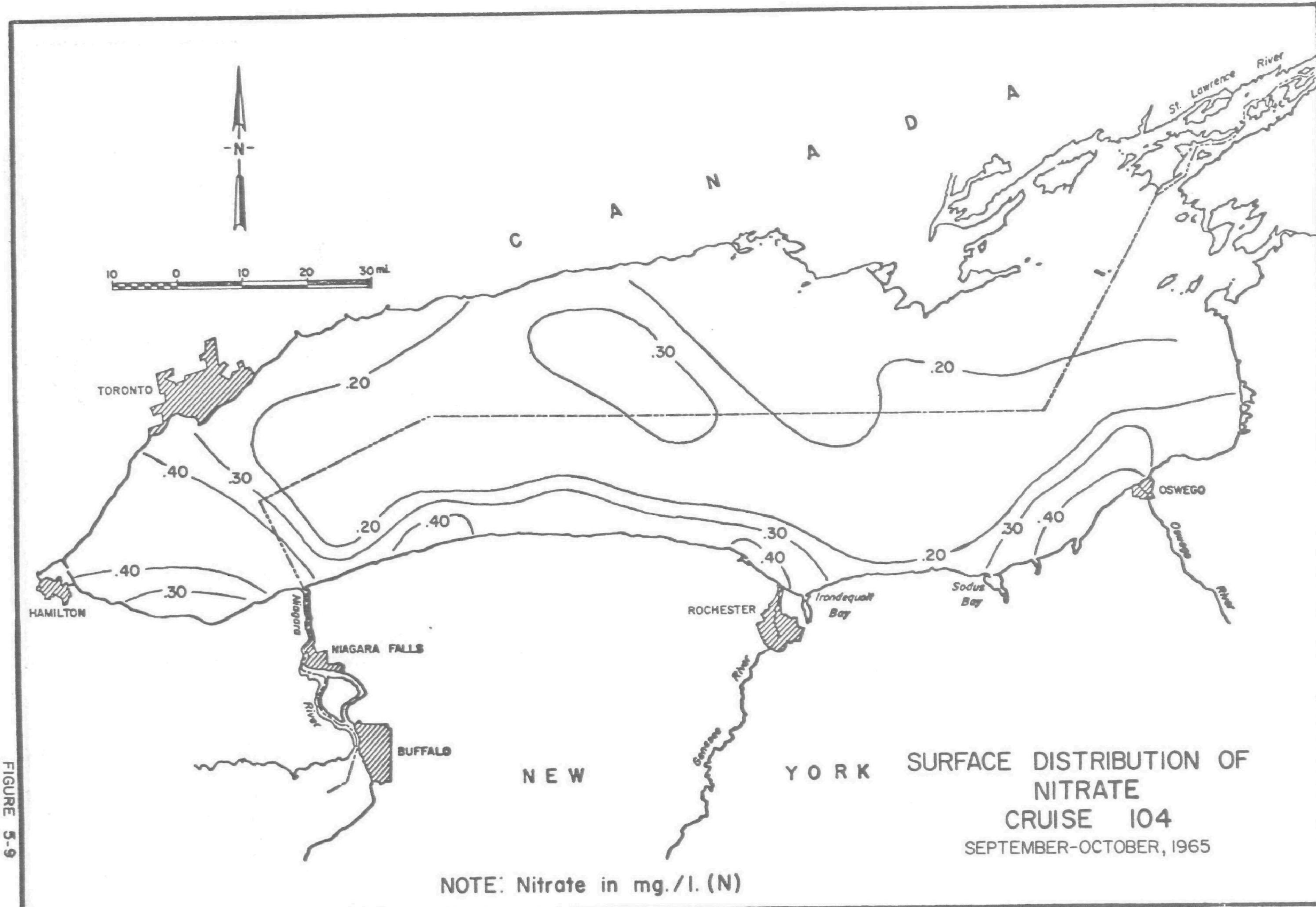
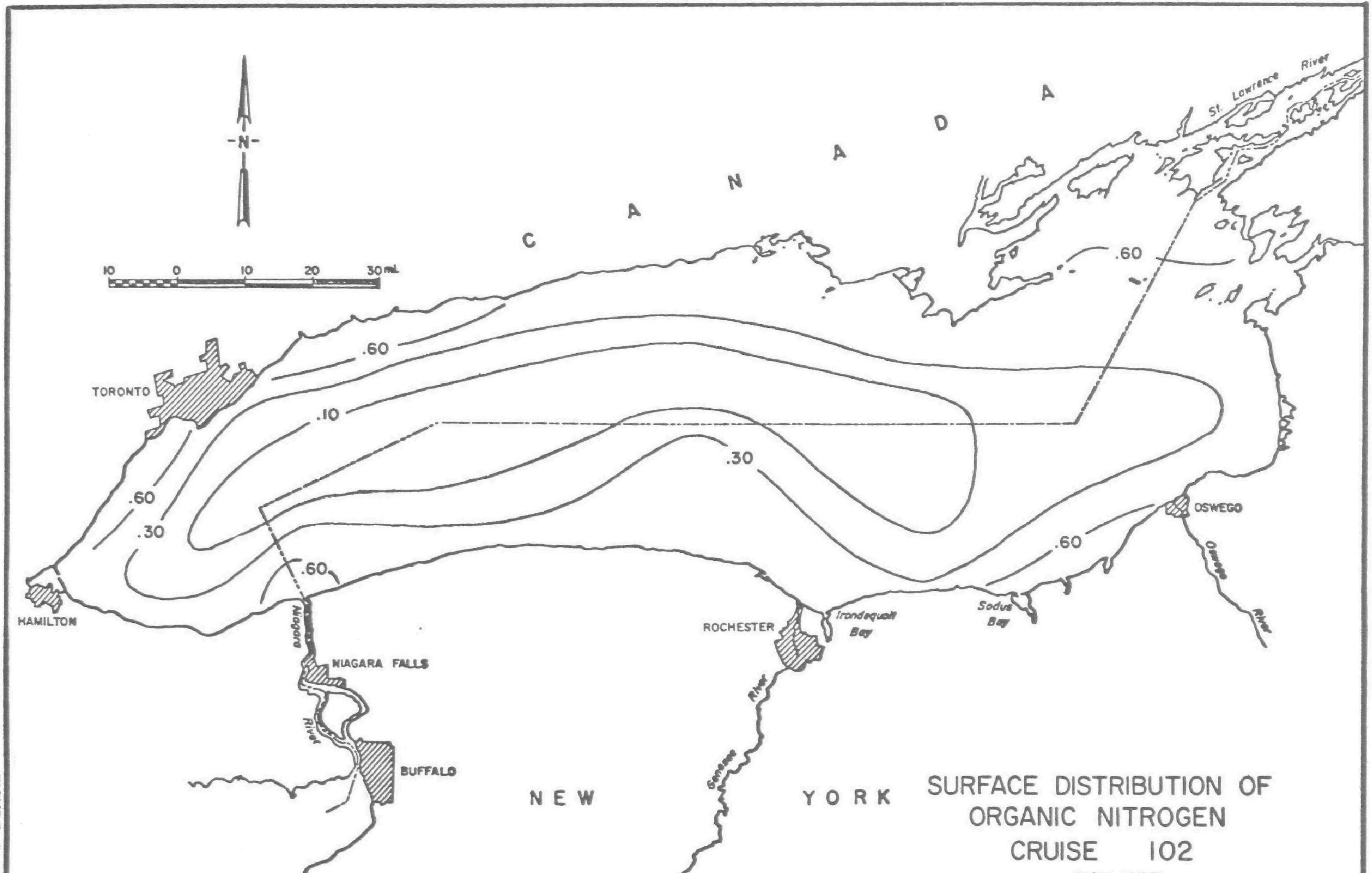

N
10 0 10 20 30 mi.
C A N A D A
St. Lawrence River
TORONTO
HAMILTON
Niagara
NIAGARA FALLS
Niagara River
BUFFALO
ROCHESTER
Irondequoit Bay
Sodus Bay
OSWEGO
Oswego River
Genesee River
NEW YORK
.20
.30
.40
SURFACE DISTRIBUTION OF
NITRATE
CRUISE 104
SEPTEMBER-OCTOBER, 1965
NOTE: Nitrate in mg./l. (N)

FIGURE 5-9

Organic Nitrogen

Organic nitrogen is the nitrogen that is bound up in organic materials, ranging from complex proteins to a simple substance, such as urea. It consists of two fractions: the dissolved organic one and the particulate one, which is the fraction bound up in the animate and inanimate particles in suspension. On decomposition, the organic nitrogen compounds are oxidized into inorganic nitrate nitrogen. The concentrations of organic nitrogen also give some indication of the lake's primary production. Figures 5-10, 5-11, and 5-12 show the distribution of organic nitrogen in Lake Ontario from FWPCA Cruises 102, 103, and 104, respectively. High organic nitrogen values are generally found in the inshore area. Correspondingly, the inshore area is also where the greatest biological activity occurs. The highest values were observed in the area of metro-industrial development and major stream mouths.

The weighted averages for organic nitrogen, FWPCA Cruises 102, 103, and 104 were 0.20 mg/lN, 0.21 mg/lN, and 0.20 mg/lN, respectively. Inasmuch as most of the organic nitrogen is found in the epilimnion, the use of weighted averages gives greater weight to samples taken from deeper depths (greater water mass and lower concentrations). This is the reason for the apparent high organic nitrogen content of the lake during

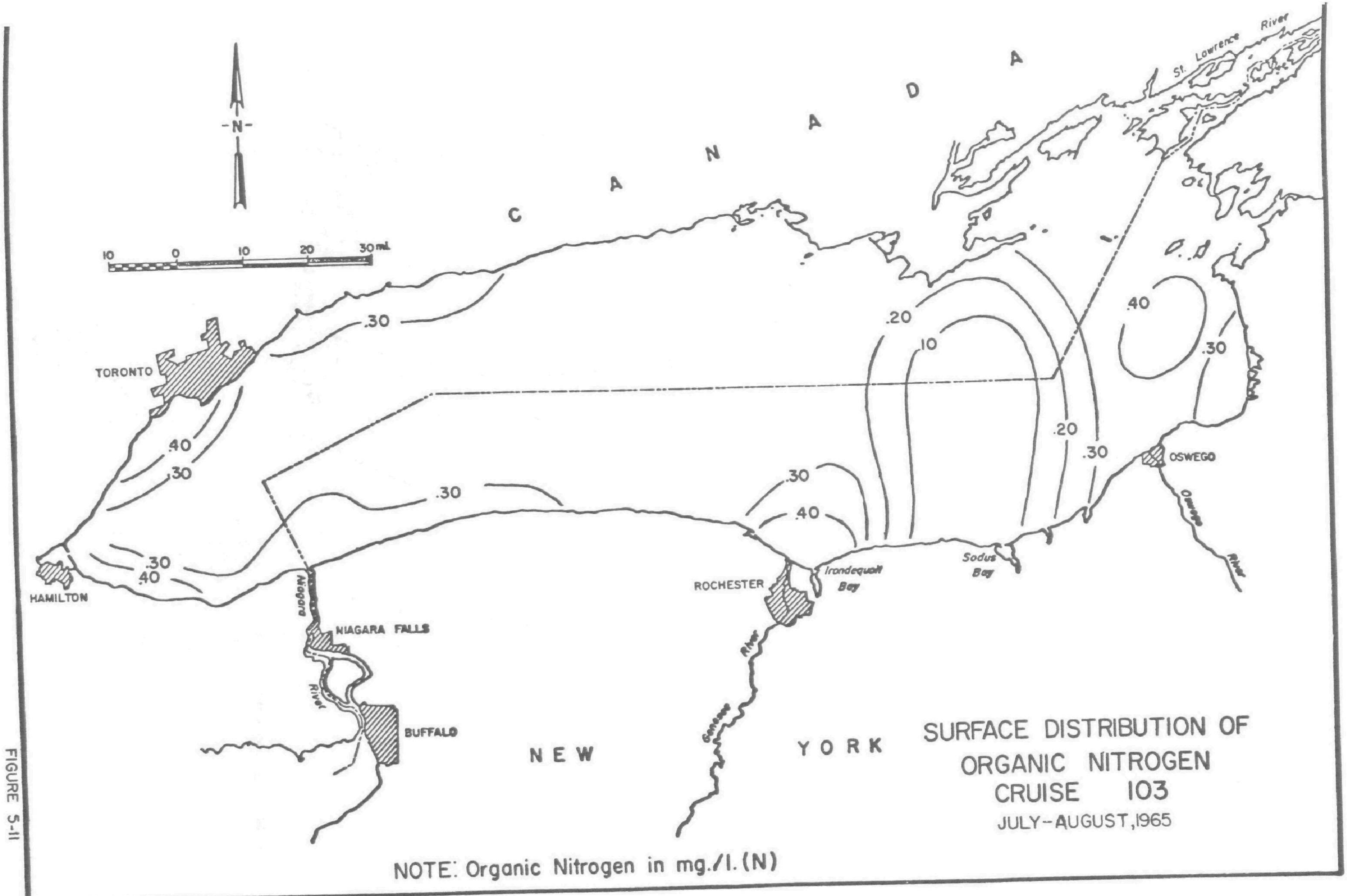


SURFACE DISTRIBUTION OF ORGANIC NITROGEN CRUISE 102

MAY, 1965

NOTE: Organic Nitrogen in mg./l. (N)

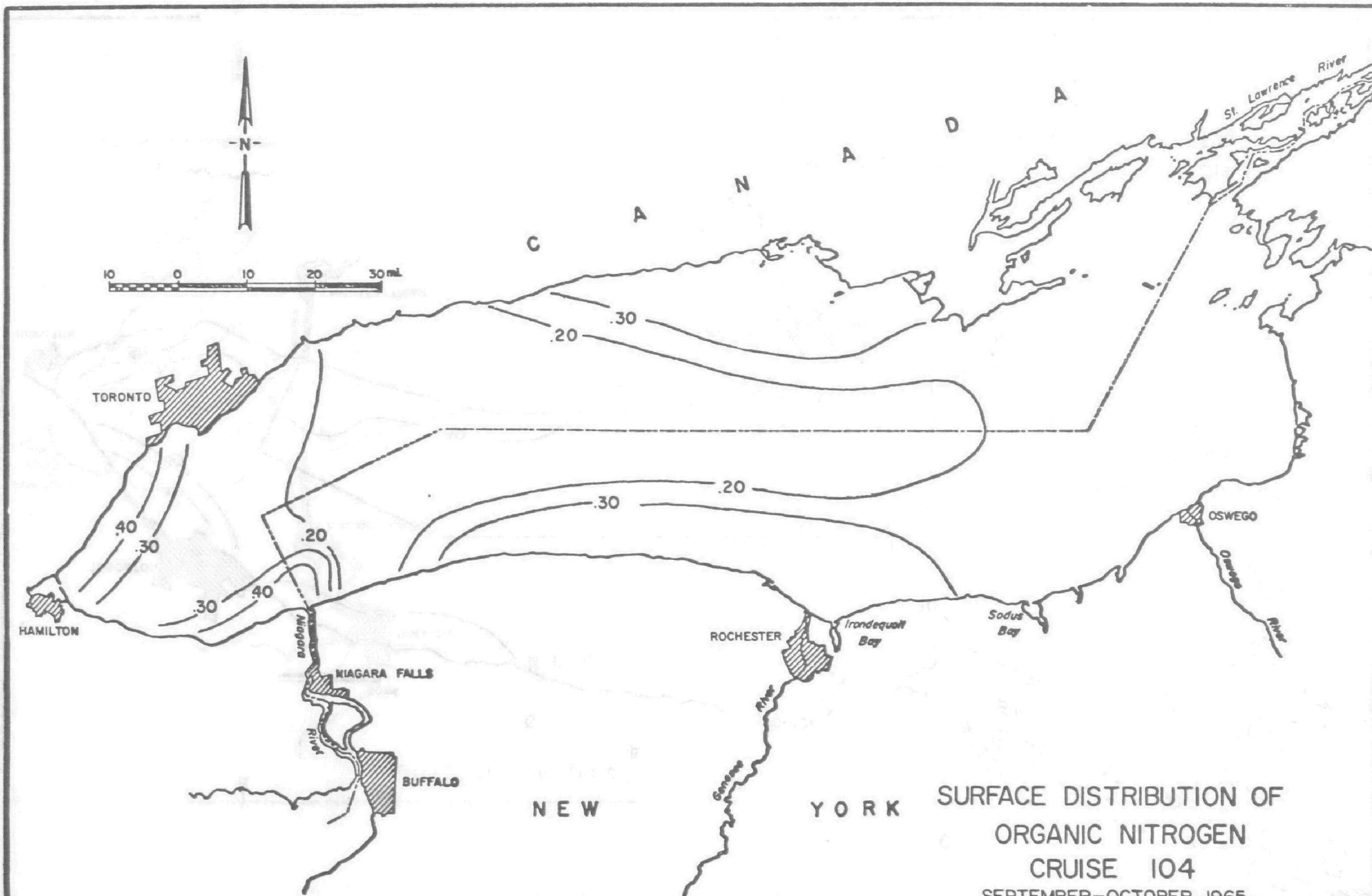
FIGURE 5-10



SURFACE DISTRIBUTION OF
ORGANIC NITROGEN
CRUISE 103
JULY–AUGUST, 1965

NOTE: Organic Nitrogen in mg./l. (N)

FIGURE 5-11



SURFACE DISTRIBUTION OF ORGANIC NITROGEN CRUISE 104 SEPTEMBER-OCTOBER, 1965

NOTE: Organic Nitrogen in mg./l. (N)

FIGURE 5-12

the spring cruise, for at this time the lake water was still in a state of flux. These figures do represent, however, the amount of organic nitrogen occurring in the water mass. In comparison, the arithmetic averages for organic nitrogen in the lake for FWPCA Cruises 102, 103, and 104 were 0.26 mg/lN, 0.25 mg/lN, and 0.23 mg/lN, respectively.

General Discussion

The problem of eutrophication is one of the chief concerns about Lake Ontario. The eutrophication of a lake is the buildup of nutrients in the lake's environment caused by an interplay of erosional materials and numerous biological, chemical, and physical processes. As the buildup of nutrients progresses, the lake acquires the capacity to progressively produce a larger biomass. One way that the eutrophication process could be slowed down is simply to determine which of the major nutrients in the water mass was deficient relative to the others and then to further control the input to the lake of the deficient (limiting) nutrient.

The protoplasm of algae (Fleming, 1940) contains nitrogen and phosphorus in a mean ratio of 15:1. Sawyer suggested further that one could determine if nitrogen or phosphorus was the limiting nutrient by determining what the ratio of nitrate nitrogen to phosphorus was in a lake. In lakes where the ratio of N:P in the water mass was less than

15:1, the production of algae would be limited by the availability of nitrogen. Conversely, where the N:P ratios were higher than 15:1, phosphorus would be the limiting nutrient. N:P ratios must, however, be used with caution. The biomass can alter their relative demands for nitrogen and phosphorus in response to changes in the relative supply of these two nutrients. A change in the relative uptake of nitrogen and phosphorus by the biomass would also affect the N:P ratio. Fresh water algae grown under a phosphorus deficient condition can increase their relative demand for nitrogen and,conversely, algae grown under nitrogen deficient conditions lowered their relative demand for nitrogen (Ketchum & Redfield, 1949). In Lake Ontario surface waters, the N:P ratios in 1965 were 23:1 in the spring (FWPCA Cruise 102), 18:1 in the summer (FWPCA Cruise 103), and 26:1 in the fall (FWPCA Cruise 104). While these nitrogen to phosphate ratios must be interpreted with caution, as outlined previously, the suggestion is that phosphorus rather than nitrogen is the major limiting nutrient in Lake Ontario.

Phosphorus (Phosphate)

Phosphorus as phosphate is part of a complex biogeochemical cycle in the lake environment, the details of which are not clearly understood

Soluble phosphate is the phosphate measured after filtering through a 45 micron filter. Total phosphate is all the phosphate.

Soluble Phosphate

Figure 5-13 (Cruise 102) shows the distribution of soluble phosphate in the surface layer of the lake. Of particular note are the high values of soluble phosphate found in the western end of the lake and off the Oswego River. The distribution is similar to the distribution patterns found for pH, temperature, and dissolved oxygen, which is as it should be inasmuch as all of these parameters are inter-related to a certain extent and influence phosphate equilibria. The shape of the high soluble phosphate area off Oswego is probably due to change in circulation (See Figure 5-18) which occurred while sampling this area.

Figure 5-14 shows the areal surface distribution of soluble phosphate observed during Cruise 103. High values of phosphate are found in the vicinity of river mouths. It is difficult to say where the pool of water in the vicinity of Main Duck Island, with its high phosphate values, formed; it may have broken away from the Oswego River flow, or its source may have been the Black River.

Figure 5-15 shows the distribution of soluble phosphate in the lake's surface layer observed during Cruise 104. An increase in soluble phosphate was observed during this period, particularly in the eastern

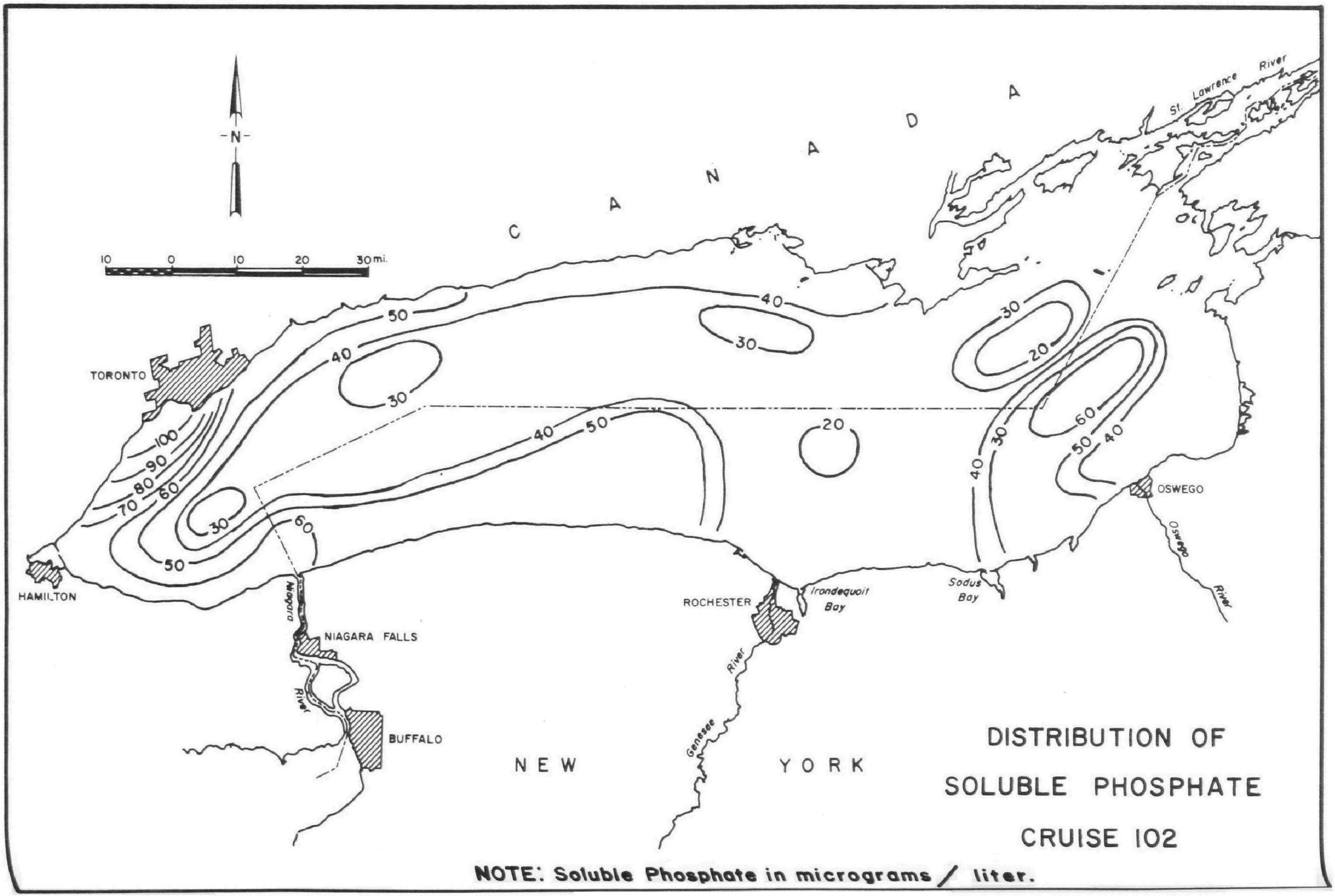
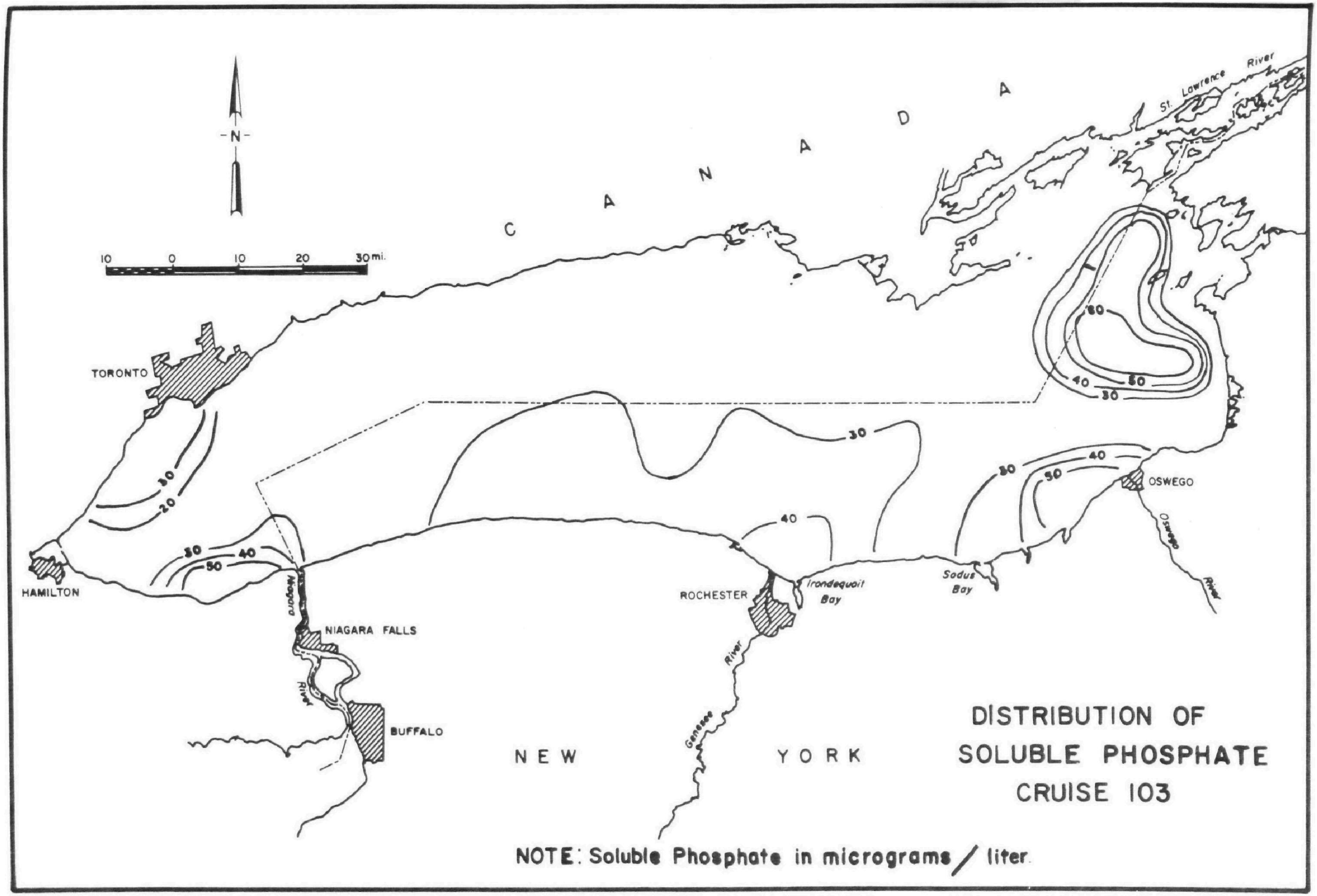
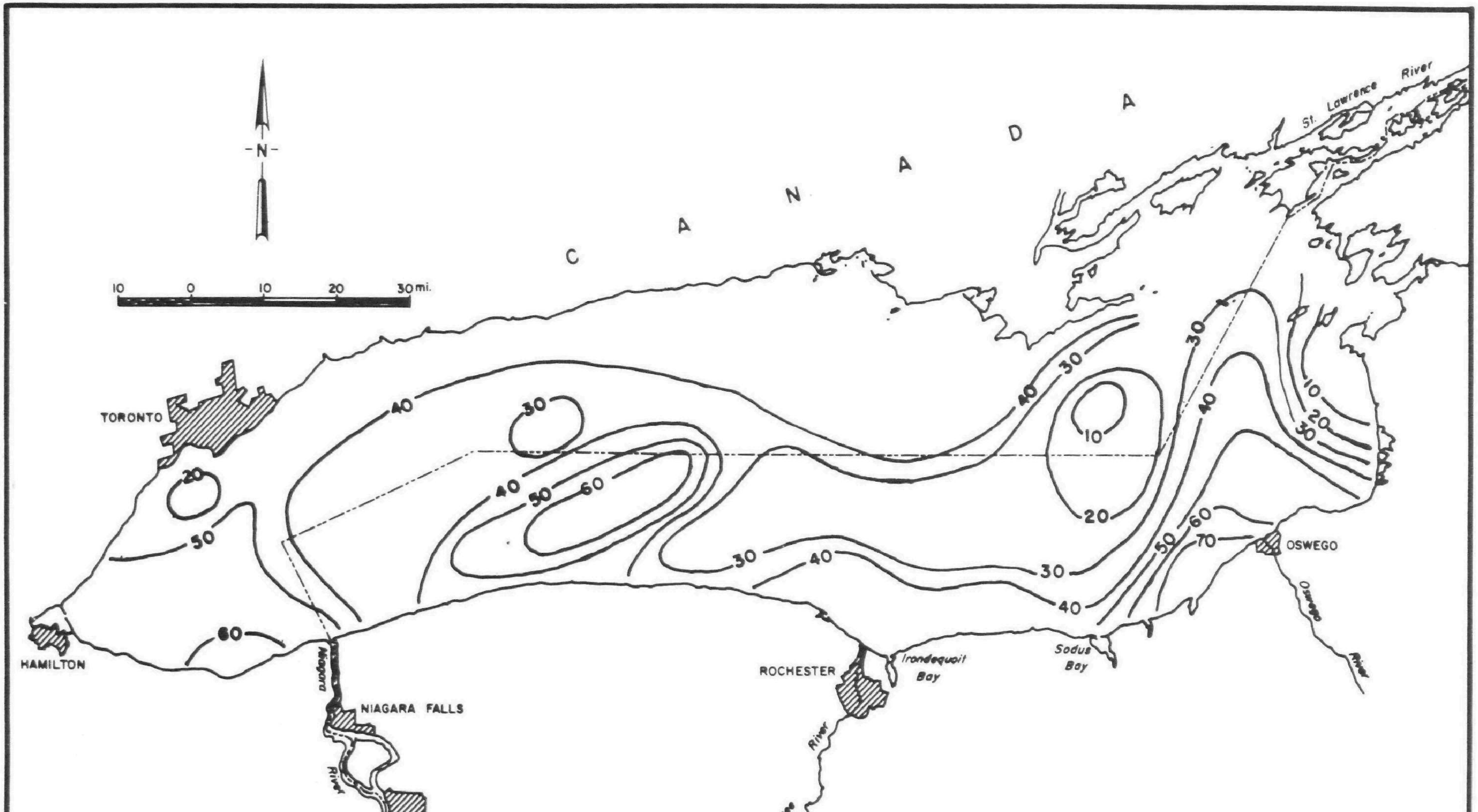

N
10 0 10 20 30 mi.
C A N A D A
St. Lawrence River
TORONTO
HAMILTON
Niagara River
NIAGARA FALLS
BUFFALO
ROCHESTER
Irondequoit Bay
Sodus Bay
OSWEGO
Oswego River
Genesee River
N E W Y O R K
100
90
80
70
60
50
40
30
20
DISTRIBUTION OF
SOLUBLE PHOSPHATE
CRUISE 102
NOTE: Soluble Phosphate in micrograms / liter.

FIGURE 5-13



DISTRIBUTION OF
SOLUBLE PHOSPHATE
CRUISE 103
NOTE: Soluble Phosphate in micrograms / liter.
C A N A D A
N E W
Y O R K
N
10 0 10 20 30 mi.
St. Lawrence River
TORONTO
HAMILTON
Niagara
NIAGARA FALLS
River
BUFFALO
ROCHESTER
Irondequoit Bay
Sodus Bay
OSWEGO
Oswego River
Genesee River
30
20
30
40
50
40
30
30
40
50
60
50
40
30

FIGURE 5-14



DISTRIBUTION OF SOLUBLE PHOSPHATE CRUISE 104

NOTE: Soluble Phosphate in micrograms / liter.

FIGURE 5-15

end of the lake. Once again, the surface waters near the mouth of the Niagara River are rich in phosphate. Pools of phosphate concentrations are scattered throughout the rest of the lake. A large area of soluble phosphate appears to originate at the mouth of the Oswego River, decreasing in concentration as it extends into the lake. The reason for the overall increase in soluble phosphate at this time is unknown. Inasmuch as the source of the phosphate appears to be from river inflow, it may be related to a reduction in phosphate uptake by biota.

Total Phosphate

The total phosphate content of a water sample includes all the soluble orthophosphate, polyphosphates, and insoluble phosphates. No samples from Cruise 102 were analyzed for total phosphate.

Figure 5-16 indicates the surface distribution of total phosphate observed during Cruise 103. Total phosphate values of .10 mg/l PO_4^{-3} (.033 mg/l P) were found off the Rochester embayment; these were the highest recorded values during this study. Distinct distribution patterns occur in the vicinity of the Toronto-Hamilton-Niagara River area, and the Oswego River.

The results of Cruise 104, Figure 5-17, show a rather contorted distribution of total phosphate, much like the data for soluble phosphate (Figure 5-15). The concentrations of total phosphate near the mouth of the Niagara River have increased since Cruise 103, while the other major streams show a decrease in total phosphate concentration.

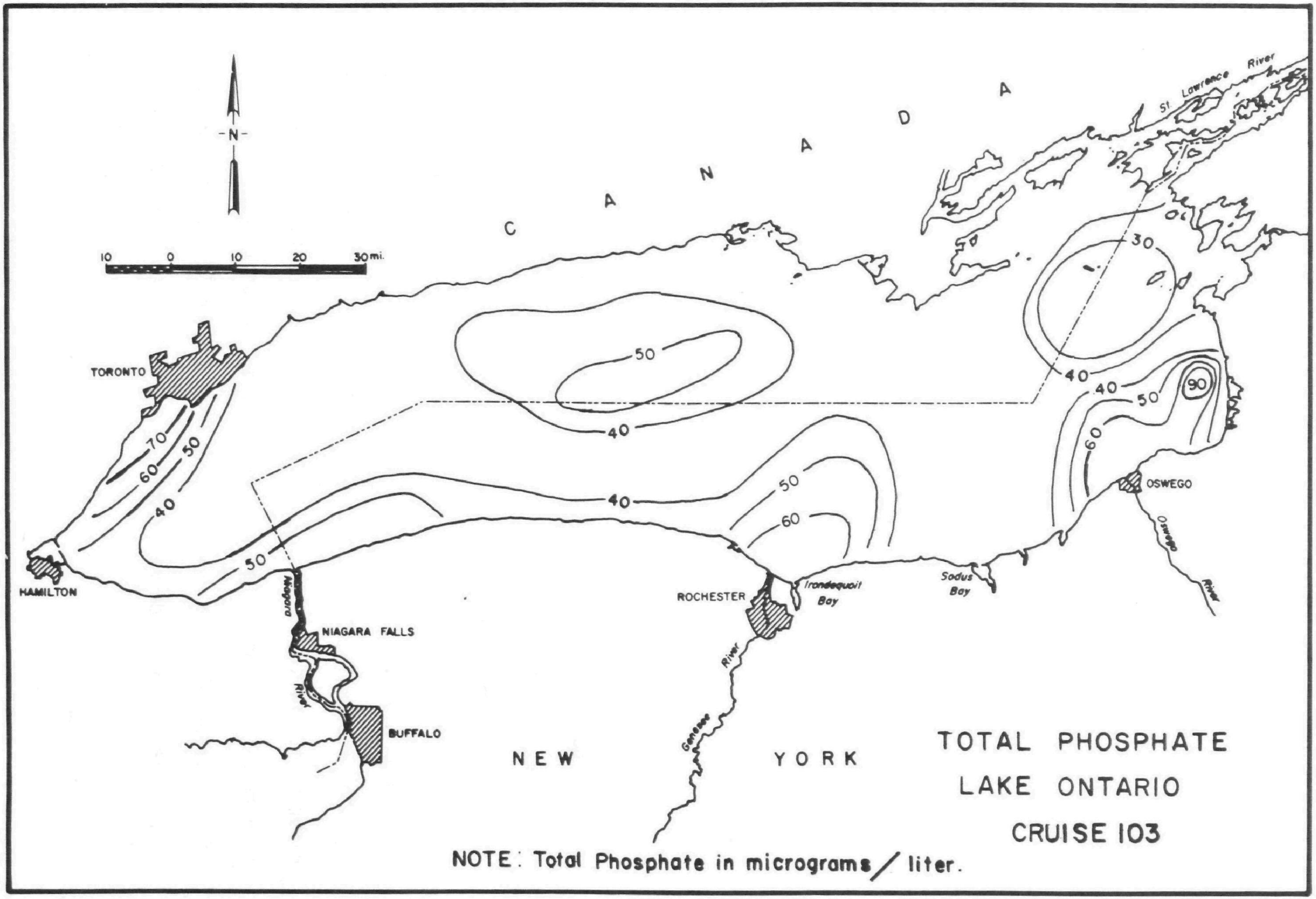
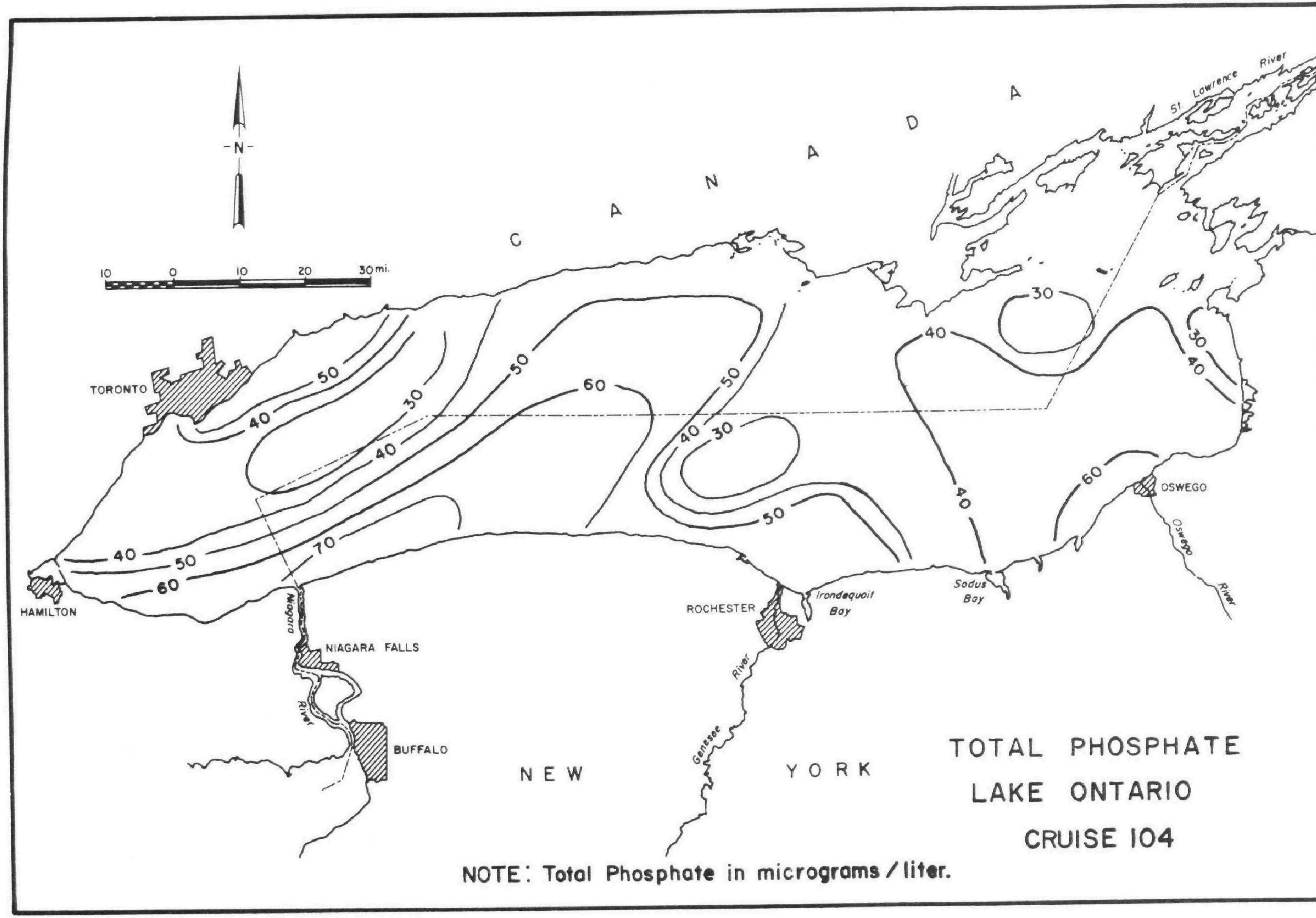

N
10 0 10 20 30 mi.
C A N A D A
St. Lawrence River
TORONTO
HAMILTON
Niagara River
NIAGARA FALLS
BUFFALO
ROCHESTER
Irondequoit Bay
Sodus Bay
OSWEGO
Oswego River
Genesee River
NEW YORK
30
40
50
60
70
90
TOTAL PHOSPHATE
LAKE ONTARIO
CRUISE 103
NOTE: Total Phosphate in micrograms / liter.

FIGURE 5-16



TOTAL PHOSPHATE
LAKE ONTARIO
CRUISE 104
NOTE: Total Phosphate in micrograms / liter.
C A N A D A
NEW YORK
TORONTO
HAMILTON
NIAGARA FALLS
BUFFALO
ROCHESTER
OSWEGO
Irondequoit Bay
Sodus Bay
St. Lawrence River
Niagara River
Genesee River
Oswego River
N
10 0 10 20 30 mi.
30
40
50
60
70

FIGURE 5-17

In summary, phosphates in the lake's watermass are transitory in nature, due to the biogeochemical cycling of phosphate, and the areal extent of input by streams and the metropolitan-industrial complexes is variable, consequently, it would seem that the reference for phosphate levels in maintaining water-quality control should be located at the point source of input to the lake, rather than establishing a phosphate water-quality criteria for the water mass as a whole. What is important is the amount and type of phosphate available to the biota and not just what is in solution (low phosphate levels can be caused by the biota taking up the phosphate).

General Discussion

If one considers how long the Great Lakes have been in existence, the question is why haven't they become more contaminated? The answer to this question is that a systematic depoisoning of the hydrosphere has occurred in the past and is occurring now. Without this depoisoning process a number of biologically damaging elements would have caused serious poisoning of the lakes naturally in the past. What then is this process or group of processes as regards to phosphate?

The phosphate cycle is part of a very complex biogeochemical system. However, some generalizations can be made. The same mechanisms that account for the removal of phosphate and various other compounds from the water mass are also responsible for the build-up of the chemistry of the total lake environment[1]. For example, soluble phosphate in the river waters is carried into the lake where the biota, in effect, filter some of it from the water mass and deposit it, through various processes, on the bottom.

Colloids in the lake waters are also responsible for the removal of phosphate ions from the hydrosphere. An important property of colloidal particles is their ability to bind and concentrate certain substances through physical and chemical adsorption. Both types of adsorption act together and all gradations between extremes exist.

Clay particles[2] display a marked sorptive capacity for phosphate ions either by acceptance into the crystal lattice or by adsorption. If one considers the number of clay and colloidal particles that are present in the lake water, the amount of uptake of phosphate and other ions by these particles must be great.

The iron cycle also has an effect on the phosphate cycle. Just as waste treatment plants use ferric hydroxide to adsorb and precipitate phosphate ions, this occurs naturally in the lake water. Iron is generally carried in surface waters as ferric oxide hydrosol stabilized by organic colloids. The compound of iron that is precipitated,

---

[1] Chemical buildup here includes materials that are stored in the biota and sediments, hence not necessarily in solution.

[2] Clays are found in the collodial state as well as suspended, and their importance in lake chemistry is emphasized here.

while also a function of the pH, is principally a function of the oxidation reduction potential (Garrels, 1950). At the lowest, only ferrous sulphide will form; at slightly higher potential ferrous carbonate is precipitated. Under fully oxidizing conditions, such as found in Lake Ontario, ferric hydroxide and ferric phosphate are formed. The ferric hydroxide precipitate carries phosphate ions with it as it drifts to the bottom.

Another factor in the phosphate cycle as regards Lake Ontario is that phosphate (Sutherland, 1966) appears to be in equilibrium with respect to the hydroxyapatite $(Ca_{10}(PO_4)^{\hat{6}}\ (OH_2)$ system; therefore, excess phosphate ions tend to precipitate with other metallic ions and be removed in order to maintain equilibrium in the water mass.

The lake's biogeochemical systems all tend to reach an inter-equilibrium, which explains why, up to a point, nature appears to be most forgiving of man's activities. However, while these phosphate removal mechanisms are a good thing, there is the danger that if any one factor is changed, the whole equilibrium shifts. Several examples of this are as follows: In late summer when the die-off of algae and other organisms begin to put a load on the oxygen in the hypolimnion, the oxidized microzone on the bottom, which is rich in ferric hydroxide and ferric phosphate, may be reduced, the associated organic material being a good reducing agent; the ferric ion changes to the ferrous state and the result is that (if a disequilibrium of phosphate demand exists in the water mass) phosphate ions are again released into solution, and increase in sodium sulphate (at lower pH) or calcium ions also upsets the phosphate equilibrium by causing more phosphate to move into solution. Calcium is in saturation as regards Lake Ontario.

Sawyer, in his studies, found that phosphate concentrations of .010 mg/l P would cause algae blooms. In reality, his results only apply to the specific lakes that he studied. Inasmuch as nutrient uptake by the biota is a function of the concentrations maintained at the cellwater interface, it is suspected that in the case of lakes with good circulation and large nutrient reserves, such as Lake Ontario, the concentration of phosphate needed to cause algal blooms is less than Sawyer's results show.

Bass Becking and Kaplan, 1960, in a study of the limits of pH and Eh (oxidation-reduction potential) in the natural environment, make the generalization that oligotrophic waters have pH values on the acid side and eutrophic waters tend to be alkaline. Of the Great Lakes, only Lake Superior would fit the definition for an oligotrophic lake on the basis of pH. This does not mean that all of the Great Lakes except Superior are eutrophic, but it does suggest that there is a natural tendency for them to become so as regards availability of nutrients. This, of course, is due to the areal geology of the region with its numerous limestone formations. Since 1900, a large increase of sulphate ions in the Great Lakes has occurred, the effect of which, as mentioned previously, may be to make more phosphate available to any biological system. Also, since 1900, a change in the fish population has occurred. A good example of this is the increase in the number of alewives, whose life cycle appears to be two years; thus, where phosphate may have been stored in a large lake trout for several years, in the case of the alewives, it is recycled every two years. This extra shot of phosphate[1], due to the die-off of alewives, comes at the worst possible time--early summer. Another factor is that, unlike other fish, the alewife is not now harvested. Assuming that the Lake Ontario alewife population is proportional to the Lake Michigan population (U.S. Bureau of Commercial Fisheries, 1966), approximately 5.0 x 10^6 lbs. containing 150,000 lbs. of phosphate could be harvested each year without affecting the alewife population. The effect of reducing phosphate in the lake by harvesting alewives would be felt during the start of the growing season.

Phosphate Removal at Treatment Plants

No one ideal situation exists for reducing the algal growths in Lake Ontario, and several methods of attack on the problem must be used. However, a program of phosphate control, including maximum removal of

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[1] Bacterial working of the dead fish make the phosphate available to the algae in a readily assimilated form.

phosphates at treatment plants, may, in the case of Lake Ontario, bring the most rewarding results. The reason for this is that this lake has a tremendous oxygen reserve in the hypolimnion, having a small surface area in relation to volume. It has been known for some time that a self-regulating system exists in the phosphate cycle between the water mass and the lake muds. The oxidized sedimentary microzone which develops at the mud -water interface is rich in ferric hydroxide and ferric phosphate. This microzone forms a chemical barrier that keeps phosphate ions from the reduced sedimentary layer beneath it from going into solution and, also, assimilates material falling to the bottom. Thus, as long as the oxidized microzone exists, phosphate raining onto the bottom from various biogeochemical systems remains tied up. The longer this microzone remains in the oxidized state, the more phosphate will be removed from the water mass.

In Lake Ontario, the oxidized microzone may exist most of the year, possibly all year. If this is the case, reduction of phosphate input to the lake could bring almost immediate results. In shallower lakes, because of their physical characteristics, the oxidized microzone which develops during the winter months probably disappears in early summer; this causes a recycling of phosphate, which will supply phosphate ions to the water mass for some years after the phosphate inputs are reduced.

Hydrogen-Ion Concentration (pH)

The hydrogen-ion concentration of the lake waters is of great significance for it represents the overall balance of a series of chemical and biological equilibria existing in the lake waters. In distilled water at 20°C, the hydrogen ion concentration is 10^{-7} moles/liter, or, using the negative logarithm to simplify matters, the pH is 7. If the concentration is greater than that of distilled water, the solution is considered acid (pH less 7), and, in the opposite case, alkaline. The pH of most natural waters is controlled by the buffer systems $CaCO_3$-CO_2-H_2O; a saturated solution of carbon dioxide at its partial pressure in the atmosphere has a pH of 5.2, and a solution of calcite ($CaCO_3$) in air-saturated water has a pH near 8, (Mason, 1952).

Solutions of phosphates, silicates, borates and fluorides also affect the pH of the waters, but to a lesser extent than the CO_2-$CaCO_3$ system. Important here, as regards nutrients for development of an abundant biota, is that most calcite minerals are not pure and usually they contain various amounts of the mineral apatite ($Ca_5(PO_4)_3F$; thus, natural solutions of calcite also contain apatite. Rocks containing large amounts of apatite are called phosphate rock and are used for fertilizer. This helps to explain why lakes that have high pH values are usually productive, whereas so-called acidic lakes are not usually productive. Bass Beckling (1960) classifies lakes on the basis of pH as being either oligotrophic or eutrophic, eutrophic lakes being those with a pH above 7.

The pH of a solution also is important in regulating the iron cycle. The importance of this is that phosphate ions can be either removed or released to or from solution in conjunction with the iron cycle.

Figure 5-18 shows the distribution of surface pH observed during Cruise 102. The pattern observed in the western end of the lake is much like the patterns obtained for dissolved oxygen, temperature, soluble phosphate, and circulation during this cruise. In the eastern end of the lake the pH was lower than in the western end, and, unlike the western end, the highest values are found toward mid-lake. The reason for this apparent difference in areal distribution of pH at either end of the lake is that a wind shift occurred. During sampling in the eastern end, the winds were, at times, out of the northeast and during sampling in the western end they were from the southwest.

Several separate pools of water are discernible in the eastern and central parts of the lake. These pools were probably formed as one water mass in the area behind the Duck Islands and were pushed out into the lake, mixing with deeper waters which have a lower pH. Originally, the distribution of pH was probably much like that of the western end, with higher pH values inshore. In a change of regime, however, these

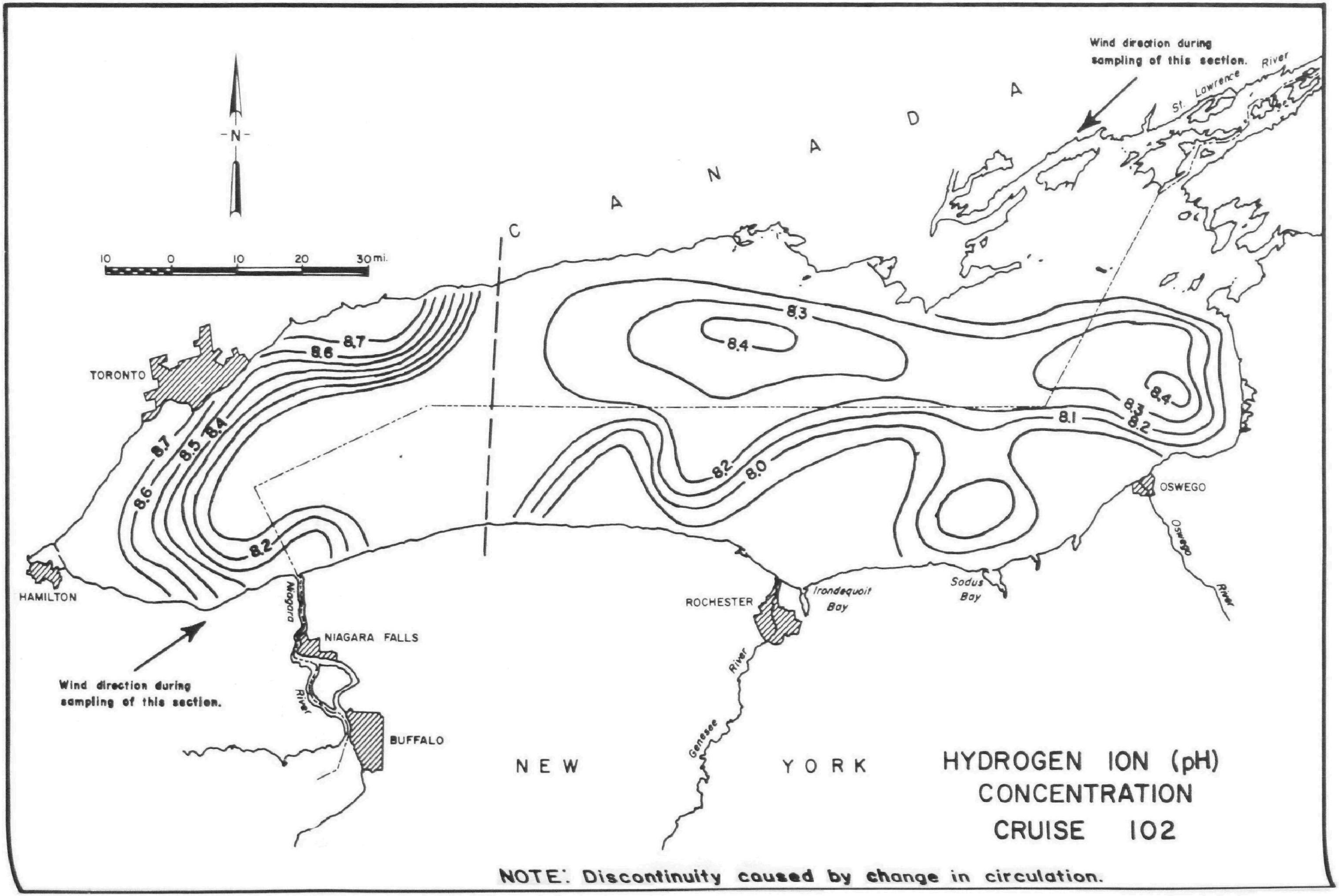

HYDROGEN ION (pH)
CONCENTRATION
CRUISE 102
NOTE: Discontinuity caused by change in circulation.
Wind direction during
sampling of this section.
Wind direction during
sampling of this section.
N
10 0 10 20 30 mi.
C A N A D A
NEW YORK
St. Lawrence River
TORONTO
HAMILTON
NIAGARA FALLS
Niagara River
BUFFALO
ROCHESTER
Genesee River
Irondequoit Bay
Sodus Bay
OSWEGO
Oswego River
8.7
8.6
8.5
8.4
8.3
8.2
8.1
8.0

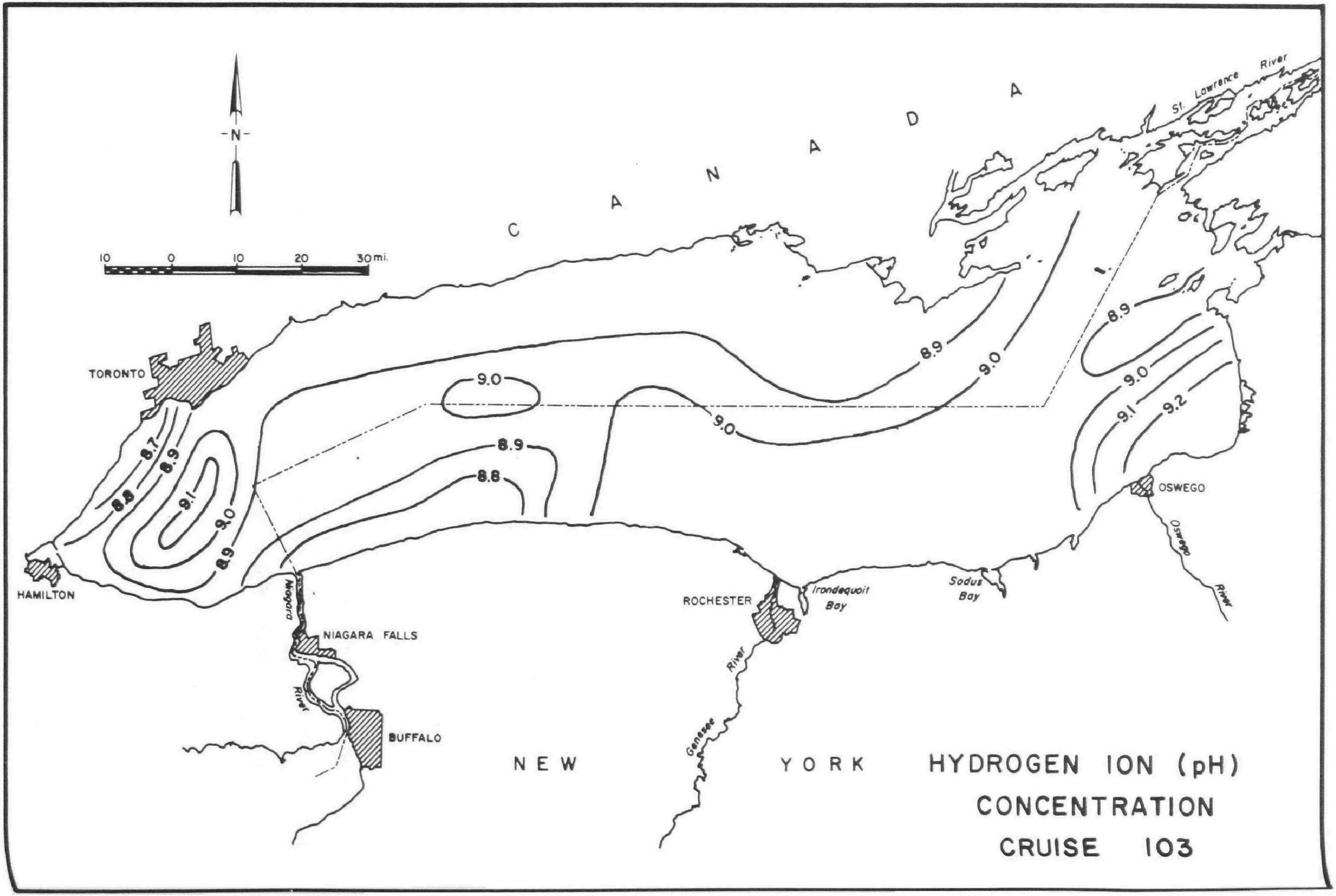
FIGURE 5-18

waters would be the first to lose their identity because of mixing due to the increased turbulence inshore. This change in the wind regime is not as readily apparent in the distribution of other chemical parameters, inasmuch as the higher pH values in the surface waters may have been due to biological activity at the surface and were readily changed by mixing.

Figure 5-19 shows the distribution of pH observed during Cruise 103. The surface of the lake was quite calm during this period and the circulation was sluggish. Notable is the overall increase in pH; pH values of 9 and above are common and occur generally away from shore. The increase in observed pH is probably the result of biological activity, heating, and quiescent lake conditions (little mixing). This increase in pH may indirectly be related to the availability of nutrients.

Figure 5-20 shows the distribution of pH observed during Cruise 104. Here the values of pH have dropped since the July-August (103) cruise. The pH distribution during this period follows the observed circulation and surface temperatures of the lake.

Lake Ontario surface waters are near saturation in calcium carbonate; pH values higher than 8 are probably due to lake warming and biological activity and hence are related to, in part, the avail-



HYDROGEN ION (pH)
CONCENTRATION
CRUISE 103
N
10
0
10
20
30 mi.
C A N A D A
N E W
Y O R K
St. Lawrence River
TORONTO
HAMILTON
Niagara
NIAGARA FALLS
River
BUFFALO
ROCHESTER
Irondequoit Bay
Sodus Bay
OSWEGO
Oswego River
Genesee River
8.7
8.8
8.9
9.0
9.1
9.2

FIGURE 5-19

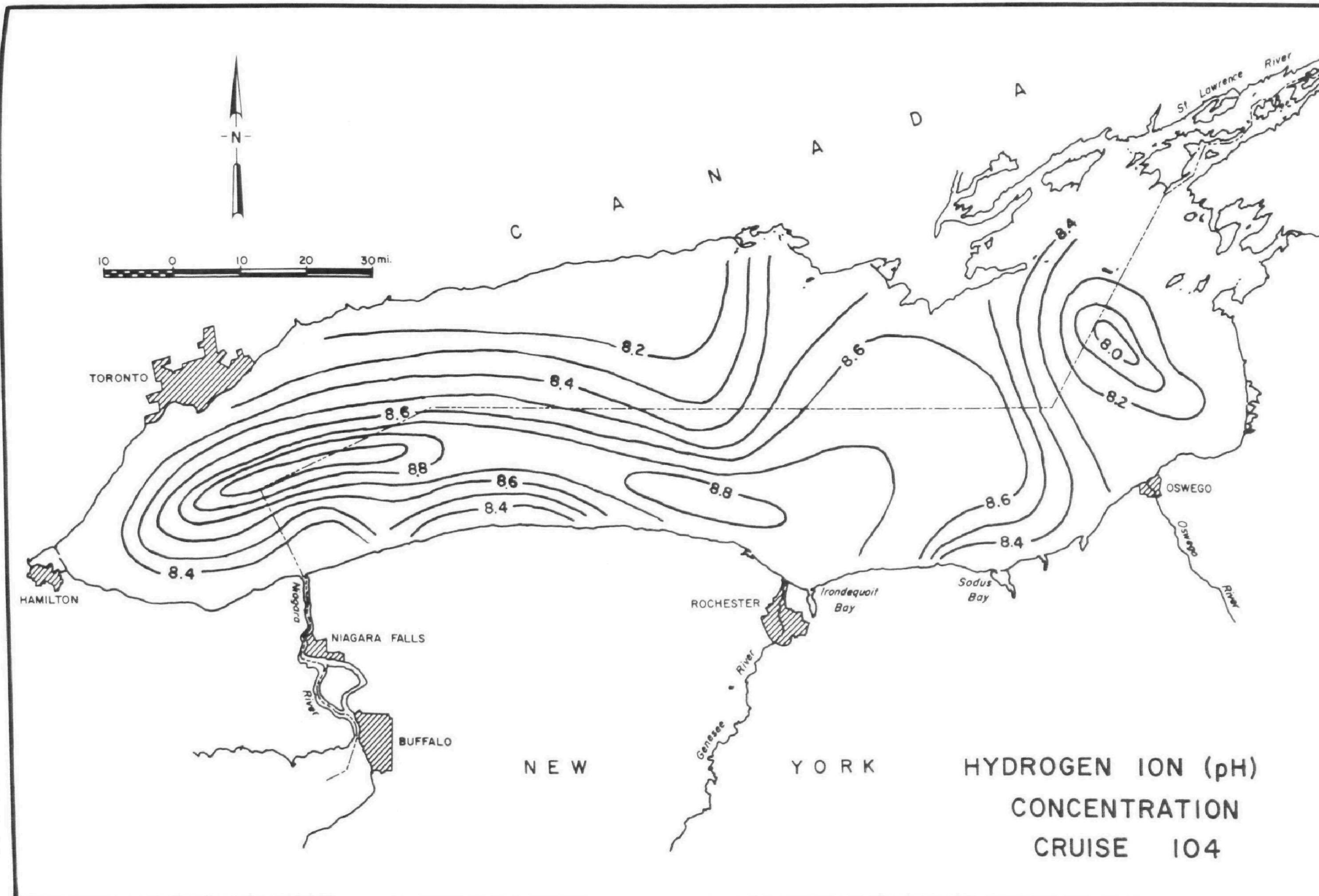

C A N A D A
St. Lawrence River
TORONTO
HAMILTON
Niagara River
NIAGARA FALLS
BUFFALO
ROCHESTER
Irondequoit Bay
Sodus Bay
OSWEGO
Oswego River
Genesee River
NEW YORK
10 0 10 20 30 mi.
N
8.0
8.2
8.4
8.6
8.8
HYDROGEN ION (pH)
CONCENTRATION
CRUISE 104

FIGURE 5-20

ability of nutrients.

In conclusion, pH is representative of the 'total' lake environment.

Dissolved Oxygen

Oxygen dissolved in water is necessary to support life and to oxidize organic material. The amount of dissolved oxygen also plays an important role in the regulation of the iron cycle and, thus, indirectly in the amount of phosphate that is either removed or put into solution (see phosphates).

Figure 5-21 shows the percent of oxygen saturation observed during Cruise 102. At this time the lake water was still isothermal and was well mixed. Nowhere were dissolved oxygen values below 100 percent saturation observed. The high values above 100 are most likely due to photosynthesis occurring because of a 'spring pulse' of phytoplankton.

These areas of supersaturation correspond to the shallower areas of the lake. Of particular note are the values occurring in the Toronto-Hamilton area.

Figure 5-22 indicates the percent of oxygen saturation (Cruise 102) found near the bottom of the lake. At no place were values of

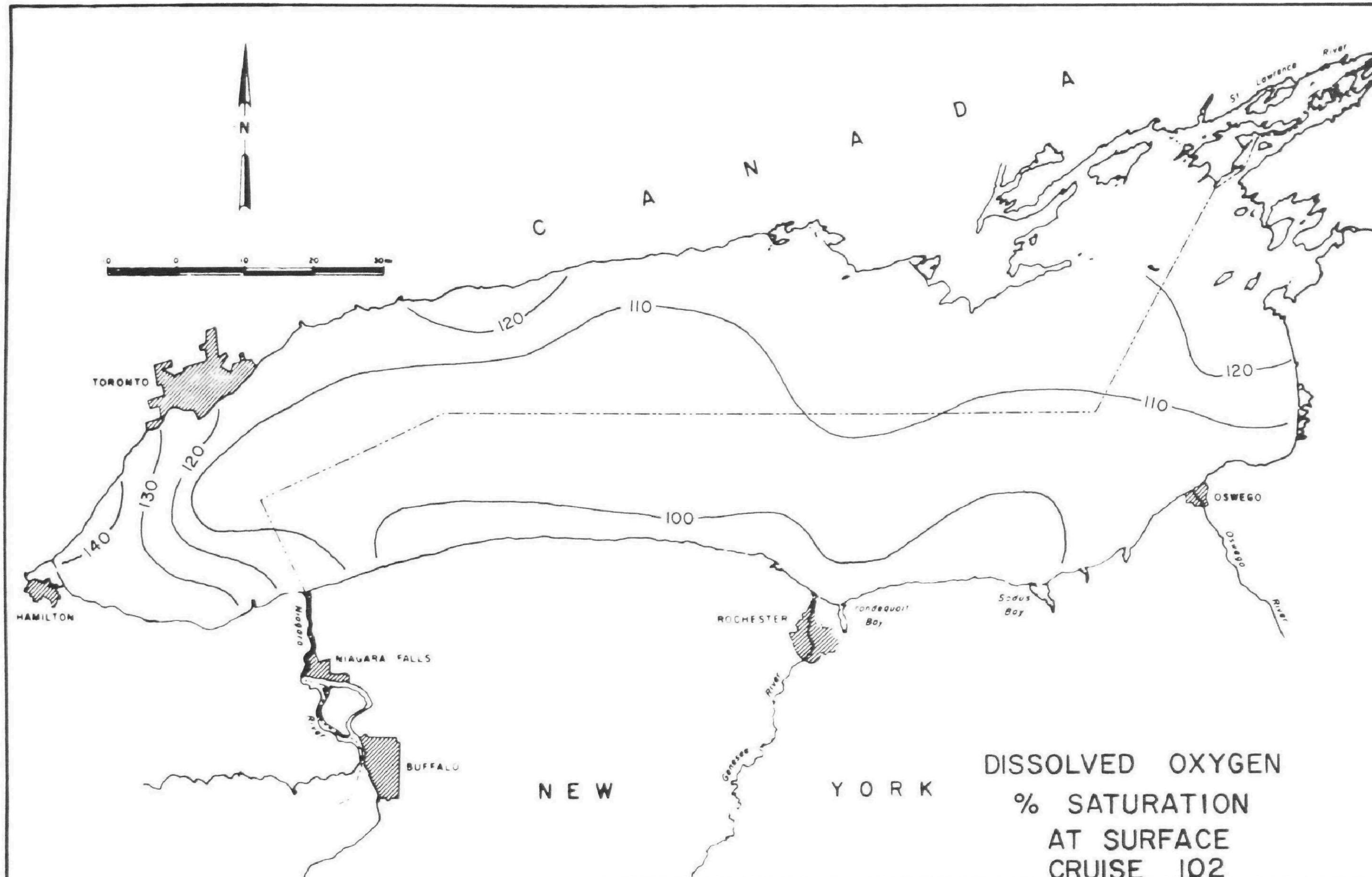

N
CANADA
St Lawrence River
TORONTO
HAMILTON
Niagara River
NIAGARA FALLS
BUFFALO
ROCHESTER
Irondequoit Bay
Sodus Bay
OSWEGO
Oswego River
Genesee River
NEW YORK
140
130
120
110
100
DISSOLVED OXYGEN
% SATURATION
AT SURFACE
CRUISE 102

FIGURE 5-21

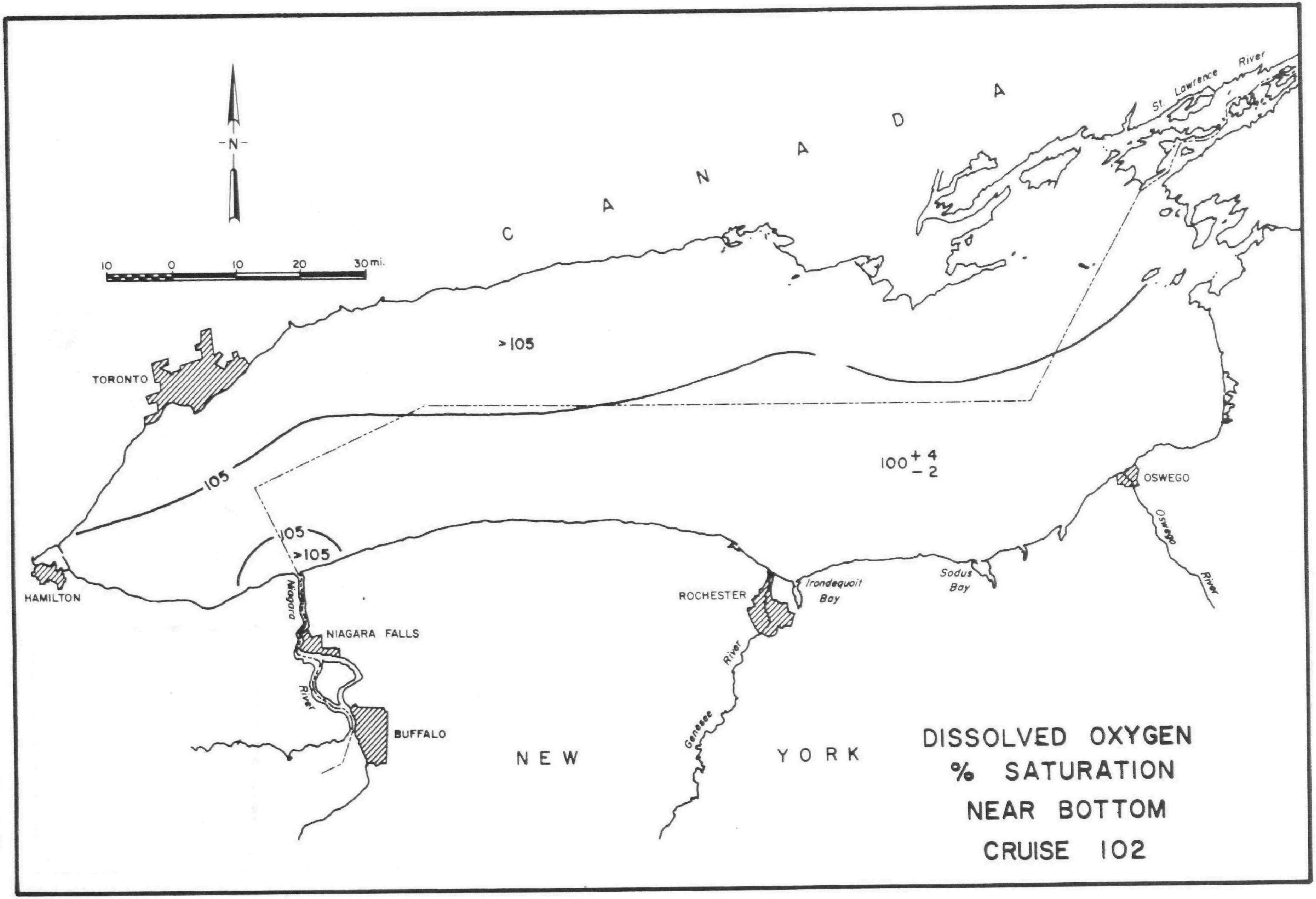
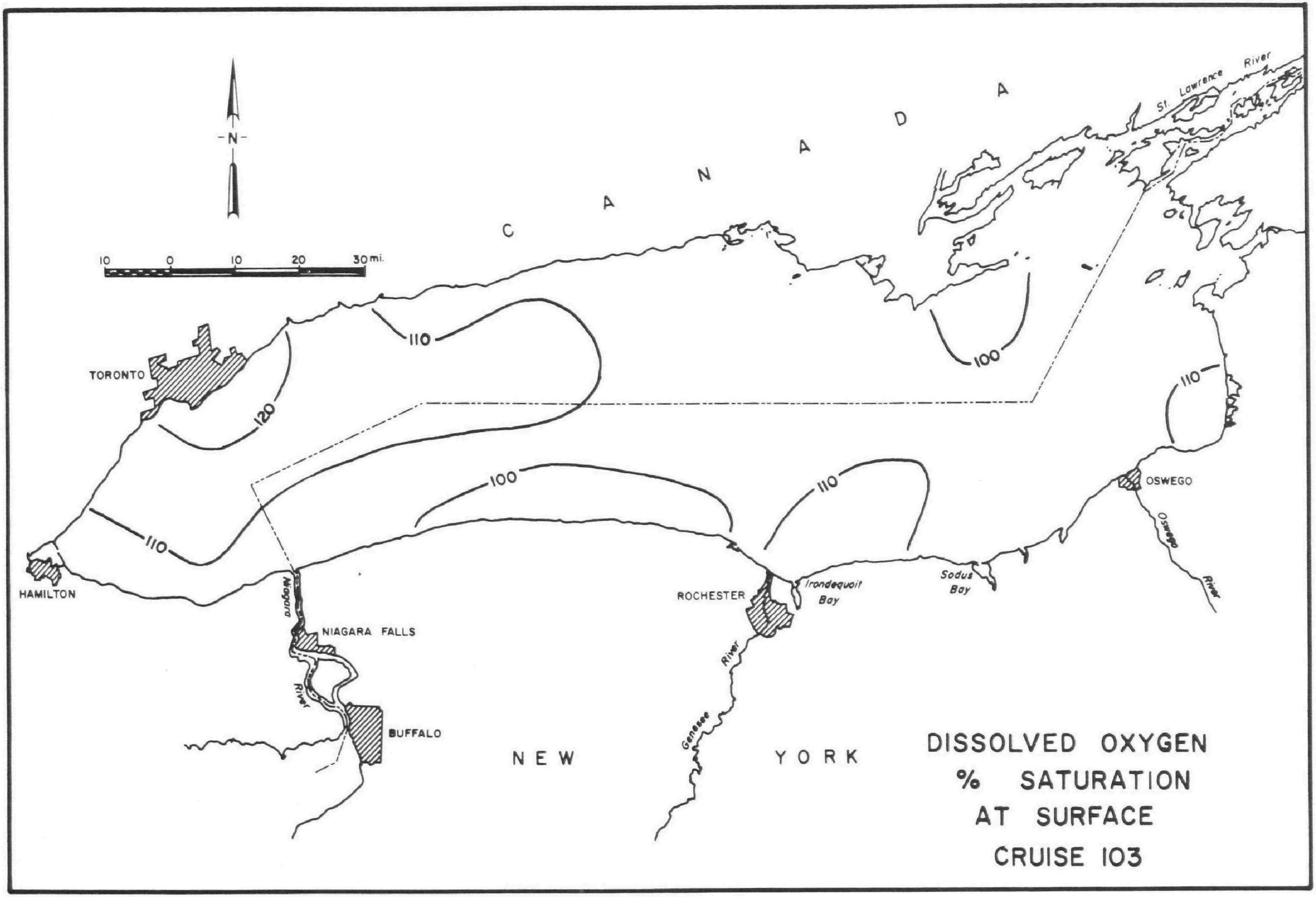

N
10 0 10 20 30 mi.
C A N A D A
St. Lawrence River
>105
TORONTO
105
HAMILTON
105
>105
100 +4 −2
OSWEGO
Oswego River
ROCHESTER
Irondequoit Bay
Sodus Bay
Niagara River
NIAGARA FALLS
BUFFALO
Genesee River
N E W Y O R K
DISSOLVED OXYGEN
% SATURATION
NEAR BOTTOM
CRUISE 102

FIGURE 5-22

less than 98 percent of dissolved oxygen saturation observed.

Figure 5-23 gives the results of Cruise 103. Once again, the dissolved oxygen concentrations are above or very near saturation values. The effect of what may be nutrient input by the major cities can be seen in the higher values of dissolved oxygen caused by photosynthesis found in their vicinity. Surprisingly enough, no effect of the Niagara River was discernible.

Figure 5-24 shows the distribution of dissolved oxygen concentrations in percent of saturation in the bottom waters for Cruise 103. One can readily see that some consumption of oxygen has occurred in that levels slightly below 80 percent of saturation were observed in the lake proper and a low value of 70 percent saturation was observed in the bay area behind Duck Island. During the latter part of July 1965, samples of the lake sediments were taken. All of the sediment samples from the deep areas of the lake were observed to have a red, oxidized microzone approximately 1/4 inch thick, indicating that oxidizing conditions existed at the mud-water interface. How long this oxidized microzone exists is not known, but it is suspected that it remains all year long. If this is true much of the phosphate that goes out of solution in conjunction with the iron may never get back into solution (see phosphate discussion).



DISSOLVED OXYGEN
% SATURATION
AT SURFACE
CRUISE 103

FIGURE 5-23

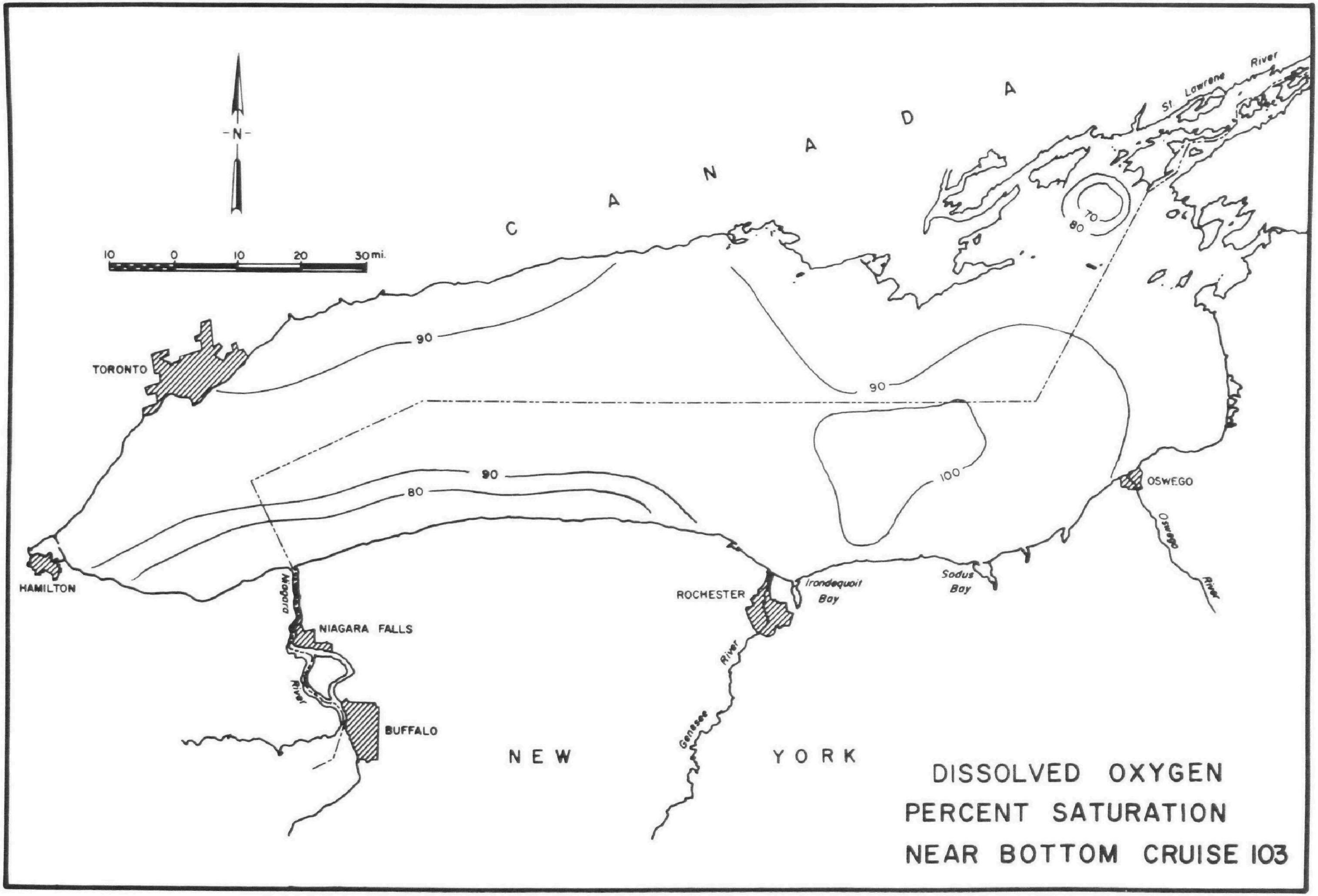

C A N A D A
St. Lawrene River
N
10 0 10 20 30 mi.
TORONTO
HAMILTON
90
90
90
80
70
80
100
Niagara
NIAGARA FALLS
River
BUFFALO
ROCHESTER
Irondequoit Bay
Sodus Bay
OSWEGO
Oswego River
Genesee River
NEW YORK
DISSOLVED OXYGEN
PERCENT SATURATION
NEAR BOTTOM CRUISE 103

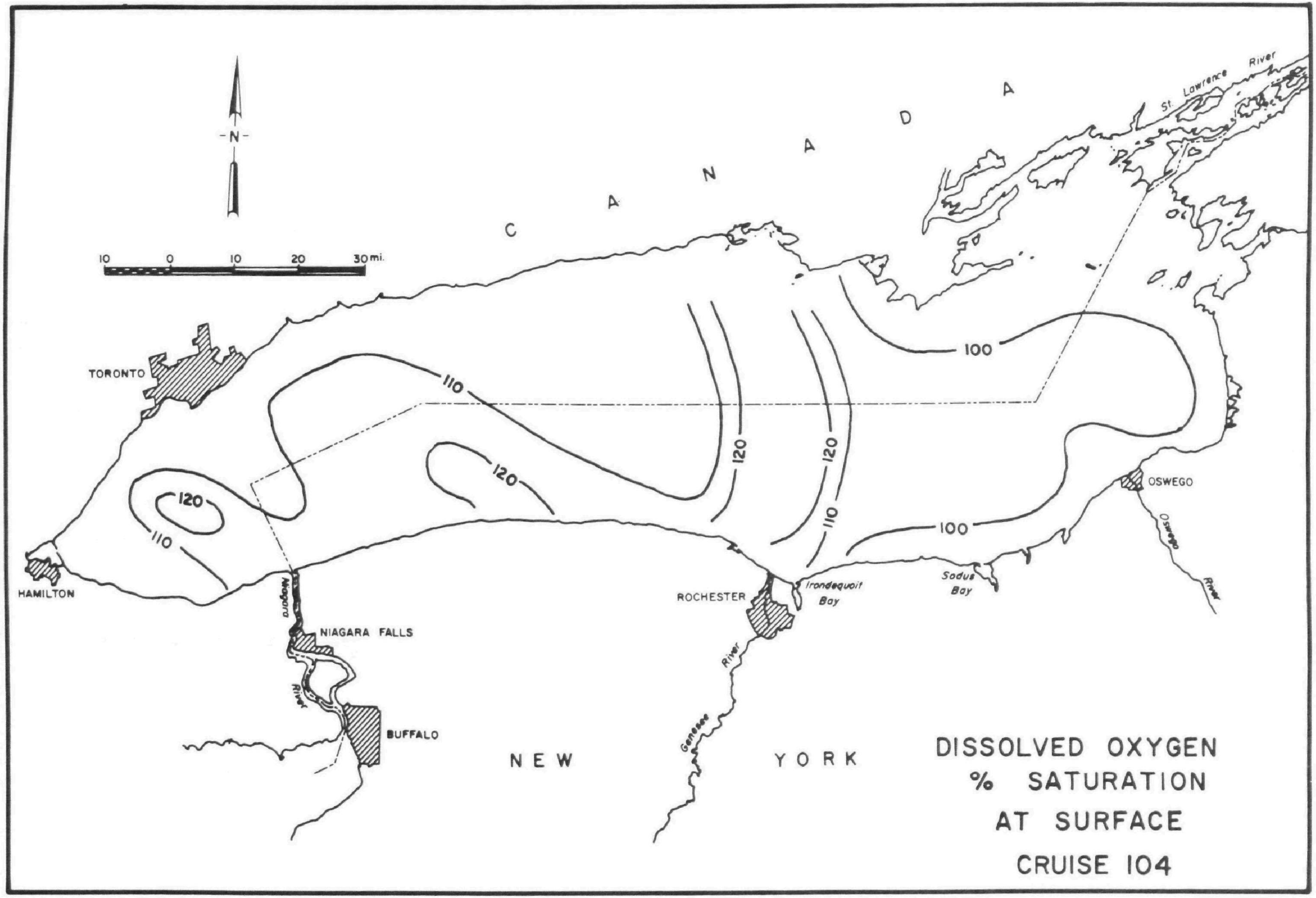
FIGURE 5-24

Figure 5-25 shows the distribution of dissolved oxygen in percent of saturation during Cruise 104. The amount of dissolved oxygen has increased in the surface waters from the previous cruise. Distinct, individual, chemically identifiable masses of lake water seem to exist. Figure 5-26 shows the percent of dissolved oxygen observed in the bottom waters during this same cruise. Values slightly below 70 percent saturation occur off the Toronto, the Niagara River, Rochester, and Oswego. Scotch Bonnet Shoal and the ridge separating the two basins are marked off by a value of 90 percent.

These oxygen data suggest that no zones of serious oxygen depletion occur in the main part of the lake; therefore, on the basis of these data the lake is considered to be oligothrophic. The reason why no significant oxygen depletion occurs is that 85 percent of the lake's water mass is below the thermocline, so a large reserve of oxygen is available during the period of stratification.

Chlorides

It is not surprising that Lake Ontario, being the downstream lake, has the highest chloride levels of all the Great Lakes. The chloride ion is considered a good tracer element because most of its compounds are soluble. The principal source of chloride in the



N
10 0 10 20 30 mi.
C A N A D A
St. Lawrence River
TORONTO
HAMILTON
Niagara River
NIAGARA FALLS
BUFFALO
ROCHESTER
Irondequoit Bay
Sodus Bay
OSWEGO
Oswego River
Genesee River
NEW YORK
120
110
120
120
120
110
100
100
DISSOLVED OXYGEN
% SATURATION
AT SURFACE
CRUISE 104

FIGURE 5-25

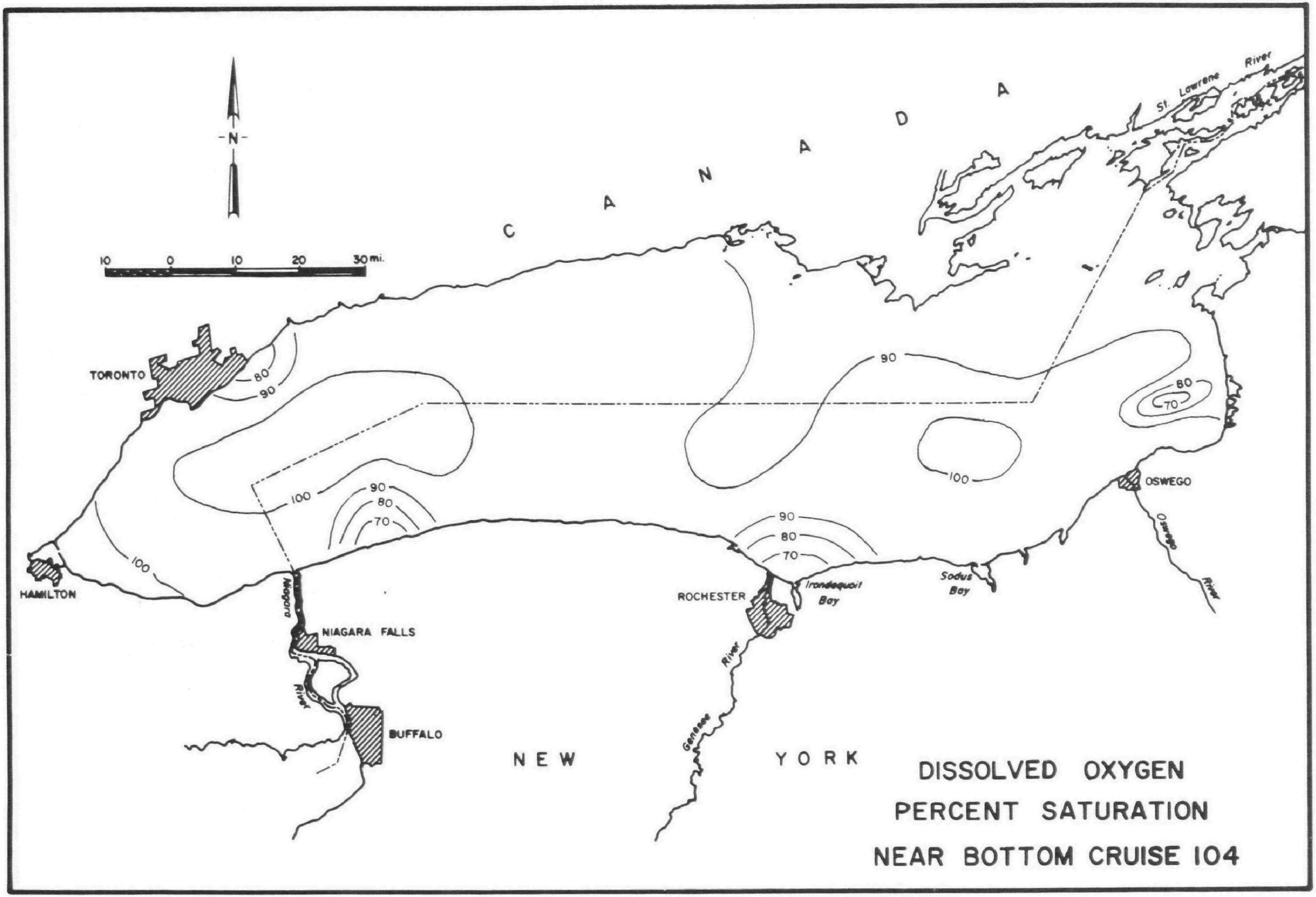

N
10 0 10 20 30 mi.
C A N A D A
St. Lawrene River
TORONTO
HAMILTON
Niagara
NIAGARA FALLS
River
BUFFALO
ROCHESTER
Irondequoit Bay
Sodus Bay
OSWEGO
Oswego River
Genesee River
N E W Y O R K
80
90
100
70
DISSOLVED OXYGEN
PERCENT SATURATION
NEAR BOTTOM CRUISE 104

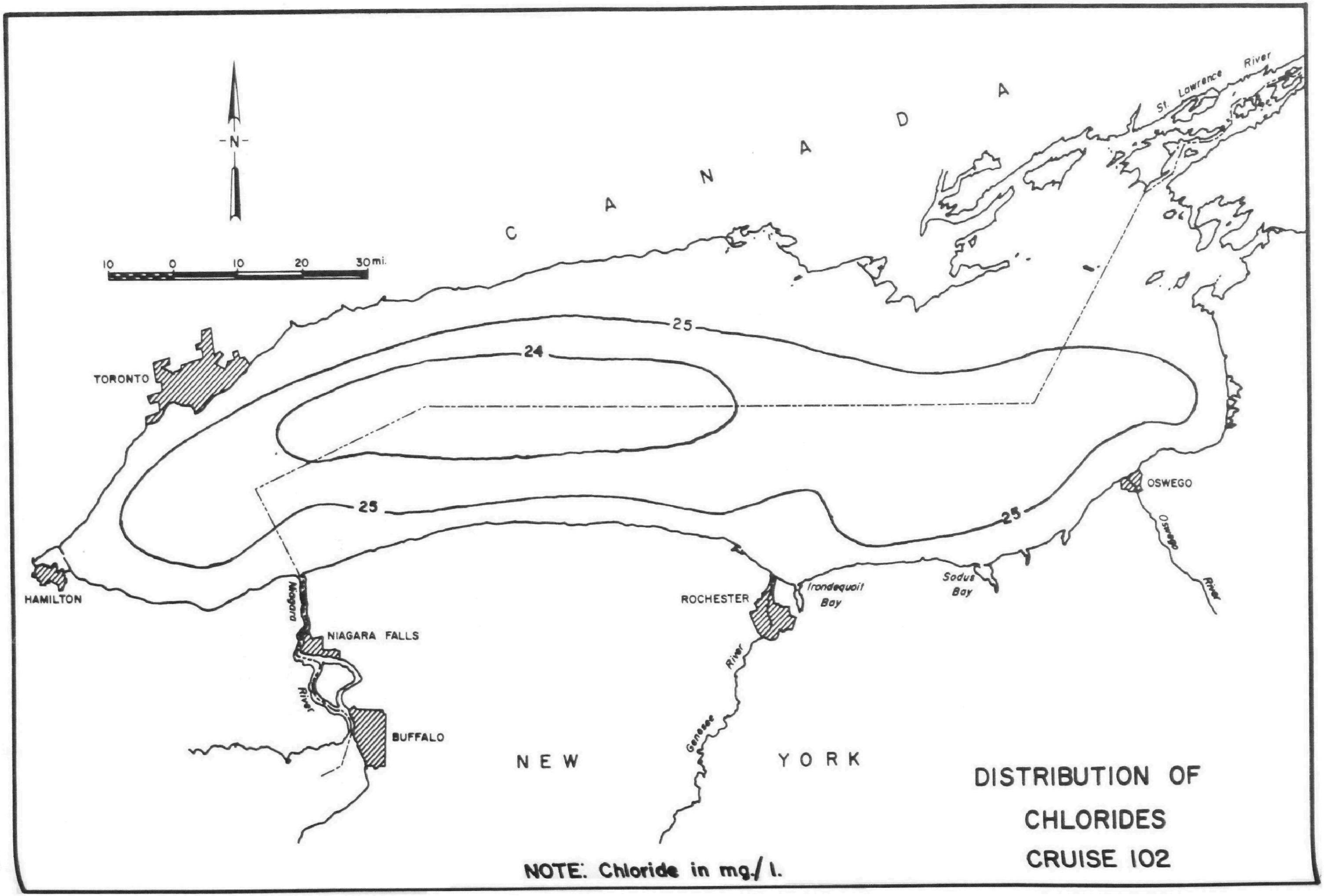
FIGURE 5-26

Great Lakes is industrial and municipal pollution. Since the 1900's a steady increase in chloride content has been observed. The practice of spreading salt on roads in winter to melt the snow has also increased in recent years, and this salt ultimately reaches the lake waters.

Figure 5-27 indicates the surface distribution of chloride ion observed during Cruise 102. The pattern is quite simple; the inshore waters have the highest concentrations and a large pool of 24 ppm water is found in the west-central part of the lake. Some evidence of an effect from the Niagara and Genesee Rivers can be seen.

Figure 5-28 shows the chloride ion distribution observed during Cruise 103. The effect of both the Toronto area and the Niagara River can readily be seen. The effect of the Genesee River is not apparent. The area of high cloride concentration is the same as that where the lowest light penetration was observed during this cruise.

Figure 5-29 shows the chloride ion distribution observed during Cruise 104. Again, areas of high chloride concentration are found in the inshore waters near the Toronto-Hamilton-Niagara River area. The highest concentration of chloride occurred in Mexico Bay



DISTRIBUTION OF CHLORIDES CRUISE 102

NOTE: Chloride in mg./l.

FIGURE 5-27

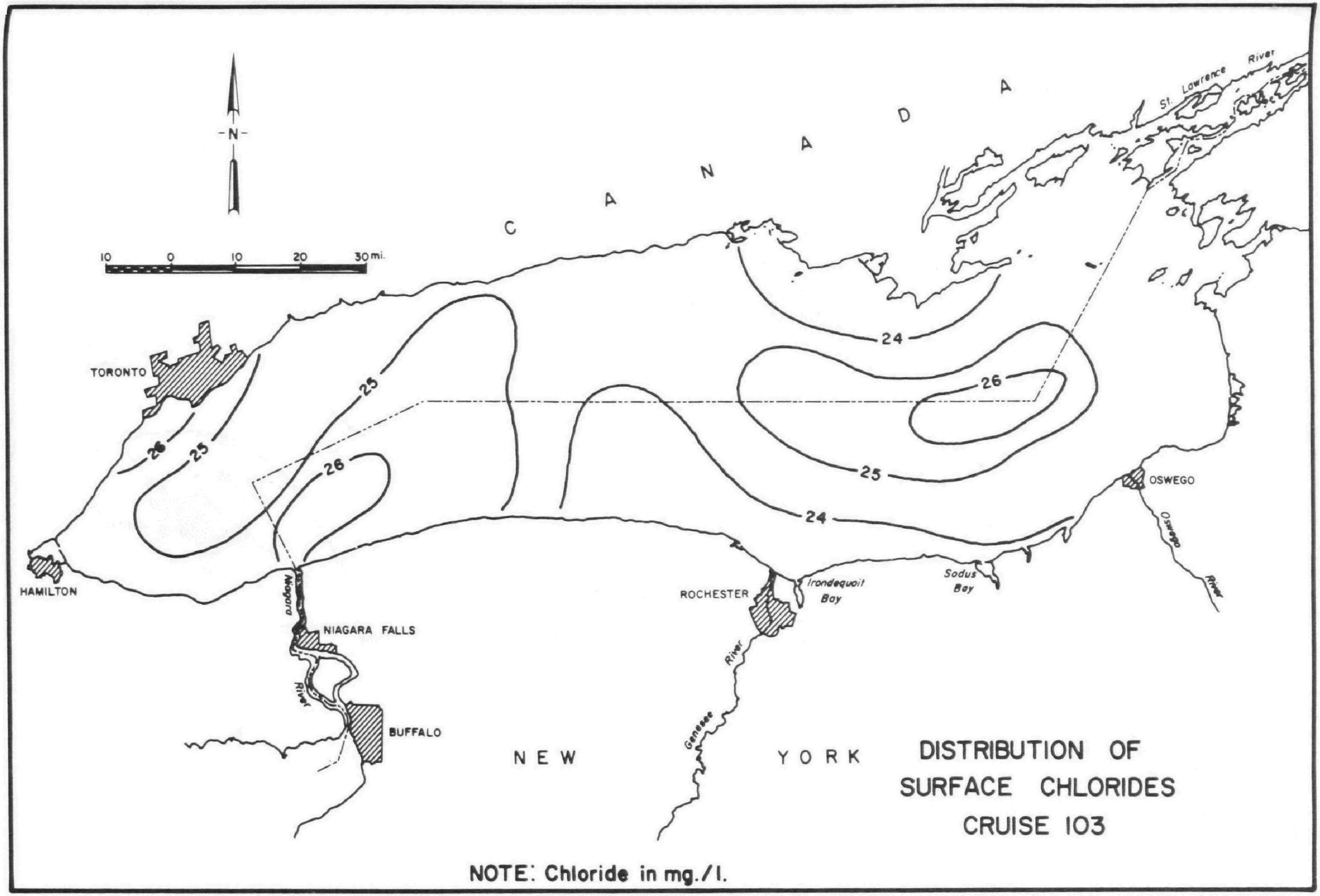

N
10 0 10 20 30 mi.
C A N A D A
St. Lawrence River
TORONTO
HAMILTON
Niagara
NIAGARA FALLS
River
BUFFALO
ROCHESTER
Irondequoit Bay
Sodus Bay
OSWEGO
Oswego River
Genesee River
NEW YORK
24
25
26
DISTRIBUTION OF SURFACE CHLORIDES CRUISE 103
NOTE: Chloride in mg./l.

FIGURE 3-28

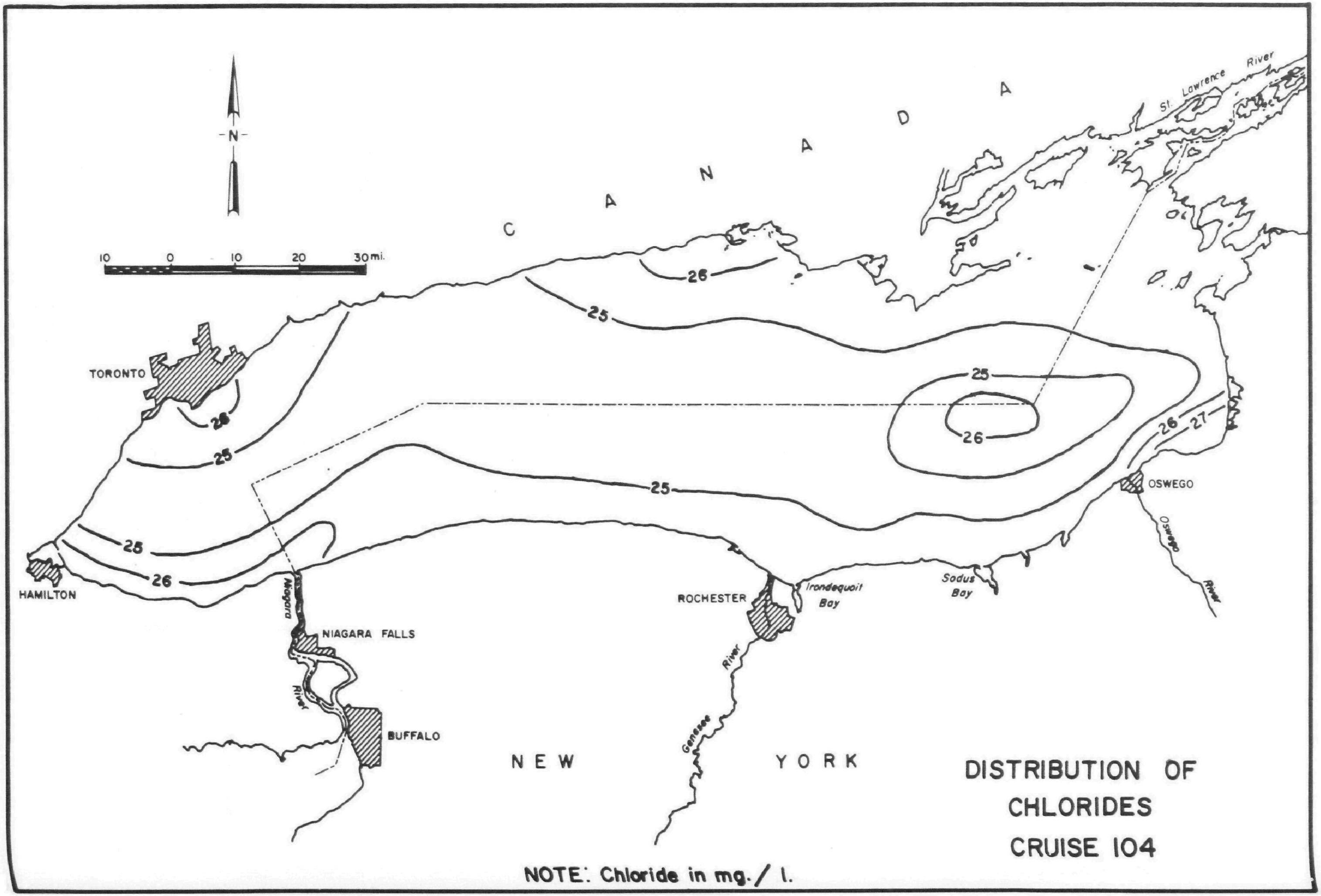

N
10 0 10 20 30 mi.
C A N A D A
St. Lawrence River
TORONTO
HAMILTON
NIAGARA FALLS
Niagara
River
BUFFALO
ROCHESTER
Irondequoit Bay
Sodus Bay
OSWEGO
Oswego River
Genesee River
NEW YORK
25
26
27
DISTRIBUTION OF CHLORIDES CRUISE 104
NOTE: Chloride in mg./ l.

FIGURE 5-29

near Oswego. The source of this high concentration is probably the Oswego River, which drains an area in which many rock horizons contain salt. The pool of high chloride concentration observed during Cruise 103 is still seen to exist. In the area of Scotch Bonnet Shoal, an area of 26 mg/l chloride water was observed.

While the concentrations of chloride ion measured during this study only ranged from 22 to 27 mg/l in the deep waters of the lake, a pattern in the distribution of these values was observed and the sources of the chloride can at times be identified.

Silicon

Silicon, one of the most abundant elements in the earth's crust, is never found as the element. It occurs in the oxidized state in true solution, as colloidal silica and as sestonic mineral particles. The principal natural source of silica in Lake Ontario is probably the clay minerals (the alumino-silicates) and dead diatom skeletons. The solubility of the silicates is dependent upon the pH; the higher the pH the greater the solubility. While the silicates are not a constituent of the protoplasm, they form the skeletal material for diatoms. A value below 0.5 mg/l is considered limiting for several species of diatoms. Dissolved silica values in Lake Ontario waters are well below the maximum standard for most water uses with the exception of water used in boilers.

Dissolved silica values (reported as SiO_2) for Lake Ontario were the highest during Cruise 102 (May 1965), Figure 5-30. The highest values were generally found at the mid-lake stations and the lowest values near the river mouths. Silica concentrations for this cruise agree well with biological findings. It was during this cruise that the highest diatom populations were observed.

Data from Cruise 103 (July and August 1965), Figure 5-31 shows a marked reduction in the amount of dissolved silica in the surface waters, suggesting that it was taken up by the diatom population during the late spring and that an apparent die-off occurred by the time of Cruise 103. To a certain extent, this agrees with the biological data which shows a reduction in diatom population from the previous cruise (102).

Data from Cruise 104 (September-October 1965) Figure 5-32, shows that the values of dissolved silica levels have tended to become more evenly distributed.

The obvious question is, where did the large amount of dissolved silica in the spring months come from? That it didn't come from the rivers is apparent in Figures 5-30, 5-31, and 5-32. One likely conclusion is that the silica was recycled from bottom

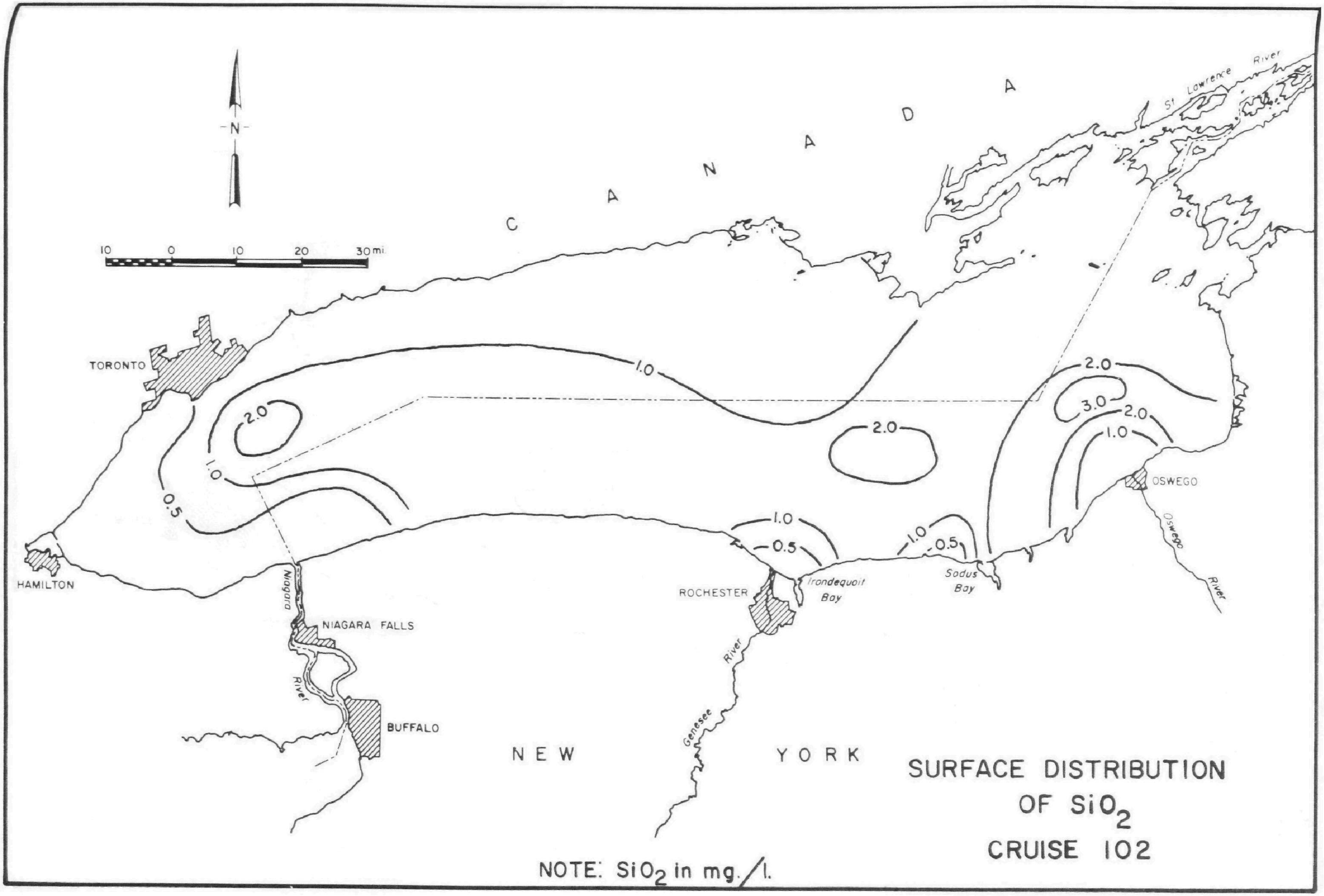
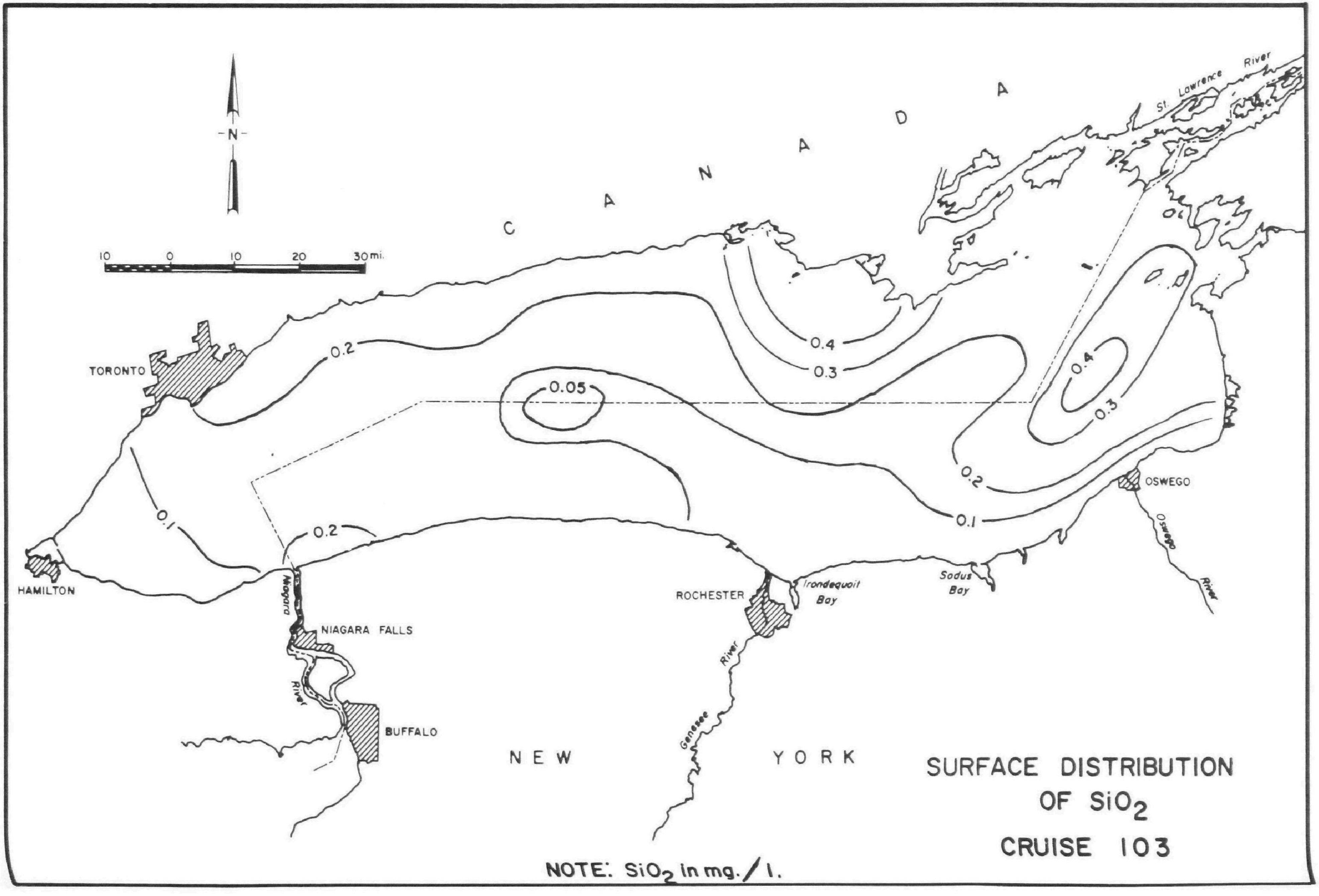
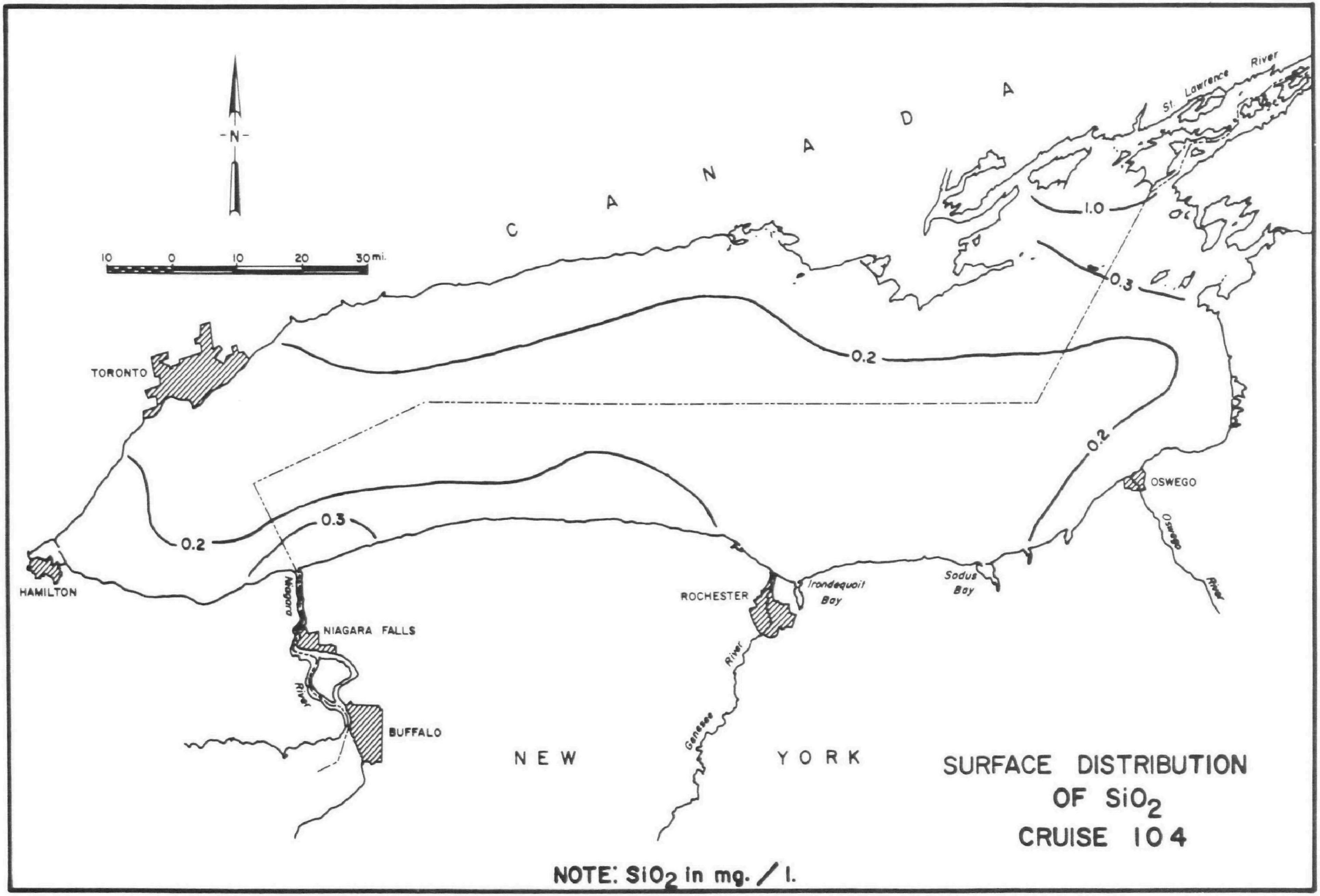

N
10 0 10 20 30 mi.
C A N A D A
St. Lawrence River
TORONTO
HAMILTON
Niagara
NIAGARA FALLS
River
BUFFALO
ROCHESTER
Irondequoit Bay
Sodus Bay
OSWEGO
Oswego River
Genesee River
N E W Y O R K
1.0
2.0
0.5
3.0
SURFACE DISTRIBUTION OF SiO_2
CRUISE 102
NOTE: SiO_2 in mg./l.

FIGURE 5-30



SURFACE DISTRIBUTION OF SiO_2 CRUISE 103

FIGURE 5-31



SURFACE DISTRIBUTION OF SiO_2
CRUISE 104
NOTE: SiO_2 in mg. / l.
C A N A D A
N E W
Y O R K
N
10 0 10 20 30 mi.
TORONTO
HAMILTON
NIAGARA FALLS
BUFFALO
ROCHESTER
OSWEGO
Niagara River
Genesee River
Oswego River
St. Lawrence River
Irondequoit Bay
Sodus Bay
1.0
0.3
0.2
0.2
0.2
0.3

FIGURE 5-32

material, perhaps from diatom skeletal material. Although no winter data was obtained that would either support or disapprove this conclusion, this process has been observed by other researchers.

Sodium

Sodium is a very active metal and, like silica, is never found free in nature. It is one of the most abundant cations found in lake waters because nearly all sodium compounds are soluble. The high sodium content of the oceans also demonstrates the tendency of this element to remain in solution once it has been dissolved.

In Lake Ontario no significant distribution or range of sodium concentrations was observed. This is not too surprising when again we consider the solubility and the lack of an important chemical or biological system that would remove it from solution (Sodium in water in some circumstances does participate in base exchange reactions whereby sodium replaces cations in clay minerals. What importance this has in Lake Ontario is at present difficult to say, but the very even distribution of sodium in these waters suggests it is not of great importance). The principal natural source of sodium in Lake Ontario waters is probably the sedimentary rocks in the Great Lakes Basin inasmuch as calcium is the dominant cation by a factor of about 4.

Sodium concentrations found in Lake Ontario waters is very close to 11.5 mg/l, which is well below any standards for water use. Since 1900, when sodium and potassium were reported in Lake Ontario as 6 mg/l, an almost twofold increase has occurred (Beeton 1956) in the concentration of sodium; this increase can only be attributed to man-caused pollution.

Biochemical Oxygen Demand(BOD)

Biochemical oxygen demand determinations were made on the water samples collected in the lake. The standard 5-day 20 C°BOD was used in this study. The BOD of a sample of sewage, industrial waste, or water is a measure of the concentration of decomposable organic matter in that sample. The BOD concept involves not only the amount of organic material which is decomposable by bacteria, but also the rate at which it will decompose aerobically. The results of Cruises 102, 103, and 104 show that in Lake Ontario, because of the low values observed, the BOD test is of limited value. All surface values were less than 3 mg/l; most of them were well below 2 mg/l, and the deeper waters were usually less than 1 mg/l. One surface station (37) has a BOD of 7.8 mg/l. More important, 60 percent of all depths sampled had a BOD of less than 1 mg/l.

Dissolved Solids

Concentrations of dissolved solids vary little in Lake Ontario. The Mean concentrations observed were 175 mg/l in the spring,

TABLE II

WEIGHTED AVERAGES OF CHEMICAL PARAMETERS FOR LAKE ONTARIO DEEP WATER STATIONS

	Cruise 102	Cruise 103	Cruise 104	
Magnesium	8.9	9.4	9.4	mg/l
Calcium	45	46	43	"
Silica	1.56	1.18	0.85	"
Chloride	24.7	24.7	24.6	"
Sulfate	31.3	30.7	29.5	"
Nitrogen:				
Organic	0.29	0.21	0.20	" (N)
Ammonia	0.06	0.04	0.07	" (N)
Nitrate	0.34	0.31	0.41	" (N)
Phosphate:				
Total		.0163	.0196	" (P)
Soluble	.0163	.0131	.0163	" (P)
Specific Conductance	320	312	323	Mmhos @25°C
Dissolved Solids	175	194	183	mg/l
Alkalinity	97	95	100	"
Chemical Oxygen Demand	6.9	7.4	6.8	"
Dissolved Oxygen	13.6	11.9	11.6	"

190 mg/l in the summer, and 185 mg/l in the fall. No significant areal distribution of dissolved solids was observed other than the fact that the highest values occurred near river mouths and large cities. In Lake Ontario, the dissolved solids consist principally of sulphates, bicarbonates, carbonates, and chlorides.

Potassium

Potassium was determined only for Cruise 102. The results were so uniformly distributed that it was felt to be of little water-quality significance. The potassium range was between 1.4 mg/l and 2.1 mg/l for the lake.

Conclusion

Table II shows weighted averages* for all (deep water) chemical observations made in Lake Ontario. In conclusion, the results of this study and those of previous studies, notably Beeton 1962, point to the continued increase of chemical input to Lake Ontario.

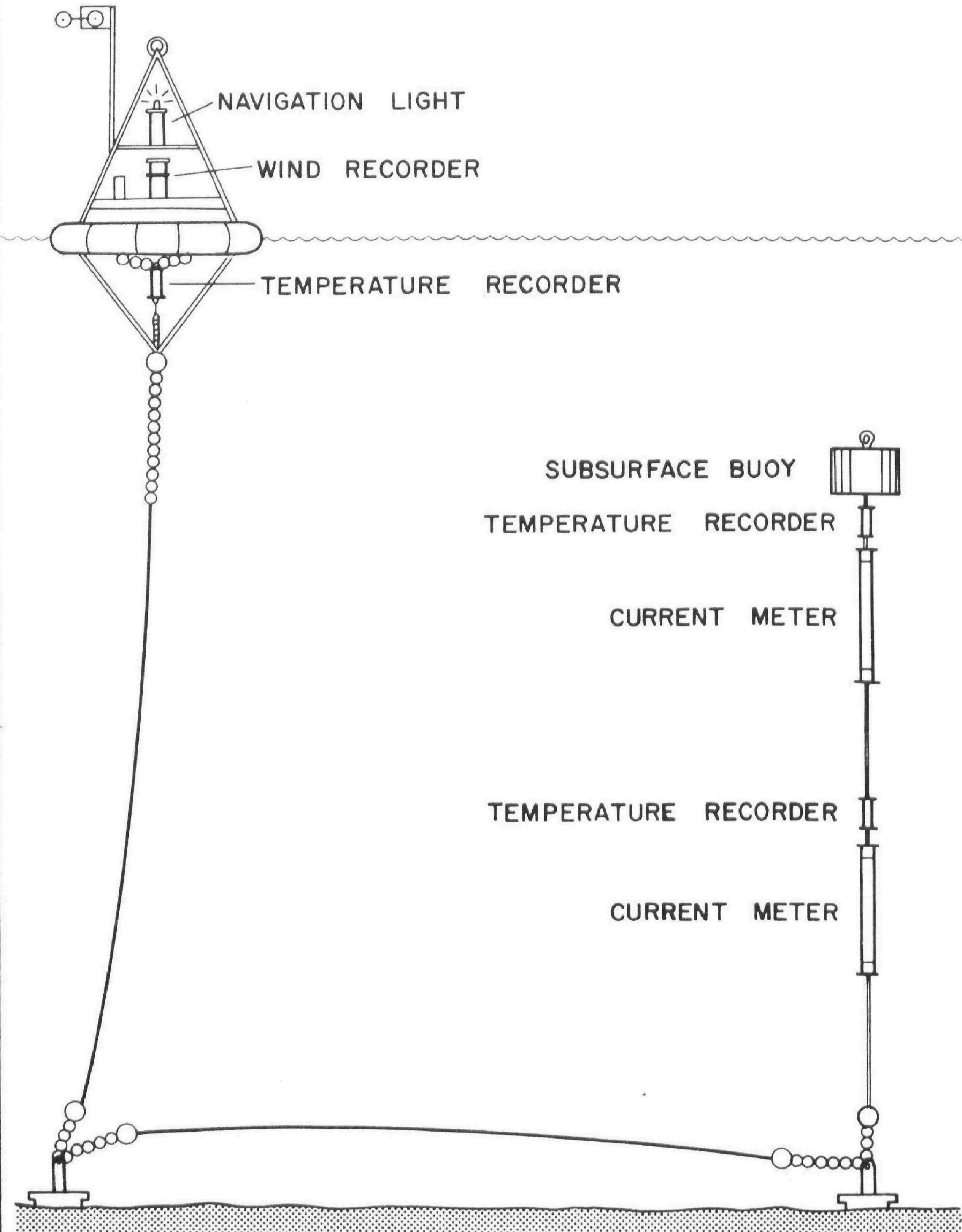
* The averages were weighted in relation to total water mass represented in all individual water samples taken at the various depths and are based on Figure 2-2.

Chapter 6

PHYSICAL CHARACTERISTICS

Introduction

Circulation studies of Lake Ontario were begun in August 1964. Their purpose was to determine the water circulation of the lake, to establish the cause and effect relationships so as to be able to predict the movement of pollutants occurring in, and being discharged into, the lake, and to develop a more accurate description and understanding of the physical, biological, and chemical phenomena of the lake. To accomplish this, 17 current-metering stations were set in Lake Ontario. The current meters were Richardson type self-contained recording instruments clock-activated periodically (every 30 minutes in this case), recording directional and speed data for one minute on 16 mm film and then shutting off. At each station, current meters were suspended at depths of 10, 15, 22, and 30 meters, and every 30 meters thereafter. Temperature recorders were also installed. A recording anemometer was mounted on an anchored surface buoy at each station, except during the winter months. Figure 6-1 is a schematic diagram showing the make-up of a typical current-metering station. The stations were in operation for 14 months, August 1964 to early November 1965. In order to supplement the current data obtained from these 17 stations, several temporary nearshore stations were operated.



TYPICAL CURRENT METERING STATION

FIGURE 6-1

Factors Governing Water Circulation

Four principal factors govern water motion in Lake Ontario: wind, its velocity and direction; water temperature, as it affects density variations within a water column; barometric pressure, as regards to high and low pressure cells, their areal extent and magnitude; and inflow from the Niagara River*, which establishes a gradient flow from its mouth to the lake's outlet. All four factors are acting on the water mass, but the dominant factor is the wind over the water surface. Other factors, in addition to those above, are the harmonic reinforcement or attenuation due to the physical shape of the lake basin and the rotation of the earth, or the Coriolis effect.

Winds

The wind data collected at the current-metering stations shows that the prevailing, or net transport, direction is from the southwest (Figure 6-2) in the summer and fall months. In winter and spring months, data from land stations show a slight northerly shift in the prevailing winds; the directions are from the west to northwest. Monthly histograms from lake stations that are near the shore show the effects of onshore and offshore winds, which skews their directional modes. The direction

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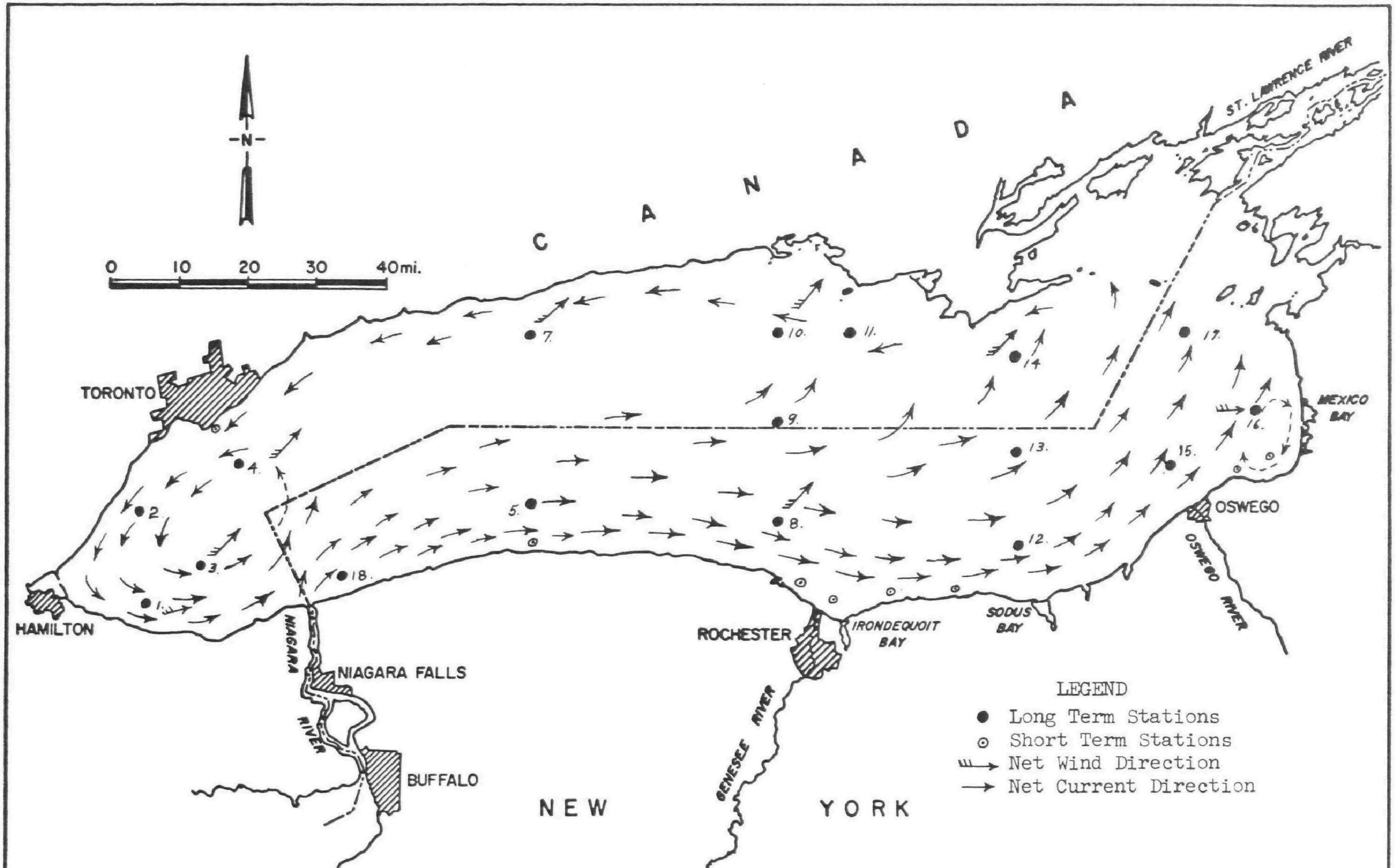
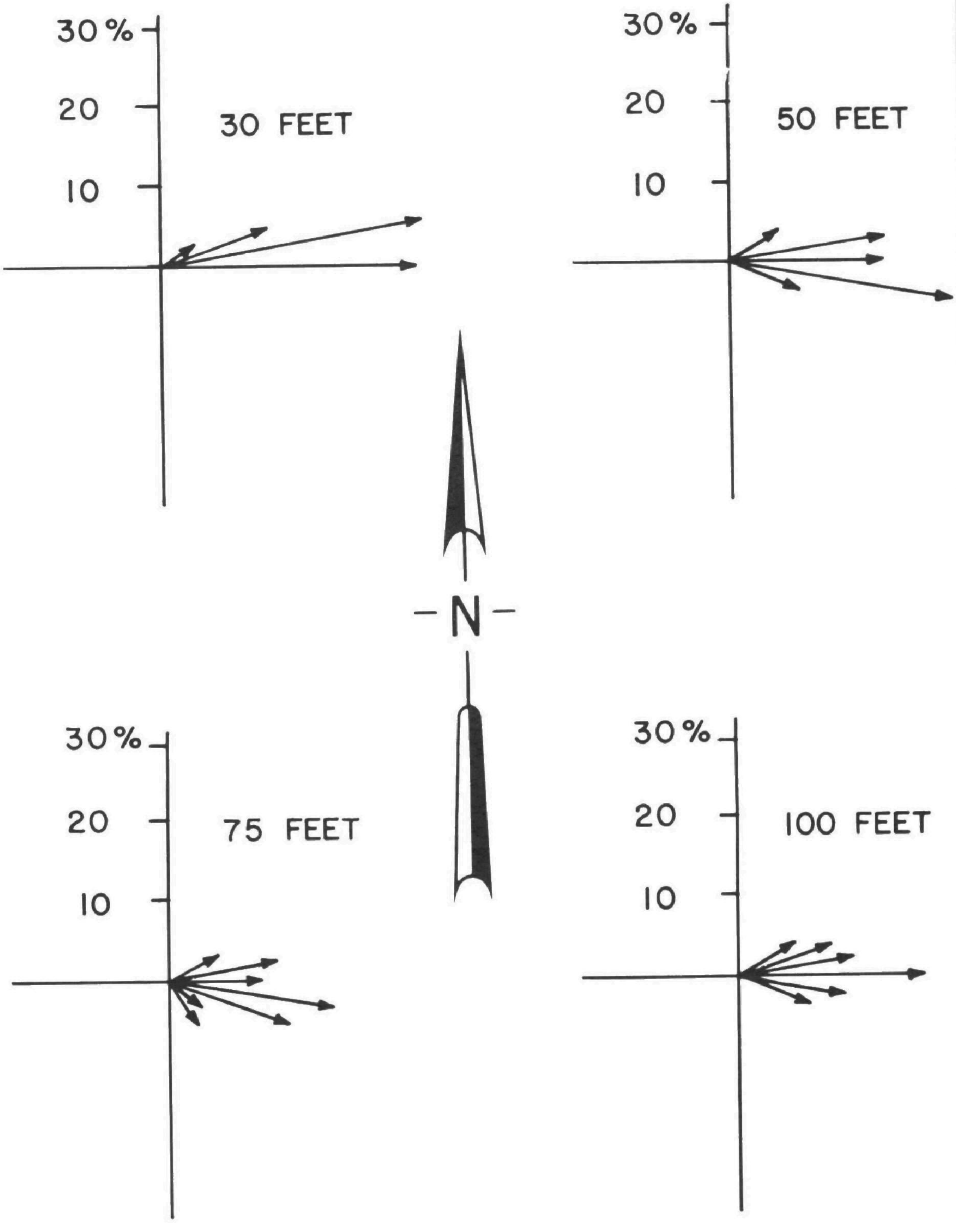
*The importance of the steady Niagara inflow on circulation is difficult to assess. In the area of Station 18 (Figure 6-13), it is quite important, but its real influence on the basis of physical factors alone is not adequately known. The reader should refer to the biological and chemical sections of this report.



Net Surface Circulation During Period of Stratification and Net Wind Direction

FIGURE 6-2



POLAR HISTOGRAMS OF STATION 18 SHOWING NET FLOW FOR PERIOD AUGUST TO OCTOBER, 1964

FIGURE 6-3

of net wind transport corresponds well with the direction of the prevailing land winds. However, the total flow directions do not correspond so well. Winds observed over the lake quite often have no readily apparent relation to the winds on land. Also, due to the altering of air masses passing over the lake, lake winds vary from one area of the lake to another. Thus, it would be difficult to predict the direction of lake currents solely from shore-based stations without a lake reference.

The average wind velocities observed over the lake at a height of 4 meters were about 15 miles (24 km) per hour. The empirical relation between winds and surface currents observed by previous investigators is that currents travel approximately 45° to the right of the mean wind direction, and current velocities are approximately 2 percent of mean wind velocity. Our data show surface currents in Lake Ontario to flow approximately 35° to the right of the mean wind direction and current velocities slightly less than 2 percent of the wind velocity. In consideration of the data above, it should be pointed out that the so-called "surface" current meter was approximately 10 meters below the surface, and interpolation of the observed data suggests that surface velocities are higher than 2 percent, possibly 3 percent of the wind velocity, and that current directions at the surface are less than 35°

to the right of the mean wind direction. These differences from previous observations by other researchers on various lakes can probably be explained by the shape of the lake basin, the placement of the current meters, and the fact that the long axis of the lake is nearly aligned with the mean wind direction.

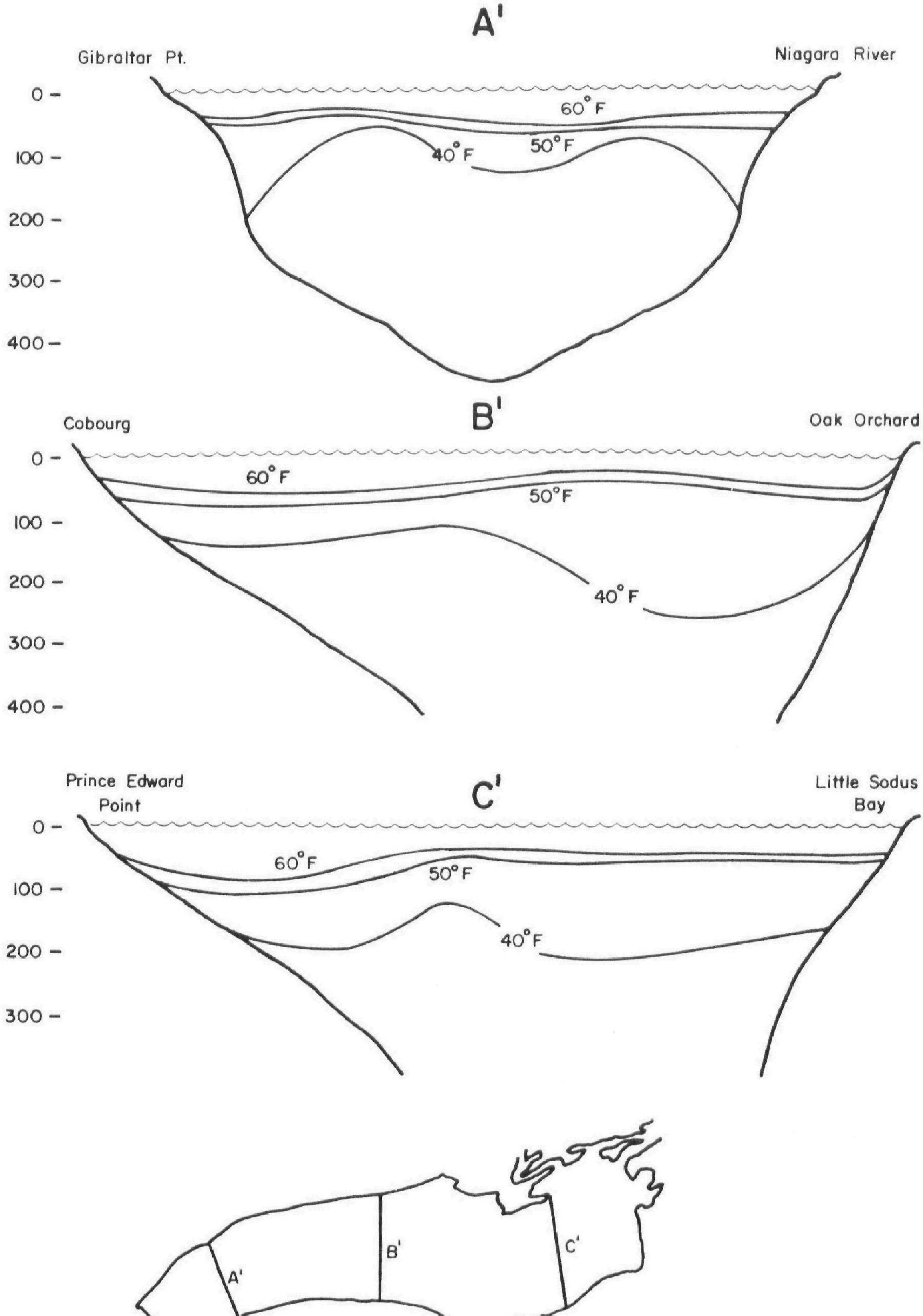
Temperatures

Lake Ontario is a dimictic lake, having a surface temperature above 13°C in summer and below 4°C in winter, a large thermal gradient, and two top to bottom circulation periods, one in spring and one in fall.

In the summer, the water becomes divided into an upper layer of warm, readily circulating, turbulent water called the epilimnion, and a lower layer of cold and relatively undisturbed water called the hypolimnion. The layer separating the epilimnion and hypolimnion, a region where a rapid temperature change takes place, is called the thermocline. When the lake is thus stratified, the waters in the hypolimnion (the lower layer) are physically and chemically isolated. As a result, little oxygen replacement takes place in this zone during this period and any chemical or biological system must operate on a reserve supply. Fortunately, in the case of Lake Ontario, 85 percent of the lake's volume is in the hypolimnion. This is not the case in the shallow-water lakes, such as Lake Erie, where less than 20 percent of the total volume is contained in the hypolimnion, and serious oxygen depletion is common. During this period of stratification, the volume of water with which a pollutant could mix is greatly reduced. What may be considered a safe input in the winter months, when the lake is essentially isothermal, may in summer months be critical, particularly in embayments during periods of quiescence.

In the winter months, the lake again becomes stratified, but the stratification is not as pronounced as in summer, so that for practical purposes the lake can be considered to be essentially isothermal. At this time, the bottom layer will again be made up of water that is denser than the surface water. Its minimum temperature, however, will be about 2°C (Rodgers and Anderson, 1963), while the surface layer may cool to as low as 0°C. Lake Ontario usually does not freeze over in the winter. Thus, in winter there is a layer of warmer but denser water at the bottom of the lake and a colder but lighter layer at the surface. The period of thermal change between summer and winter conditions is called the spring or fall overturn.

The lake begins to stratify in late May, reaching its maximum heat content in August. From September, the epilimnion begins to cool until the stratification becomes unstable and overturn occurs, usually in conjunction with a storm. This fall overturn can occur as early as October; usually, however, it occurs some time in November. A point to remember here is that while the lake is cooling and the temperature of the epilimnion becomes less, the thickness of the epilimnion becomes greater because of increased mixing.



TEMPERATURE PROFILES FOR AUGUST, 1964

FIGURE 6-4

Figure 6-4 shows three temperature profiles of the lake during the month of August. The isotherms are depressed on both the northern and southern side of the lake and bulged upward in center. This type of thermal structure is what we would expect if the water circulation were counterclockwise; thus, the temperature data, in general, supports the observed summer current-metering data.

During approximately seven months of the year, the water of the Niagara River is warmer and, therefore, less dense than the Lake Ontario water that is below the thermocline. This means that during this time Niagara River water mixes only with waters in the epilimnion and that the retention time for Niagara River water is short if compared to what is normally considered the overall retention time of the lake.

During the spring and sometimes in the fall, when the main body of lake water is essentially isothermal, a horizontal stratification occurs along the shoreline (Figure 6-5). In the spring, the water of the rivers entering the lake are warmer than the lake water; this, in conjunction with more rapid heating of the inshore waters, causes a strong density interface, the "thermal bar" (Rodgers, 1965), to develop at the 4°C isotherm or temperature of maximum density. Development of the thermal bar begins in local embayments and areas of stream inflow. At times the thermal bar may encircle the lake, separating the main body

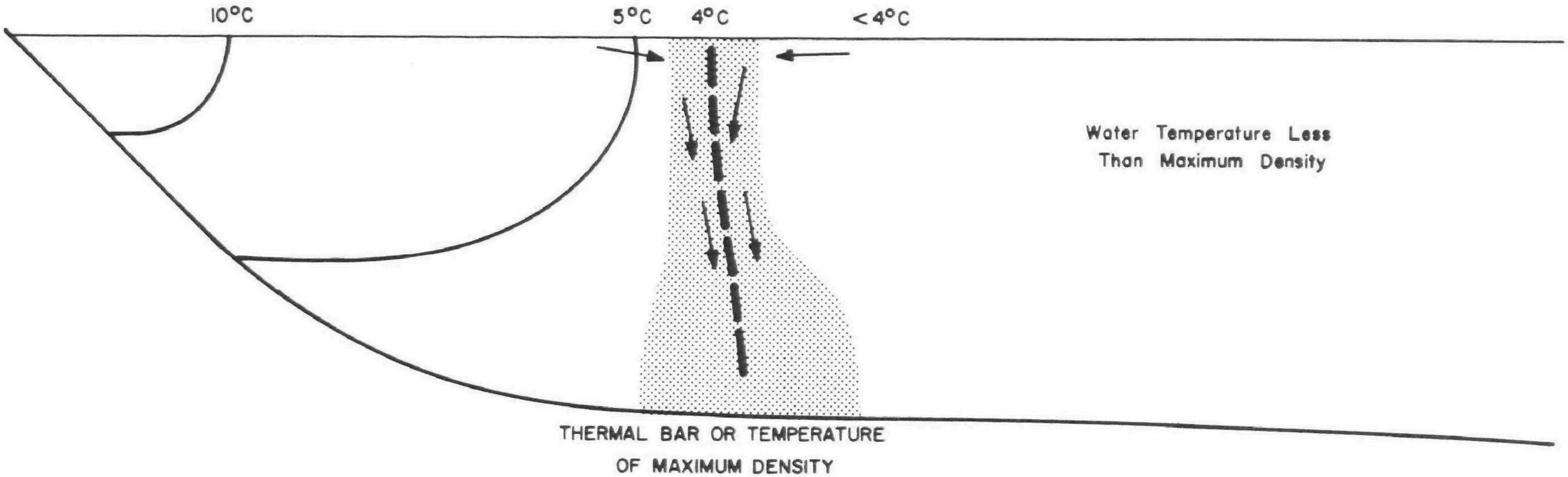


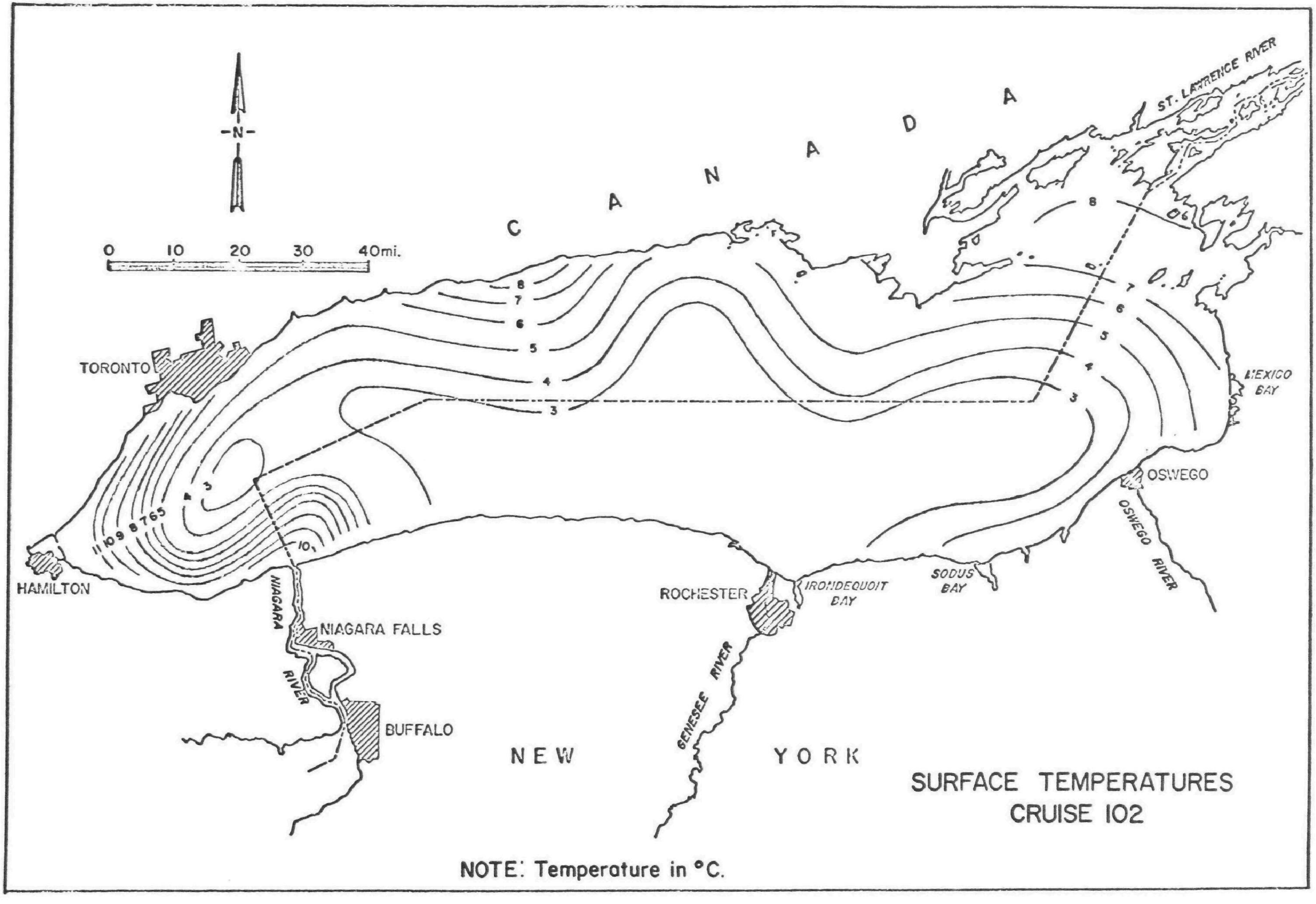
FIGURE 6-5

SPRING THERMAL BAR WITH ASSOCIATED VERTICAL CIRCULATION, AFTER RODGERS,'65 of lake water from inshore waters. Implicit in the development of a thermal bar is the fact that it can only exist when water masses above and below the temperature of maximum density are present and the fact that it is a lake boundary condition.

In the fall, the conditions of thermal bar development are reversed. However, the fall thermal bar is not as extensive or as well developed as the one that occurs in the spring.

Figure 6-6 shows the lake surface temperatures during Cruise 102. The isotherms in the western end of the lake are as one would expect at this time of year, with the warmer waters inshore. This thermal structure agreed with the lake's circulation obtained from current-metering studies. The areal influence of the Niagara River is also readily apparent.

During Cruise 102 the winds shifted from the prevailing westerly direction to the northeast. The effects of this are seen in the central and eastern ends of the lake. The 4°C, 5°C, and 6°C isotherms have apparently been displaced southward and warmer waters are moving southwest from the bay area north of Duck Island. These observations agree with the current-metering studies in that at Stations 16 and 17 in the eastern end of the lake near Duck Island a flow towards the southwest at the 10 meter level was observed and a compensating north-northeast flow at the 30 meter level occurred.



SURFACE TEMPERATURES
CRUISE 102

NOTE: Temperature in °C.

FIGURE 6-6

Data from Cruise 103 (Figure 6-7) shows a warm pool of water in the eastern end of the lake off of Oswego. The isotherm distribution suggests that this pool formed along the southern shore near Rochester, New York. The areal extent of this warm pool corresponds to the area of low light penetration also found during this cruise (See Figure 3-9). There is a strong suggestion that the shallowness of the trophogenic zone observed at this time was due to biological activity, although confirmation of such activity is lacking.

Figure 6-7 also shows the existence of colder waters along the northern shore. It may be that deep, cold waters moving along the northeastern rim of the lake are diverted westward and forced upward as they pass along Scotch Bonnet Shoal, mixing with and displacing other surface waters; this westward flow is focused somewhat in the vicinity of Toronto.

The temperature distribution observed during Cruise 104 (Figure 6-8) shows water in the vicinity of Scotch Bonnet Shoal being drawn southward. This suggests that there is a counterclockwise circulation in the eastern end of the lake. The temperature structure in the western end of the lake suggested that another counterclockwise circulation is occurring here, also.

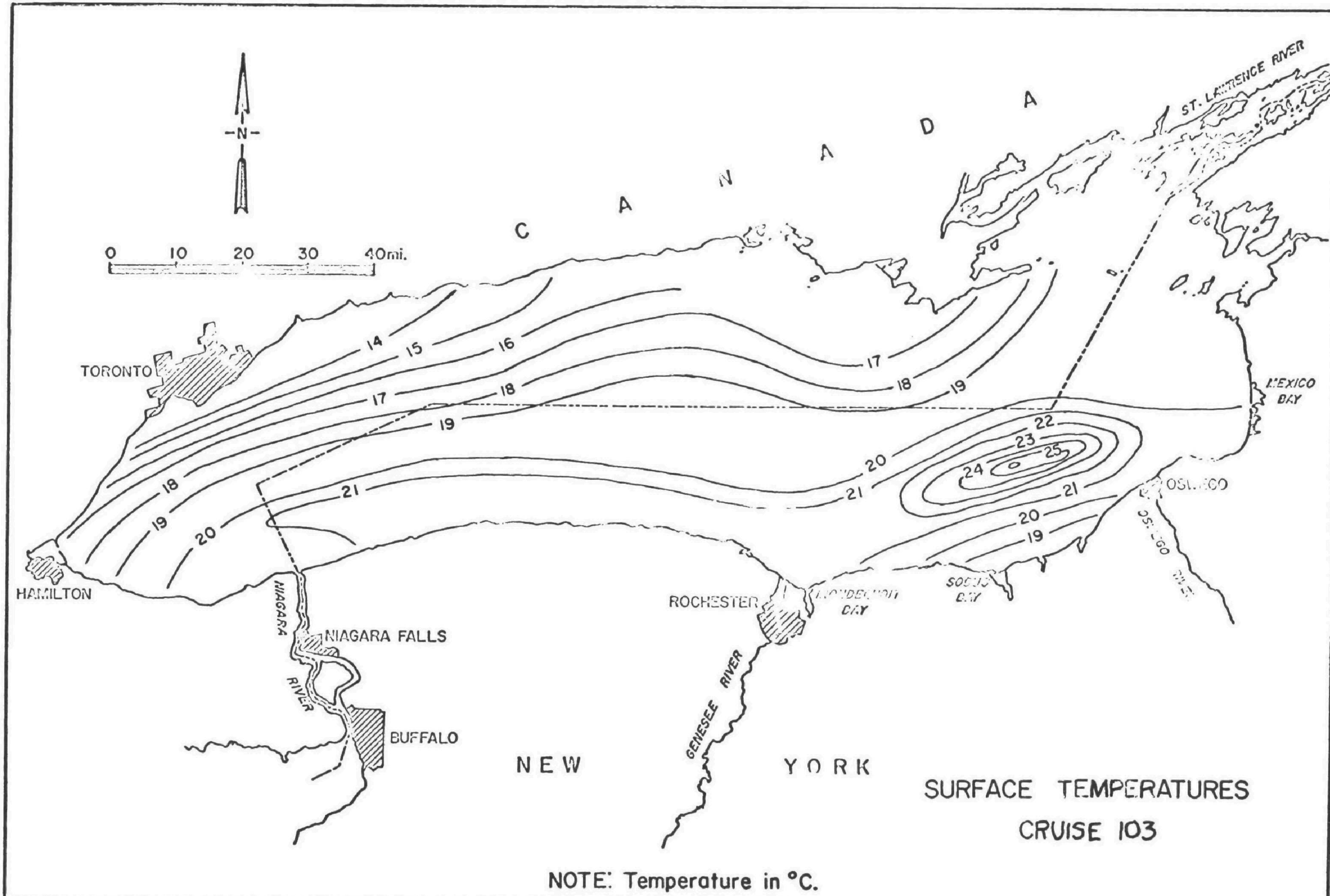
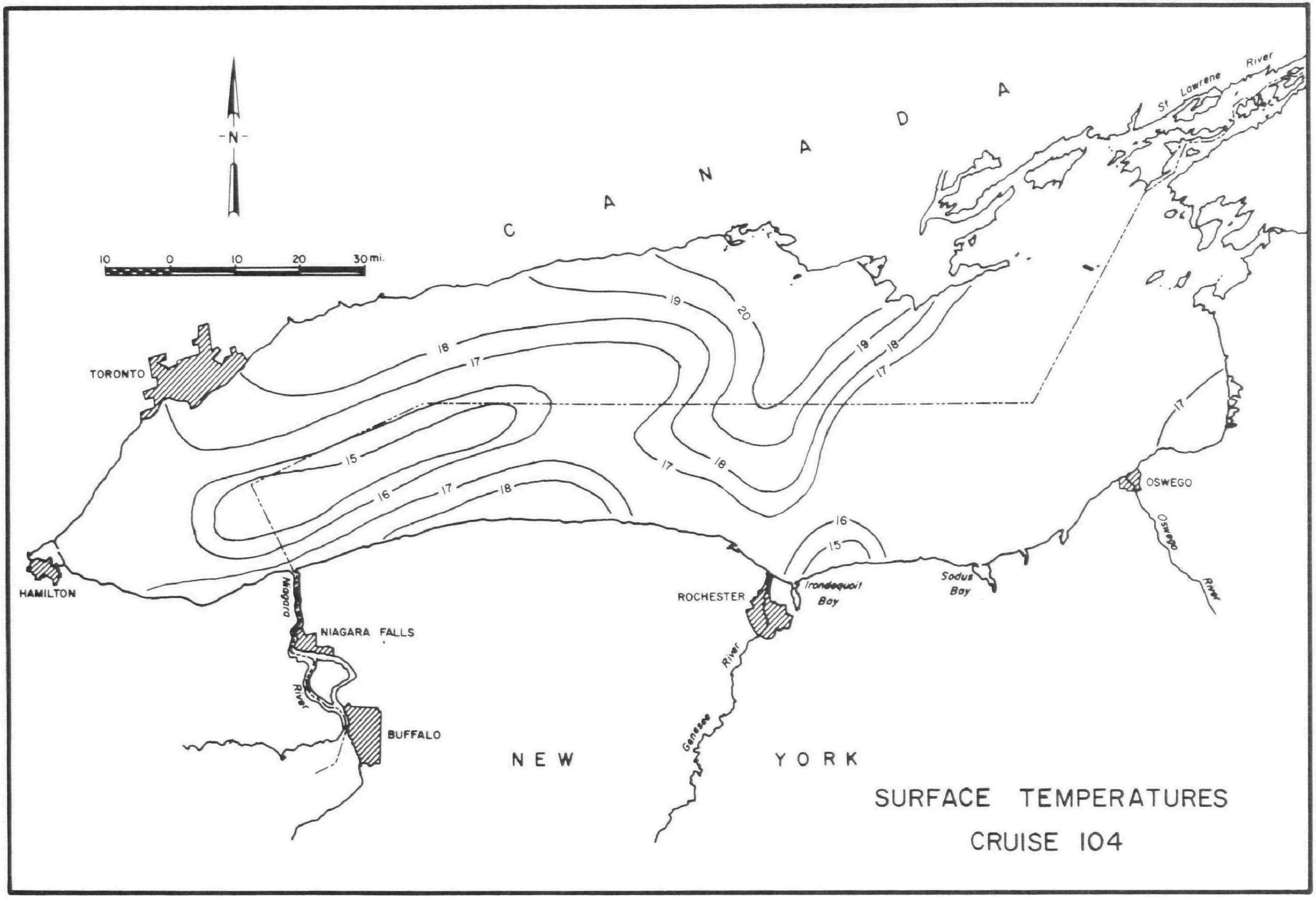

N
0 10 20 30 40mi.
CANADA
ST. LAWRENCE RIVER
TORONTO
HAMILTON
NIAGARA
RIVER
NIAGARA FALLS
BUFFALO
ROCHESTER
GENESEE RIVER
MEXICO BAY
SODUS BAY
NEW YORK
SURFACE TEMPERATURES
CRUISE 103
NOTE: Temperature in °C.

FIGURE 6-7



SURFACE TEMPERATURES
CRUISE 104

FIGURE 6-8

Currents

Two distinct net surface circulations occur in Lake Ontario. One circulation pattern occurs when the lake's water mass is stratified, and the other pattern is developed when the lake's water mass is isothermal.

When the water mass is stratified (June to November), the net surface flow (Figure 6-2) is well developed toward the east along the southern shore, with a lesser return flow to the west along the northern shore; the return originates in the area of Scotch Bonnet Shoal. This western return flow is made up in part of deeper waters flowing northwest from the eastern basin, which, after making contact with the rim of the lake, are diverted upward and to the west. In the eastern end of the lake, flows are generally towards the northeast and are less sharply defined than in the western end of the lake. The surface circulation in the area of Scotch Bonnet Shoal, due principally to its bathymetry, varies greatly with the frequent development of eddies. The net surface flow of what is essentially Niagara River water is strongly developed towards the east. There is a suggestion of a gyral occurring, at times, in the western end of the lake. If this gyral is there and is strictly a counterclockwise surface flow, retention times for a pollutant would naturally be longer and some build-up could occur.

This net circulation pattern reaches its maximum development in September and remains dominant until November.

In November, fall overturn occurs and the lake's water mass becomes essentially isothermal; also, the direction of the prevailing winds shifts and increases in velocity so that the winds are now principally from the west-northwest, whereas before they were from the southwest. As a result, the whole net surface flow of the lake is eastward and a bottom return flow is developed westward, or, in other words, the circulation develops a vertical tendency, with the surface layer in the western end being displaced to the east and replaced by deeper water (upwelling). As the surface layer moves eastward, it cools and mixes with other surface waters. Other waters sink to replace the bottom water being displaced westward. This pattern lasts until the lake again becomes stratified and the winds become more southerly, which is some time in June.

The average effective velocity (the velocity of net water transport) is approximately 5 cm/sec. in summer months and 7 cm/sec. in the winter months. The average velocity is on the order of 15 cm/sec. in the summer months and 21 cm/sec. in the winter months. Velocities observed ranged from the starting speed of the current meters, 0.5 cm/sec., to over 50 cm/sec.

The surface waters of Lake Ontario can respond very rapidly to wind stress. A current change less than six hours after a major wind shift is common in mid-lake. In inshore areas, the response is even more rapid. The net circulation, while on a long-term basis may be considered the circulation pattern of the lake, exists only for short periods of time. One week would be considered a long period of time for the net circulation flow pattern to be operating. Figures 6-9, 6-10, 6-11, 6-12, 6-13, 6-14, 6-15, and 6-16 show what the circulation of the surface waters are under a mean wind condition and areas where upwelling may occur. The data for these drawings were taken by visually comparing graphs that show velocity and direction for both winds and currents, selecting times when major changes of winds occurred (10 miles per hour [16 km/hr] and 90° in direction), and then looking for and noting changes in current direction and magnitude. While this is a tedious procedure at best and accuracy is not of the highest order, it is felt that the results are fair (the problem of air-sea interaction is a difficult one and, as a step towards studying it, a computer program that will do a straight statistical analysis of the data as regards wind speed and velocity and current direction and speed is presently being initiated).

Also, the circulation shown should be considered only on a short-

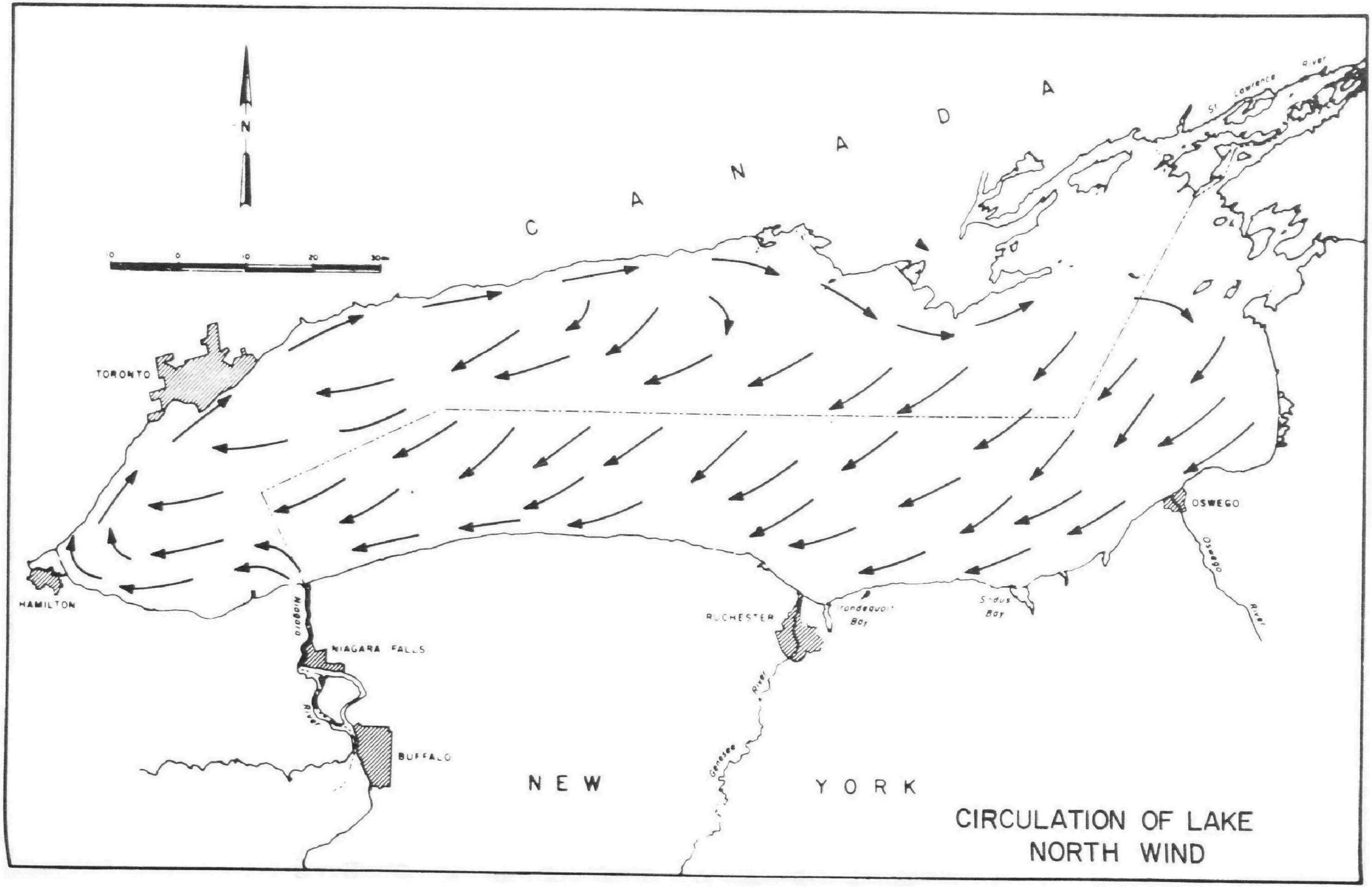
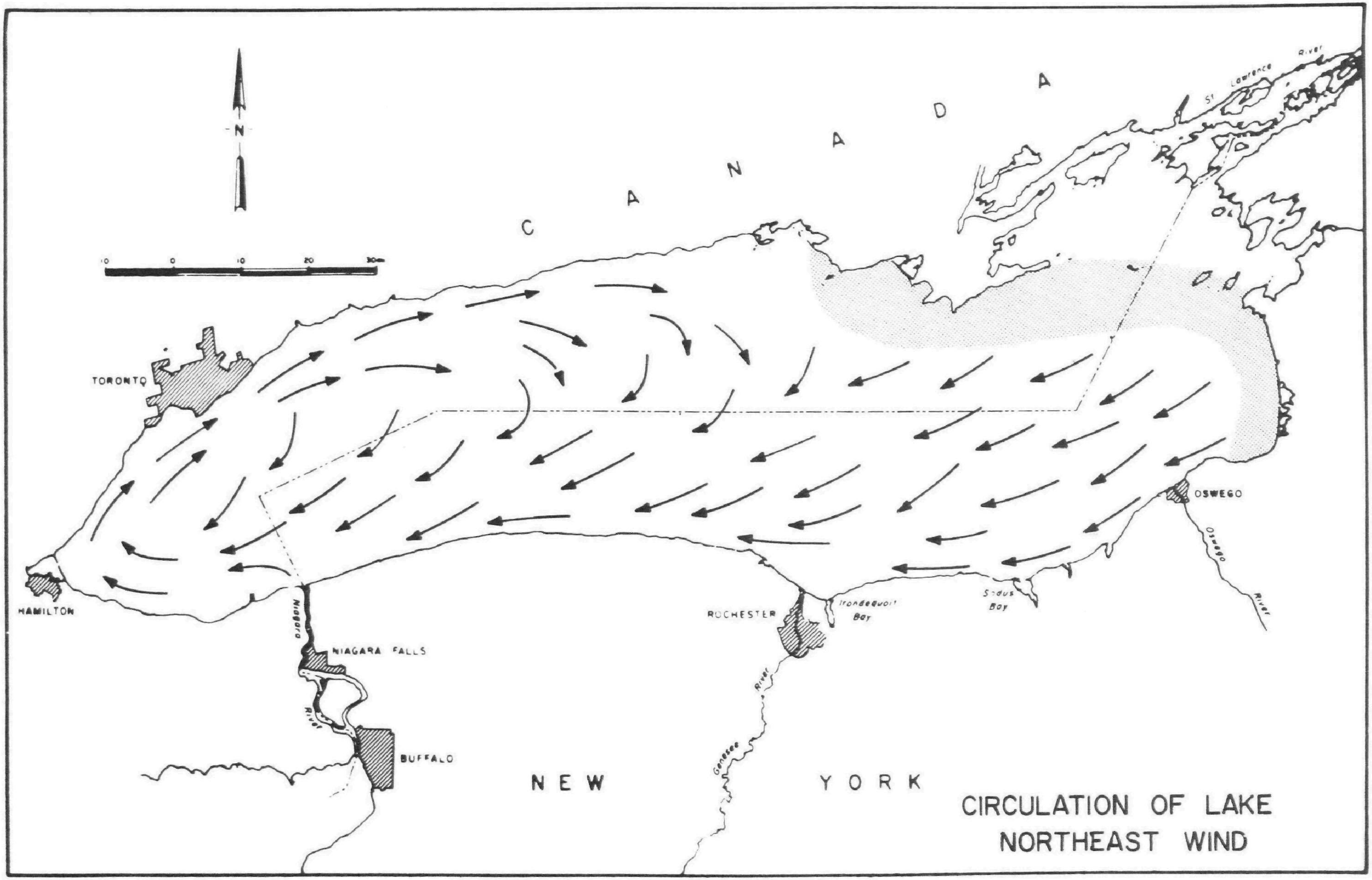
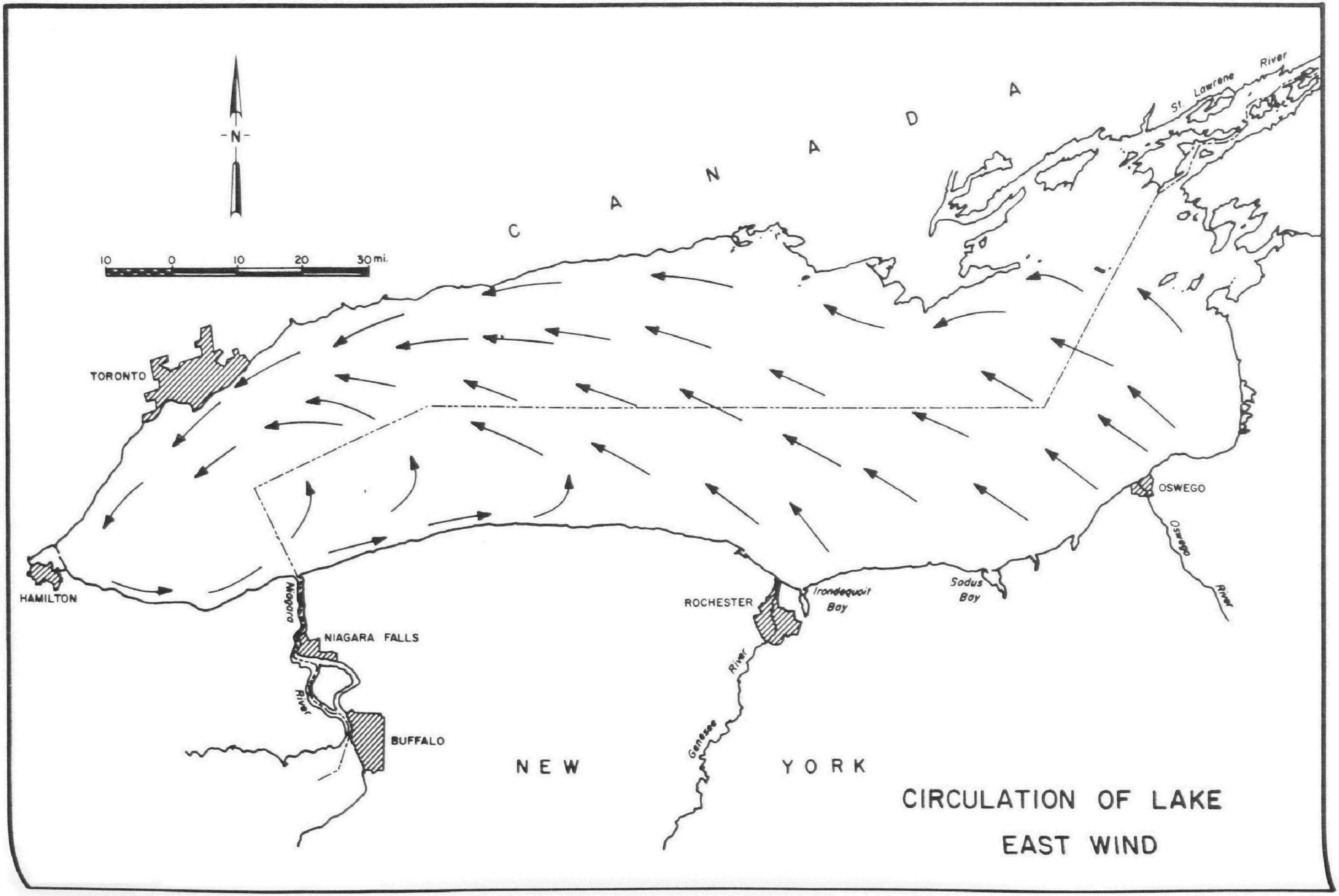

N
10 0 10 20 30mi
C A N A D A
St. Lawrence River
TORONTO
HAMILTON
Niagara
River
NIAGARA FALLS
BUFFALO
ROCHESTER
Irondequoit Bay
Sodus Bay
OSWEGO
Oswego River
Genesee River
N E W
Y O R K
CIRCULATION OF LAKE
NORTH WIND

FIGURE 6-9



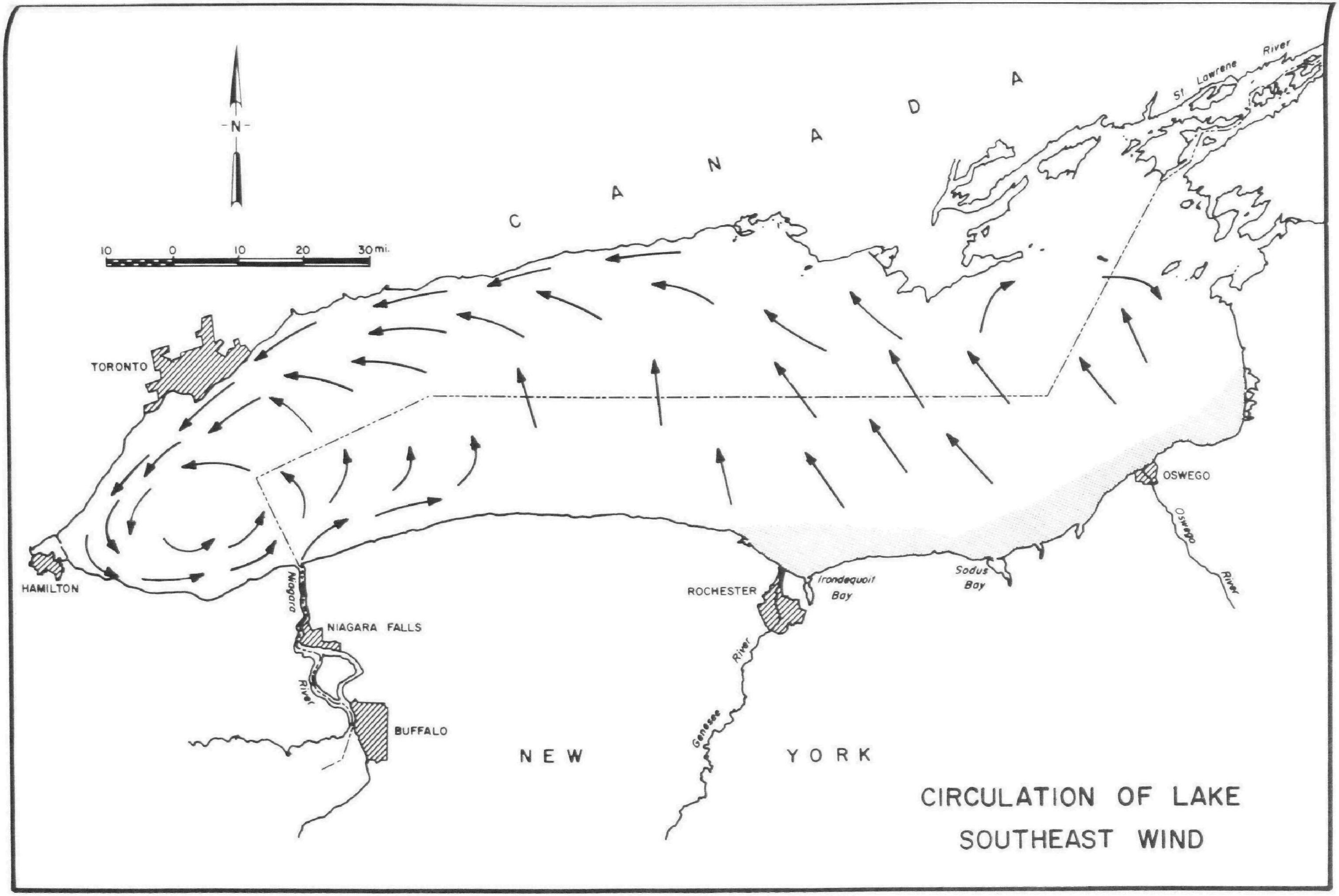
CIRCULATION OF LAKE
NORTHEAST WIND

FIGURE 6-10



CIRCULATION OF LAKE
EAST WIND

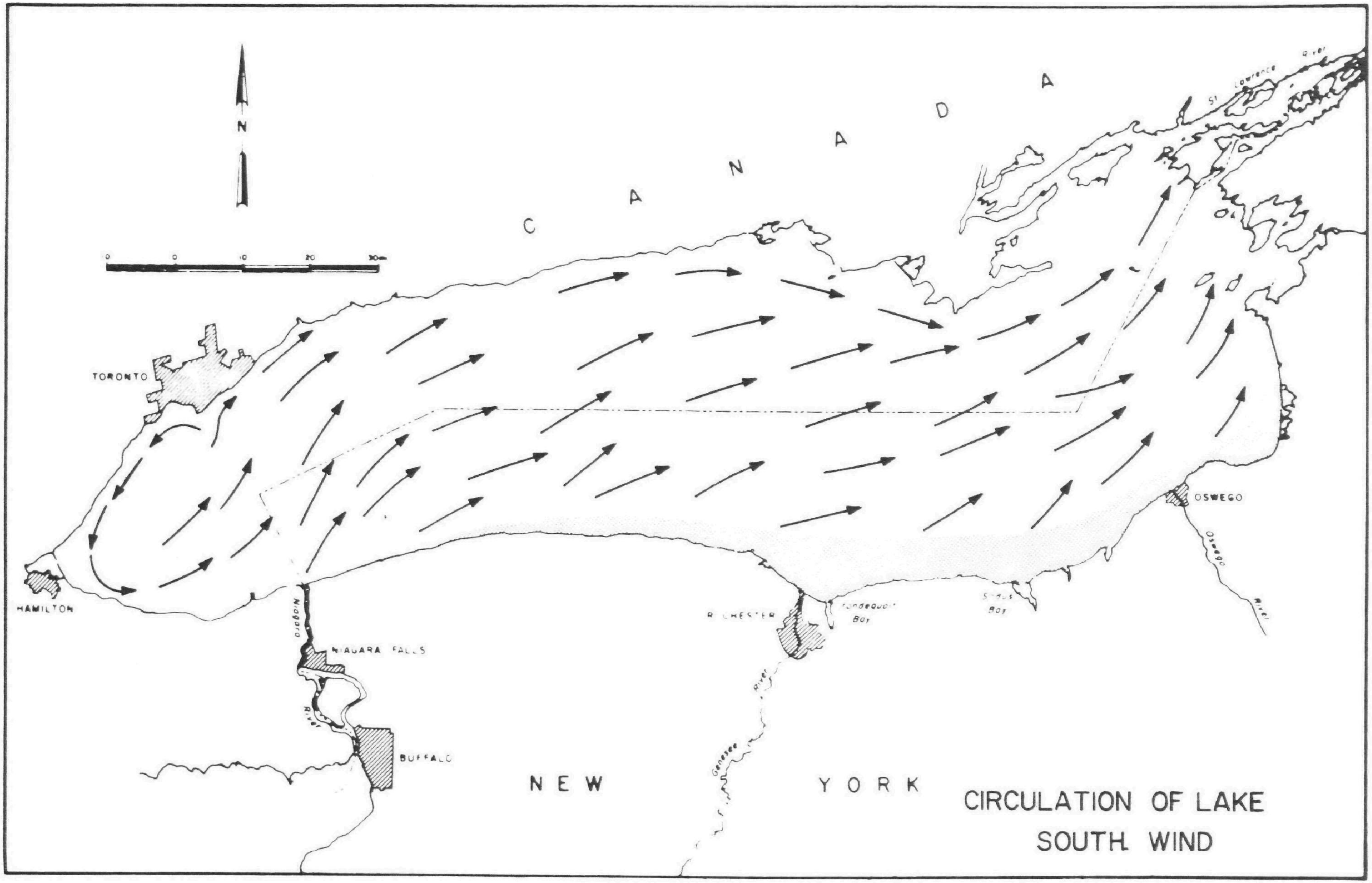
FIGURE 6-11



CIRCULATION OF LAKE
SOUTHEAST WIND

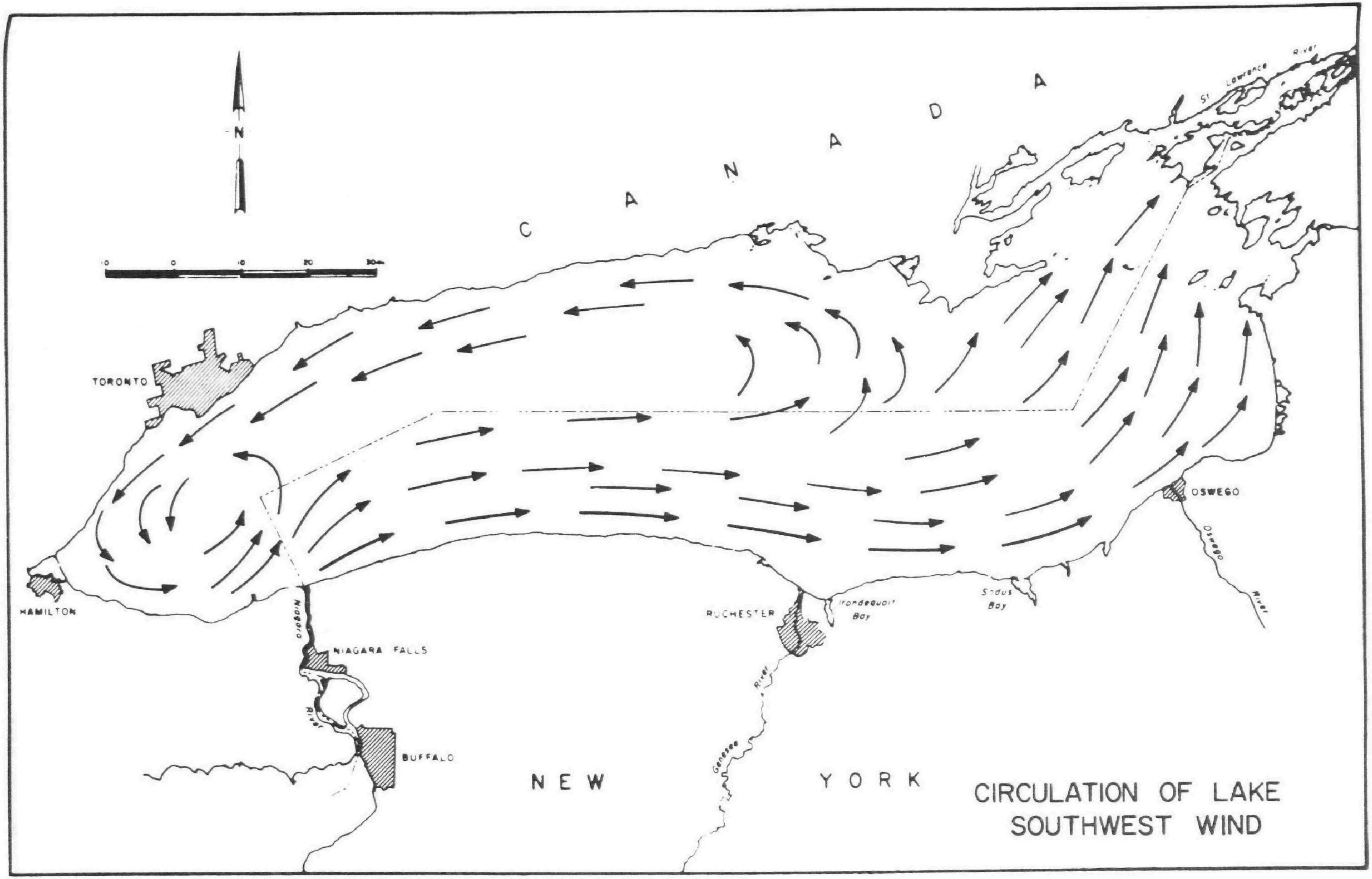
FIGURE 6-12

FIGURE 6-13

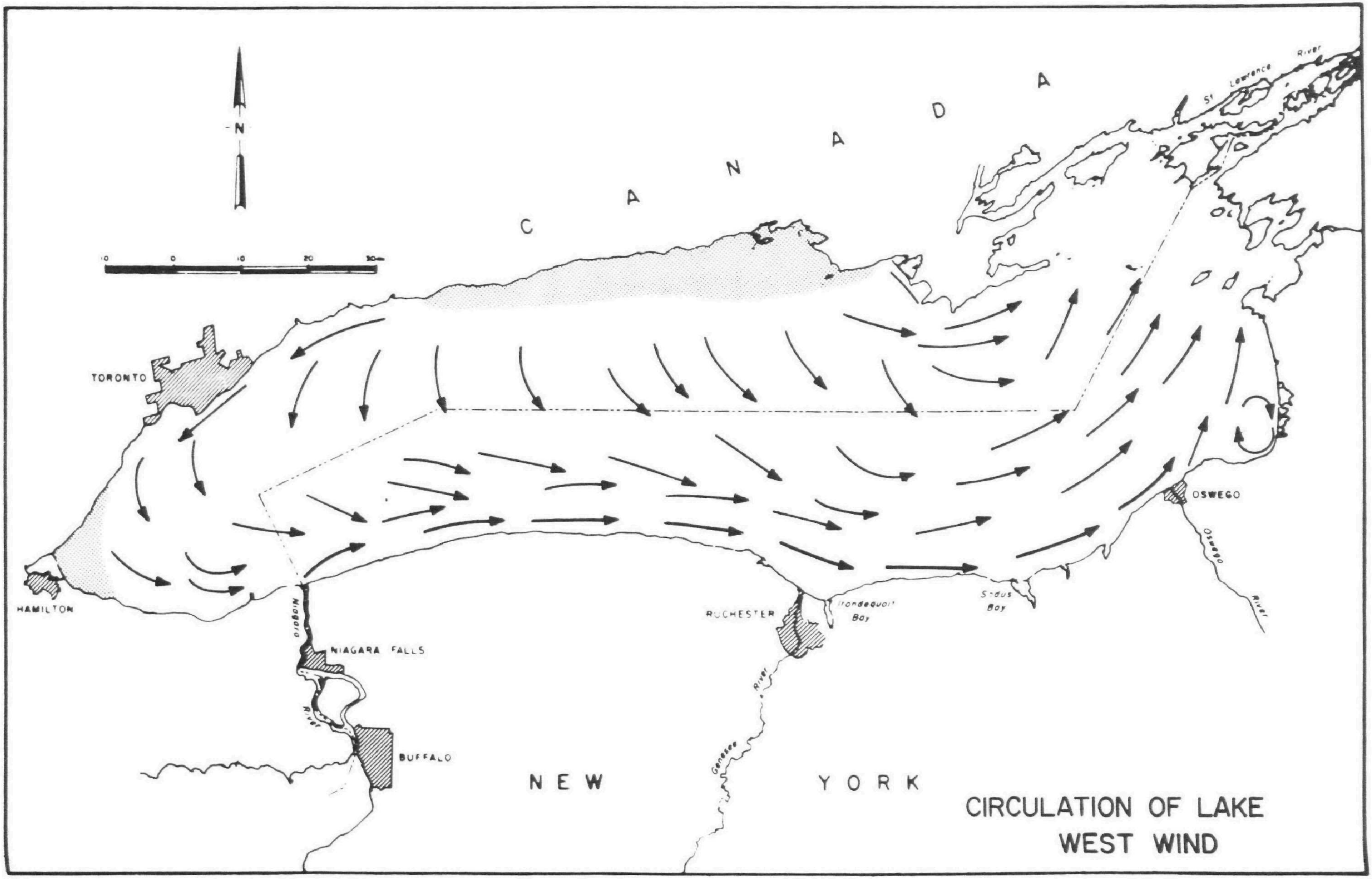


CIRCULATION OF LAKE
SOUTH WIND

FIGURE 6-14

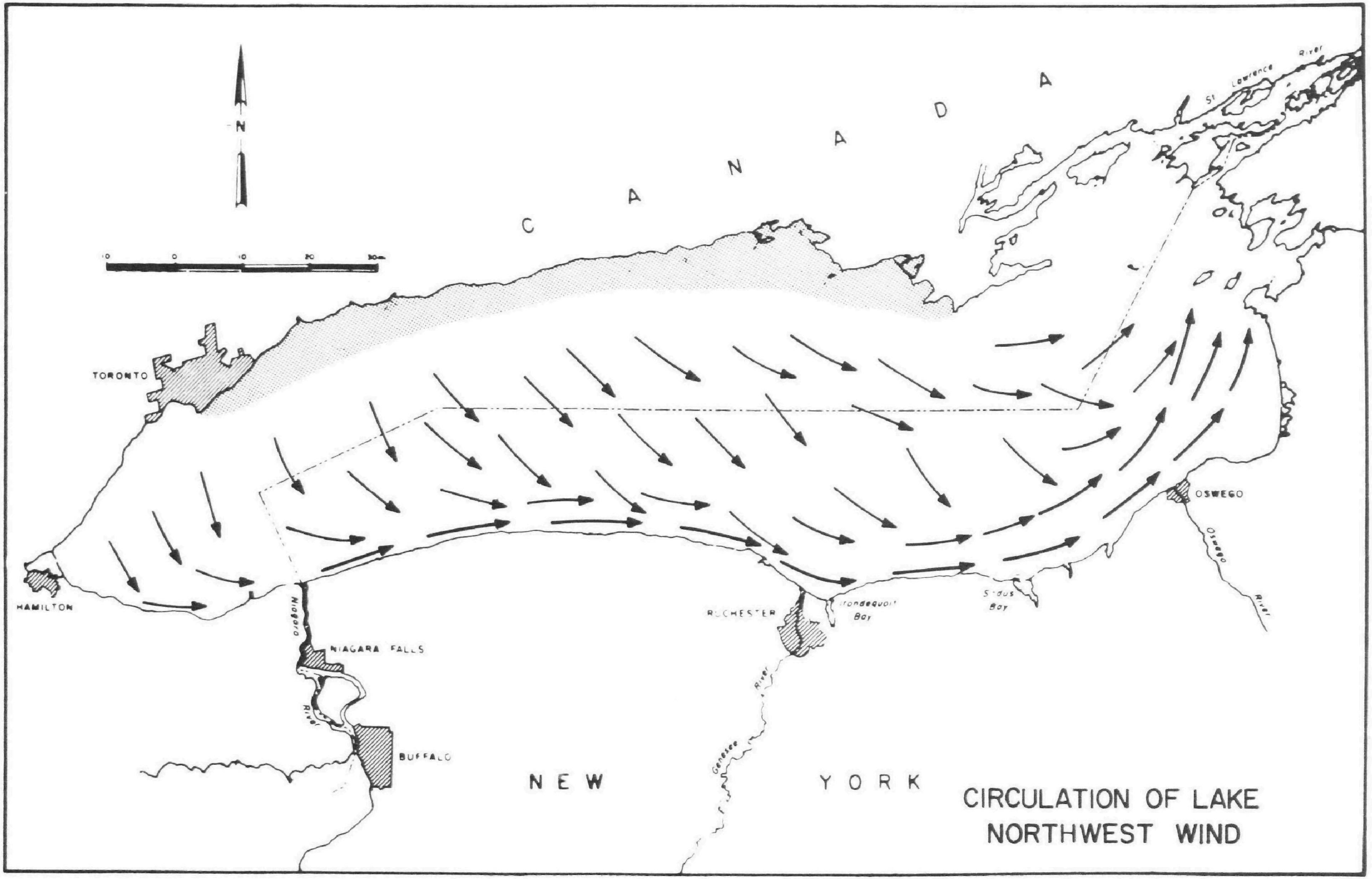


CIRCULATION OF LAKE
SOUTHWEST WIND



CIRCULATION OF LAKE
WEST WIND

FIGURE 6-15



CIRCULATION OF LAKE
NORTHWEST WIND

FIGURE 6-16

term basis. For example, if the wind is strong from the southwest, a flow towards the east will naturally result; however, if it blows from this direction long enough the waters that are moved eastward will pile up on the windard shore and, particularly if wind intensity is diminishing, will cause the generation of a return surface current flowing against the wind. Needless to say, the most perplexing problem as regards to current-metering studies, using a recording type instrument, is trying to establish an accurate time base.

Littoral Drift

The currents in the inshore areas are most important as regards the supply of nutrients for plant and fish life in the areas where light penetrates to the bottom, the movement and dispersion of pollutants discharged into the inshore area by streams and outfalls, and in their effect upon the quality of water at water supply intakes. (See section on Rochester Embayment).

The littoral drift in Lake Ontario, because of its rather even oval shape, is much as one would expect. The flow along the southern shore is eastward and the flow around the northern shore is variable east of Scotch Bonnet Shoal (Figure 6-17) and becomes westward west of Scotch Bonnet Shoal. This inshore current focuses its energy somewhat at, but parallel to the Toronto area. This probably is the reason for the development of Gibraltar Point, at Toronto, with its very

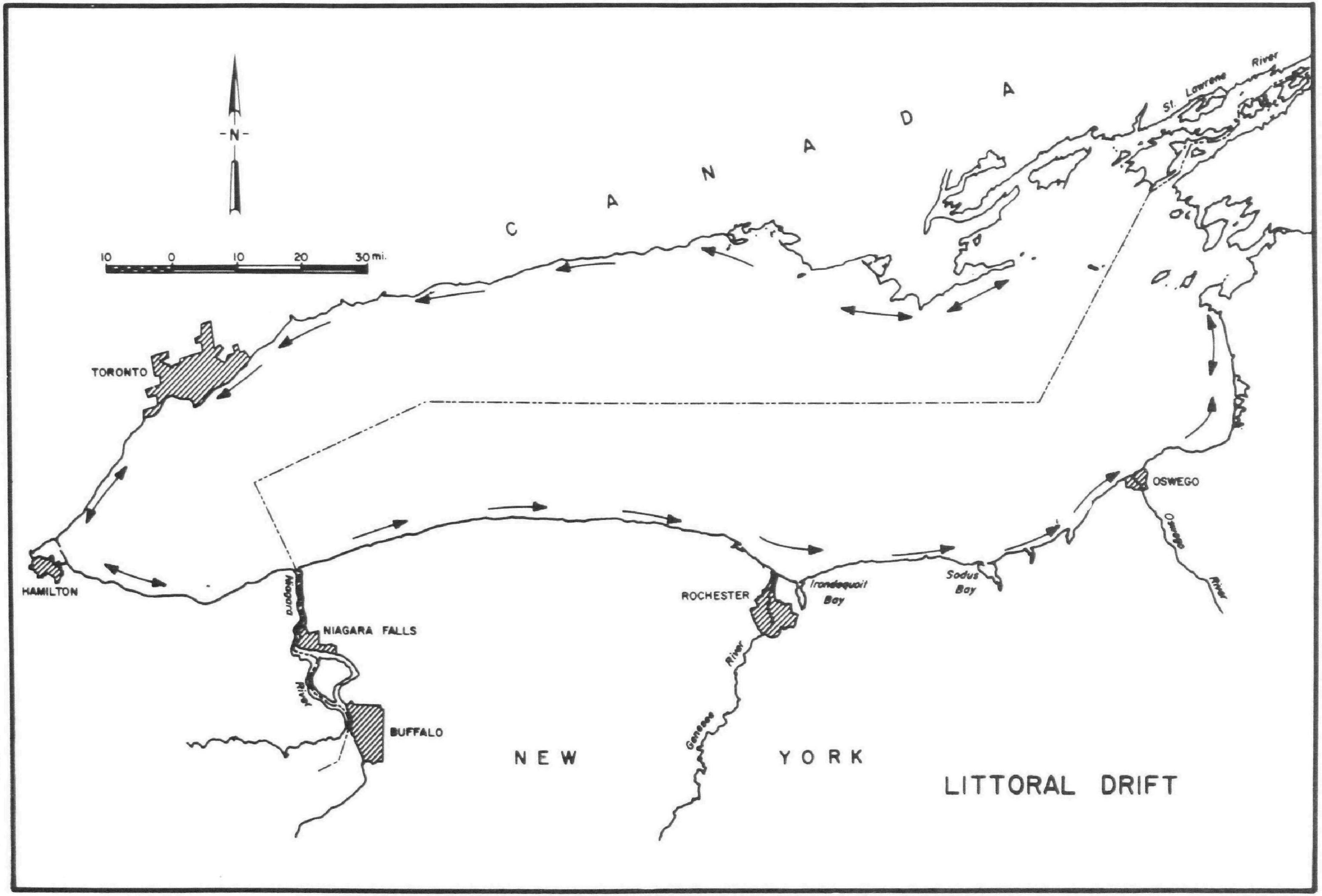

N
10 0 10 20 30 mi.
C A N A D A
St. Lawrence River
TORONTO
HAMILTON
Niagara
River
NIAGARA FALLS
BUFFALO
ROCHESTER
Genesee River
Irondequoit Bay
Sodus Bay
OSWEGO
Oswego River
NEW YORK
LITTORAL DRIFT

FIGURE 6-17

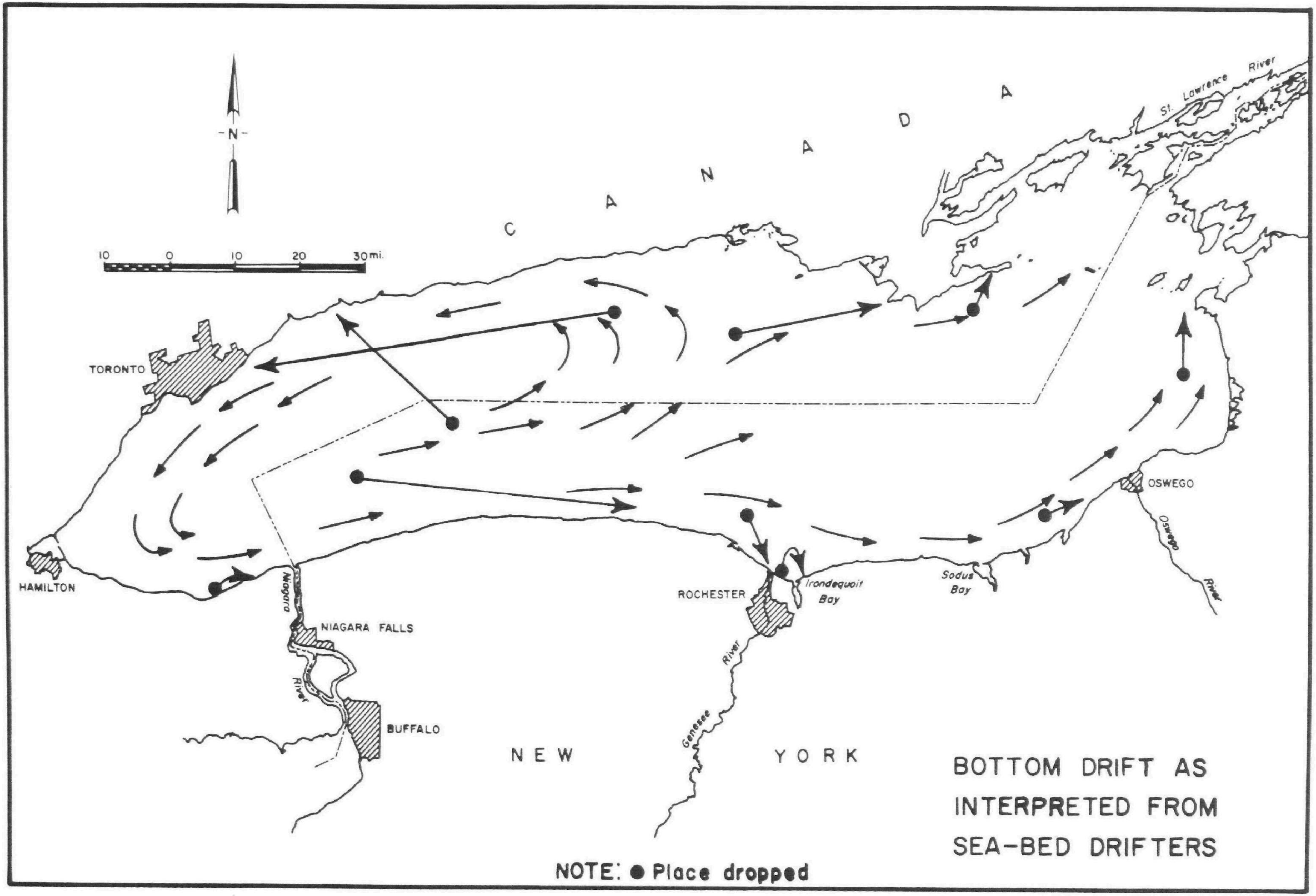
steep sides. At either end of the lake, the littoral drift is variable, dependent upon the set-up of the lake's surface waters at any particular time.

Bottom Currents

During the summer of 1965, three hundred and fifty seabed drifters (bottom drogues) were released in Lake Ontario in order to determine the character of the bottom drift. These drifters are mushroom-shaped and have a long stem. They are given a slight negative buoyancy by the addition of a small weight added to the end of the stem. A small label is attached so that anyone finding a seabed drifter can return it with the recovery location noted.

Of the 350 seabed drifters released, only 16 were recovered. This low recovery rate, notably from the eastern basin, suggests that bottom current velocities are not strong enough in Lake Ontario to move the seabed drifters out of the deeper parts of the lake onto shore. Another possibility is that some beached drifters were not found, owing to poor public access to the shore.

Eight seabed drifters were dropped well out in the lake northeast of the Niagara River. These are significant in that the two most northeastern ones, while being fairly close initially, traveled in opposite directions, and the recovery paths of the others crossed.



N
10 0 10 20 30 mi.
C A N A D A
St. Lawrence River
TORONTO
HAMILTON
Niagara
NIAGARA FALLS
River
BUFFALO
ROCHESTER
Irondequoit Bay
Sodus Bay
OSWEGO
Oswego River
Genesee River
NEW YORK
BOTTOM DRIFT AS INTERPRETED FROM SEA-BED DRIFTERS
NOTE: ● Place dropped

FIGURE 6-18

Two drifters dropped at the same location (N.E. Niagara River) ended up in opposite locations, one near 30 Mile Point and the other between Hamilton and Toronto. This seabed drifter was recovered more than two years after the one found at 30 Mile Point which was recovered about two months after it was emplaced in the lake. The pattern of recovery suggests (Figure 6-18) that a counterclockwise bottom circulation exists in the western end of the lake, the areal extent of which corresponds to the area of the western basin.

All of the other seabed drifters that were recovered had been placed within a few miles of shore, where bottom currents naturally would be stronger. The overall pattern of recovery agrees with the current-metering data. None of the seabed drifters dropped in the deep waters of the eastern basin were recovered.

Rochester Embayment

Of special interest in water pollution control is the effect that pollution, stemming from several sewer outfalls and the Genesee River, has on bathing beaches and various water intakes within the Rochester Embayment.

Braddock Point to the west and Nine Mile point to the East form the general limits of the Rochester Embayment. The total area of the Bay is approximately 35 square miles (90 sq. km.), and it contains

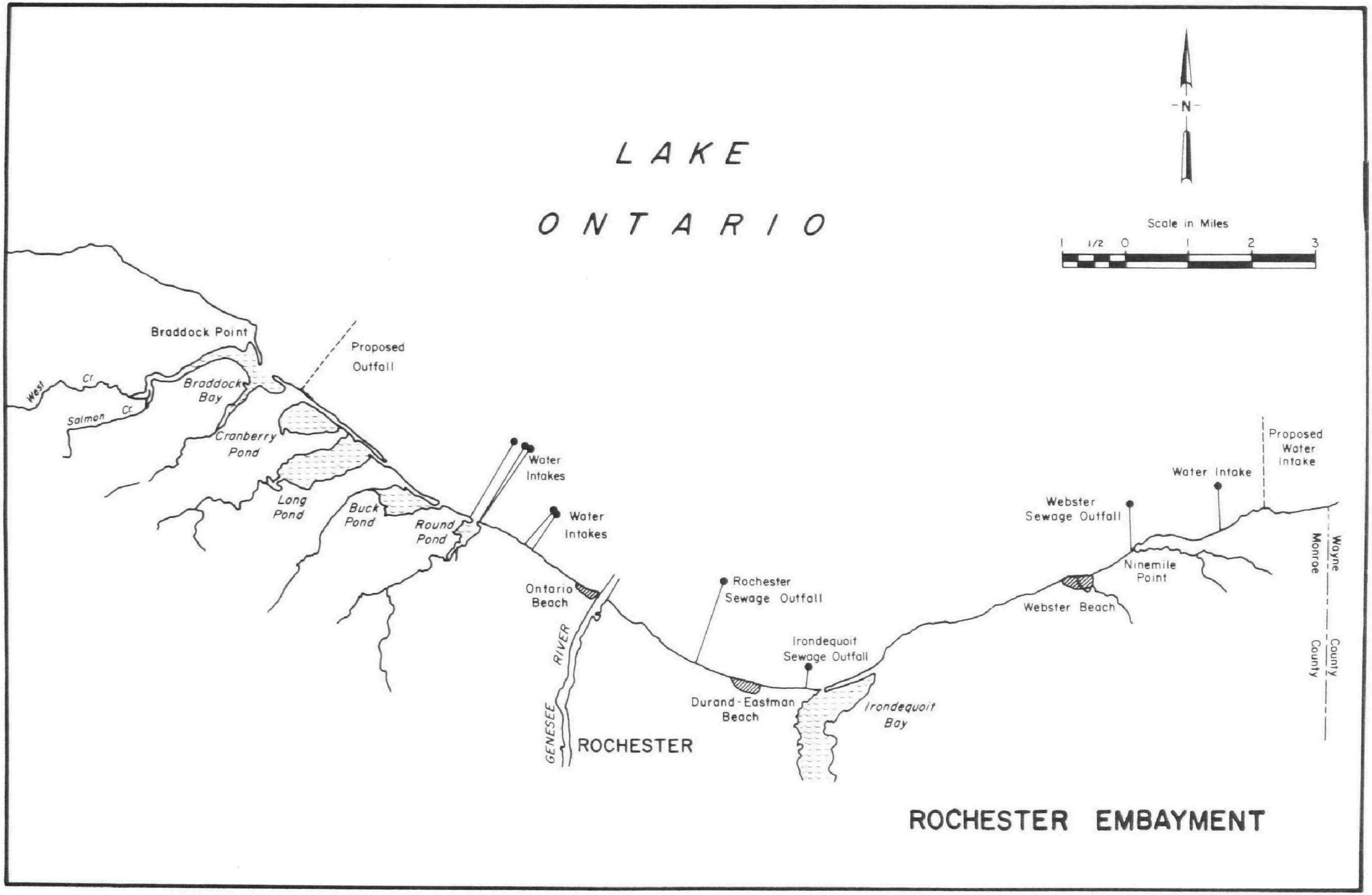

LAKE
ONTARIO
N
Scale in Miles
1 1/2 0 1 2 3
Braddock Point
Proposed
Outfall
West Cr.
Salmon Cr.
Braddock
Bay
Cranberry
Pond
Long
Pond
Buck
Pond
Round
Pond
Water
Intakes
Water
Intakes
Ontario
Beach
GENESEE RIVER
ROCHESTER
Rochester
Sewage Outfall
Irondequoit
Sewage Outfall
Durand-Eastman
Beach
Irondequoit
Bay
Webster
Sewage Outfall
Webster Beach
Ninemile
Point
Water Intake
Proposed
Water
Intake
Monroe
County
Wayne
County
ROCHESTER EMBAYMENT

FIGURE 6-19

approximately 44 billion cubic feet (1.3 billion cubic meters). The average stream flow of the Genesee River, the principal stream discharging into the Bay, is 2,726 cubic feet/sec. (77 cubic meter/sec.).

The Lake Ontario Program Office placed a total of five current-metering stations within the Embayment (Figure 6-19) in order to determine what the water circulation is and how it relates to the winds and the movement of pollutants. Station 19 was in operation from November 15, 1964, to December 3, 1964, and was located on the western side of the Embayment near the Monroe County Water Authority's intake at a depth of 14 meters. Stations 1E, 2E, and 3E were in operation from November 1965 to May 1966. Station B was a part of a series of temporary stations that were in operation during July 1965.

Temperatures

The temperature characteristics of the Rochester Embayment are much like those of the rest of the lake. Stratification develops in May-June and lasts until November. During approximately eight months of the year, the waters of the Genesee River are warmer and therefore less dense than the Embayment waters. This means that during this time Genesee River water will float out on top of the Embayment's surface waters and be in a position to be most readily affected by the winds.

RELATION OF WINDS AND CURRENTS IN ROCHESTER EMBAYMENT: STATION 19

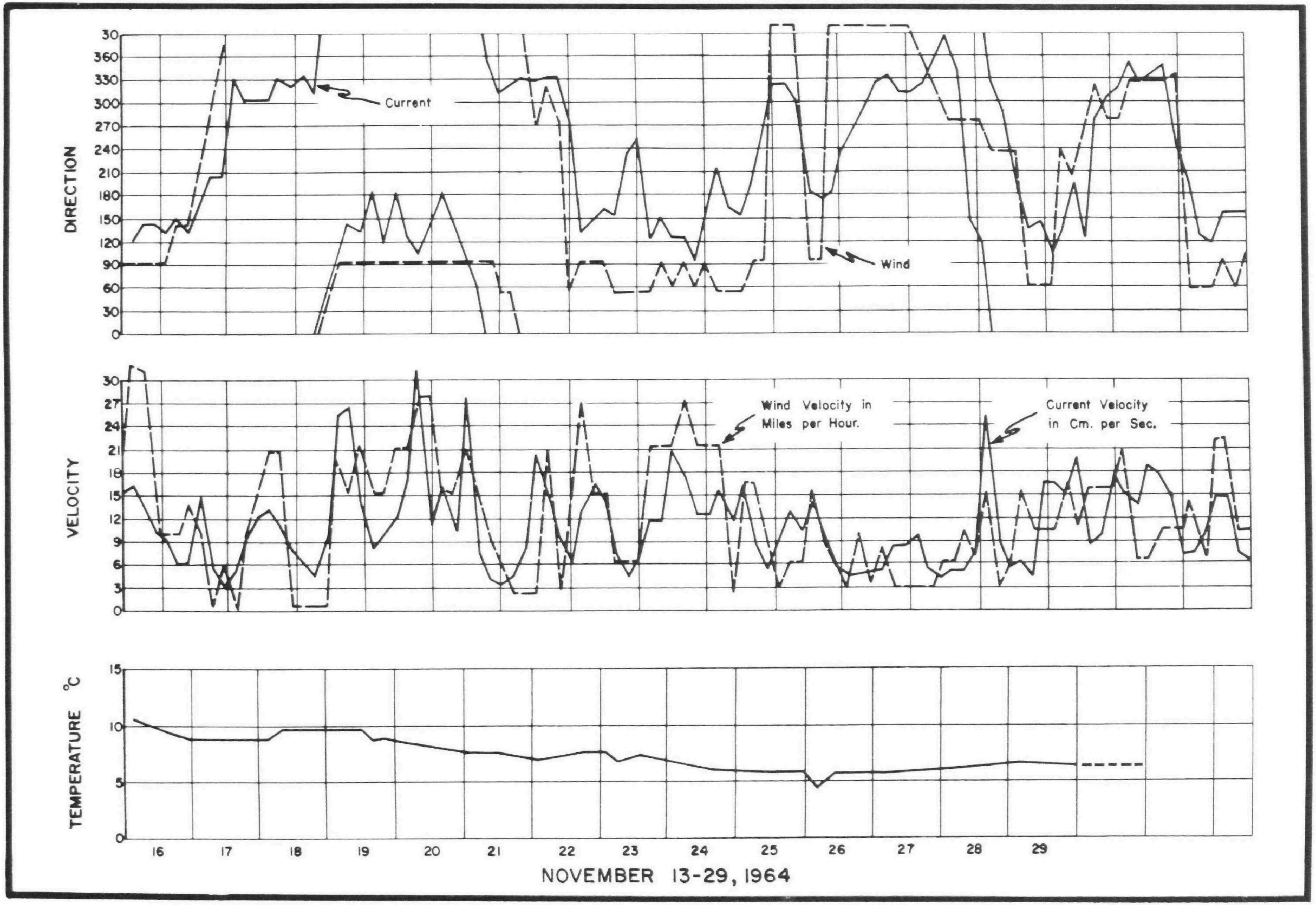


FIGURE 6-20

The important point here is that, while the volume of water moving through a prismatic cross-section of the Embayment at any one time is huge compared to the discharge of the Rochester Sanitary Outfall and Genesee River, the waters from the Genesee River and the Sanitary Outfall are confined generally to a thin layer on the surface. Pollutants can thus be readily transported in any direction about the Embayment by the winds until the polluted layer is mixed with the lake waters. Throughout the summer months this mixing will occur only in the epilimnion. It is fortunate that most of the time the pollution in the Embayment is initially confined to the surface waters; otherwise the water intakes would be affected.

Currents

There exists a very close relation between wind direction and current direction and between wind velocity and current velocity in the Rochester Embayment (Figure 6-20). The response of the water mass to a change is quite rapid, sometimes taking less than four hours. Except for times when a current reversal is taking place, the currents move either in a westerly or an easterly direction and the flow of the Genesee River and the discharge from the Rochester Sanitary Outfall will be included. Both the westerly and easterly flow have a tendency to move inshore, particularly the surface waters.

Winds from the northwest (because of the shape of the Embayment) at times generate a westerly current. As the winds come more from the north, the likelihood of a westerly flow increases. Winds from the north and northeast will definitely generate a current flowing toward the west. This current is probably the most important as regards pollution to the western beaches and the water intakes in that it has a strong tendency to slide the surface waters into shore where they can concentrate. Added to this is the fact that winds from these directions will most likely be somewhat higher in velocity than winds from other directions.

Winds from the east and southeast will also cause currents to flow westerly; however, this current will tend to move surface waters away from shore. Winds from the west-northwest, west-southwest, south-southeast will generate an easterly flow. The current generated by a west-northwest to west wind will have a strong inshore tendency; the tendency will be reduced as the wind comes more from the south.

Predictions of current directions based on wind records for a five-year period from the U.S. Coast Guard Station at Rochester, N.Y. are that currents flowing towards the east will occur annually 55 percent of the time, currents flowing to the west will occur 35 percent of the time, and currents will be in the process of reversal 10 percent of the time.

Usually, during a period of wind change, from west to northeast, for example, there is a period of calm at which time the current velocities become quite low. A possible hazard lies in the fact that during this period of quiescence a pool of polluted water could form in the area of the sewer outfall, spreading out on the surface, and then, as the wind shifts to the northeast and picks up in velocity, the polluted water could be moved rapidly inshore, affecting the bathing areas. A continuing shift in wind conditions and inshore turbulence would break the pool up and move it away. Thus, no biological evidence of this pollution would exist, unless a sample was fortuitously taken during this period. Such conditions as this rapid in and out movement of water could occur in a day or less. Further, if, after the sample was tested and it was determined that pollution was serious enough to close the beaches, the decision would be a day late and the beaches could be closed because of pollution that was no longer existing. To carry it further, if the winds had a periodicity of 24 hours, beaches might be open when pollution existed and closed when no pollution existed. Obviously, an understanding of the relation between wind, currents, and bacteriology is needed in order to make intelligent decisions.

Chapter 7

SUMMARY AND CONCLUSIONS

SUMMARY

Morphology

Lake Ontario has a large volume of water mass per unit surface area, with approximately 85 percent of the water mass during the period of stratification below the epilimnion. This physical characteristic has far-reaching effects on the biological and geochemical systems in the lake. For example, a large reserve of nutrients and oxygen exists in the hypolimnion.

The Niagara River, with a mean annual inflow into Lake Ontario of approximately 200,000 cfs is by far the greatest hydrologic factor influencing the lake environment.

Most of the streams draining into Lake Ontario are characteristic of limestone terrains, having high flows in the spring and having very low flows in the summer.

Due to circulation patterns and summer stratification, the mean retention time for inflowing water is estimated to be over 15 years.

While the Lake Ontario Basin is considered to have a continental climate, the lake has a moderating effect and brings to the area influences of a marine climate.

Lake Ontario lies wholly in Paleozoic rocks of Ordovician Age excavated along the axis of a former valley by glaciers in Pleistocene time. The common rocks are shales and limestones.

An oxidized sedimentary microzone exists at the mud water interface.

Most of the sedimentation is occurring in the western end of the lake off of the Niagara River. Normally, the lake sediments grade laterally, from the shore, from sand to silt to clay.

Biology

The biota of Lake Ontario represent the overall effect on the environment of the chemical and biological systems existing in the lake.

The benthic fauna of Lake Ontario is comprised of seven principal organisms. Two types, Amphipods (scuds) and Oligochaeta (sludgeworms), constitute 95 percent of all organisms collected; the remaining 5 percent consists of Sphaeriidae (fingernail clams), Chironomidae (bloodworms), Isopoda (aquatic sow bugs), and Hirudinea (leeches) in order of importance. Amphipods were the dominant organisms at all sampling stations except one near the mouth of the Niagara River.

Areas where higher levels of biota generally existed were the western end of the lake (in the Toronto-Hamilton-Niagara River area) near the mouths of the Genesee, Oswego, and Black Rivers and Mexico Bay.

The distribution of chlorophyll concentrations reflected the temperature and circulation patterns at the time of sampling.

Prolific growths of *Cladophora* were reported in the lake as far back as 1932. The distribution of *Cladophora* is governed to a certain extent by water movements, for the growths are most prolific where currents can keep the supply of nutrients high.

Commercial fishing in Lake Ontario has declined since early 1930. The decline in the commercial fishery is related to the decline of the desirable species, such as lake trout and cisco, and is not indicative of the total fish life contained within the lake, inasmuch as the numbers of certain other species of fish have increased, particularly the alewife, white perch and smelt.

An annual die-off of alewives occurs in Lake Ontario. Decomposition of these fish enriches the inshore waters with large amounts of nutrients, notably phosphorus. This may stimulate the heavy growths of *Cladophora* that begin to develop in May.

The microbiological study in Lake Ontario investigated the parameters of total coliform and total plate counts. Microbiological activity was found to be greatest in the areas of municipalities and affected by the circulation patterns.

Chemistry

The chemistry of the lake waters is constantly changing, adjusting to biological, physical, and chemical demands or changes. Many elements and/or compounds are part of a biogeochemical system. Consequently, a measurement of a particular element or compound represents only what is existing in that part or phase of the system; it does not represent the quantity or speed of an element or compound moving through the system. In a lake, such as Ontario, the concept of availability to a biogeochemical system as opposed to concentration of a dissolved substance per se is important since these lakes have a stability (long retention time) unlike streams, where the chemical part of these biogeochemical systems can, and in some cases may, reach and remain at equilibrium and may or may not remain in that state.

Phosphorus as phosphate is part of a complex biogeochemical cycle in the lake environment, the details of which are not clearly understood.

Concentrations of phosphate are highest in the inshore areas particularly near cities and rivers.

The iron cycle affects the phosphate cycle.

One ideal solution does not exist for reducing the algal growths in Lake Ontario, and several methods of attack on the problem must be used. However, a program of phosphate control, including maximum removal of phosphates at treatment plants, may, in the case of Lake

Ontario, bring the most rewarding results. The reason for this is that this lake has a tremendous oxygen reserve in the hypolimnion, having a small surface area in relation to volume. It has been known for some time that a self-regulating system exists in the phosphate cycle between the water mass and lake muds. The oxidized sedimentary microzone which develops at the mud-water interface is rich in ferric hydroxide and ferric phosphate. The microzone forms a chemical barrier that hinders phosphate ions from the reduced sedimentary layer beneath it from going into solution and, also, assimilates material falling to the bottom. This oxidized sedimentary microzone exists in Lake Ontario for most of the year and quite likely all year.

The oxygen data suggest that serious oxygen depletion does not occur in the main part of the lake. The reason why no significant oxygen depletion occurs is that 85 percent of the lake's water mass is below the thermocline during summer stratification, so a large reserve of oxygen is available during the period of stratification.

The lowest values of dissolved oxygen were near 70 percent saturation in the bottom water. The dissolved oxygen in the surface waters was very near saturation or above saturation.

Since the early 1900's chloride content has steadily increased in Lake Ontario. The concentration of chloride is now approaching 30 mg/l.

Concentrations of dissolved silica in Lake Ontario are related to the diatom populations. Silica is taken up from the lake water during the spring by diatoms. Later in the fall, the silica is recycled back into the water from the skeletal material of the dead diatoms.

The biochemical oxygen demand test (BOD) in Lake Ontario is of limited use because of the low values observed (generally 3 mg/l or less).

The mean concentration of dissolved solids in Lake Ontario ranged from 175 mg/l in the spring to 185 mg/l in the fall. No significant areal distribution was observed, other than that the highest values were observed near river mouths and large cities.

Potassium concentrations ranged from 1.4 to 2.1 mg/l.

The greatest single source of pollutants in Lake Ontario is the Niagara River inflow.

The results of our study point to the continued increase of chemical input to Lake Ontario and the resultant deterioration of the lake water.

Physical

The wind data show that the prevailing, or net transport, direction is from the southwest in the summer and fall months (no data are available for the winter months). The average wind velocities were about 15 miles (24 km/hr) per hour.

Lake Ontario is stratified during the summer and fall months. During this period of stratification, the volume of water with which a pollutant and/or inflowing stream can mix is greatly reduced. At the time of maximum stratification, the thermocline is approximately 30 meters below the surface.

During the late fall and early spring a vertical stratification develops which, in effect, separates the inshore and the lake water. This vertical stratification is called the 'thermal bar' and may or may not act as a barrier to the mixing of inshore and offshore lake waters.

The temperature structure of the lake in the spring, summer and fall months suggests an overall counterclockwise circulation.

Two distinct surface circulations occur in Lake Ontario. One circulation pattern occurs when the lake's water mass is stratified, and the other pattern is developed when the lake's water mass is isothermal.

When the lake is stratified the net surface circulation is counterclockwise.

The main current is east along the southern shore, with a lesser return flow to the west along the northern shore. There is a suggestion of a gyral occurring at times in the western end of the lake.

The effect of the Niagara River flow is to impose an essentially steady state gradient flow in Lake Ontario, from its mouth eastward to the St. Lawrence River.

During the winter months, when the lake's water mass is isothermal, the net surface flow is eastward.

The surface waters of Lake Ontario respond very rapidly to wind stress; current changes in less than six hours after a wind shift are common in mid-lake.

The average effective velocity (the velocity of net water transport) is approximately 2 cm/sec. in summer months and 5 cm/sec. in the winter months. The average velocity is on the order of 5 cm/sec. in the summer months and 10 cm/sec. in the winter months. Velocities observed ranged from the starting speed of the current meters, 0.5 cm/sec. to over 50 cm/sec.

The circulation of Lake Ontario is such that the water from inflowing streams and pollutants discharged into the nearshore area will tend to remain in the inshore zone, thus keeping the most productive zone well supplied with nutrients.

CONCLUSIONS

The following conclusions are made as a result of studies of Lake Ontario:

A thorough biogeochemical study should be initiated. The goal of this study would be to find one or several biological and/or chemical parameters that truly reflect the lake's water quality and to determine what is the most practical approach to the proper management of the lake environment.

When planning outfalls and intakes in Lake Ontario, an oceanographic study be required, as part of an overall engineering study for approval of such intakes and outfalls, in order to determine the proper location or distribution of such. The study should cover surface and subsurface currents, waves, temperature, submarine topography, bottom materials, diffusion characteristics, and amounts and quality of effluent.

An effort be made to establish a fishery on Lake Ontario, (such as rainbow trout and/or coho salmon) so as to cut down on the population of alewives.

The feasibility of commercial harvesting and the possible subsequent conversion to fish flour of the alewives should be investigated.

When evaluating the practicability or desirability of constructing groins in order to stop the littoral transport of sand, the fact that these groins also provide an ideal trap for dead fish and Cladophora should be given consideration.

Future industrial zoning be such that it would encourage industrial 'symbiosis', that is, where an industry would live on the waste of another; implicit in this recommendation is the concept of waste disposal planning as part of an overall system which, in the case of the Great Lakes and in particular the lower Great Lakes is vital.

The development of a computerized model of the total lake basin environment should be begun, including economics, engineering, chemistry, geology, biology, stream flow, groundwater, etc. This model would be used to help manage the water resources of the whole basin. In the development of this proposed computerized model, advantage should be taken of remote sensing techniques to constantly update the model.

Stream standards should be implemented as rapidly as possible, and these standards should be strict enough so that an improvement in lake water quality will result. Along with this is the necessity of setting standards for wastes discharged directly into the lake.

An intensive program of applied research to develop a substitute for the phosphate ion in detergents, petroleum additives, paints, etc. must be carried out.

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