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Lake Huron 1980 Intensive Survey. Summary Report: Report to the Surveillance Work Group

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Surveillance Work Group

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Preface

Now gentlemen, in their interflowing aggregate, these grand freshwater seas of ours -- Erie, and Ontario, and Huron, and Superior, and Michigan -- possess an ocean-like expansiveness with many of the ocean's noblest traits.....they contain round archipelagoes of romantic isles. They have heard the fleet thunderings of naval victories. They are swept by Borean and dismasting waves.....as direful as any that lash the salted wave. They know what shipwrecks are; for out of sight of land, however inland, they have drowned full many a midnight ship with all its shrieking crew.

Herman Melville
Moby Dick

In many ways, the Great Lakes ecosystem is unique in the world. Not only do the Great Lakes represent the largest continuous freshwater system on earth, but also in no other aquatic system is the potential for problems as great. Most of the world's other great lakes -- Baikal in the USSR, Tanganyika and Victoria in Africa, Balkash in Soviet Central Asia, and Great Slave Lake in Canada -- are geographically situated in relatively remote areas, generally removed from the direct cultural and industrial influences of activities attributable to man.

The North American Great Lakes, however, are located in the geographic heartland of two great industrial nations, the United States and Canada. The Great Lakes, unlike their counterparts elsewhere on earth, not only attracted major concentrations of population, but also facilitated the early exploration of the center of the continent. Later, their shores served as ideal areas for settlement.

The historical navigation and transportation system that developed on the Great Lakes was so successful, that today, it is still a primary attraction for many kinds of industry. The number of ships passing through the locks on the St. Marys River at Sault Ste. Marie between Lake Superior and Lake Huron is a mute testimony to the efficacy of the transportation system developed on the Great Lakes. These locks handle more gross tonnage of shipping annually than the Suez and the Panama Canals taken together.

This transportation system serves the industrial center of the two great nations. Fifty-five per cent of all the heavy industry in the United States is located in the eight Great Lakes states. Some 37 million people reside in the Great Lakes basin; 20 per cent of the United States population, and nearly 50 per cent of all Canadians live in areas adjacent to these giants.

Historically, in North America, as indeed throughout the rest of the world, the degree of degradation of aquatic resources is often directly related to the degree of urbanization, and the extent of adjacent industrial development. It is not surprising, then, that the ecology of the Great Lakes has been severely altered by the effects of anthropogenic activities. The purpose of this volume is to examine one of the Great Lakes, Lake Huron, to note the impacts of human activity, and to assess the effectiveness of remedial efforts to preserve this remarkable body of water, and to offer projections for the future of the lake.

Overview

Freude trinken alle Wesen
    An dem Brusten der Natur;
Alle Guten, alle Bosen
    Folgen ihrer Rosenspur.

Kusse gab sie uns und Reben,
    Einen Freund, gepruft in Tod;
Wollust ward dem Wurm gegeben,
    Und der Cherub steht vor Gott.*

Schiller
Ode to Joy

Lake Huron is the second largest of the Great Lakes by surface area. Its nearly 60,000 square kilometers of rolling water call to mind idyllic scenes of leisure and recreation. The very name of the lake itself evokes images of clear, crystalline water surrounded by white, sandy beaches; of areas ideal for swimming, boating, diving, fishing and sailing. When one thinks of Lake Huron, a series of images spring to mind: herring gulls wheeling and turning above bright blue water; perch and walleye in the sandy shallows; pintails, redheads, and canvasbacks moving quietly through the reed beds; lunker lake trout, lurking in its frigid, stygian depths; and along its shores where the restless water laps in never-ending measure, a quiet cabin where the weary can rest and watch a magnificent sunrise, or contemplate an inspiring sunset.

Outwardly, Lake Huron is all of these things, and more. But, to what degree is this spectacular body of water threatened by the activities of man? To what extent can these man-induced alterations be reversed? What progress has been made toward this end? The Lake Huron Intensive Program Summary Report has been developed to answer these questions, using the best scientific evidence currently available.

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*All beings drink Joy
    From nature's breast;
All good, all evil
    Follow her trail of roses.

Kisses she gave us, and the wine of the vineyards,
    Our friend, faithful even unto death;
Voluptuousness was given to the Worm,
    And the Cherubim stands before God.

Executive Summary

On the basis of information collected in 1980, the Lake Huron ecosystem can be described as generally healthy. Only a relatively few areas currently display unmistakable signs of human alteration and impairment. In such areas, particularly southern Lake Huron and Saginaw Bay, there have been definite and measurable improvements in ecosystem quality since conditions were last evaluated in the 1977 Upper Lakes Reference Report. Saginaw Bay has responded to reduced phosphorus loadings from remedial programs, both in terms of phytoplankton biomass and community structure, showing a reduced proportion of nuisance species. Southern Lake Huron has also demonstrated a shift in community structure to more oligotrophic species.

With respect to phosphorus, there is some evidence of a slight decrease in Georgian Bay but the greater part of the main lake and the North Channel showed little change from 1971/74. Total phosphorus is the only nutrient controlled by remedial programs and on a whole lake basis showed no increase since 1971, meeting the requirements of non-degradation in the 1978 Agreement. However, both nitrogen and silica have shown increases since 1971 and require further attention.

Other components of the Lake Huron ecosystem have also shown improvement. Decreases have been observed in contaminant concentrations in herring gull eggs between 1974-80 and are encouraging. The herring gull population of Lake Huron is generally quite healthy and while some problems of contamination still exist, particularly in and around Saginaw Bay, for the most part waterfowl of the Lake Huron ecosystem appear to have normal lifespans and breeding success. In fish, edible portion contaminant data indicate an increasing trend for all fish species for PCB and a decreasing trend for DDT.

The bacteriological quality of Lake Huron waters remains good, with a virtually unchanged and stable structure since 1974. In some localized nearshore areas which showed signs of impairment in 1974, e.g. Owen Sound and Parry Sound, substantial progress has been made. These areas were considered to be definitely improved in the 1980 study.

On the whole, the Lake Huron Intensive Program Summary Report may be considered to present a very positive outlook on progress to date, and offer considerable optimism for the future water quality of Lake Huron.

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1. Introduction

Ik heb van't leven vrijwel niets verwacht.
Geluk is nu eenmal niet te achterhalen.
Wat geeft het, in de koude voorjaarsnacht
Zingen de onsterflijke nachtegalen.*

Jaques Bloem

PHILOSOPHY OF THE LAKE HURON INTENSIVE PLAN

"One of the troubles of our age is that habits of thought cannot change as quickly as techniques, with the result that as skill increases, wisdom fades."

Lord Bertrand Russell

Early in the history of the co-operative efforts on the Great Lakes between the governments of the United States and Canada a concern developed for the use of a management approach which would provide for maximum cost-effectiveness, yet which would be sufficiently encompassing to protect the integrity of these remarkable bodies of water. When the international accord between the two countries was signed in 1972, it was generally believed that a management philosophy based upon criteria and standards developed to protect water quality was the method of choice, affording a satisfactory level of protection for the Great Lakes at an optimal cost-benefit ratio.

By the time of the 1978 re-negotiation of the Great Lakes Water Quality Agreement, it became clear that this criteria-based approach was not likely to be able to address all the problems of ecosystems as complex as those found in the Great Lakes. Thus, while the earlier, more simplistic approach is still in use, it is now recognized that often this approach cannot properly consider the more subtle interrelationships which exist, and are inherent in the Great Lakes. For this reason, a new concept emerged in which the water quality objectives were linked to a much broader spectrum of human and ecosystem needs. Thus, within this new approach, not only are water quality

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*I have not expected much from life.
Happiness has not often overtaken me.
But it does not matter, for throughout the cold spring night
Sings the immortal nightingale.

interrelationships considered, but also those which exist between all the inhabitants--human, plant, and animal--and their environment.

As complex as the machinery of the computer age has become, there is no machine or device on earth which rivals the complexity, or which can perform as many diverse functions as the simplest of living creatures. Unlike machines, living organisms have the capability to feed themselves, reproduce, repair injuries or malfunctions, and adapt to new influences, stresses, and changing external conditions. Just as the incredible arrangement of interdependencies among the separate organs and parts enables the complex organization we have come to regard as a "living organism" to exist, so also the complex interrelationships between and among living creatures, and between these organisms and their environment, form an intricate and inexorable set of linkages effecting each organism's functioning as an individual, and its relationship to the whole. This expanded scale of concern for the Great Lakes has been called the "ecosystem approach".

An ecosystem can be defined as any area of nature that includes plants and animals occurring together, interacting reciprocally with their abiotic environment to produce an exchange of materials between the living fractions, and between the living and the non-living parts.

The intent of the concept is to briefly express all of the mandatory relationships and interdependencies which exist between living creatures and their surroundings. It is composed of all parts of the biological community and the environment, which together form a functioning whole. This whole is called nature.

This broadening of our viewpoint, this recognition that the Great Lakes are more than a source of water, has revised the thrust of the Great Lakes Water Quality Surveillance Program, and has prompted the substitution of the ecosystem approach for the water quality-based approach, which did not have the broadly based perspective required to address the problem.

Viewed from this frame of reference, Lake Huron can be seen as a very complex living system in which the chemical, physical, and biological processes all interlink and overlap in such a way as to be virtually inseparable. Further, because of the response of the individuals and communities of organisms to stress, all of these relationships are subject to constant alteration, change, and evolution. Because of this incredibly complicated array of relationships some of the descriptive material now used to express these relationships has become more qualitative in nature, as opposed to the strictly quantitative approach used in the past.

Recognition of this fact has made us realize how complex the management of the Great Lakes really is. An example is to be found in the report of the Phosphorus Management Strategies Task Force. This group recommended that a staged approach to phosphorus management be adopted because of the uncertainties associated with the phosphorus loading-water quality relationship.

Similar uncertainties exist with other aspects of the Lake Huron ecosystem and its complex interrelationships. An example of the dilemma faced by managers is the need to relate the concentrations of the organic contaminants in various parts of the Lake Huron ecosystem to potential impacts upon human health. At present, this can only be done using inferential epidemiology and statistical probability, disciplines which, while quantitative, are often heavily dependent upon qualitative data.

Because of the stage of development of many of the ideas associated with the Great Lakes, and the relative immaturity of the concept and the sciences supporting the idea of the use of the ecosystem approach on Lake Huron, it is clear that for a time it will be necessary to continue to utilize the water quality criteria concept. While considering the needs of the ecosystem, this report will make use of the water quality objective approach utilizing criteria and standards where appropriate.

THE INTENSIVE SURVEY

Following from the 1978 Water Quality Agreement in response to Annex 1, the Great Lakes International Surveillance Plan (GLISP) was developed by the Surveillance Subcommittee of the Water Quality Board to provide a framework for involved government agencies to coordinate the assessment of remedial programs and identify the current status of water quality in the Great Lakes. The GLISP called for an intensive survey of Lake Huron every nine years as part of the surveillance plan. This document reports the results of the first surveillance on Lake Huron as developed in the GLISP.

During 1980, six open lake cruises were conducted; three by the C.S.S. Limnos and three by the R/V Roger R. Simons. The cruises occurred between the months of April and November. Ninety-four stations were sampled in Lake Huron and forty-four stations were sampled in Georgian Bay. Areas of concern (those areas where beneficial uses have been or may be impaired) were sampled extensively, with individual plans designed for the specific problems in each area. Nearshore areas, tributaries and the atmosphere were also sampled. To undertake a monitoring task of such a large magnitude, a diverse group of individuals affiliated with a large number of agencies or institutions was necessary for success. These participating agencies or institutions are listed in Table 1. Individuals whose works have been used in preparing this report are cited where appropriate in the text.

TABLE 1

AGENCIES AND INSTITUTIONS PARTICIPATING IN THE 1980 INTENSIVE SURVEILLANCE OF LAKE HURON

Argonne National Laboratory
Canadian Wildlife Service
Cranbrook Institute of Science
Fish and Wildlife Service, United States Department of Interior
Great Lakes Environmental Research Laboratory, National Oceanic and Atmospheric Administration
Great Lakes Fisheries Research Branch, Department of Fisheries and Oceans
Great Lakes National Program Office, United States Environmental Protection Agency
Great Lakes Regional Office, International Joint Commission
Great Lakes Research Division, The University of Michigan
Large Lakes Research Station at Grosse Ile, United States Environmental Protection Agency
Mar, Inc.
Michigan Department of Natural Resources
Michigan District Office, United States Geological Survey
Ohio State University
Ontario Ministry of the Environment
Ontario Ministry of Natural Resources
University of Minnesota
Water Quality Branch, Inland Waters Directorate, Environment Canada

2. Lake Habitats

WATER

Physical

Chemical and biological conditions observed in lakes are affected by such physical processes as water movements, thermal stratification, air-water interaction and ice cover, exchanges of water between lake compartments thus affects the distribution of substances. Water quality of lakes also is influenced by the seasonal thermal cycle in which thermal bars, fall and spring overturns, and vertical stratification affect the distribution of materials. Consequently, discussion of the biological and chemical conditions of the lake must consider the physical factors influencing them. A brief discussion of the prevailing physical conditions during the period 1980 is described below.

Water Exchange

Description of the water movement in Lake Huron or Georgian Bay can be accomplished using direct measurements or from mass balance techniques. Unfortunately, current meter observations were not performed in 1980. Figures 1 and 2 give an example of the summer-mean upper layer circulations determined for Lake Huron and Georgian Bay (IJC, 1977) for the year 1974. An estimate of the 1980 total exchanges across the major interfaces of Lake Huron was derived (Table 2) from exchanges computed by performing a materials balance using the conservative substance chloride. The technique used was the same as was previously applied to Saginaw Bay (Richardson, 1976). Comparison of 1980 and 1974 total exchanges show that agreeement with 1974 values is within 15% for the exchanges at the Straits of Mackinac, North Channel, Georgian Bay, and Saginaw Bay-North Lake Huron. Large discrepancies occurred in computations of the exchange between North Channel and Georgian Bay and between Saginaw Bay-South and Lake Huron. Since the 1974 results were based on extensive current meter data the large discrepancies may indicate an error in the chloride balance at these locations.

Temperature

The thermal regime of Lake Huron and Georgian Bay is typical of northern temperate dimictic lakes. In general, the spatial distribution of surface temperatures is a reflection of latitude and lake bathymetry, with the near-shore areas and southern basin of Lake Huron warming faster in the spring and cooling more rapidly in the fall. The following is a description of the thermal regime in 1980 based on the results of the six cruises.

The first cruise coincided with spring turnover, when the lake was essentially isothermal.

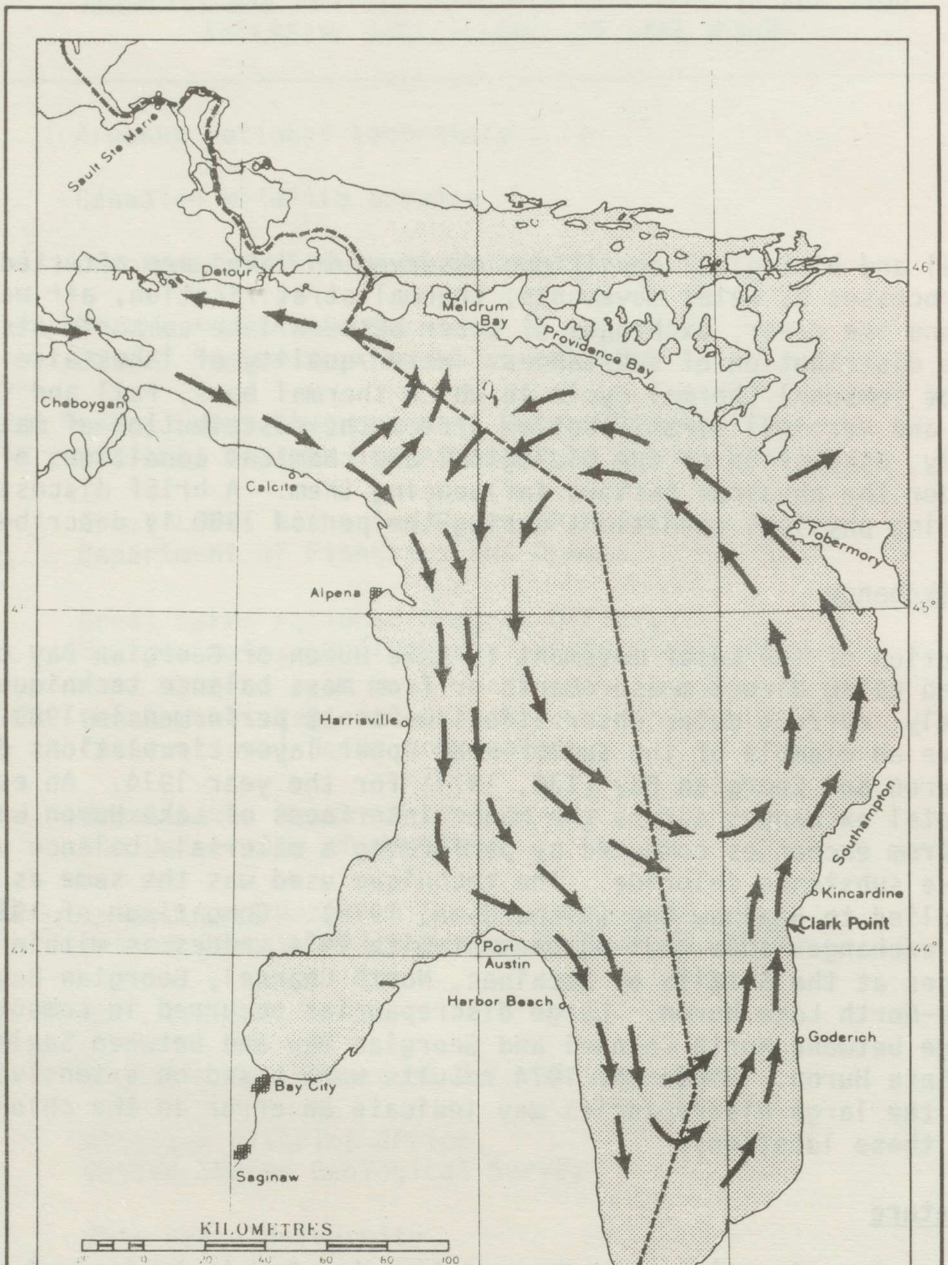


FIGURE 1 LAKE HURON SUMMER CIRCULATION IN THE EPILIMNION

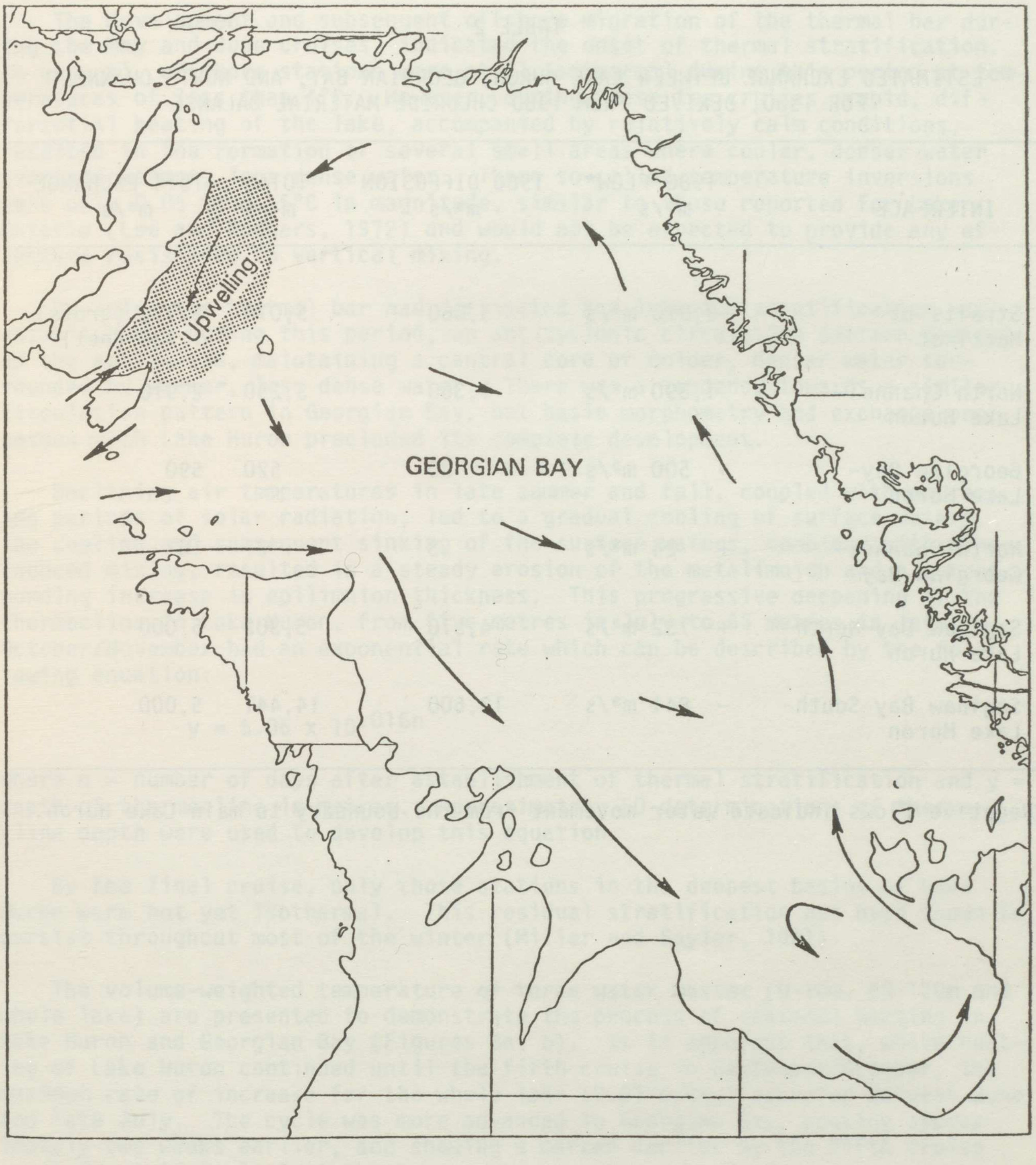


FIGURE 2 SUMMER SURFACE CIRCULATION IN GEORGIAN BAY

The development and subsequent offshore migration of the thermal bar during the May and June cruises, indicated the onset of thermal stratification. In general, offshore stations were still isothermal during this period at temperatures of less than 4°C. However, during these two cruises, rapid, differential heating of the lake, accompanied by relatively calm conditions, resulted in the formation of several small areas where cooler, denser water overlaid warmer, less dense water. These so-called temperature inversions were only 0.05 to 0.15°C in magnitude, similar to those reported for Lake Ontario (Lee and Rodgers, 1972) and would not be expected to provide any effective resistance to vertical mixing.

By July, the thermal bar had dissipated and lakewide stratification was established. During this period, an anticyclonic circulation pattern dominated the epilimnion, maintaining a central core of colder, denser water surrounded by warmer, less dense water. There was a tendency towards a similar circulation pattern in Georgian Bay, but basin morphometry and exchange processes with Lake Huron precluded its complete development.

Declining air temperatures in late summer and fall, coupled with decreasing periods of solar radiation, led to a gradual cooling of surface waters. The cooling and subsequent sinking of the surface waters, combined with wind-induced mixing, resulted in a steady erosion of the metalimnion and a corresponding increase in epilimnion thickness. This progressive deepening of the thermocline in Lake Huron, from five metres in July to 65 metres in late October/November had an exponential rate which can be described by the following equation:

$$y = 6.06 \times 10^{.016n}$$

where n = number of days after establishment of thermal stratification and y = depth of thermocline in metres. Approximately 60 determinations of thermocline depth were used to develop this equation.

By the final cruise, only those stations in the deepest basins of Lake Huron were not yet isothermal. This residual stratification has been shown to persist throughout most of the winter (Miller and Saylor, 1981).

The volume-weighted temperature of three water masses (0-10m, 60-120m and whole lake) are presented to demonstrate the process of seasonal heating in Lake Huron and Georgian Bay (Figures 3a, b). It is apparent that, while heating of Lake Huron continued until the fifth cruise in September/October, the maximum rate of increase for the whole lake (0.07°C/day) occurred between June and late July. The cycle was more advanced in Georgian Bay, peaking approximately two weeks earlier, and showing a marked decline by the fifth cruise carried out in early September.

The seasonal temperature cycle of the 0-10m layer gradually diverged from that of the deep (60-120m) layer. With the establishment of thermal stratification, this divergence increased markedly due to the 0.20°C/day rate of warming in the surface waters of both Lake Huron and Georgian Bay. With the progressive deepening of the surface mixed layer after July, the rate of warming decreased, due to both reduced insolation and increased entrainment of cooler metalimnetic water into the epilimnion.

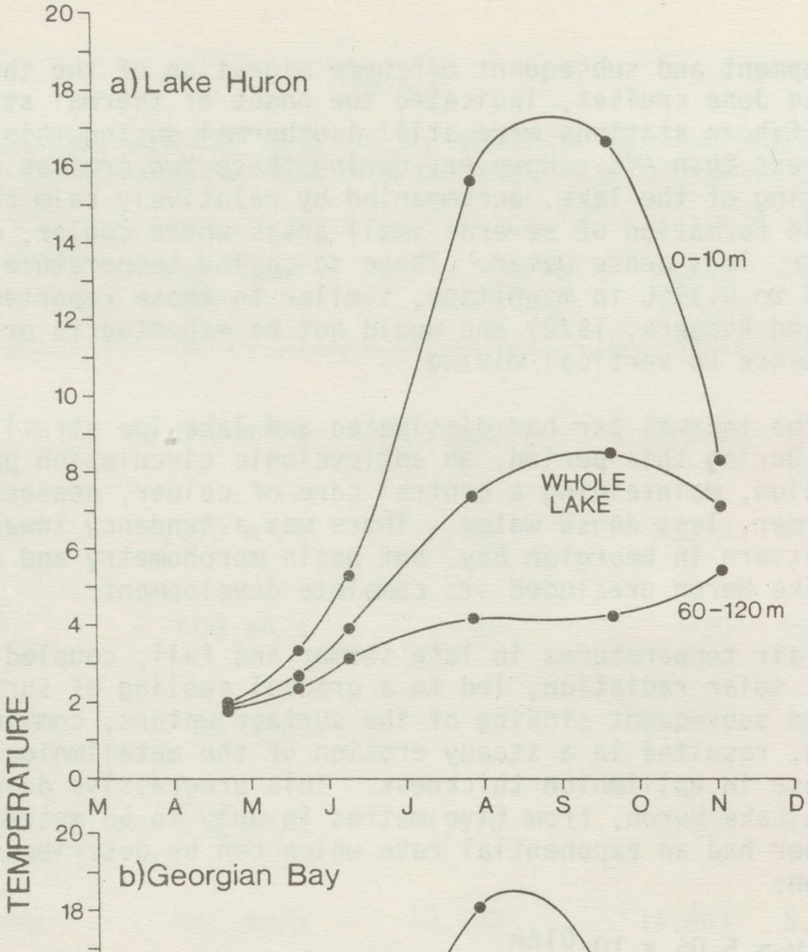


FIGURE 3 THERMAL REGIME OF LAKE HURON AND GEORGIAN BAY

The deep (60-120m) layer showed a somewhat different seasonal pattern from that of both the whole lake and the surface layer. During the first four cruises, a slight warming trend was observed. However, once lakewide stratification was established, this rate decreased to almost zero, indicating that the hypolimnion was effectively isolated from the warmer overlying waters. It was only when the deepening thermocline penetrated this layer prior to the last cruise that a substantial temperature increase was noted.

<u>Ice</u>

Ice formation on the lake in 1980 was slower than usual and by January 4 Saginaw Bay was only 50 per cent covered, and the northern shores of the North Channel and Georgian Bay were thinly covered with shore ice. Colder weather initiated ice growth along most of the coastline during the second week in January. This growth continued until the beginning of March when the lake was entirely ice covered, except for an area in the center of the lake and two nearshore areas; one in southwestern Georgian Bay and the other along the southern part of the Michigan coast (Figure 4).

During March, the ice cover began to break up due to winds and warming. However, Saginaw Bay remained completely covered until March 17, and was not completely free of ice until April 7. The main lake and Georgian Bay were free of ice by the beginning of April except in some nearshore areas. The North Channel did not lose its ice cover until the end of April. The per cent ice cover for Lake Huron on a weekly basis is summarized in Table 3.

TABLE 3

SUMMARY OF PER CENT ICE COVER FOR HURON 1980,
BEGINNING JANUARY 21, 1980

NUMBER OF DAYS BETWEEN OBSERVATIONS	PER CENT LAKE COVERED BY ICE
	4.2
7	7.7
7	4.3
8	10.3
6	29.3
7	40.5
7	44.4
7	37.2
7	42.7
7	74
7	54
7	37.5
7	40.3
7	21.9
7	4
7	1.5

Source: Weaver and Rockwell (Unpublished).

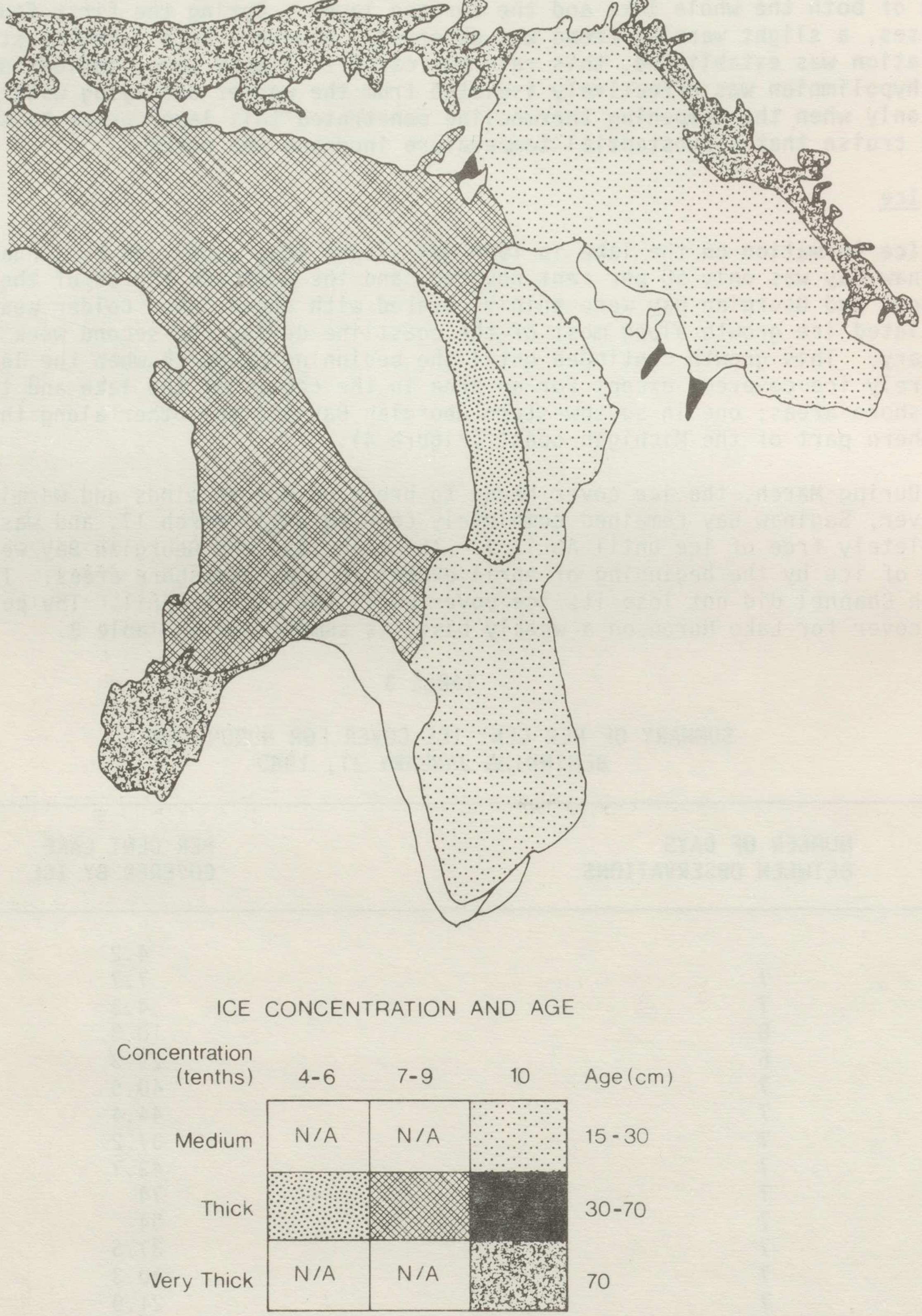


FIGURE 4 ICE CONCENTRATION AND AGE

Chemical

The essence of an ecosystem is that it is constantly changing. Since nothing remains the same in the Lake Huron Basin ecosystem or in any of the living organisms which are a part of it, any change in the quality of this system will be incorporated by all the living components of it, including man. For this reason, a knowledge of both the abiotic and biotic components of the Lake Huron ecosystem is essential in order to understand what changes are occurring.

Loadings

Phosphorus - During the past decade, a major thrust of pollution control efforts has been the reduction of phosphorus loadings. While many other nutrient parameters were measured in 1980, only phosphorus loads are summarized here since these are of major interest.

A comparison of the loading estimates in 1974 and 1980 are presented in Table 4. Obvious decreases have occurred in both direct sources and in monitored tributaries. Table 4 contains some information previously reported (IJC, 1977; IJC, 1981) but includes updates on the atmospheric and Lake Superior contributions. The estimated atmospheric contribution (31% of total loading) is subject to considerable uncertainty and currently there is no general agreement about how to determine this important part of the loading more accurately. Limited data from U.S. EPA monitoring sites suggest that the load may be as low as 600 tonnes/year (Dolan, 1982).

Seven years of data on the major United States tributary, the Saginaw River, indicate a substantial reduction in total phosphorus loading since 1974. This is discussed further in Chapter 4.

Contaminants - Loading determinations for organic contaminants have focused primarily on the atmosphere since this is thought to be a major source (Eisenreich, Looney, and Thornton, 1981). For example, it is estimated that airborne deposition of PCBs represents a greater input to Lake Huron than all other possible sources combined (Eisenreich, Looney, and Thornton, 1980). However, this is still a subject of current research. This is reflected by the disagreement between estimates of various investigators (Table 5). For reference purposes, the total load of PCBs from the Saginaw River in 1979 was 277 kg/year (Richardson, Smith, and Wethington, 1983).

Concentrations

Major Ions, Conductivity, Alkalinity and pH - The ionic composition of the Lake Huron-Georgian Bay system is governed largely by the composition of influents from adjoining drainage basins, atmospheric inputs and contributions from Lakes Michigan and Superior. The lithology of the numerous drainage basins in the system varies markedly. The north shore of Georgian Bay and the North Channel is dominated by Precambrian Shield, the runoff from which is of low salinity due to its resistance to weathering. In contrast, the south shores are predominantly dolomitic limestone which, being both rich in carbonates and more susceptible to weathering, contribute runoff of comparatively high salinity. The catchment area of Lake Huron is more varied but, in general, is dominated by a variety of limestones in the north, and shales and

TABLE 4

SUMMARY OF 1974 AND 1980 ESTIMATED PHOSPHORUS LOADING DATA
TO LAKE HURON
(All values are in tonnes/year)

	MICHIGAN		ONTARIO		TOTALS	
	1974	1980	1974	1980	1974	1980
Direct Industrial Discharge	67	2	14	1	81	3
Direct Municipal Discharge	62	18	128	103	190	121
Tributary:						
Monitored	1,670	559	1,950	994	3,620	1,553
(Standard Error)	-	(13)	-	(134)	-	(134)
Subtotals	1,799	579	2,092	1,098	3,891	1,676
Atmospheric					620	1,495[1]
Tributary: Adjustment for Unmonitored Area	172	315	174	328	346	643
(Standard Error)[2]	-	(25)	-	(43)	-	(50)
TOTAL						
Estimated inputs from: Lake Superior					402	730
(Standard Error)					-	(146)
Lake Michigan					255[3]	255[3]
Total Lake Input					657	985
Total estimated input to Lake Huron					5,514	4,799
Target Load, 1978 Great Lakes Water Quality Agreement						4,360

Total may not sum due to rounding.

[1]Estimate uses Canadian monitoring sites only.

[2]Standard errors calculated from tributary loading estimates used in making adjustments.

[3]Upper Lakes Reference Group 1974-1975 estimates.

TABLE 5

ATMOSPHERIC PCB LOADS TO LAKE HURON

	kg/yr	REFERENCES
Total PCB Wet Deposition		
Lake Huron	825.0+	Murphy, *et al.*, 1981, 1982
Lake Huron (less Saginaw Bay, Georgian Bay, and North Channel)	124.1 ± 88.82	Mullin, 1982
Lake Huron	1500.0*	Eisenreich, *et al.*, 1980
Total PCB Dry Deposition		
Lake Huron	1500.0+	Murphy, *et al.*, 1981, 1982
Lake Huron	5700.0*+	Mullin, 1982
Total Bulk Deposition		
Lake Huron	2325.0	Murphy, *et al.*, 1981, 1982
Lake Huron	7200.0*	Mullin, 1982

+Value calculated from the proportion of bulk deposition to either wet or dry deposition.

*Estimated value which is calibrated from best fit data for the Great Lakes basin.

sandstones in the south (Sly and Lewis 1972, Bolton 1957, Hewitt 1972). While these areas are susceptible to weathering, thereby serving as a source of ions, the waters of Lake Huron are also strongly influenced by inputs from Lake Superior and Lake Michigan. The relative impact of these various sources is best illustrated by the distribution of conductivity in the surface waters (Figure 5). Specific conductance is a measure of the total ionic strength of the water and, consequently, is directly proportional to the concentrations of the major ions. Listed in order of their dominance in the Lake Huron-Georgian Bay system, these ions are:

Cations: Calcium, Magnesium, Sodium, and Potassium
Anions: Bicarbonate, Sulphate, and Chloride

Apart from bicarbonate, all other ion concentrations were determined directly. Bicarbonate concentrations were approximated by determining alkalinity. While alkalinity is a measure of the total acid neutralizing capacity of the water, and hence can include a variety of compounds, at pH values characteristic of Lake Huron and Georgian Bay (pH $\simeq$ 8), it is imparted largely by bicarbonate ion (Hutchinson, 1957).

Since conductivity is directly proportional to the major ion content of the water, examination of ion distributions could provide insight into the controlling mechanisms of conductivity. However, this interpretation is limited by the fact that the major cations were only investigated on the first cruise. Further, while the major anions were monitored during all six cruises, due to analytical problems, no results for chloride or sulphate were available for the first cruise. Consequently, it was not possible to calculate total ionic balances for any cruise.

The areal distributions of alkalinity, sulphate and chloride in Lake Huron are highly correlated with conductivity ($r = 0.92, 0.77, 0.84$, respectively). To determine which of these parameters was the most important in influencing conductivity, data were subjected to a stepwise linear multiple regression analysis. Essentially, this technique attempts to account for the most variation in conductivity with the three major anions by considering the influence of these anions in order of their importance.

Results of this analysis indicated that chloride was the best determining variable of conductivity in Lake Huron, accounting for 84% of the annual variation. Of the remaining 16% variation, alkalinity accounted for only 3% and sulphate only 0.1%, leaving approximately 13% of the variation unaccounted for by the major anions. The fact that chloride was the largest anionic determinant of conductivity suggests that variations in the ionic composition of Lake Huron waters are determined primarily by inputs from Lakes Michigan and Superior since the chloride composition of these source waters is so different. The magnitude of these influences are such that they mask any biologically mediated changes in the less conservative anions.

Similar treatment of data from Georgian Bay indicates that its anionic chemistry differs markedly from that of Lake Huron. Whereas, in Lake Huron, 87% of the variation could be accounted for by chloride, alkalinity and sulphate over the period of May to November, these three ions accounted for

FIGURE 5 DISTRIBUTION OF CONDUCTIVITY IN THE SURFACE WATERS

only 50% of the variation in conductivity in Georgian Bay over a similar period. Of these, alkalinity was the most important controlling variable in Georgian Bay, accounting for 46% of the variation. Sulphate and chloride accounted for 3.5% and 1.0% of the remaining variation, respectively.

Since almost 50% of the annual (May to November) variation in conductivity in Georgian Bay remained unaccounted for, two possible interpretations may be considered. First, it is possible that one linear equation may be inadequate to describe the relationship between the major anions and conductivity throughout the sampling period. This situation could arise if biologically mediated changes and/or changes in inputs resulted in differing relationships between the anions and conductivity between cruises. A second interpretation, not necessarily exclusive of the first, is that much of this residual variation could be accounted for by cation distributions.

To investigate the first interpretation, the regression was repeated on Georgian Bay data on a cruise-by-cruise basis. Results of this analysis are summarized in Table 6.

TABLE 6

VARIATION IN CONDUCTIVITY DUE TO ANIONS (%)

	CRUISE				
ION	May	June	JULY	SEPTEMBER	NOVEMBER
Alkalinity	96.7	82.2	88.7	32.6	16.2
Chloride	0.1	1.6	0.5	12.6	6.3
Sulphate	0.0	0.3	0.2	0.0	0.0

These findings indicate that, during the spring and summer, alkalinity was the principal determinant of conductivity accounting for greater than 80% of its variation. During the fall, however, alkalinity accounted for less than 35% of the variation. It is likely during this period that the major cations exerted a more pronounced influence on conductivity.

Mean concentrations for these parameters for each cruise are contained in Tables 7-12.

Oxygen - Oxygen in Lake Huron and Georgian Bay exhibited a distribution indicative of moderately oligotrophic lakes. Concentrations were high throughout the study period, ranging from 7.9 to 15.5 mg/L. In general, oxygen saturation levels were in excess of 90%. Samples that had lower saturation levels were, for the most part, confined to the lake bottom during the stratified period.

Nutrients - Due to the interest and concern over phosphorus, nitrogen and silicon loadings to, and their concentrations in, Lake Huron and Georgian Bay, considerable resources were expended in 1980 to determine ambient levels and to provide data for the analysis of trends. Similarly, when data from this

TABLE 7

APRIL CRUISE DESCRIPTIVE STATISTICS

VARIABLE	UNITS	N	MINIMUM	MAXIMUM	MEAN	STD. DEV.
pH		435	7.44	8.46	8.02	0.12
Conductivity	µmho/cm^2	435	86.0	253	194	21.4
Dissolved Oxygen	mg/L	149	10.6	15.4	14.0	0.60
NH -N	µg/L	378	0	460	3.24	5.02
NO -N	µg/L	434	33.0	485	283	39.7
Ortho P	µg/L	380	0.10	9.0	0.89	0.67
Soluble SiO_2	mg/L	433	0.86	2.64	1.46	0.28
Kjeldahl Nitrogen	µg/L	403	107	950	201	76.8
Total P	µg/L	403	2.0	58.1	5.74	4.14
Total Filtered P	µg/L	428	1.6	9.2	2.84	1.1
Chlorophyll	µg/L	206	0.80	10.0	1.79	1.17
POC	mg/L	206	0.11	0.90	0.26	0.16
Secchi	m	71	1.0	12.5	7.70	7.70

TABLE 8

MAY CRUISE DESCRIPTIVE STATISTICS

VARIABLE	UNITS	N	MINIMUM	MAXIMUM	MEAN	STD. DEV.
pH		502	7.44	8.72	8.01	0.14
Conductivity	µmho/cm²	503	98.0	238	191	22.1
Dissolved Oxygen	mg/L	163	9.4	15.5	13.4	0.66
NH_3-N	µg/L	492	1.0	35.0	2.54	3.42
NO_3-N	µg/L	503	180	735	279	48.5
Ortho P	µg/L	503	0.10	3.90	0.59	0.27
Soluble SiO_2	mg/L	502	0.77	2.68	1.44	0.32
Kjeldahl Nitrogen	µg/L	500	68.0	762	168	68.0
Total P	µg/L	501	3.20	16.1	5.18	1.49
Total Filtered P	µg/L	494	1.40	6.40	2.38	0.62
Chlorophyll	µg/L	256	0.90	7.80	1.99	1.03
POC	mg/L	256	0.2	0.73	0.21	0.13
Secchi	m	54	3.50	16.0	9.27	2.94

TABLE 9

JUNE CRUISE DESCRIPTIVE STATISTICS

VARIABLE	UNITS	N	MINIMUM	MAXIMUM	MEAN	STD. DEV.
pH		544	7.99	8.76	8.26	0.15
Conductivity	µmho/cm²	545	98.0	251	194	21.6
Dissolved Oxygen	mg/L	543	10.8	14.1	12.9	0.71
NH_3-N	µg/L	540	1.0	38.0	2.78	2.83
NO_3-N	µg/L	545	161	765	279	38.9
Ortho P	µg/L	547	0.20	2.10	0.72	0.23
Soluble SiO_2	mg/L	547	0.51	2.68	1.42	0.32
Kjeldahl Nitrogen	µg/L	545	60.0	322	124	33.0
Total P	µg/L	545	2.80	19.9	4.66	1.15
Total Filtered P	µg/L	547	0	5.0	2.09	0.42
Chlorophyll	µg/L	311	0.90	4.70	1.99	1.59
POC	mg/L	311	0.11	0.60	0.23	0.07
Secchi	m	73	2.50	12.0	6.84	2.04

TABLE 10

JULY CRUISE DESCRIPTIVE STATISTICS

VARIABLE	UNITS	N	MINIMUM	MAXIMUM	MEAN	STD. DEV.
pH		675	7.01	9.22	8.05	0.23
Conductivity	µmho/cm²	674	101	264	190	19.1
Dissolved Oxygen	mg/L	130	9.40	13.0	11.8	0.86
NH_3-N	µg/L	674	1.0	21.0	4.89	3.63
NO_3-N	µg/L	674	138	334	256	32.4
Ortho P	µg/L	666	0	3.50	0.42	0.33
Soluble SiO_2	mg/L	675	0	2.58	1.24	0.45
Kjeldahl Nitrogen	µg/L	674	76.0	297	164	34.4
Total P	µg/L	674	2.30	19.4	4.95	1.60
Total Filtered P	µg/L	671	1.40	6.0	2.37	0.48
Chlorophyll	µg/L	435	0.30	9.40	1.25	0.80
POC	mg/L	435	0.11	0.34	0.20	0.05
Secchi	m	93	1.50	17.6	9.09	2.38

TABLE 11

SEPTEMBER CRUISE DESCRIPTIVE STATISTICS

VARIABLE	UNITS	N	MINIMUM	MAXIMUM	MEAN	STD. DEV.
pH		601	7.29	8.66	8.17	0.18
Conductivity	μmho/cm²	597	95.0	234	187	14.4
Dissolved Oxygen	mg/L	601	7.91	14.4	10.9	1.23
NH_3-N	μg/L	600	1.0	17.0	1.67	1.91
NO_3-N	μg/L	600	172	354	266	38.2
Ortho P	μg/L	600	0.10	3.20	0.85	0.35
Soluble SiO_2	mg/L	600	0.56	2.54	1.27	0.41
Kjeldahl Nitrogen	μg/L	600	88.0	372	171	44.1
Total P	μg/L	600	2.90	12.9	4.76	1.23
Total Filtered P	μg/L	598	–	4.80	2.17	0.38
Chlorophyll	μg/L	287	0.80	2.80	1.44	0.36
POC	mg/L	287	0.15	0.48	0.23	0.06
Secchi	m	68	1.50	11.0	6.25	2.32

TABLE 12

NOVEMBER CRUISE DESCRIPTIVE STATISTICS

VARIABLE	UNITS	N	MINIMUM	MAXIMUM	MEAN	STD. DEV.
pH		481	7.15	8.56	8.13	0.17
Conductivity	µmho/cm²	475	99.0	267	201	17.4
Dissolved Oxygen	mg/L	480	9.63	13.9	11.6	0.56
NH_3-N	µg/L	481	1.0	10.0	2.57	1.67
NO_3-N	µg/L	481	163	343	276	31.1
Ortho P	µg/L	481	0.20	3.10	0.63	0.37
Soluble SiO_2	mg/L	481	0.75	2.21	1.39	0.31
Kjeldahl Nitrogen	µg/L	481	84.0	504	169	47.2
Total P	µg/L	481	3.10	15.7	5.22	1.47
Total Filtered P	µg/L	474	1.40	6.80	2.38	0.62
POC	mg/L	206	0.11	0.60	0.23	0.10
Secchi	m	69	1.0	9.0	4.28	1.89

effort became available, several investigators undertook to analyze and interpret it. The results are in general agreement, but naturally there are some discrepancies in details. These do not affect the conclusions about nutrients in Lake Huron.

The distribution of nutrients in the open waters of Lake Huron and Georgian Bay are the result of anthropogenic inputs, thermal structure, regeneration within the water column and assimilation by phytoplankton (Gachter, Vollenweider, and Glooschenko, 1974). Maximum concentrations were generally observed during the spring in the nearshore zones, associated with increased loadings due to runoff and thermal bar formation which restricted nearshore/offshore water mass exchange. Accompanying these high nutrient levels was a spring pulse of phytoplanktonic growth, comprised primarily of diatoms (Lin and Schelske, 1981; Munawar and Munawar, 1979). While production of the vernal diatom crop is attributed to a combination of factors including light, temperature and physical regime (Happey, 1970b), the net result is the assimilation of available dissolved nutrients into particulate (i.e. phytoplanktonic) matter. This process of assimilation is accelerated in the warmer, nutrient-rich nearshore areas and, if of sufficient magnitude to exceed loading rates, can lead to relative depletion in the nearshore. Only soluble reactive silica showed consistent and significant ($P < 0.001$) depletion in the nearshore zone for all three spring cruises. Soluble reactive phosphorus, which is rapidly depleted to limiting levels in the lower lakes, showed only a marginally significant ($P < 0.1$) depletion during the June cruise.

<u>Data Interpretation</u> - In studying a large lake, inconsistencies in data interpretation can arise due to spatial and temporal variation, complicated by a relatively coarse station pattern and the serrated profiles being sampled. Spatial variability can be accomodated by regarding the lake as a set of discrete "homogeneous" zones. The zonation pattern adopted for this study, illustrated in Figure 6, was subjectively determined on the bases of basin geomorphology, location of nearshore inputs and the summer epilimnetic circulation patterns, all of which serve to determine nutrient distributions in the lake.

<u>Phosphorus</u> - One objective of the 1978 Great Lakes Water Quality Agreement is to maintain the oligotrophic state and relative algal biomass of Lake Huron. As various authors have demonstrated that phytoplankton growth in Lake Huron is generally limited by phosphorus availability (Lin and Schelske, 1981; Schelske and Roth, 1973), programs have been instituted, where appropriate, to control phosphorus input. To assess the effectiveness of these remedial programs, as well as to identify significant inputs and determine ambient concentrations, monitoring of phosphorus levels in Lake Huron, the North Channel and Georgian Bay was undertaken. Four forms of phosphorus were measured: total phosphorus (TP), a measure of both particulate (i.e. incorporated into living matter and adsorbed onto inorganic complexes or detrital organic matter); dissolved P, comprised of orthophosphate, polyphosphates and organic colloids; total filtered phosphorus (TFP), a measure of dissolved P; and, soluble reactive phosphorus (SRP) which provides an estimate of that component of TFP most readily available for phytoplanktonic utilization. The lakewide mean values for TP, TFP, and SRP are listed by cruise in Tables 7 to 12. In addition, the areal surface distribution of total phosphorus in Lake Huron for the April cruise is presented in Figure 7, when spring runoff was at a maximum, thereby delineating the sources of anthropogenic and tributary inputs to the lake.

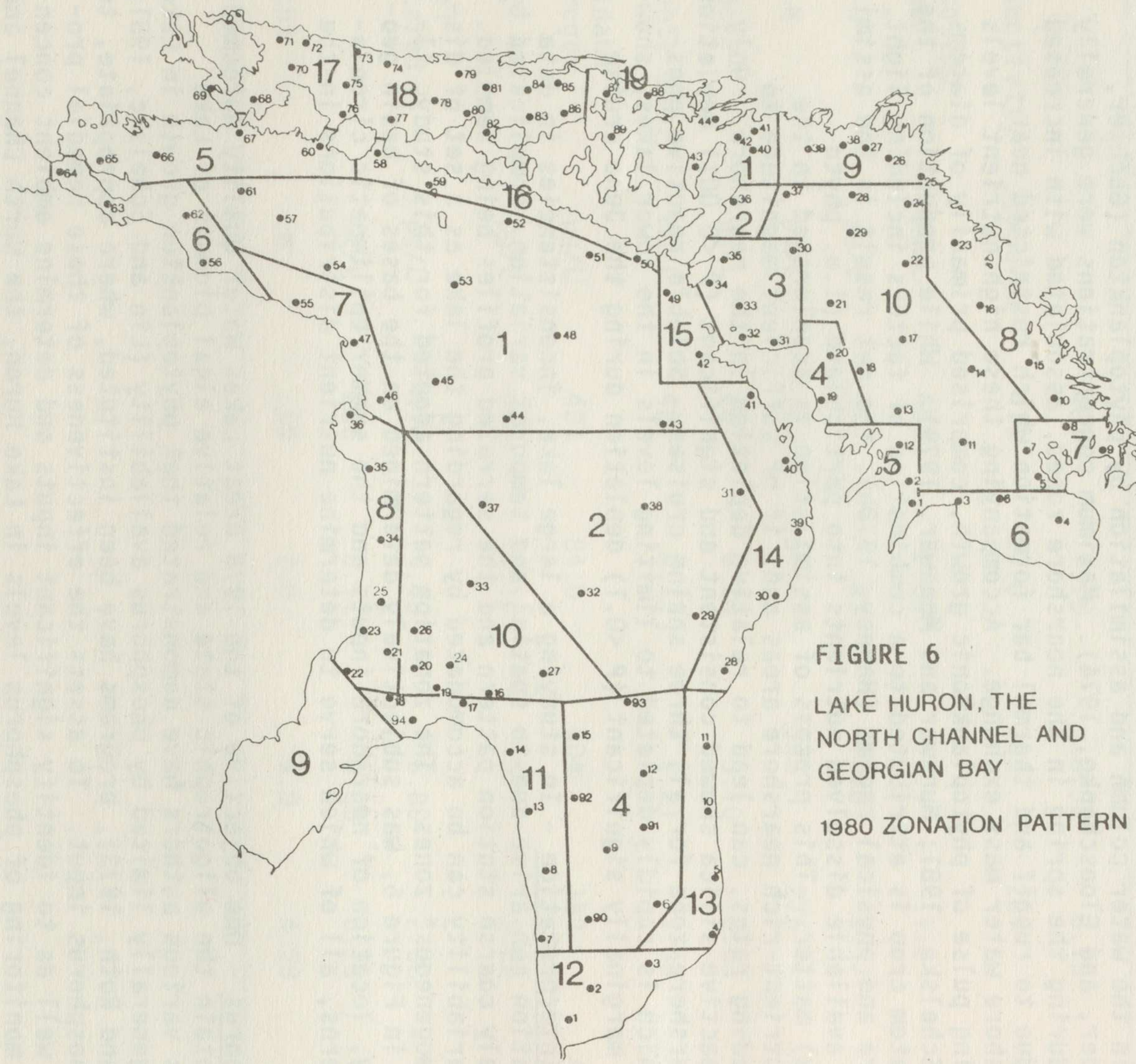


FIGURE 6

LAKE HURON, THE NORTH CHANNEL AND GEORGIAN BAY

1980 ZONATION PATTERN

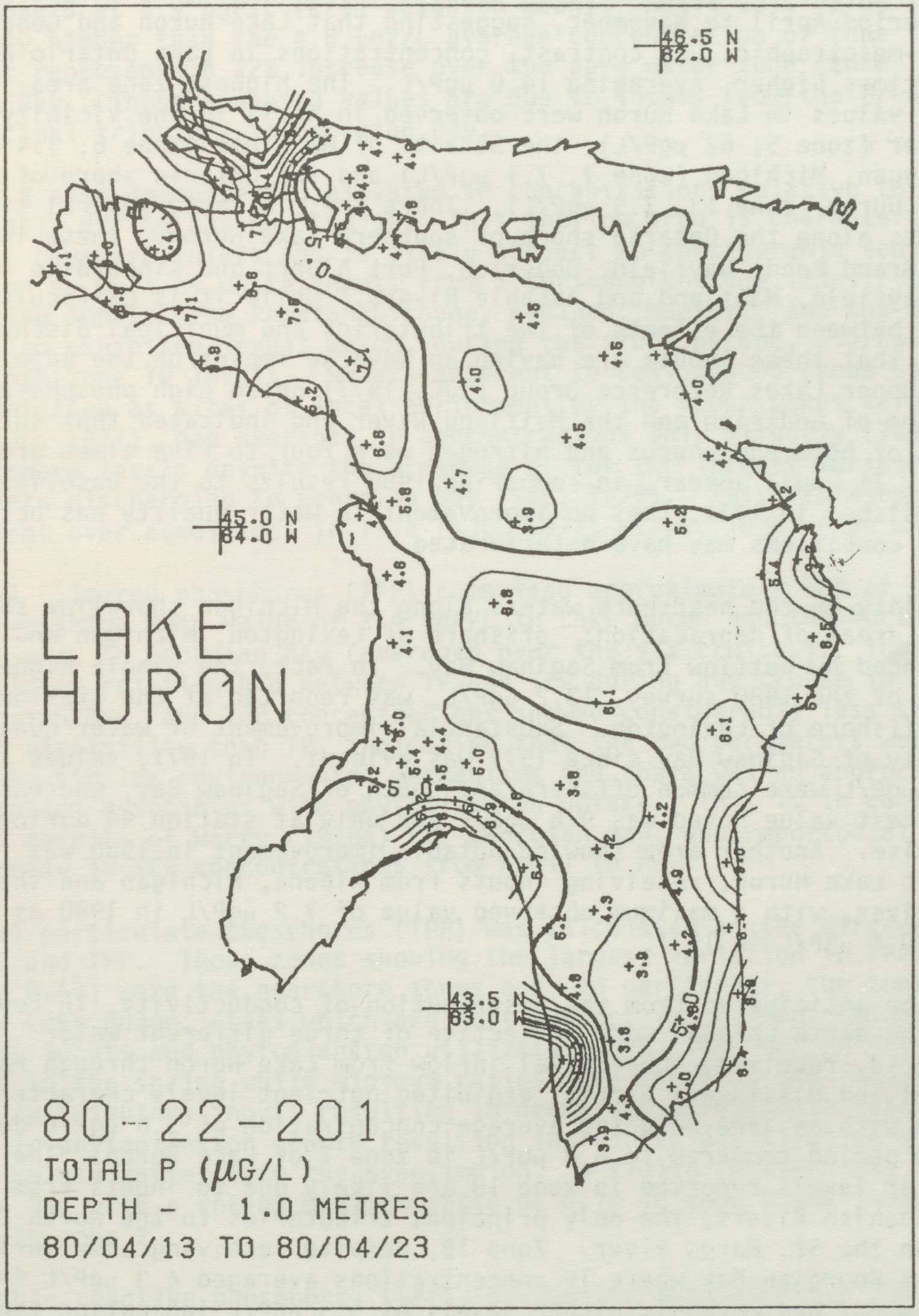


FIGURE 7 TOTAL PHOSPHORUS DISTRIBUTION IN LAKE HURON

Levels of TP were low throughout the system, averaging 5.0 µgP/L (area-weighted mean) in the surface waters of Lake Huron and 4.2 µgP/L in Georgian Bay for the period April to November, suggesting that Lake Huron and Georgian Bay are oligo-mesotrophic. In contrast, concentrations in Lake Ontario are nearly three times higher, averaging 14.0 µgP/L. The highest zone area-weighted mean values in Lake Huron were observed in April in the vicinity of St. Marys River (zone 5, 62 µgP/L), the Straits of Mackinac (zone 6, 7.4 µgP/L), Cheboygan, Michigan (zone 7, 7.1 µgP/L) and the Ontario shore of southern Lake Huron (zone 13, 7.9 µgP/L). There are, in fact, several significant inputs along the Ontario shore of southern Lake Huron. These include the towns of Grand Bend, Bayfield, Goderich, Port Albert and Kincardine as well as the Bayfield, Maitland and Ausable Rivers. While it is difficult to differentiate between the effects of the tributaries and municipal discharges, it is evident that these inputs are having an adverse impact on the adjoining waters. The Upper Lakes Reference Group (IJC, 1977) noted high phosphorus levels offshore of Goderich and the Maitland River and indicated that spring peak loadings of both phosphorus and nitrogen were four to five times greater than in 1966. It would appear, in comparing 1980 results to the baseline conditions established in 1971, that no improvement in water quality has occurred and, in fact, conditions may have deteriorated.

Water quality in the nearshore waters along the Michigan shoreline show two principal areas of degradation: offshore of Lexington, Michigan and those waters influenced by outflow from Saginaw Bay. In fact, the single highest TP concentration of the 1980 survey, 13.2 µgP/L, was reported at the station immediately offshore of Lexington. Substantial improvement of water quality in the vicinity of Saginaw Bay since 1971 was evident. In 1971, values in excess of 10 µgP/L were common offshore and south of Saginaw Bay, whereas in 1980, the highest value noted was 9.6 µgP/L and only at station 94 during the first cruise. Another area showing notable improvement in 1980 was Thunder Bay in Lake Huron, receiving inputs from Alpena, Michigan and the Thunder Bay River, with a maximum observed value of 7.2 µgP/L in 1980 as compared to 10.4 µgP/L in 1971.

As would be anticipated from the distribution of conductivity, TP concentrations in the North Channel were reflective of three different water masses. Zone 18, receiving substantial inflow from Lake Huron through False Detour Channel and Mississagi Strait, exhibited nutrient levels characteristic of Lake Huron with an area-weighted average concentration of 5.0 µgP/L during the study period compared to 4.8 µgP/L in zone 1 of Lake Huron. The slightly higher levels reported in zone 18 are likely due to inputs from the Serpent and Spanish Rivers, the only principal tributaries to the North Channel other than the St. Marys River. Zone 19, despite receiving some inflow from zone 1 of Georgian Bay where TP concentrations averaged 4.3 µgP/L from April to November, had markedly higher levels at 5.3 µgP/L indicating that minor local sources were present. Most distinctive were the consistently high values of TP reported in zone 17 due to inputs from the St. Marys River. The average area-weighted TP concentration during the study period was 6.4 µgP/L, the highest zonal average reported in the entire Lake Huron-Georgian Bay system. Considering an average monthly flow of approximately 2,200 m^3/sec from the St. Marys River in 1980, this represents a substantial loading of phosphorus to Lake Huron, presumably due to inputs from Sault Ste. Marie, Ontario and Sault Ste. Marie, Michigan.

The highest average concentration from April to November in Georgian Bay was in zone 9 at 4.9 µgP/L (area-weighted mean). While this value is only marginally higher than the 4.8 µgP/L average concentration of zone 1 in Lake Huron, it represents a 22% increase over the open water zone (zone 10) of Georgian Bay. These elevated values are due to inputs from the French River, the principal tributary to Georgian Bay.

Zone 8 also demonstrated elevated TP concentrations relative to zone 10, particularly during the May cruise. This shallow area is characterized by a myriad of bays and inlets and is likely subject to considerable sediment resuspension as well as waste inputs from a thriving cottage industry. Zone 7,receiving inputs from Penetanguishene, Midland, Meaford, and the Severn River, also exhibited levels which, during the study period, averaged 14% higher than zone 10 levels. Waters adjacent to Collingwood (zone 5), which were identified as sites of local enrichment by the Upper Lakes Reference Group (IJC, 1977), had averaged TP concentrations only slightly (7%) higher than offshore levels despite the presence of the two largest municipal treatment plants discharging to Georgian Bay (IJC, 1979). This represents a slight improvement over conditions in 1974 (IJC, 1977; Warry, 1978) (see Chapter 4).

Total filtered phosphorus (TFP) comprised approximately 50% of the TP with an area-weighted mean value of 2.4 µgP/L in Lake Huron and the North Channel and 2.1 µgP/L in Georgian Bay (averaged over the six cruises). There was no strong linear relationship between TP and TFP during any cruise in Lake Huron and Georgian Bay, and TFP concentrations showed considerably less spatial and temporal variability than TP, indicating that the two parameters were not controlled by similar environmental mechanisms and there was no appreciable summer depletion associated with phytoplankton uptake. This is in contrast to the 1974 results of Warry (1978a) for Georgian Bay, who reported at least a 50% decrease in TFP concentrations from April to May.

Total particulate phosphorus (TPP) was calculated as the difference between TP and TFP. Those zones showing the largest variation in TPP:TP ratios (0.25 to 0.67) were the nearshore zones and, in particular, the zones in southern Lake Huron, areas which are most subject to sediment resuspension, tributary inputs and phytoplankton utilization. Maximum TPP:TP ratios were observed in the spring while minimum ratios were found in the summer due to a decline in tributary inputs resulting in decreased particulate loadings, and a decline in phytoplankton growth resulting in reduced assimilation and settling of particulate matter into the hypolimnion. A similar pattern was observed in Georgian Bay with a spring maximum ratio of 0.70 in zone 8 and summer minimum of 0.29 in zone 2.

Soluble reactive phosphorus (SRP) constituted approximately 30% of the TFP and 15% of the TP with area-weighted mean values of 0.9 µgP/L in Lake Huron and 0.7 µgP/L in Georgian Bay during the spring. Maximum values of 1.1 µgP/L (area-weighted mean) in Lake Huron were reported in zones 2 and 10, presumably a remnant of winter circulation and low phytoplankton abundance. High concentrations were also observed during the April cruise in the North

Channel (1.1 µgP/L), due to inputs from the St. Marys River, and in zone 12 during the May cruise (1.0 µgP/L), due to elevated levels offshore of Lexington, Michigan.

During July, when chlorophyll a concentrations (i.e. phytoplankton standing crop) were at a minimum implying nutrient limitation, minimum levels of SRP were reported for both Lake Huron (0.5 µgP/L) and Georgian Bay (0.4 µgP/L). The open lake zones of Lake Huron (zones 1 and 2) and Georgian Bay (zone 10), least subject to nearshore influences, showed depletions relative to spring maximums of 50% and 57%, respectively. This is supported by enrichment studies which have demonstrated summer phytoplankton populations to be limited by phosphorus availability (Lin and Schelske, 1981) when less than 0.2 µgP/L.

Nitrogen - The principal sources of nitrogen to a lake are atmospheric loading, nitrogen fixation, and inputs from surface and groundwater drainage. Balancing these inputs are losses from lake outflow, bacterial denitrification and sedimentation. Atmospheric loading contributes substantially more nitrogen (37%) to the total load of Lake Huron than it does phosphorus (14%) (IJC, 1977). Since this source is essentially uncontrollable, and since phytoplankton growth is limited by phosphorus availability, no control measures for nitrogen inputs exist.

Of the numerous forms of nitrogen occurring in fresh water, four were measured: nitrate + nitrite (NO_3+NO_2), ammonia (NH_3), total kjeldahl nitrogen (TKN) and total particulate nitrogen (TPN). Nitrogen as NO_3+NO_2 and NH_3 is readily available for assimilation by phytoplankton. TKN minus NH_3 is a measure of the total organic nitrogen (TON), both particulate and dissolved, including products of biological processes such as amino acids, polypeptides and proteins. TPN was collected as a biomass indicator and therefore will be discussed in Chapter 3.

Lakewide mean values of NO_3+NO_2, NH_3 and TKN for each cruise are given in Tables 7 to 12. NO_3+NO_2 concentrations, averaged over the six cruises, were greater in Lake Huron (274 µgN/L) and the North Channel (271 µgN/L) than in Georgian Bay (253 µgN/L). The highest area-weighted values (greater than 300 µgN/L) reported for 1980 were in the nearshore zones of southern Lake Huron, specifically zones 11, 12, 13 and 14. The shoreline of southern Lake Huron is comprised mainly of sedimentary rock, which is high in inorganic nitrogen (Sly and Thomas, 1974). Weathering of this material would, therefore, contribute to the elevated levels of NO_3+NO_2 in these southern waters. In addition, these elevated levels are associated with spring snowmelt from tributaries. For example, concentrations offshore of the Ausable River were consistently high in the spring, reaching a maximum of 765 µgN/L at station 3 by the June cruise.

Consistently lower values of NO_3+NO_2 were observed in zones 6, 7 and 8 of Lake Huron. While inputs into these zones from Lake Michigan, Little Black River and Thunder Bay River were relatively reduced in NO_3 content, thereby contributing to the low observed values, phytoplanktonic assimilation of dissolved inorganic nitrogen was undoubtedly a contributing factor, attested to by the elevated chlorophyll concentrations observed in these areas throughout the study period.

The high levels of NO_3 observed in Lake Huron have been attributed to inputs from Lake Superior (Lin and Schelske, 1981; Schelske and Roth, 1973). While such inputs are likely to be a contributing factor to ambient concentrations, it is unlikely that, considering the complexity of the nitrogen cycle and the numerous other sources to the lake, it is the predominant cause. In fact, if ambient concentrations were merely a result of partitioning between Lake Michigan and Lake Superior inputs, then levels in zone 1 of Lake Huron should be approximately 60 µgN/L lower.

The distribution of NO_3+NO_2 in the North Channel is similar to that reported by Warry (1978b) with a concentration gradient from high to low moving from west to east. The elevated concentrations observed in the west were as a result of inputs from the St. Marys River. However, the maximum station concentration observed in zone 17 was only 307 µgN/L, considerably less than values reported in southern Lake Huron. Substantial input of NO_3+NO_2 to the North Channel was also contributed by the Serpent river where a maximum concentration of 345 µgN/L was observed at station 79 (Figure 6) during the June cruise. Concentrations of NO_3+NO_2 in zone 19 were considerably less than zones 17 and 18 as a result of influx of waters low in nitrate from Georgian Bay.

Levels of NO_3+NO_2 averaged approximately 7% less in Georgian Bay than Lake Huron during the study period. Unlike Lake Huron, large point source inputs of NO_3+NO_2 were lacking in Georgian Bay. There was, however, a distinct southwest to northeast gradient in concentration apparent during all cruises. The higher values in the southwest, in particular zones 3, 4, 5 and 6, were a result of drainage through the sedimentary rock of this shoreline, as well as water mass exchange with Lake Huron. Low values observed along the north and east coasts reflected the low nitrogen content of drainage through the shield rock of this coast and was particularly apparent offshore of the French River.

Levels of NH_3 were low throughout most of the Lake Huron-Georgian Bay system, ranging from 1 to 7 µgN/L (area-weighted zone surface values). Unlike other nutrients, NH_3 levels in the epilimnion reached their maximum in the summer in most zones. This is particularly evident in the more productive zones in southern Lake Huron where levels increased up to 7 µgN/L. Several processes are responsible for this increase but it is difficult to differentiate between their relative impacts. During the July cruise, phytoplankton development, as indicated by chlorophyll a levels, was at a minimum. This decline, accompanied by an increase in the detrital fraction, probably resulted in increased heterotrophic decomposition in the relatively shallow (5M), warmer epilimnion. In addition, tributary inputs are at a minimum during this period (Environment Canada, 1981) and, as such, industrial and, particularly, municipal discharge will have a considerably greater impact on the shallow, epilimnetic waters.

The highest NH_3 concentrations were observed in zone 17 of the North Channel where a maximum area-weighted value of 14 µgN/L was reached during the first cruise. These elevated levels are attributable to industrial discharge from Algoma Steel Corporation and municipal discharge from both the Sault Ste. Marie, Ontario and Sault Ste. Marie, Michigan sewage treatment plants (see Chapter 4). Considerable improvement in NH_3 levels in the North Channel has been noted since 1974. According to Warry (1978b), an average concentration of 13.0 μgN/L was observed in zone 17 from the period May to October, 1974. During a similar period in 1980, concentrations averaged 3.7 μgN/L, representing a 72% decrease.

Total kjeldahl nitrogen (TKN) is comprised of dissolved organic nitrogen (DON), particulate organic nitrogen (PON) and NH_3 and consequently can be related to both incidences of organic pollution and the dynamics of the plankton biomass. In most instances, NH_3 contributed less than 2% to TKN, except in the vicinity of the St. Marys River, where it contributes up to 18%, again highlighting a degree of contamination in the river. Correcting for NH_3 gives total organic nitrogen (TON) of which, in average lake conditions, DON usually constitutes approximately 80% (Wetzel, 1975). The ratio of DON to PON was investigated in this study by subtracting total particulate nitrogen (TPN) from TKN (corrected for NH_3). This can only be considered an approximation as TPN samples were collected using a 20 meter integrating sampler while TKN samples were collected using a discrete sampler.

Lake Huron results were consistent with the average conditions reported by Wetzel (1975) with DON constituting, on the average, 79 to 82% of TON during all the June cruises. During this particular cruise, the DON fraction decreased to 69% of TON. The relatively small ratio of PON to DON is indicative of oligotrophic conditions (Wetzel, 1975). Several stations did show values characteristic of eutrophic conditions, with PON to DON ratios approaching 1:1, specifically those stations in nearshore zones 6, 8, 11, 12 and 13.

Results were similar in Georgian Bay, with DON contributing 79 to 86% of TON during all cruises. Again, several stations showed values indicative of more eutrophic conditions although not as much as in nearshore Lake Huron. Those stations indicative of the most eutrophic conditions were usually in the shallowest nearshore zones, specifically 1, 7, 8 and 9 (Georgian Bay, Figure 6).

While the ratio of PON to DON gives a general index of trophic status, absolute concentrations of TKN are useful in identifying those areas receiving excessive organic pollution. TKN concentrations exhibit a consistent seasonal trend with maxima in the early spring and fall and a distinct minimum in late spring. In most instances, those zones with the largest PON:DON ratios exhibited the highest TKN values, with surface station values being more than twice the lake-wide area-weighted mean values. Specific areas in Lake Huron and the North Channel with high TKN values were those stations directly offshore of Grand Bend, Goderich, Bayfield and Southampton, Ontario and Lexington, Harbour Beach, Saginaw Bay and Alpena, Michigan as well as in the vicinity of the Straits of Mackinac, the St. Marys River and the Serpent and Spanish Rivers. In Georgian Bay, those stations with elevated TKN values were at the Lake Huron/Georgian Bay interface, offshore of the French River, the southwest portion of Nottawasaga Bay and in the area of Penetanguishene and Midland. These areas were close to the most developed regions of the basin and, as such, reflected increased municipal and industrial discharges.

Silica - Diatoms are the dominant phytoplankton taxa in Lake Huron (Munawar and Munawar, 1979), often accounting for more than 90% of the species (Lin and Schelske, 1981). This algal group is unique in their requirement for silica as a cell wall constituent (Happey, 1970b) and consequently, can effect pronounced changes on the dissolved silica distribution in the trophogenic zone of Lake Huron and Georgian Bay.

Tables 7 to 12 summarize the lakewide mean values of soluble reactive silica (SRS) for each cruise. Lake Superior, via the St. Marys River, was by far the principal source of SRS at levels in excess of 2 mg SiO_2/L throughout the study period. In contrast, SRS concentrations in the remaining surface waters of Lake Huron exhibited large spatial and temporal variation, but were generally less than 1.6 mg SiO_2/L. As discussed previously, when the thermal bar was present, SRS was the only nutrient to be consistently and significantly depleted in the nearshore regions of Lake Huron. This was in response to rapid phytoplankton growth in the warmer waters. By July, area-weighted mean surface levels of SRS in the open lake had decreased by 20%, from 1.5 mg SiO_2/L to 1.2 mg SiO_2/L. However, the open waters were still elevated relative to the nearshore. This difference was partially a result of the anticyclonic circulation pattern of the epilimnion, which continued to maintain a separation of waters. During this period differences between nearshore and offshore epilimnetic concentrations were at a maximum.

The lowest area-weighted mean surface value (0.671 mg SiO_2/L) was observed in Zone 12 (Lake Huron). However, the minimum single station values were found at stations 63 and 64, in the vicinity of the Straits of Mackinac, where concentrations at 1 meter were 0.360 and 0.340 mg SiO_2/L. Levels of silica less than 0.5 mg/L are generally considered limiting to diatom growth (Wetzel, 1975). These low concentrations are due to inputs from Lake Michigan, where summer epilimnetic values fall in this range (Rockwell, et al., 1980).

The September whole lake area-weighted surface silica values decreased 39% from the maximum levels observed in the spring due to both widespread horizontal mixing and an increase in phytoplankton standing crop associated with the onset of fall turnover. Continued inputs from Lake Superior and, in particular, entrainment of enriched hypolimnetic waters were responsible for the increasing levels observed during the October cruise.

As expected, the concentrations of SRS in the North Channel were considerably greater than Lake Huron due to continued inputs from Lake Superior. A summer minimum was observed, due to phytoplankton utilization and water mass exchange with Lake Huron, but was never less than 1.3 mg SiO_2/L.

Spring levels of SRS in Georgian Bay were 17% less than in Lake Huron and exhibited considerably less spatial variation. The only apparent inputs were via the North Channel connection (zone 1) and from the French River (zone 9). Epilimnetic depletion of SRS, while evident, was not as pronounced as that observed for Lake Huron. Based on area-weighted surface (1 m) values, the largest summer decrease in Georgian Bay was observed in zone 9 (43%), reflecting both biological utilization and reduced summer discharge from the French River. On a whole lake basis, however, the summer minimum represented only a 29% depletion.

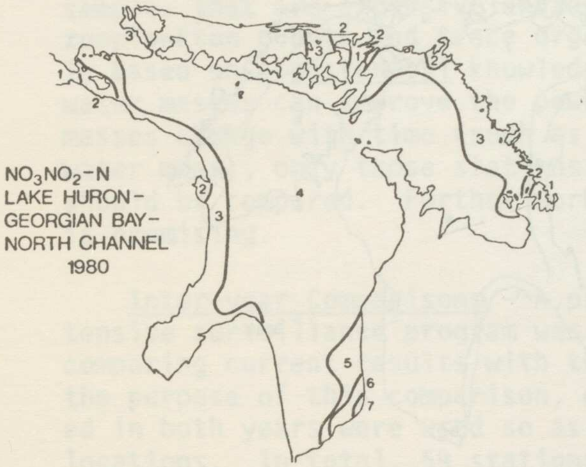
Distinct Water Masses - Kwiatkowski (1984) used the 1980 data base (Tables 7-12) in a regression model (El-Shaarawi and Kwiatkowski, 1977) that divides the lake into statistically homogeneous regions. These (Figure 8) zones support quite well the subjective zones in Figure 6. Lake Huron is dominated by a large central homogeneous area. Higher concentrations of TP and SRS enter north Lake Huron from the St. Marys River and the North Channel and lower concentrations of SRS and NO_3+NO_2 from Lake Michigan, which distinguish the water masses. The difference between nearshore and open lake are clearly evident, also the effects of Saginaw Bay continue to influence water quality in southern Lake Huron, but these have been modified to a degree that inputs from the Sarnia-Goderich-Ausable River area can be seen, particularly for nitrate nitrogen and chlorophyll.

The information from nutrient and major ion concentrations can also be combined using a multivariate statistical procedure to determine distinct water masses in Lake Huron (Moll, et al., 1985). The primary motivation behind identifying specific water masses is to determine if the water body has spatial structure across several variables, and the nature of that spatial structure. For a body of water such as Lake Huron, identification of spatial variability is not surprising since such a large lake cannot be completely mixed both vertically and horizontally. The input of several different water types into Lake Huron is a major source of spatial variability (IJC, 1977). Anthropogenic loadings in the nearshore zone contribute further to spatial inhomogenities (Davis, Schelske, Kreis, 1980).

The sequence of these distinct water masses is shown in Figure 9. For July, areas a and b are the open lake water masses for southern and northern Lake Huron, respectively. Area c represents Saginaw Bay inputs on the United States side and Goderich inputs on the Canadian side. Area d shows the extent of mixing of Lake Michigan, Lake Superior and Lake Huron waters. Area e is representative of nearshore inputs on the Michigan side and of inputs to Georgian Bay on the Canadian side. Area f is the rest of Georgian Bay. Area g is the zone of mixing of North Channel and Lake Superior waters and area h represents the rest of the North Channel.

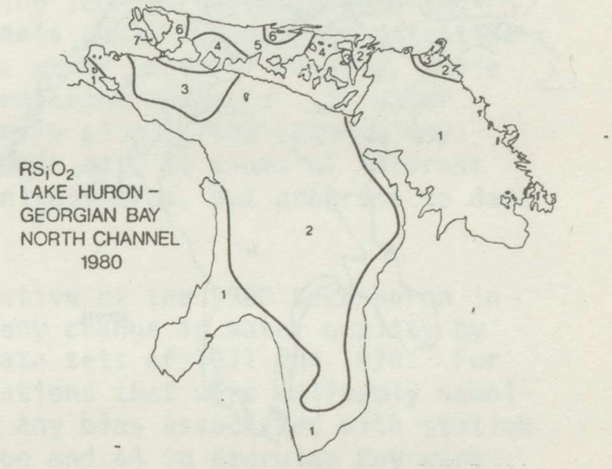
Two areas deserve particular attention because of previous research. In 1973, a long, distinct water mass was observed along Lake Huron's western shore from the Straits of Mackinac to Thunder Bay (Moll, Schelske, and Simmons, 1976). This water mass was taken to represent Lake Michigan water entering Lake Huron through the Straits of Mackinac. This same water mass was observed in three of the six cruises (May, June, and November). The other specific water mass of historical interest was also a long segment on Lake Huron's western shore. In 1974 this segment was observed running from the mouth of Saginaw Bay, around the "Thumb" of Michigan, and into the southern basin. This water mass was taken to represent Saginaw Bay water flowing into Lake Huron. This segment was only observed during the first three cruises of 1980, and was only partially present during the April cruise, which demonstrates the reduced impact of Saginaw Bay in 1980.

The identification of distinct water masses has implications for design of future monitoring schemes. If consistently similar water masses can be located, then fewer sampling stations will be needed to characterize the different areas of the lake because between-station variance will be reduced. Also,



NITRATE-NITRITE

ZONE	
1.	183.9 µg•L
2.	213.7 "
3.	245.3 "
4.	269.8 "
5.	295.2 "
6.	375.6 "
7.	420.5 "

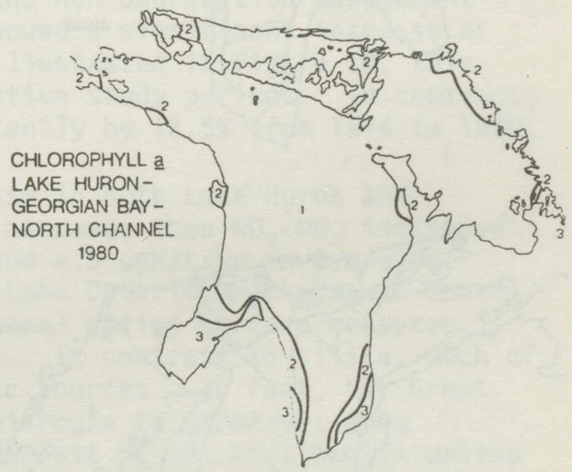


SOLUBLE REACTIVE SILICA

ZONE	
1.	1.1 mg•L
2.	1.3 "
3.	1.4 "
4.	1.6 "
5.	1.8 "
6.	2.0 "
7.	2.2 "

TOTAL PHOSPHORUS

ZONE	
1.	4.5 µg•L
2.	5.8 "
3.	8.0 "



CHLOROPHYLL a

ZONE	
1.	1.4 µg•L
2.	1.9 "
3.	2.7 "

FIGURE 8 HOMOGENEOUS WATER MASSES IN LAKE HURON, 1980

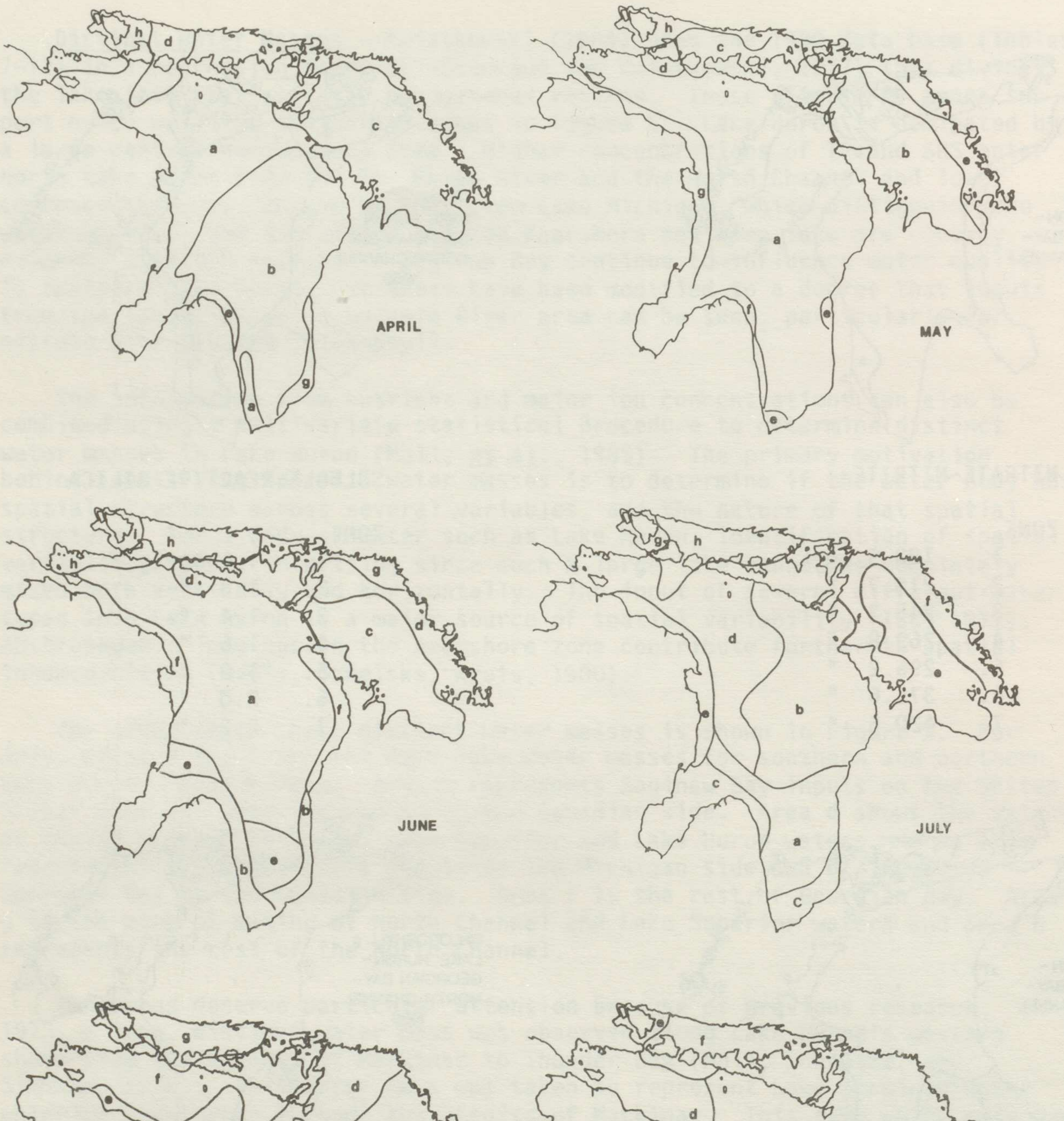


FIGURE 9 WATER MASSES IN LAKE HURON DEFINED BY CLUSTER ANALYSES, 1980

samples that are expensive and/or time consuming such as phytoplankton and zooplankton counts and trace organic contaminants could be analyzed selectively based on a posteriori knowledge of specific water masses. Finally, these water masses can improve the power of long-term trend analysis. If water masses change with time (such as the reduction in size of the Saginaw Bay water mass), only those stations within the water mass at times of interest should be compared. Further work is needed in this area, but progress to date is promising.

Inter-year Comparisons - A principal objective of the 1980 Lake Huron intensive surveillance program was to document any change in water quality by comparing current results with the baseline data sets of 1971 and 1974. For the purpose of this comparison, only those stations that were uniformly sampled in both years were used so as to eliminate any bias associated with station locations. In total, 59 stations in Lake Huron and 44 in Georgian Bay were comparable. To further eliminate bias, statistical comparisons were performed on results from the 1 metre depth at spring (April) turnover when conditions were nearly isochemical. The mean and standard deviation for conductivity, TP, NO_3+NO_2 and SRS for the 1971 and 1980 spring cruises on Lake Huron and the 1974 and 1980 spring cruises on Georgian Bay are presented in Table 13 (Stevens, Neilson, and Warry, 1984).

When a t-test was performed on similar stations, conductivity showed a significant decrease ($P < 0.05$) from 1971 to 1980 in Lake Huron, reflecting the 2% difference in spring mean values. Results for Georgian Bay indicated that no significant change had occurred between 1974 and 1980. TP demonstrated no significant change since 1971 in Lake Huron and 1974 in Georgian Bay ($P > 0.05$). These results were in keeping with the non-degradation management philosophy for the upper Great Lakes. SRS showed a significant increase of 12% from 1971 to 1980 in Lake Huron and, as illustrated in Figure 10, this increase was consistent throughout the respective study periods. In contrast, SRS levels in Georgian Bay decreased significantly by 13.5% from 1974 to 1980.

NO_3+NO_2 demonstrated a significant increase in both Lake Huron and Georgian Bay. If a constant annual rate was assumed, then NO_3+NO_2 increased at approximately 5.4 µgN/L/yr in Lake Huron and 4.5 µgN/L/yr in Georgian Bay. Similar results have been reported for Lake Ontario which has an annual rate of increase of 8.8 µgN/L/yr, based on annual spring surface measurements since 1969 (Chapin and Uttermark, 1973). In contrast to silica, much of the nitrogen input is derived from atmospheric sources. In fact, the Great Lakes region receives the largest inputs of nitrogen (1 $gN/m^2/yr$) from precipitation and bulk fallout compared to the rest of the continental United States (Chapin and Uttermark, 1973). Further, high inputs of inorganic nitrogen are received from runoff through sedimentary formations, such as in the southern Lake Huron and Georgian Bay watershed (Wetzel, 1975). Considering that these two factors account for more than 50% of the water budget of Lake Huron and Georgian Bay, such an increase is not unexpected (IJC, 1977).

The ability to detect a real difference between the 1980 data and that of the baseline years is dependent on the variability associated with the mean parameter value. On a whole lake basis, variability was large, reflecting the influence of tributary inputs on the nearshore stations. To reduce this vari-

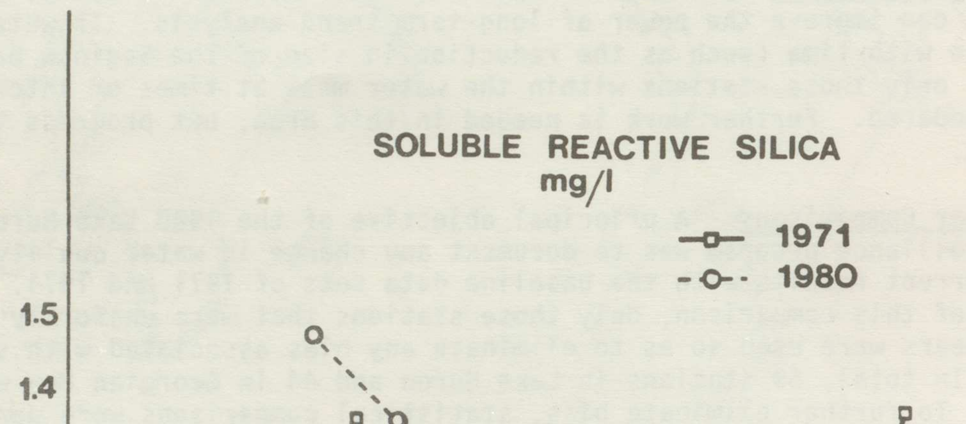


FIGURE 10 SOLUBLE REACTIVE SILICA

ability, the nearshore stations were eliminated from the analysis and the comparisons repeated. Substantial reduction in variability was noted but, in all cases, the tests of significance remained unaltered. Kwiatkowski (1984) also compared 1980 data with 1971 (Georgian Bay - North Channel) and 1974 (Lake Huron) data, but superimposed the zones depicted in 1980 (Figure 8) on 1971-74 data sets. In Lake Huron no change was detected in phosphorus. In zone 1 (Figure 8) in Georgian Bay, phosphorus concentrations decreased from 5.1 (s^2 = 5.3) to 4.3 (s^2 = 1.2). While this decrease of 0.8 μg/L was statistically significant ($P < 0.01$) this was most likely due to the extremely large number of replicates ($n = 652$) and it is debatable whether a change of 0.8 μg/L can be considered biologically meaningful. Other changes described by Kwiatkowski (1985) for nitrate-nitrogen and silica concur with those described above in this report.

Moll, et al. (1985) used the historical EPA data base available for Lake Huron since 1954 to determine if any long-term trends in nutrients could be observed. Because data from the earlier years were most consistently available during the summer months, data for this time period were used for this long-term trend analysis, however, they also examined spring data to reduce annual differences due to climatic seasonal effects which are greater in the summer months. Results of these analyses indicate in the summer no significant linear trend in SRP although the authors indicate concentrations decreased from 1966 to 1970, increased from 1970 to 1977, and decreased from 1977 to 1980. These could be due to either physical or biological variables or changes in sampling and analytical methods. Spring data showed no significant long term trend in SRS, SRP and TP. NO_3+NO_2 showed a significant linear increase over the period. Although SRP and TP showed no long term trends, there were, as Moll, et al. (1985) points out, annual differences, as one would expect with nutrient parameters which are affected by a range of physical and biological variables as well as changes in sampling and analytical methods that occurred over the period of record.

From these analyses Moll, et al. (1985) concluded that over the period 1954 to 1980 sulfate and NO_3+NO_2 had increased at a rate of 0.3-0.8% and 1.1-3.1% per year respectively. Since 1954 dissolved silica had decreased at an annual average rate of 2.8-3.6% per year. However, this "average decline" is greatly affected by very high values at the beginning of the period of record, since 1971 their data suggest concentrations were increasing. No significant long term trends were demonstrated for TP and SRP.

The magnitude of the increase for NO_3+NO_2 for the long-term is consistent with that observed for 1971 - 1980 (i.e. 5-6 μg N/L/year). TP showed no long term change in either data set, although Moll, et al. (1985), because of their more extensive data set, illustrated the considerable year to year differences and the fact that shorter time trends, both increasing and decreasing can exist in a long (25 year) data set. This is cautionary in interpreting trends over a few years and demonstrates the need for both continuity in data collection and the value of long term data sets, but also shows the importance for continuity in methods. The agreement with SRS is not as good, Moll, et al. (1985) state that dissolved reactive silica decreased since the

TABLE 13

INTERYEAR COMPARISONS

STUDY AREA	PARAMETER	YEAR	MEAN + STANDARD DEVIATION	COEFFICIENT OF VARIABILITY(%)
Lake Huron	Conductivity	1980	202.6 + 1.92*	0.9
	(μmhos/cm²)	1971	206.6 + 5.39	2.6
	Total	1980	4.62 + 0.71**	14.4
	Phosphorus (μg/L)	1971	4.13 + 1.50	35.5
	Nitrate +	1980	283.0 + 10.1*	3.5
	Nitrite (μg/L)	1971	235.0 + 10.62	7.9
	Soluble Reactive	1980	1.497 + 0.096*	7.5
	Silica (mg/L)	1971	1.395 + 0.050	3.5
Georgian Bay	Conductivity	1980	184.0 + 13.87**	7.5
	(μmhos/cm²)	1974	188.4 + 6.29	3.3
	Total	1980	5.08 + 2.03**	40.0
	Phosphorus (μg/L)	1974	4.66 + 3.02**	64.7
	Nitrate +	1980	267.1 + 26.82*	10.0
	Nitrite (μg/L)	1974	240.3 + 20.39*	8.5
	Soluble Reactive	1980	1.248 + 0.176*	14.1
	Silica (mg/L)	1974	1.444 + 0.184	12.7

*Significant difference (5% level).
**No significant difference (5% level).

mid-1970's. The data they present for dissolved silica, however, shows a clear increase from 1971 to 1980 in summer epilimnion and from 1971 - 1975 in the spring data.

Summary - The water quality of Lake Huron, North Channel and Georgian Bay in 1980, with respect to the nutrient phosphorus, demonstrated little change from conditions of 1971/74 and, dependent upon the criteria used, was characteristic of oligotrophic to mesotrophic conditions. TP, the only nutrient controlled by remedial programs, on a whole lake basis had not changed from 1971, thereby meeting the requirements of non-degradation identified in the 1978 Great Lakes Water Quality Agreement. Continued monitoring of TP should be maintained, at a more frequent rate, to ensure that levels do not increase.

Both nitrogen (as NO_3+NO_2) and silica (as SRS) have shown significant increases since 1971. It is recommended that attention be given to these parameters to ascertain the factors responsible for the observed increases, and the impact these increases may have on the biotic community and water quality. Greater cooperation between the jurisdictions is needed to achieve this.

Trace Metals

Knowing the quantities of trace metals in water is important because small changes in the quantities of these substances frequently mean the difference between life and death for numerous biological organisms found in the lake ecosystem. While small amounts of these substances are essential for life processes, levels only slightly in excess of these necessary amounts are often toxic. As a consequence, monitoring the concentrations of these metals was a manadatory part of the Lake Huron surveillance plan.

In general, total metal water concentrations exhibited some seasonal variation (Rossmann, 1982). Silver, arsenic, cobalt, chromium, copper, iron, and manganese were highest in April 1980 in Georgian Bay. Of these, silver, cobalt, copper, iron, and manganese exhibited a continuous decrease between April and July. In the North Channel, arsenic and cobalt were highest in mid-May. Silver, chromium, and iron were lowest in July. In general, highest total metal concentrations occurred in April and May. This observation is consistent with that described for the same area in 1974 (Warry, 1978a,b) and is likely caused by the metal-laden snowmelt entering the lake at this time of year.

Metal concentrations varied with depth as well. Total silver concentrations were consistently higher in the epilimnion than in the hypolimnion as were total copper, manganese, iron, arsenic, and chromium. Consistently higher metal concentrations above the thermocline are suspected to be a result of atmospheric inputs to the lakes.

There was no apparent spatial pattern in the distribution of the trace metals, although total iron was observed to be higher in southern Lake Huron than anywhere else.

The 1978 Water Quality Agreement objective for mercury was exceeded twice (8.8% of all samples) during 1980. This was most likely a result of sample contamination. The proposed objective for selenium was exceeded once (4.4% of all samples).

Using the available historical data, detection of trace metal trends is difficult. Improvements in instrumentation and methodology have lowered detection limits and the amount of sample contamination. Thus, metals which appear to be decreasing in concentration may appear so only because of the advancement of technology. The following trends are to be considered tentative. A number of metals appear to be decreasing in concentration. These include dissolved arsenic, total cadmium, dissolved cadmium, dissolved copper, total lead, dissolved lead, total nickel, dissolved nickel, total zinc, and dissolved zinc (Table 14). Total cobalt and total vanadium concentrations appear to have increased (Table 14).

TABLE 14

SUMMARY OF PROBABLE METAL TRENDS IN LAKE HURON WATER

METAL	INCREASE	TREND DECREASE	NONE	NOT DISCERNIBLE FROM DATA
Al				X
As		X		
Cd		X		
Co	X			
Cr				X
Cu		X		
Fe		X		
Hg				X
Pb		X		
Mn			X	
Ni		X		
Se				X
V	X			
Zn		X		

The Toxic Unit Concept as recommended by the Aquatic Ecosystem Objectives Committee (IJC, 1981) has been applied to the 1980 trace metals data (Table 15). Briefly, the concept is that the ratio of measured concentration of each metal to its water quality objective should be calculated and summed. If the sum is greater than 1.0, there may be cause for concern. Metals contributing 0.2 or greater toxic units to the sum are flagged in Table 15.

Organics

The levels of PCB in the water column ranged from 0.1 ng/L in Georgian Bay to 3.2 ng/L in the North Channel. The mean values for Lake Huron, North Channel and Georgian Bay in 1980 were, respectively, 0.4, 1.7, and 1.4 ng/L. The mean for Lake Huron in 1981 was 0.6 ng/L (Filkins and Smith, 1982).

TABLE 15

EVALUATION OF TOXIC UNIT CONCEPT (AEOC, 1981) AS APPLIED TO 1980 TRACE METAL CONCENTRATION (µg/L) OF LAKE HURON WATER. A STATION WITH THE OVERALL HIGHEST VALUES WITHIN A GEOGRAPHICAL LOCATION WAS USED TO CALCULATE Mi/Oi, WHERE Mi IS THE OBSERVED CONCENTRATION AND Oi IS THE WATER QUALITY OBJECTIVE.

DATA SOURCE: R. ROSSMANN (1982) TRACE METAL CHEMISTRY OF THE WATERS OF LAKE HURON THE UNIVERSITY OF MICHIGAN, GREAT LAKES RESEARCH DIVISION, PUBL. NO. 21

		LOCATION AND STATION NO.													
METALS	CURRENT IJC WATER QUALITY OBJECTIVE	UPPER L. HURON STA. 61	Mi/Oi	NORTH CHANNEL STA. 84	Mi/Oi	GEORGIAN BAY STA. 114	Mi/Oi	CENTRAL LAKE HURON STA. 44	Mi/Oi	LOWER LAKE HURON STA. 10	Mi/Oi	ALL* STATIONS HIGHEST VALUE		Mi/0.004	ALL STATIONS MEDIAN VALUE	Mi/Oi
Fe	300	7.2	0.02	5.0	0.02	3.1	0.01	2.2	0.007	22	0.07	25	(NC)	0.08	4.8	0.02
Cd	0.2	0.061	0.30	0.016	0.08	0.017	0.085	0.016	0.06	0.033	0.16	0.061	(UH)	0.30	0.015	0.08
Cu	5	0.40**	0.08	0.64	0.13	0.47	0.09	0.50	0.1	0.23	0.05	0.64	(NC)	0.13	0.4	0.08
Cr	50	0.14	0.003	0.11	0.003	0.12	0.002	0.047	0.001	0.16	0.003	0.19	(CH)	0.004	0.13	0.003
Pb	3	0.051	0.02	0.022	0.007	0.039	0.013	0.10	0.03	0.0	0.00	0.11	(UH)	0.04	0.022	0.007
Ni	25	0.74	0.03	3.8	0.15	1.2	0.05	0.54	0.02	0.31	0.01	3.8	(NC)	0.15	0.54	0.02
Zn	30	0.79	0.03	0.56	0.02	0.21	0.007	0.28	0.009	0.38	0.01	0.56	(NC)	0.02	0.29	0.01
Hg	0.2	0.10**	0.5	0.099	0.5	0.012	0.06	0.21	1.05	0.097	0.48	0.35	(UH)	1.75	0.011	0.055
As	50	0.20	0.004	0.16	0.003	0.072	0.001	0.37	0.007	0.27	0.005	0.53	(CH)	0.01	0.21	0.004
Ag	0.1	0.042	0.42	0.002	0.02	0.011	0.11	0.01	0.10	0.013	0.13	0.042	(UH)	0.4	0.009	0.09
Se	1	0.58	0.58	0.41	0.41	0.62	0.62	0.43	0.43	0.86	0.86	1.2	(LH)	1.2	0.48	0.48
Mi/Oi			2.25		1.34		1.05		1.81		1.78			4.08		0.86
***		Cd, Hg, Ag, Se		Hg, Se		Se		Hg, Se		Hg, Se		Cd, Hg, Ag, Se			Se	

*NC = North Channel, UH = Upper Lake Huron, CH = Central Lake Huron, LH = Lower Lake Huron.
**Reported values of 1.7 and 2.8 were ignored and replaced by value of next closest station, respectively.
***Contribution greater than 0.2 toxic units.

Mean concentrations of pentachlorobenzene were 0.003 and 0.009 ng/L and hexachlorobenzene were 0.002 and 0.004 ng/L for 1980 and 1981, respectively, in the open lake.

Long-term trends are difficult to establish, as is the case with metals. It appears, however, that phenols are decreasing in the St. Marys River and Canadian nearshore regions. Toxaphene had not been detected previously, but was found at 1.6 ng/L in 1980.

SEDIMENT

Physical

Depositional Areas

In Lake Huron, less than one-half and perhaps as little as one-third of the lake bottom are depositional areas (Robbins, 1980). Areas of sand, bed-rock, till and glaciolacustrine clay are considered as non-depositional. Figure 11 illustrates the surficial sediment distribution in Lake Huron. Because most contaminants in the water column are associated with fine-grained sedimentary materials, these tend to accumulate in the depositional basins.

Within southern Lake Huron, there are two principal depositional basins (Figure 12), the Port Huron basin to the west (mean depth = 88 m) and the Goderich basin to the east (mean depth = 119 m). Along the narrow escarpment between these basins, there is no significant accumulation of post-glacial muds. Thus sampling was concentrated in these two basins. The results for northern Lake Huron are unavailable at this time.

Sedimentation Rates

The mean sedimentation rate for the Goderich basin is 35.7 mg/cm² year, while for the Port Huron basin it is 12.8 mg/cm² year. These values imply that about 10 tonnes of fine-grained sediments are being deposited annually which corresponds to an area-wide rate of 11.4 mg/cm² year for southern Lake Huron. This is not much different from the main lake average of 10 mg/cm² year reported by Kemp, et al. (1974). Higher sedimentation rates in the Goderich basin are due to intense deposition of dolomite. The linear rate of sedimentation is quite low in southern Lake Huron, ranging from 0.5-1.0 mm/year in the Port Huron basin to 1.5 mm/year in the northern section of the Goderich basin.

Sediment mixing is important because it increases the contact time between contaminated sediments and the overlying water. However, the concentration of these contaminants on the sediment can be diluted as a result. On the average, a sediment particle resides in the mixed zone of sediment for about 20 years in southern Lake Huron. In certain areas of the Goderich basin, however, this residence time is less than 10 years. Because of these long residence times, any recent improvements in water quality will not be seen in sediment profiles for quite some time.

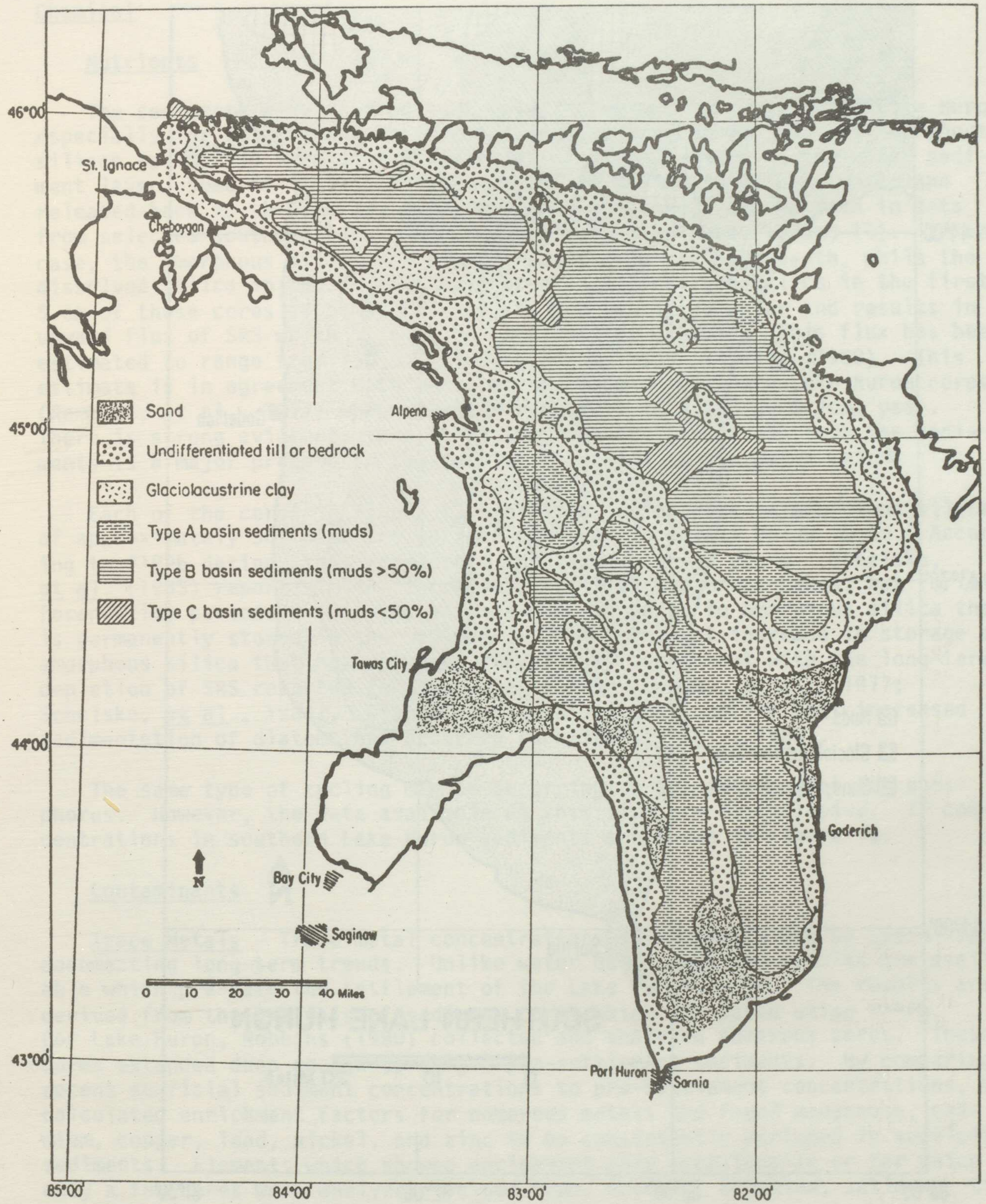


FIGURE 11 SURFICIAL SEDIMENT DISTRIBUTION IN LAKE HURON

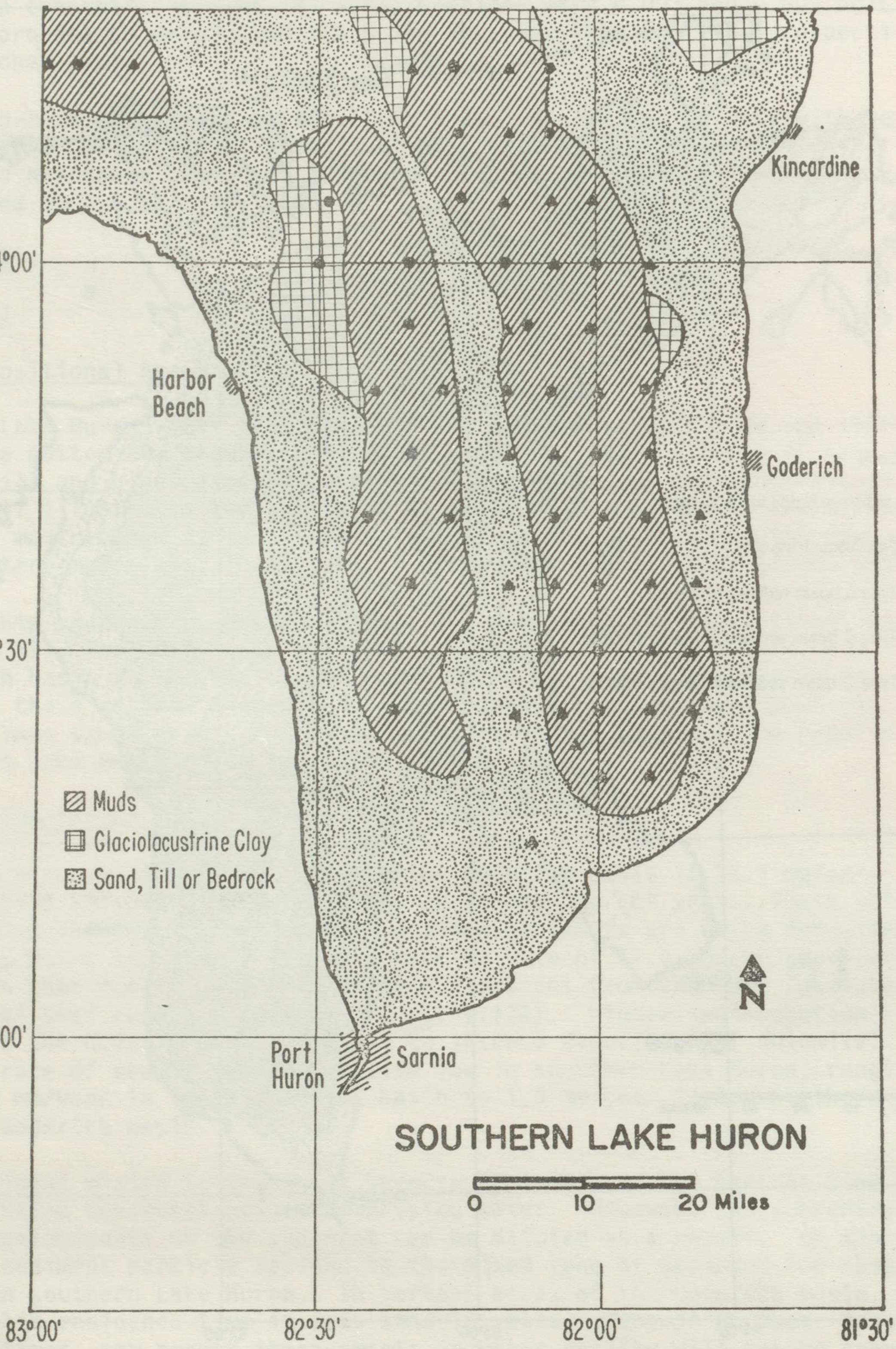


FIGURE 12 SURFICIAL SEDIMENT DISTRIBUTION IN SOUTHERN LAKE HURON

Chemical

Nutrients

The sediments play an important role in the nutrient cycles of Lake Huron, especially for silica, and to a lesser degree, for phosphorus. As amorphous silicon (primarily from diatom frustules) fluxes downward to the mixed sediment layer, some of it is converted to SRS in the sediment pore water and released back to the overlying water. This phenomenon can be seen in data from selected southern Lake Huron sediment cores (Figures 13 and 14). In each case, the amorphous silica rapidly decreases with sediment depth, while the dissolved silica in the pore water increases. Dissolved silica in the first 5 cm of these cores is being released to the overlying water and results in an upward flux of SRS which is a major nutrient for diatoms. This flux has been estimated to range from 750 to 1,700 μg Si/cm year (Robbins, 1980). This estimate is in agreement with measurements made on northern Lake Huron cores (Remmert, et al., 1977) which ranged from 1,016 to 2,050 μg Si/cm year. There is strong evidence, then, that the regeneration of SRS from the sediments is a major process in the cycling of silica in the water column.

Each of the cores in Figure 13 exhibited an increase in amorphous silica of approximately 50% near the surface compared to levels below 10 cm. According to ^{210}Pb dating, this represents the last 30 or 40 years. Schelske, et al. (1983) report similar increases in all of the Great Lakes, but for different time periods. This increase is due, in part, to amorphous silica that is permanently stored in the sediment. This permanent increase in storage of amorphous silica that has not been recycled is consistent with the long-term depletion of SRS reported for the water column (Conway, et al., 1977; Schelske, et al., 1984). Diatom counts in sediment confirm that increased sedimentation of diatoms has occurred (Schelske, et al., 1983).

The same type of cycling may be occurring to a lesser degree for phosphorus. However, the data available at this time are inconclusive. TP concentrations in southern Lake Huron sediments are shown in Figure 15.

Contaminants

Trace Metals - Trace metal concentrations in sediments can be useful for documenting long-term trends. Unlike water data, reliable results are available which pre-date the settlement of the Lake Huron basin. The results are derived from the analysis of sediment cores which are dated using ^{210}Pb. For Lake Huron, Robbins (1980) collected and analyzed numerous cores. These cores extended deep enough to sample pre-settlement sediments. By comparing recent surficial sediment concentrations to pre-settlement concentrations, he calculated enrichment factors for numerous metals and found manganese, cadmium, copper, lead, nickel, and zinc to be consistently enriched in surficial sediments. Elements which showed enrichment only occasionally or for which only a few cores were analyzed include iron, arsenic, chromium, antimony, tin, mercury, barium, and molybdenum.

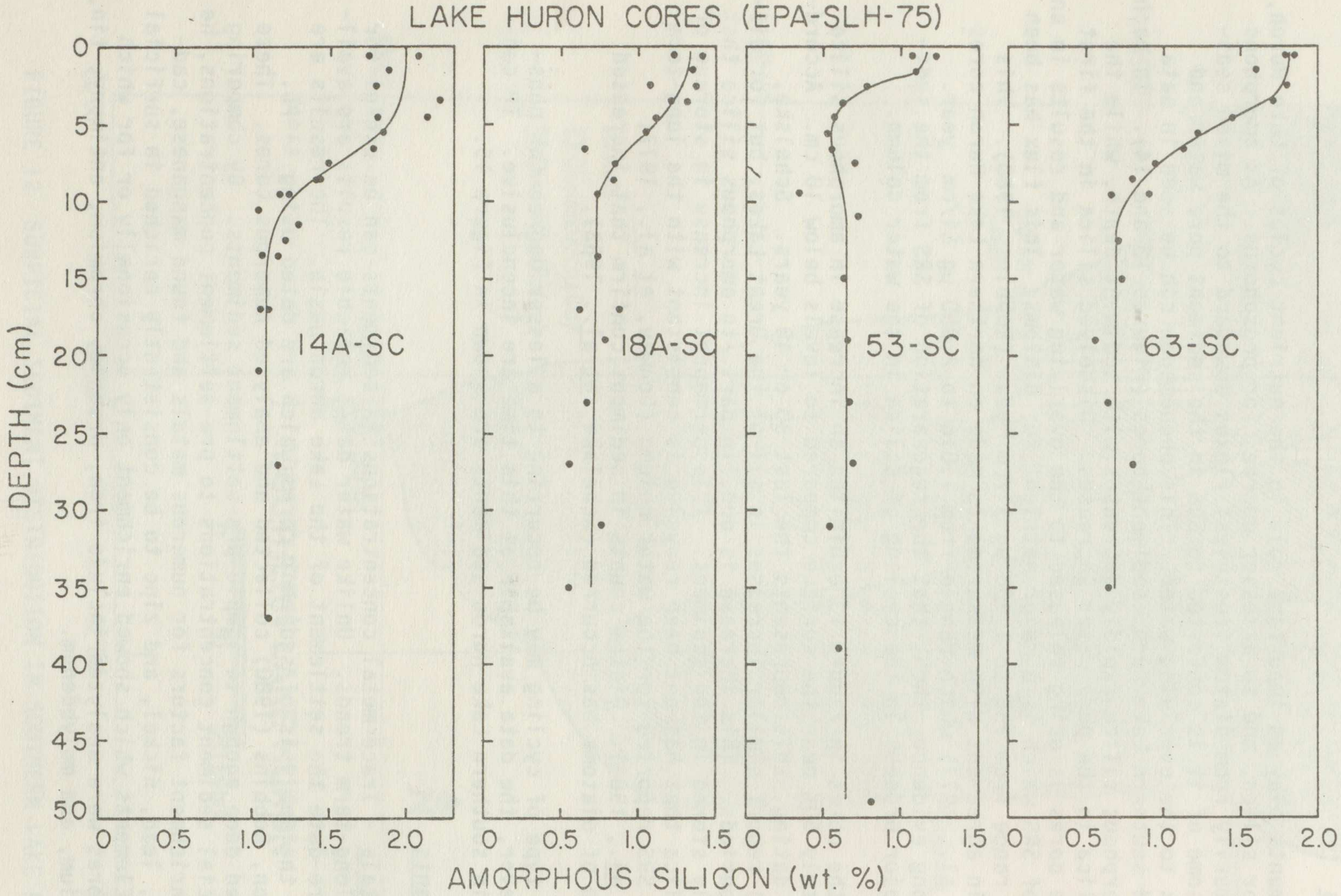


FIGURE 13 VERTICAL DISTRIBUTION OF AMORPHOUS SILICON IN SELECTED GODERICH BASIN CORES

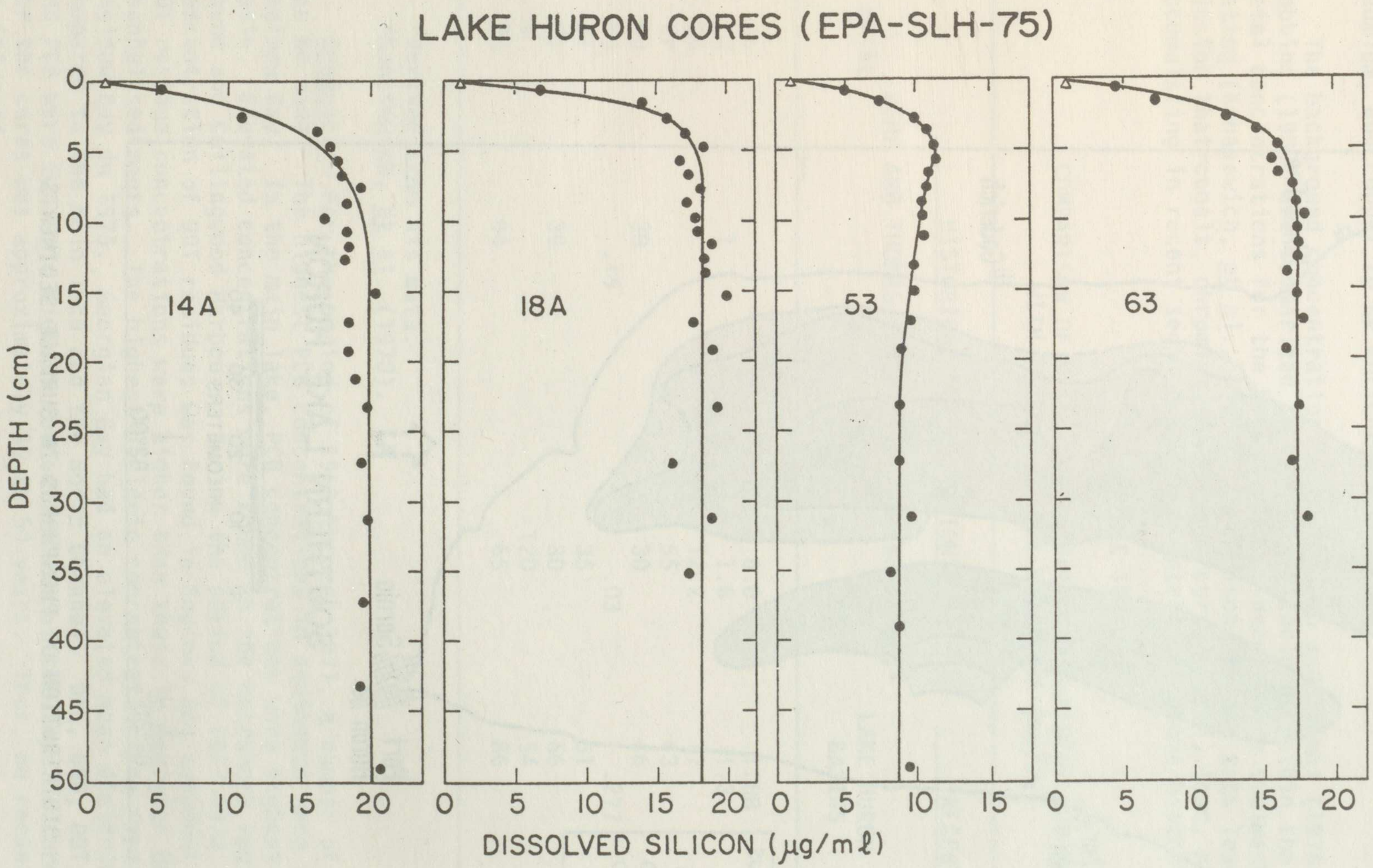


FIGURE 14 VERTICAL DISTRIBUTION OF DISSOLVED SILICON IN SELECTED CORES

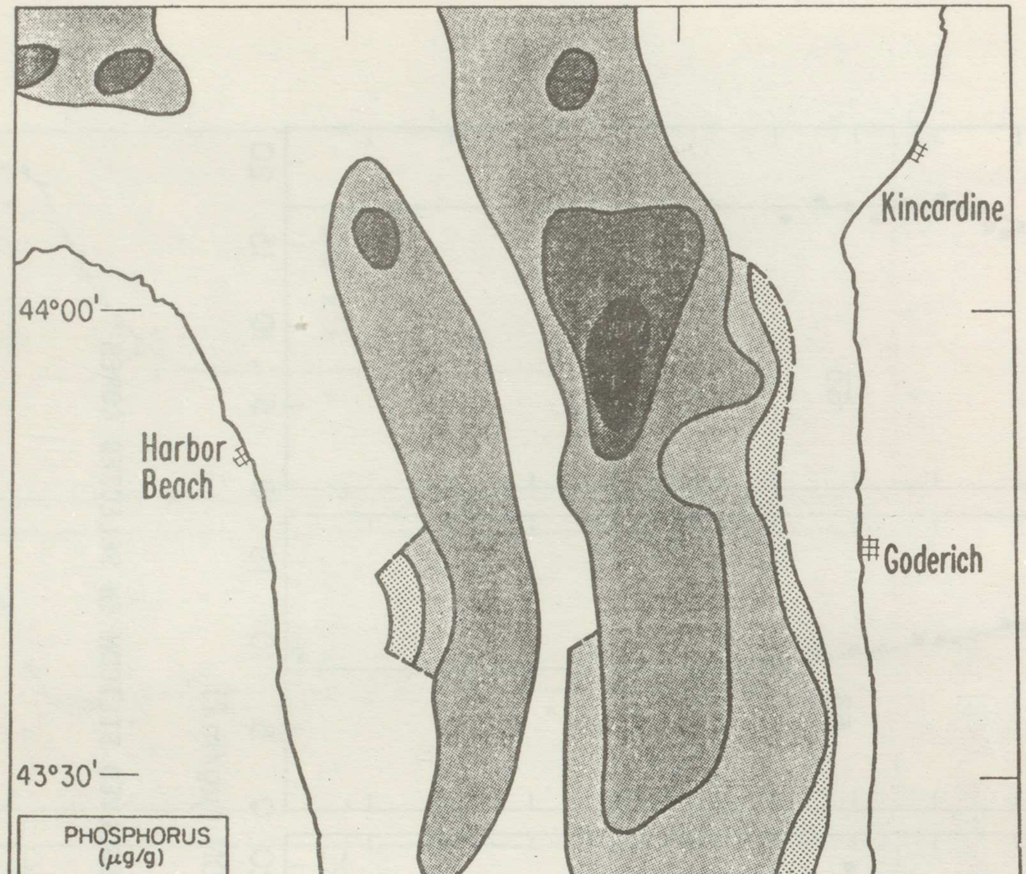


FIGURE 15 DISTRIBUTION OF PHOSPHORUS IN SURFACE SEDIMENTS

Similar work by Kemp and Thomas (1976a,b), comparing pre-colonial and recent sediments, showed mercury to be very slightly enriched and lead, zinc, cadmium, and copper to be enriched.

The background concentrations used by Kemp and Thomas (1976a,b) and Robbins (1980) are summarized in Table 16. Included within the table are metal concentrations for the basins of Lake Huron where sediments are accumulating (Konasewich, et al., 1978). Comparison of data sets leads to the conclusion that cobalt, chromium, copper, mercury, nickel, lead, and zinc are accumulating in recent sediments at concentrations above historical levels.

TABLE 16

COMPARISON OF METAL CONCENTRATIONS IN RECENT SEDIMENTS WITH THOSE IN OLDER SEDIMENTS (mg/kg)

	HISTORICAL CONCENTRATIONS		RECENT SEDIMENTS[2]	
METAL	KEMP AND THOMAS (1976a,b)	ROBBINS (1980)[1]	LAKE HURON BASINS	GEORGIAN BAY AND NORTH CHANNEL BASINS
As		6.0	1.88	7.19
Cd	1	1.6	1.3	2.01
Co		12.2	17	24
Cr		55	43	176
Cu	38	30	46	60
Hg	.15	.03	.277	.392
Ni		35	51	119
Pb	39	30	66	67
V		120	54	77
Zn	94	65	86	146

[1]Derived from his data.
[2]Konasewich, et al. (1978).

Organics - For the period of 1969 through 1977, a number of conclusions can be made. The highest PCB concentrations in sediments were found in Saginaw Bay. In the main lake, PCB concentrations were highest in the Saginaw Basin. Elevated concentrations were found in the nearshore region of Owen Sound and Collingwood Harbour. During the period of 1957-1978, the highest concentration of DDT residues was found in Saginaw Bay sediment. Main lake DDT residue concentrations were higher than those in Georgian Bay or North Channel sediments. The highest dieldrin concentration was reported for Saginaw Bay in 1975. Georgian Bay had an elevated mean dieldrin concentration compared to the main lake and the North Channel. DDE, DDD, DDT, DDT residues, and PCB were found in highest concentrations at the tops of cores. Resolution for the cores was approximately 30 to 50 years. Thus, no recent trends could be inferred.

BEACHES

The State of Michigan has 48 beaches used for swimming. Of these, 22 were monitored during 1981. During both 1980 and 1981, two beaches were permanently closed. These were Bay View Beach at Alpena and St. Ignace Beach at St. Ignace. Bay View Beach is closed for aesthetic reasons; a saw mill's wastes dumped 100 years ago are now surfacing. St. Ignace Beach is closed until the combined storm and sanitary sewer system is corrected.

During 1980 and 1981, temporary closings occurred only at Lexington Beach near Sanilac. The closings were due to discharge of Lexington's wastewater treatment lagoon to the lake (Witt, 1980, 1981).

3. Aquatic Life

The presence of toxic substances, many of which bioaccumulate, is a serious threat to the health of the Great Lakes ecosystem. Although many contaminant residues are virtually non-detectable in water, food chain biomagnification produces significant accumulations in upper trophic level biota. Subtle sublethal contaminant related responses of lower trophic level organisms may ultimately be translated into chronic or acute toxicity in biota at the top of the food chain. The ability of many environmental contaminants to bioconcentrate in the aquatic ecosystem has direct implications to human health in the Great Lakes basin.

Biological monitoring of the Great Lakes ecosystem provides data on the overall population characteristics of biota such as Herring Gulls at the top of the food chain, through top predator and forage fish species, sea lampreys, benthic invertebrates, zooplankton and down to single celled species of phytoplankton. Data includes observations on population dynamics, reproductive success, relative abundance, trends in contaminant levels and total biomass. Significant changes in any of the above may influence the remaining parameters both within a particular trophic level and between adjacent levels.

WATERFOWL

Observations

Herring Gull eggs from Chantry and Double Islands have been monitored annually for contaminants since 1974 (Table 17). During 1980, eggs from seven additional colonies were monitored. In 1980 the highest concentration of DDE and PCBs occurred on colonies in Saginaw Bay (Figure 16, Table 18) and on the colony at Manitoba Reef; the Black River Island colony was also high in DDE. Mirex was highest at the colony on Nottawasaga Island in southeastern Georgian Bay. Dioxin (2,3,7,8 TCDD) was considerably higher in 1980 in the Saginaw Bay colonies than in the Double Island colony in the North Channel.

Concentration of DDE, DDT, Dieldrin, HCB, Mirex and PCBs have all significantly decreased in gull eggs from both Chantry and Double Islands since 1974 (Table 17). For the years 1974-1981, the half lives for the compounds ranged between 1.9 and 8.3 years (Weseloh, Mineau, and Hallett, 1979; Weseloh, 1983).

Reproductive success (to 21 days) in Herring Gulls was normal on all colonies but showed considerable inter-colony variation (range = 1.3-2.3 young/pair). Eggshell thinning ranged from 3.2-10.9%, well below levels normally associated with reproductive failure (20%). Eggs from colonies in the North Channel had thicker shells and consistently lower residues than those from other colonies. Eggshell quality has improved significantly on one of the Lake Huron Annual Monitor colonies (Double Island-North Channel) since 1978.

TABLE 17

ORGANOCHLORINE LEVELS (MEAN ± STANDARD ERROR) IN HERRING GULL EGGS AT CHANTRY AND DOUBLE ISLANDS, 1974-1981

LAKE HURON	% FAT	DDE mg/kg	DDT mg/kg	DIELDRIN mg/kg	HCB mg/kg	MIREX mg/kg	PCBs mg/kg
CHANTRY ISLAND							
1974	8.2 ± 1.1	21 ± 8.6	0.63 ± .23	0.47 ± .18	0.47 ± .23	2.2 ± 2.1	86 ± 22
1975	8.6 ± 0.8	12 ± 4.4	0.15 ± .12	0.31 ± .20	0.18 ± .05	0.48 ± .56	39 ± 17
1977	9.4 ± 0.8	13 ± 4.6	0.09 ± .05	0.57 ± .25	0.17 ± .08	0.34 ± .22	64 ± 16
1978	11.0 ± 1.3	6.0 ± 2.5	0.05 ± .03	0.22 ± .09	0.14 ± .07	0.26 ± .33	32 ± 12
1979	7.7 ± 0.8	2.5 ± 1.7	0.06 ± .02	0.28 ± .09	0.10 ± .07	0.20 ± .33	31 ± 23
1980	9.4 ± 0.7	2.8 ± 1.4	0.04 ± .02	0.24 ± .07	0.08 ± .03	0.16 ± .15	23 ± 14
1981	9.2 ± 1.5	4.1 ± 1.9	0.03 ± .01	0.25 ± .09	0.07 ± .03	0.35 ± .37	28 ± 10
DOUBLE ISLAND							
1974	9.3 ± 0.9	14 ± 6.7	0.55 ± .28	0.53 ± .16	0.30 ± .08	0.52 ± .22	56 ± 17
1975	7.3 ± 1.1	16 ± 8.5	0.17 ± .10	0.41 ± .18	0.24 ± .08	0.55 ± .67	46 ± 15
1977	9.4 ± 2.9	15 ± 13	0.09 ± .07	0.45 ± .23	0.21 ± .05	0.55 ± .57	77 ± 48
1978	9.0 ± 0.6	7.0 ± 2.6	0.09 ± .02	0.22 ± .12	0.09 ± .05	0.16 ± .22	33 ± 9.5
1979	8.7 ± 1.0	2.1 ± .76	0.06 ± .04	0.32 ± .18	0.10 ± .04	0.17 ± .16	26 ± 7.4
1980	9.1 ± 1.5	2.6 ± 1.3	0.05 ± .02	0.24 ± .18	0.06 ± .02	0.06 ± .05	17 ± 7.8
1981	9.6 ± 0.9	3.6 ± 1.4	0.04 ± .01	0.23 ± .09	0.07 ± .03	0.17 ± .15**	23 ± 7.6

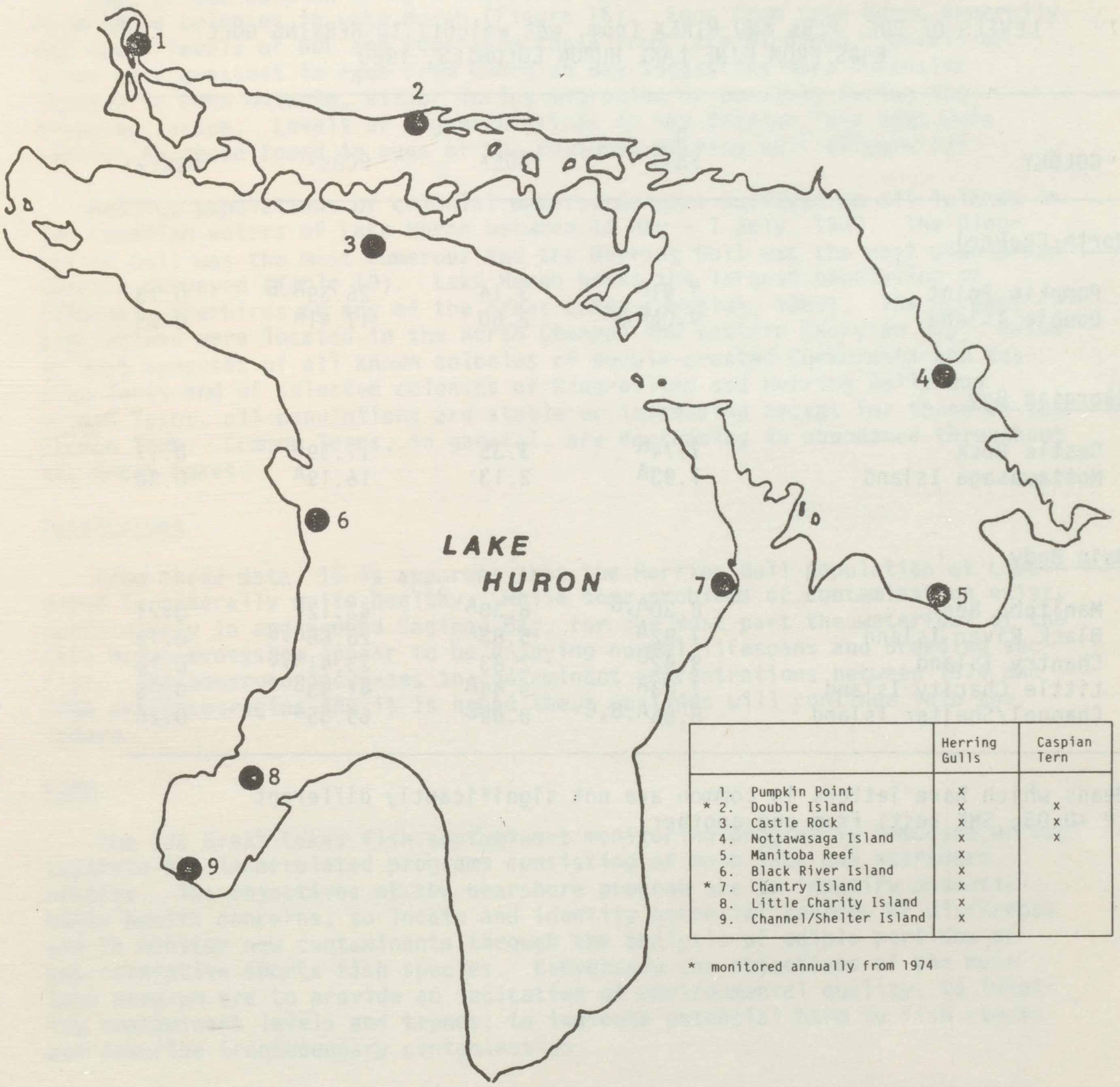


FIGURE 16 MONITORED BIRD COLONIES IN LAKE HURON, 1980

TABLE 18

LEVELS OF DDE, PCBs AND MIREX (ppm, wet weight) IN HERRING GULL EGGS FROM NINE LAKE HURON COLONIES, 1980

COLONY	% FAT[1]	DDE[1]	PCBs[1]	MIREX[1]
North Channel				
Pumpkin Point	7.91^{A}	3.14	26.39^{A,B}	0.13
Double Island	9.06^{B,C}	2.60	17.41^{A}	0.05
Georgian Bay				
Castle Rock	7.74^{A}	3.35	17.59^{A}	0.17
Nottawasaga Island	7.93^{A}	2.13	16.19^{A}	0.30
Main Body				
Manitoba Reef	8.30^{A,B}	6.38^{A}	43.12^{B}	0.21
Black River Island	7.92^{A}	5.83^{A}	28.68^{A,B}	0.12
Chantry Island	9.42^{C}	2.83	23.41^{A,B}	0.16
Little Charity Island	7.83^{A}	6.44^{A}	41.93^{B}	0.08
Channel/Shelter Island	8.85^{A,B,C}	8.89^{B}	69.55^{A}	0.20

[1]Means which have letters in common are not significantly different ($P < 0.05$, SNK test) from one another.

Eggs of the Caspian Tern, a migratory species, were collected and analyzed from three colonies in Lake Huron (Figure 16). Eggs from Lake Huron generally had lower levels of DDE and PCBs than those from Lake Michigan. Levels of mirex were greatest in eggs from Georgian Bay suggesting more intensive feeding in Lake Ontario, either during migration or possibly during the breeding season. Levels of organochlorines in the Caspian Tern eggs were similar to those found in eggs of the resident Herring Gull (Figure 17).

Nesting populations of colonial waterbirds were surveyed on all islands in the Canadian waters of Lake Huron between 15 May - 7 July, 1980. The Ring-billed Gull was the most numerous and the Herring Gull was the most widespread species surveyed (Table 19). Lake Huron hosts the largest population of colonial waterbirds of any of the Great Lakes (Weseloh, 1983). The largest populations were located in the North Channel and eastern Georgian Bay. Based on past censuses of all known colonies of Double-crested Cormorants and Caspian Terns and of selected colonies of Ring-billed and Herring Gulls and Common Terns, all populations are stable or increasing except for those of the Common Tern. Common Terns, in general, are decreasing in abundance throughout the Great Lakes.

Conclusions

From these data, it is apparent that the Herring Gull population of Lake Huron is generally quite healthy. While some problems of contamination exist, particularly in and around Saginaw Bay, for the most part the waterfowl of the Lake Huron ecosystem appear to be enjoying normal lifespans and breeding success. The observed decreases in contaminant concentrations between 1974 and 1980 are encouraging and it is hoped these declines will continue into the future.

FISH

The IJC Great Lakes fish contaminant monitoring program is composed of two separate but interrelated programs consisting of main lake and nearshore studies. The objectives of the nearshore program are to identify potential human health concerns, to locate and identify potential sources of discharges and to monitor new contaminants through the analysis of edible portions of representative sports fish species. Conversely the objectives of the main lake program are to provide an indication of environmental quality, to identify contaminant levels and trends, to indicate potential harm to fish stocks and describe transboundary contamination.

Table 20 summarizes the range of sportsfish sampled for specific edible portion contaminant analyses. In addition, there is a listing of collection periods where individual IJC contaminant objectives were exceeded in certain sportsfish species from Lake Huron.

An examination of all edible portion contaminant data indicated that, while there appeared to be an increase, no individual fish species showed a statistically significant trend for PCBs due to small sample size. Though not distinctly clear, an increasing trend for PCBs for all fish species combined was found (1968-1980). A trend that was observed for all fish species was decreasing concentrations of DDT (1966-1980). Mean dieldrin concentrations

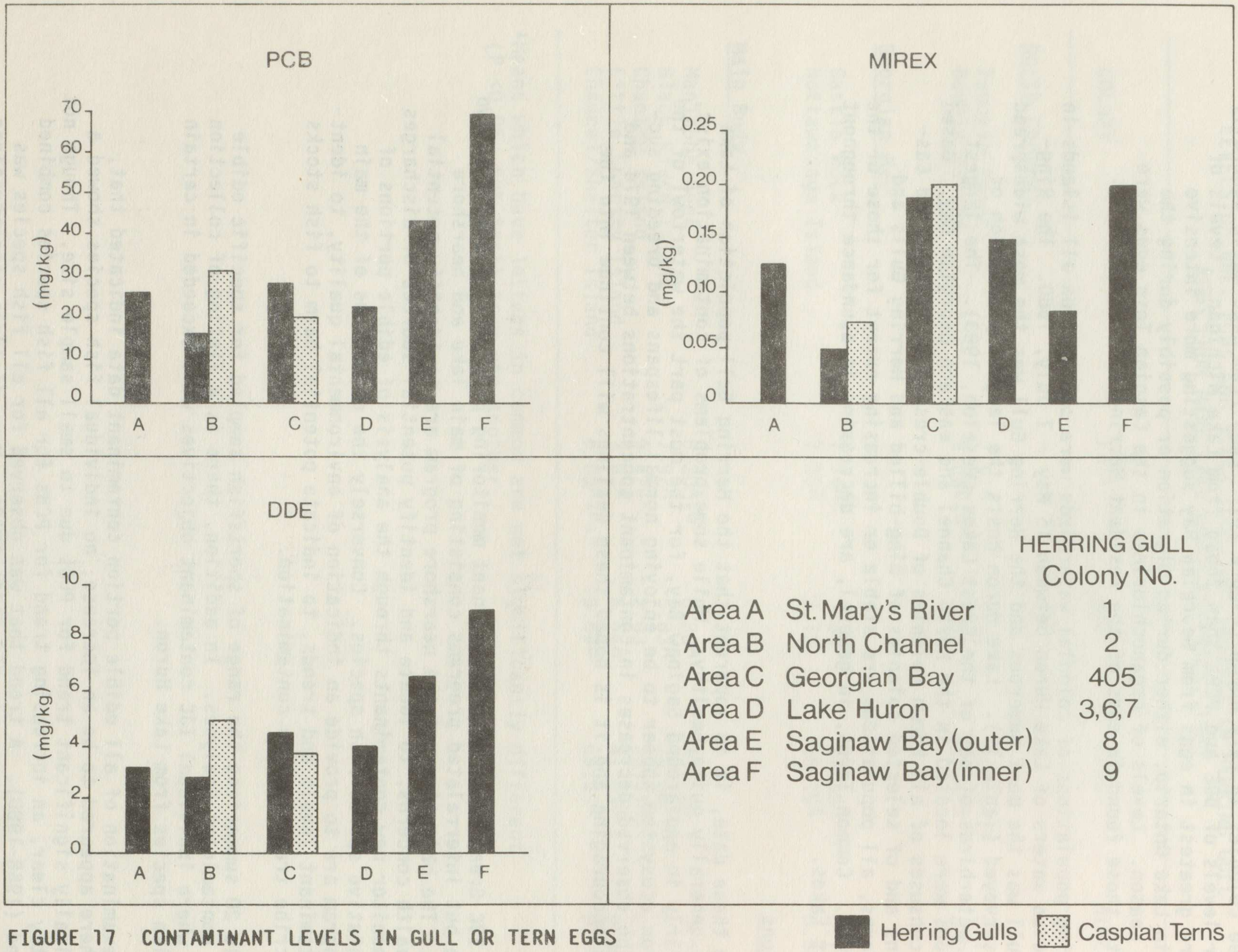


FIGURE 17 CONTAMINANT LEVELS IN GULL OR TERN EGGS

TABLE 19

NUMBERS OF PAIRS OF SELECTED COLONIAL WATERBIRDS NESTING IN CANADIAN WATERS OF LAKE HURON, 1980

SPECIES	NO. NESTING PAIRS	NO. OF COLONIES
Ring-Billed Gull	125,003	80
Herring Gull	32,858	359
Common Tern	5,348	67
Caspian Tern	2,138	8
Great Blue Heron	554	22
Double-Crested Cormorant	335	9
Black-Crowned Night Heron	328	5

TABLE 20

SUMMARY OF FISH SPECIES AND YEARS WHERE ORGANIC CONTAMINANT CONCENTRATIONS WERE IN EXCESS OF THE INTERNATIONAL JOINT COMMISSION OBJECTIVES

COMPOUND	SPECIES	YEARS
PCB	Carp	1969-1980*
	Channel catfish	1969-1980*
	Yellow perch	1968-1979*
	Lake trout	1969-1980*
	Bloater chub	1969-1978*
	Lake whitefish	1969-1976*
	Walleye	1969-1980*
	Coho salmon	1968-1980*
	Chinook salmon	1973-1980*
	Brown trout	1973-1980*
	Splake	1969-1975*
	Rainbow trout	1968-1975*
	Cisco	1969-1976*
	Burbot	1974*
	Northern pike	1974*
DDT	Carp	1967-1972
	Channel catfish	1966-1972, 1979
	Yellow perch	1967-1968, 1970
	Lake trout	1969-1979
	Bloater chub	1966, 1970-1978*
	Lake whitefish	1966, 1970
	Walleye	1966, 1969-1971
	Coho salmon	1971-1973
	Chinook salmon	1973-1974
	Brown trout	1973
	Splake	1969-1970, 1975*
	Rainbow trout	1968-1970
	Cisco	1969-1975
	Burbot	1974*
Dieldrin-aldrin	Yellow perch	1979*
	Lake trout	1977-1979
	Bloater chub	1974-1975
	Splake	1975*
Mercury	Walleye	1973-1974, 1978*

*Last year of analysis.
Reference - IJC, 1978.

were highest in fish collected from the open lake and Georgian Bay (1967-1980). Mercury concentrations were highest in fish from the main lake. Mercury concentrations were found to be significantly increasing in main lake fish (1969-1980) (Kreis and Rice, In press).

Contaminant levels measured in whole fish samples of top predator and forage fish species from several sites in Lake Huron-Georgian Bay (Figure 18) were utilized to determine spatial variation in ecosystem contamination. Trace metal and organic contaminant concentrations were measured in all top predator collections which consisted of lake trout, splake and walleye (Table 21).

The significantly greater PCB, p,p'-DDE and ΣDDT concentrations measured in lake trout from Point Edward may be due to correspondingly high lipid levels in these samples. Walleye from the French River had the lowest mean lipid level and similarly the lowest levels of these three organic contaminants. Mirex was not found in any samples at a detection limit of 0.1 μg/g.

Examination of the data indicated that contaminant concentrations and lipid levels increased with fish age. Age was a more influential factor in contaminant accumulation for walleye while lipid concentrations regulated salmonid contaminant uptake.

Contaminant burdens in forage fish species such as rainbow smelt and slimy sculpins provide an indication of the potential for food chain accumulation of contaminants. A limited number of slimy sculpins were collected near Burnt Island and off the mouth of the French River. PCB, dieldrin, p,p'-DDE and ΣDDT were all near the detection limit (Table 22). Table 23 provides a summary of the major trace metals and organochlorine residues detected in composite samples of rainbow smelt collected at four sites in Lake Huron and Georgian Bay. Greater concentrations of PCBs were detected in smelt from main lake stations than from Georgian Bay stations, probably due to higher lipid levels in the main lake smelt. Nickel levels in French River samples and concentrations of copper in smelt from Cape Rich were greater than levels measured at the remaining sites for either metal.

In order to provide data on the comparability of ecosystem and human health contaminant levels, contaminant ratios for whole fish versus edible portion (fillet) concentrations were calculated for mercury, arsenic, PCB and ΣDDT in selected samples of walleye and lake trout. With the exception of mercury, contaminant concentrations were greater in the whole fish sample of both species compared to fillet levels. A summary of these ratios is presented in Table 24.

Unweighted lakewide mean data on whole fish contaminant burdens is presented in Table 25 for comparative purposes.

INVERTEBRATES

Benthic Community

The nearshore zone of Lake Huron, Georgian Bay and North Channel is a complex environment which supports a very diverse benthic fauna. In 1980, this

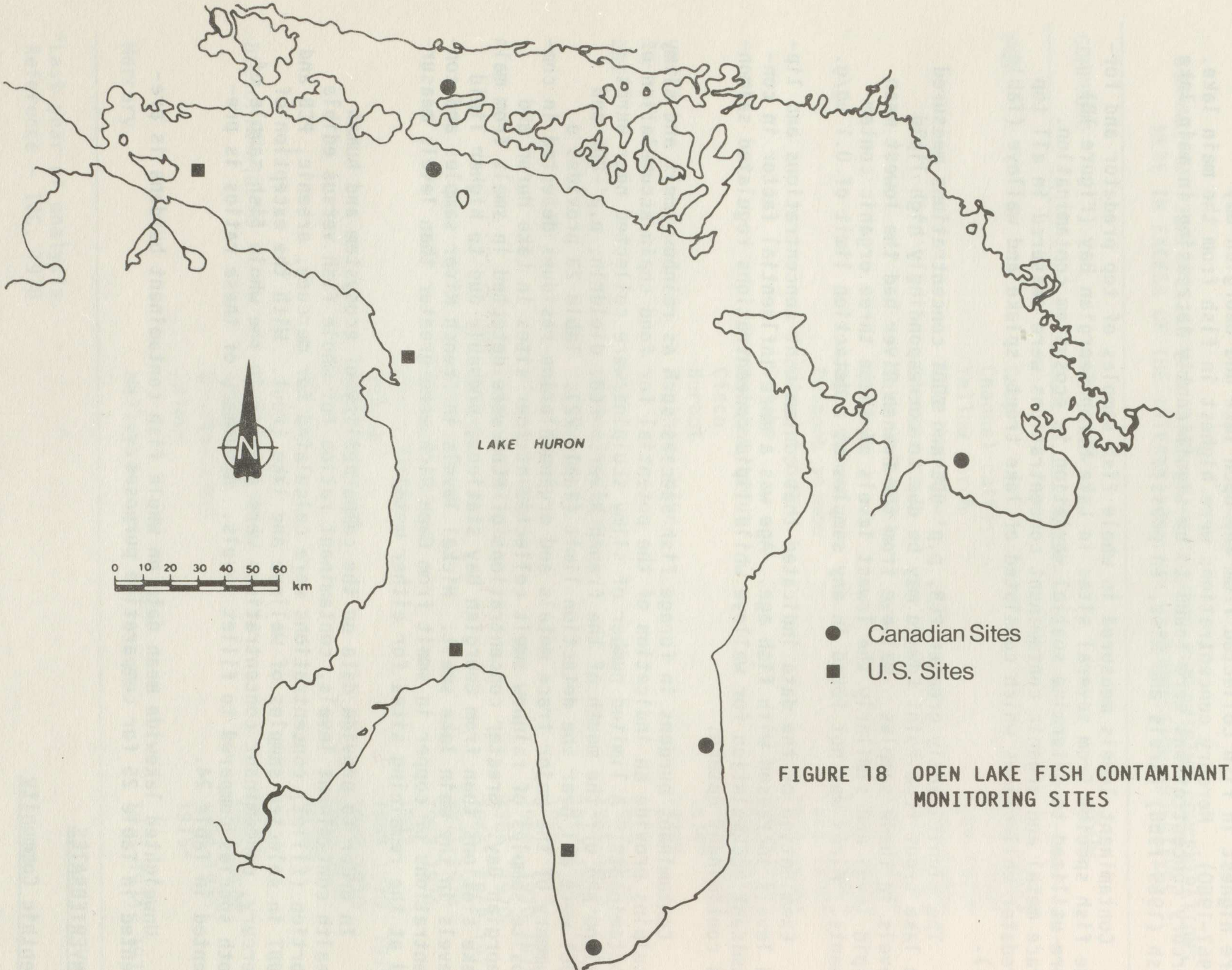


FIGURE 18 OPEN LAKE FISH CONTAMINANT MONITORING SITES

TABLE 21

TRACE METAL AND ORGANIC CONTAMINANT CONCENTRATIONS IN TOP PREDATOR FISH SPECIES (whole fish) FROM THE OPEN WATERS OF LAKE HURON AND GEORGIAN BAY*, 1980-81

	1981 PT. EDWARD (Lake Trout)	1980 CAPE RICH (Splake)	1980 BURNT ISLAND (Lake Trout)	1980 FRENCH RIVER (Walleye)
N	48	50	47	50
% Lipid	18.00 (0.49)	10.35 (0.58)	10.33 (0.63)	8.55 (0.40)
p,p'-DDE	0.60 (0.03)	0.22 (0.01)	0.34 (0.03)	0.12 (0.03)
ΣDDT	1.06 (0.05)	0.25 (0.01)	0.49 (0.04)	0.17 (0.03)
PCB	2.35 (0.14)	0.42 (0.03)	0.92 (0.08)	0.23 (0.05)
Hg	-	0.18 (0.01)	0.14 (0.01)	0.20 (0.02)
Cu	-	0.85 (0.04)	0.99 (0.04)	0.45 (0.01)
Ni	-	0.06 (0.02)	-	0.13 (0.01)
Zn	-	11.61 (0.29)	12.05 (0.23)	12.52 (0.40)
Cd	-	0.02	0.02 (0.00)	0.02 (0.00)
Cr	-	-	0.12 (0.01)	0.19 (0.01)
As	-	0.18 (0.01)	0.27 (0.02)	0.25 (0.01)
Se	-	0.75 (0.01)	0.81 (0.01)	0.74 (0.02)

*All results reported as μg/g wet weight ($\bar{x}$ ± S.E.) unless otherwise noted.

TABLE 22

MEAN LEVELS OF ORGANIC CONTAMINANTS IN SCULPINS FROM TWO SITES ON LAKE HURON AND GEORGIAN BAY IN 1980($\bar{x}$ ± S.E.)

	BURNT ISLAND	FRENCH RIVER
N([1])	4	3
Total Length (cm)	2.60 (0.20)	2.87 (0.09)
Weight (g)	0.18 (0.03)	0.27 (0.03)
% Lipid	4.47 (0.40)	4.37 (2.06)
p,p'-DDE	0.05 (0.00)	0.06 (0.04)
ΣDDT	0.06 (0.00)	0.07 (0.04)
Dieldrin	0.02 (0.00)	0.02 (0.00)
PCB	0.16 (0.00)	0.20 (0.00)

All results expressed as µg/g wet weight unless otherwise noted.
[1]Each samples consists of a composite of fish.

TABLE 23

TRACE METAL AND ORGANIC CONTAMINANT LEVEL IN RAINBOW SMELT (whole fish) FROM THE OPEN WATERS OF LAKE HURON AND GEORGIAN BAY*

	GODERICH	CAPE RICH	BURNT ISLAND	FRENCH RIVER
N**	11	12	12	12
Total Length (cm)	17.08 (0.64)	15.33 (0.77)	15.34 (0.51)	15.59 (0.28)
% Lipid	4.46 (0.35)	3.07 (0.17)	4.31 (0.26)	2.99 (0.77)
p,p'-DDE	0.07 (0.01)	0.05 (0.01)	0.07 (0.02)	0.04 (0.00)
ΣDDT	0.11 (0.02)	0.06 (0.01)	0.07 (0.02)	0.07 (0.01)
PCB	0.21 (0.01)	<0.10	0.16 (0.03)	<0.10
Hg	-	0.09 (0.02)	0.05 (0.01)	0.06 (0.00)
Ni	-	0.05 (0.01)	<0.03	0.11 (0.02)
Cu	-	0.97 (0.09)	0.62 (0.06)	0.44 (0.02)
As	-	0.22 (0.01)	0.35 (0.02)	0.23 (0.01)
Se	-	0.70 (0.02)	0.60 (0.01)	0.77 (0.02)

*All results reported as µg/g ($\bar{x}$ ± S.E.) unless otherwise noted.
**Each sample consists of a composite of five fish.

TABLE 24

RELATIVE WHOLE FISH: FILLET CONTAMINANT CONCENTRATIONS FOR LAKE TROUT AND WALLEYE IN 1980
(Percent whole fish concentration in fillet)

	N	As	Hg	PCB	DDT
Lake Trout	24	64.7	144.7	49.9	43.7
Walleye	16	23.4*	168.3	20.3	12.3

*N = 13

TABLE 25

COMPARATIVE LAKE HURON WHOLE FISH CONTAMINANT DATA IN 1980
(Unweighted Lakewide Mean - μg/g)

	N	% LIPID	PCB	ΣDDT	DIELDRIN	Hg	REFERENCES
Sculpins	50	6.2	0.67	0.66	0.12	0.08	(11)
Bloater chubs	50	18.6	1.58	2.85	0.28	0.10	(11)
Smelt	3	-	-	0.75	0.04	-	(12)
Lake whitefish	1	10.0	0.51	0.22	0.00	-	(13)

	N		Cd	As	Se	Hg	
Lake Trout	5	-	0.01	0.51	0.71	0.23	(14)

zone (except for the United States nearshore) was sampled intensively at depths of 5, 10 and 20 metres along several transects. Mean total standing stocks of invertebrates ranged from 456 to 45,700 individuals per m². The fauna of this zone was fairly homogeneous throughout. The most abundant elements of the benthic fauna of this zone were Nematoda, Oligochaeta, Mollusca and Chironomidae. There was no indication of increased eutrophication or unusual environmental stress within this zone (Barton, 1983).

In Georgian Bay, Owen Sound was sampled using three transects. The zone of enrichment from the plume of the Sydenham River does not appear to have spread further in the Sound. In fact, none of the stations sampled in 1980 showed evidence of significant organic enrichment or environmental degradation. Pollution tolerant organisms never dominated the fauna in any part of the study area.

Based on a limnological survey performed in 1980, Thunder Bay was classified oligotrophic with the exception of Alpena Harbor which is a relatively small area near the mouth of the Thunder Bay River. A review of historical data showed that, in general, the water quality of Thunder Bay had remained stable over time and that the water quality of Alpena Harbor had improved slightly. However, Alpena Harbor sediments still exhibited organic enrichment and the associated benthic macroinvertebrate community was composed of 85% oligochaetes (Horvath, et al., 1981).

Zooplankton

Zooplankton sampling was conducted on four of the six main Lake Huron cruises (April - July). Zooplankton standing stocks were characteristic of those of the more oligotrophic or meso-oligotrophic regions of the Great Lakes. Crustacean standing stocks were low, ranging from a May cruise mean of 14,000 to a July high of 75,600 individuals per m³. Species considered indicators of eutrophic waters were rare or not detected (Patalas, 1972).

Rotifer standing stocks also were indicative of oligotrophic or meso-oligotrophic conditions with abundances ranging from 4,500 in June to 15,000 individuals per m³ in July. Again, species considered indicators of eutrophic waters were rare or not detected.

The most productive area of main Lake Huron was the southern, nearshore region, particularly Goderich-Bayfield and Harbor Beach-Lexington areas. Standing stocks in these areas were high for all cruises, apparently due to the stimulation of primary productivity from nutrient runoff. In July, high phytoplankton and zooplankton standing crops occurred in the St. Marys River - North Channel area. In general, zooplankton standing crops were greater in nearshore waters than offshore.

Zooplankton standing stocks (dry weight) were dominated by crustaceans, especially copepods. These zooplankton may be better adapted to the lower productivity that is characteristic of most of oligotrophic Lake Huron than the more opportunistic rotifers.

Grazing pressure apparently was low in the spring, but relatively intense by July. As a consequence of grazing, chlorophyll a concentrations were low.

Variations in zooplankton standing stocks and species composition were related either directly or indirectly to factors affecting algal productivity. Conductivity, pH, and alkalinity had little effect. Inshore - offshore differences in zooplankton community structure were observed. Furthermore, tributary inputs affected qualitative and quantitative differences in the zooplankton community (Evans, 1983).

CONTAMINANTS

Trace metal and organic contaminant analysis was conducted on samples of net plankton, zooplankton (*Mysis relicta*) and *Pontoporeia affinis*, a benthic invertebrate, to indicate contaminant accumulation at the base of the food chain (Whittle, 1983). Tables 26, 27 and 28 provide summaries of these data. Organic contaminant residues were not detected in net plankton while levels were near detection limits in *Mysis*. Overall trace metal levels in *Mysis* were lowest at the French River site, highest at Cape Rich in southern Georgian Bay and intermediate at the three main lake stations. No significant differences in concentrations in organic contaminants were found for the samples of *Pontoporeia* from these three sites.

A significant food chain biomagnification was demonstrated for organic contaminants such as PCB and DDT. Trace metal levels did not show significant food chain accumulation. Biomagnification factors for the salmonid food chain ranged from a maximum of 10 for PCB to increases of only twofold for metals such as arsenic and selenium (Borgmann and Whittle, 1983).

Generally, contaminant burdens in the range of Lake Huron biota surveyed may be ranked between the higher levels found in biota of Lakes Erie and Ontario and the relatively low level of contamination in Lake Superior.

Phytoplankton

Phytoplankton Indicators

Three indicators of phytoplankton biomass were included as part of the 1980 Lake Huron surveillance program: chlorophyll *a*, particulate organic carbon (POC) and total particulate nitrogen (TPN). Chlorophyll *a* (uncorrected) measures both phytoplankton and detrital chlorophyll *a*. Correcting for phaeopigment removes much of this detrital component, thereby providing an estimate of phytoplankton standing crop. Interpretation of corrected chlorophyll *a* concentrations are complicated by fluctuations in cellular content due to different species composition and different growth rates as well as nutritional state and seasonal differences in cellular chlorophyll content within a species (Dolan, *et al*., 1978; Lin and Schelske, 1981; Hunter and Laus, 1981). POC and TPN both provide estimates of total seston, including phytoplankton, zooplankton, bacteria and detritus. Consequently, high percentages of non-living material can be included in their measurements. Evaluating phytoplankton biomass, therefore, becomes a question of assessing the interrelationships of these parameters.

The seasonal cycles of chlorophyll *a*, POC and TPN in the North Channel and most nearshore areas of Lake Huron and Georgian Bay were bimodal, with maxima occurring in spring and fall. The open lake areas of Lake Huron and Georgian

TABLE 26

MEAN LEVELS OF MAJOR ORGANIC CONTAMINANTS IN SAMPLES OF PONTOPOREIA AND MYSIS FROM LAKE HURON AND GEORGIAN BAY, 1980 (x ± S.D.)

Pontoporeia Sp.

	N	% LIPID	p,p'-DDE	DDT	DIELDRIN	PCB
Goderich	5	60.9 (1.45)	0.16 (0.05)	0.24 (0.05)	0.21 (0.05)	0.22 (0.05)
South Baymouth	5	43.1 (0.38)	0.09 (0.02)	0.16 (0.03)	0.12 (0.05)	0.32 (0.11)
Burnt Island	5	45.7 (2.12)	0.06 (0.03)	0.06 (0.04)	0.10 (0.14)	0.18 (0.14)

Mysis relicta

	N	% LIPID	p,p'-DDE	DDT	DIELDRIN	PCB
Goderich	5	4.55 (0.23)	0.02 (0.01)	0.03 (0.01)	0.01 (0.00)	0.09 (0.02)
South Baymouth	4	5.47 (0.29)	0.02 (0.00)	0.03 (0.00)	0.01 (0.00)	0.08 (0.00)
Burnt Island	5	13.80 (0.42)	0.05 (0.01)	0.06 (0.02)	0.03 (0.01)	0.15 (0.18)
Cape Rich	5	4.36 (0.43)	0.02 (0.01)	0.02 (0.01)	0.01 (0.00)	0.08 (0.00)
French River	5	8.75 (0.11)	0.03 (0.01)	0.03 (0.01)	0.01 (0.00)	0.08 (0.00)

- All results expressed as μg/g dry weight unless otherwise noted.

TABLE 27

TRACE METAL LEVELS IN SAMPLES OF MYSIS RELICTA FROM LAKE HURON AND GEORGIAN BAY, 1980 ($\bar{x} \pm$ S.D.)

	GODERICH	SOUTH BAYMOUTH	BURNT ISLAND	CAPE RICH	FRENCH RIVER
Hg	<0.03	<0.03	<.03	<0.03	<0.03
Cu	7.97 (0.64)	9.12 (1.55)	6.68 (3.92)	9.76 (4.02)	1.84 (0.67)
Ni	1.06 (0.11)	2.04 (0.18)	8.05 (1.85)	4.21 (0.99)	-
Zn	83.52 (5.78)	86.37 (0.75)	73.92 (6.16)	85.40 (8.14)	61.32 (0.67)
Pb	0.41 (0.20)	0.51 (0.40)	1.33 (0.11)	0.98 (0.34)	-
Cd	0.11 (0.05)	2.24 (2.01)	0.34 (0.05)	0.14 (0.05)	0.08 (0.01)
Cr	2.24 (0.29)	1.70 (0.21)	3.20 (0.01)	5.23 (0.76)	-
As	2.60 (0.10)	2.97 (0.12)	3.42 (0.18)	5.56 (2.02)	2.02 (0.10)
Se	3.82 (0.05)	3.63 (0.06)	3.24 (0.09)	3.88 (0.08)	4.70 (0.08)

- All results expressed as μg/g dry weight.

TABLE 28

TRACE METAL LEVELS IN SAMPLES OF NET PLANKTON (<153 μ) FROM LAKE HURON AND GEORGIAN BAY, 1980 ($\bar{x} \pm$ S.D.)

	GODERICH	SOUTH BAYMOUTH	BURNT ISLAND	CAPE RICH	FRENCH RIVER
Hg	<0.03	<0.03	<0.03	<0.03	<0.03
Cu	38.51 (24.81)	14.63 (3.23)	13.41 (2.51)	10.74 (3.03)	89.25 (4.51)
Zn	161.37 (21.58)	297.88 (13.04)	115.63 (4.25)	129.93 (4.10)	194.8 (6.22)
Cd	2.04 (0.52)	1.43 (0.25)	2.22 (2.16)	3.30 (0.80)	2.48 (0.04)
As	1.75 (0.07)	2.64 (0.09)	2.23 (0.21)	1.30 (0.14)	1.95 (0.07)
Se	1.70 (0.00)	0.80 (0.03)	1.43 (0.06)	2.10 (0.00)	1.60 (0.00)

- All results expressed as μg/g dry weight.

Bay, however, exhibited a unimodal distribution with a maximum in late spring or summer.

The timing and magnitude of the maxima and minima of the phytoplankton indicators may be attributed to a combination of factors including light, temperature, nutrient availability, and physical regime (e.g. turbulence) (Happey, 1970b; Tilzer and Goldman, 1978). Spring blooms of diatoms, such as that found in Lake Huron (Lin and Schelske, 1981; Munawar and Munawar 1979, 1982), are common in oligotrophic, dimictic lakes and usually occur immediately upon cessation of spring turnover when nutrient availability is high and vertical mixing is reduced (Happey, 1970b; Wetzel, 1975). Due to changes in the rate of seasonal development, a pronounced nearshore-offshore and north-south gradient was observed in both Georgian Bay and, in particular, Lake Huron during the first three cruises. Southern Lake Huron had the largest maxima due to the relatively shallow, warm waters and proximity to continual nutrient inputs. Those areas further offshore and further north were delayed in the development of their spring maxima and consequently exhibited less fluctuation in their seasonal cycles.

POC distribution in the nearshore areas apparently was affected by river runoff and locally high concentrations of phytoplankton. POC levels were consistently high in the following nearshore areas: the Ontario shore of southern Lake Huron, the southern edge of outer Saginaw Bay, eastern Georgian Bay, and the southern shore of the Straits of Mackinac. The areal extent of these elevated POC regions suggested that river runoff alone was unlikely to produce the elevated concentrations. Rather, the high nutrient loads from river runoff probably were stimulating algal productivity and increasing POC levels. Davis, et al. (1980) found this mechanism to operate along the Ontario shore of southern Lake Huron in 1974. Moll, et al. (1980) found a similar series of events in outer Saginaw Bay in 1975.

During the study period, chlorophyll a levels in Georgian Bay (1.23 µg/L) were less than those of Lake Huron (1.65 µg/L) and the North Channel (1.72 µg/L) on a whole lake basis. In general, concentrations were low throughout the entire system. Several high station values were observed in the southern, nearshore areas of Lake Huron (e.g. 10.0 µg/L at station 7) and would appear to be related to tributary inputs. These results were comparable to those reported by Glooschenko, et al. (1973), indicating that little change in average chlorophyll concentration occurred since 1971. The relatively low and invariant surface chlorophyll concentrations found in Lake Huron are indicative of an oligotrophic lake.

The areal distribution of chlorophyll is often used as an indication of areas of high algal growth due to nutrient loading (Holland and Beeton, 1972; Robertson, et al., 1971). Considered in this fashion, the spring chlorophyll distributions shown in Figure 19 again reflect the oligotrophic character of Lake Huron. During this cruise elevated chlorophyll concentrations were observed along the Ontario shore of southern Lake Huron. Other nearshore areas which exhibited elevated chlorophyll levels were: southern Saginaw Bay along Michigan's "thumb", extreme southern Lake Huron, eastern Georgian Bay, and the Straits of Mackinac. But, with few exceptions, chlorophyll concentrations in the nearshore regions mentioned above rarely exceeded lakewide means by more than 3.0 µg/L.

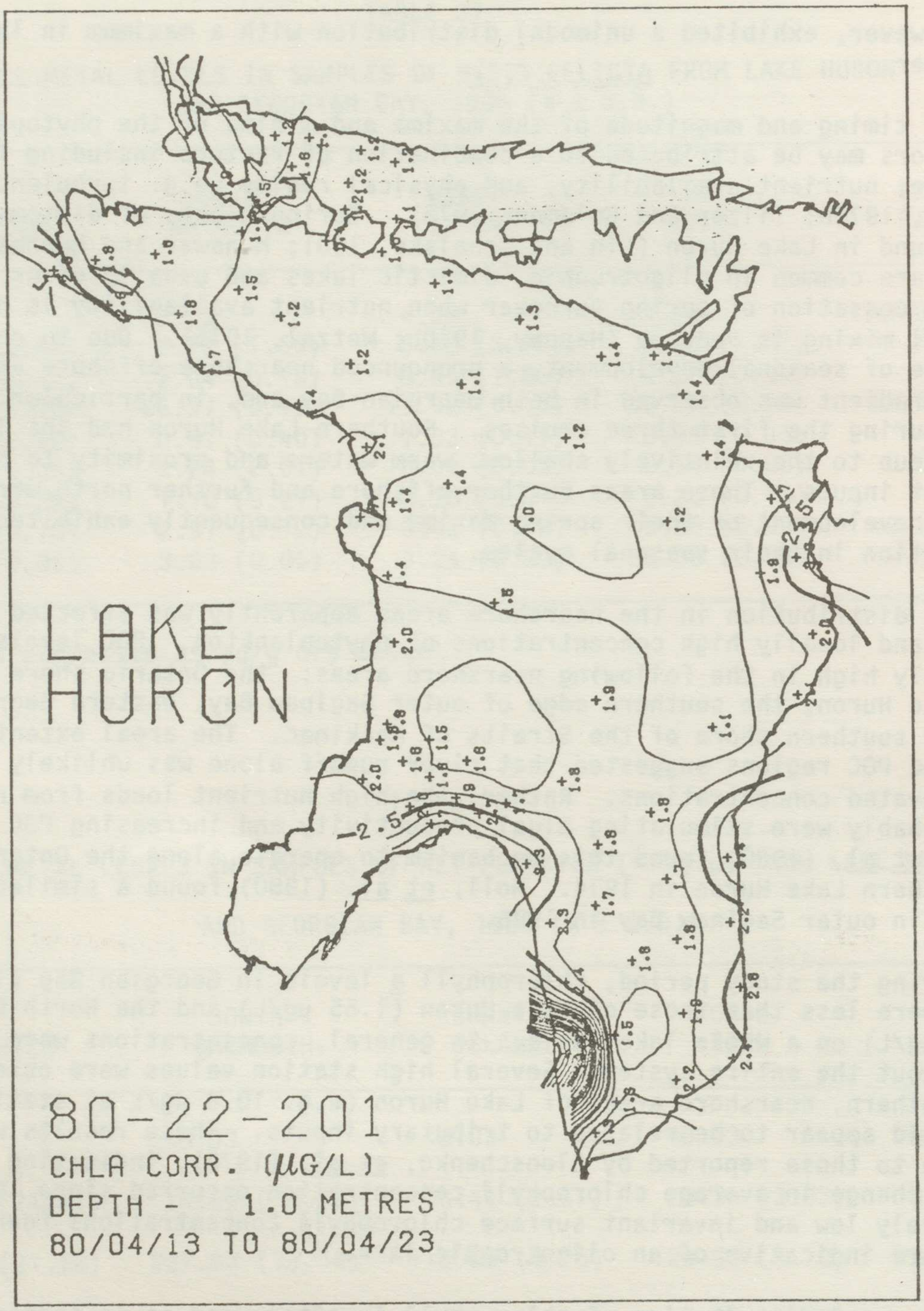
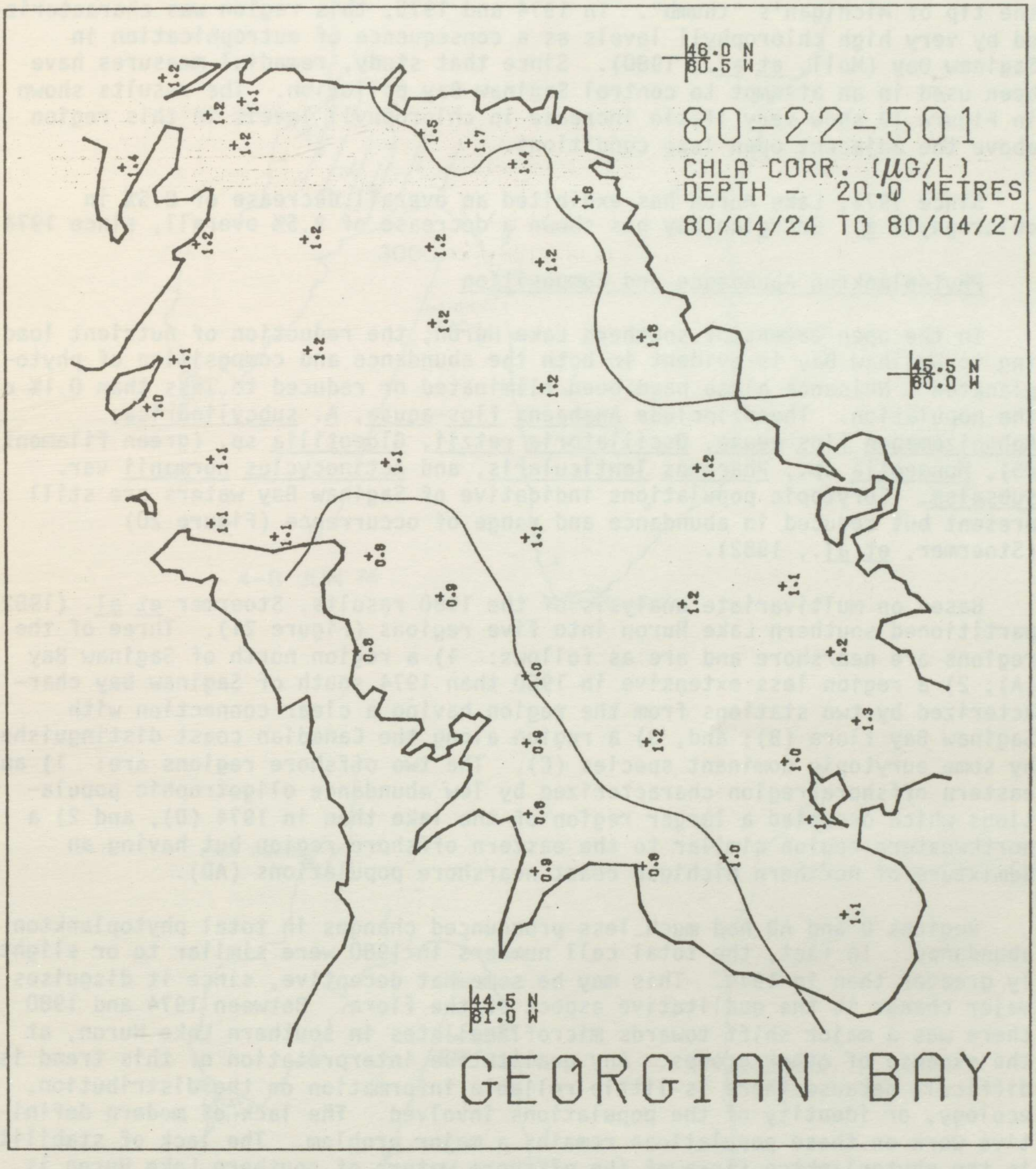


FIGURE 19a SPRING CHLOROPHYLL DISTRIBUTION IN LAKE HURON



19b SPRING CHLOROPHYLL DISTRIBUTION IN GEORGIAN BAY

One nearshore area of Lake Huron that deserved particular attention was the tip of Michigan's "thumb". In 1974 and 1975, this region was characterized by very high chlorophyll levels as a consequence of eutrophication in Saginaw Bay (Moll, et al., 1980). Since that study, remedial measures have been used in an attempt to control Saginaw Bay pollution. The results shown in Figure 19 show very little increase in chlorophyll levels in this region above the adjacent open lake conditions.

Since 1971, Lake Huron has exhibited an overall decrease of 8.5% in chlorophyll a. Georgian Bay has shown a decrease of 9.5% overall, since 1974.

Phytoplankton Abundance and Composition

In the open waters of southern Lake Huron, the reduction of nutrient loading to Saginaw Bay is evident in both the abundance and composition of phytoplankton. Nuisance algae have been eliminated or reduced to less than 0.1% of the population. These include *Anabaena flos-aquae*, *A. subcylindrica*, *Aphonizomenon flos-aquae*, *Oscillatoria retzii*, *Gloeotilia* sp. (green filament #5), *Mougeotia* sp., *Phacotus lenticularis*, and *Actinocyclus normanii* var. *subsalsa*. Eurytopic populations indicative of Saginaw Bay waters are still present but reduced in abundance and range of occurrence (Figure 20) (Stoermer, et al., 1982).

Based on multivariate analysis of the 1980 results, Stoermer et al. (1982) partitioned southern Lake Huron into five regions (Figure 21). Three of the regions are nearshore and are as follows: 1) a region north of Saginaw Bay (A); 2) a region less extensive in 1980 than 1974 south of Saginaw Bay characterized by two stations from the region having a clear connection with Saginaw Bay flora (B); and, 3) a region along the Canadian coast distinguished by some eurytopic dominant species (C). The two offshore regions are: 1) an eastern offshore region characterized by low abundance oligotrophic populations which occupied a larger region of the lake than in 1974 (D), and 2) a northwestern region similar to the eastern offshore region but having an admixture of northern Michigan coast nearshore populations (AD).

Regions D and AD had much less pronounced changes in total phytoplankton abundance. In fact, the total cell numbers in 1980 were similar to or slightly greater than in 1974. This may be somewhat deceptive, since it disguises a major change in the qualitative aspect of the flora. Between 1974 and 1980 there was a major shift towards microflagellates in southern Lake Huron, at the expense of other groups. Any qualitative interpretation of this trend is difficult because there is little reliable information on the distribution, ecology, or identity of the populations involved. The lack of modern definitive work on these populations remains a major problem. The lack of stability in the phytoplankton flora of the offshore waters of southern Lake Huron is somewhat disturbing because it is likely indicative of continued change in the system. The cause or causes of this change is a matter of speculation, but it is likely that factors other than eutrophication are involved.

Attached Filamentous Algae

Cladophora can become a nuisance algae. It grows as long strands attached to a solid substrate. During storm events it breaks off and washes up on

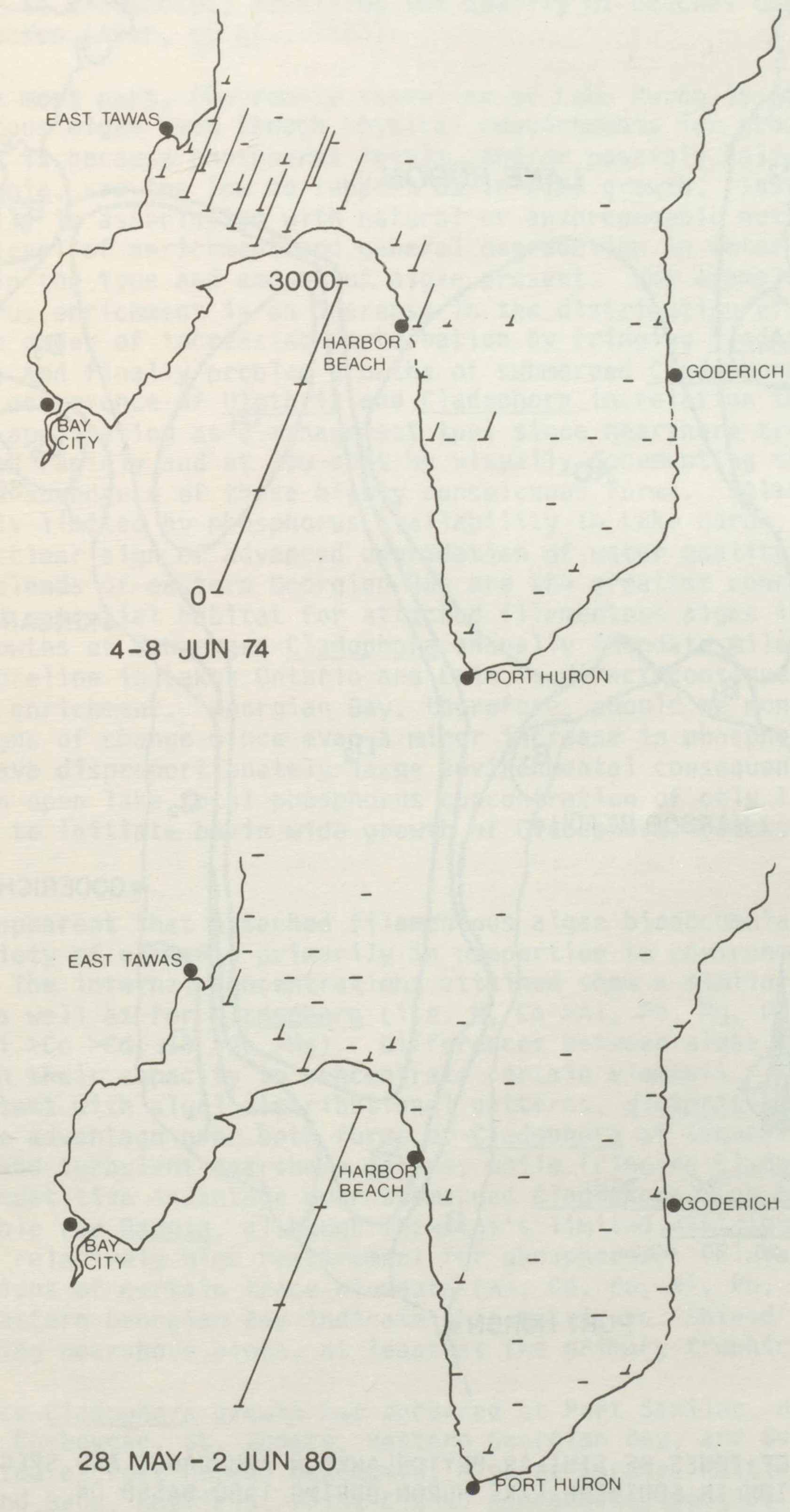


FIGURE 20 COMPARISON OF THE DISTRIBUTION OF FRAGILARIA CAPUCIAN IN SOUTHERN LAKE HURON IN 1974 AND 1980

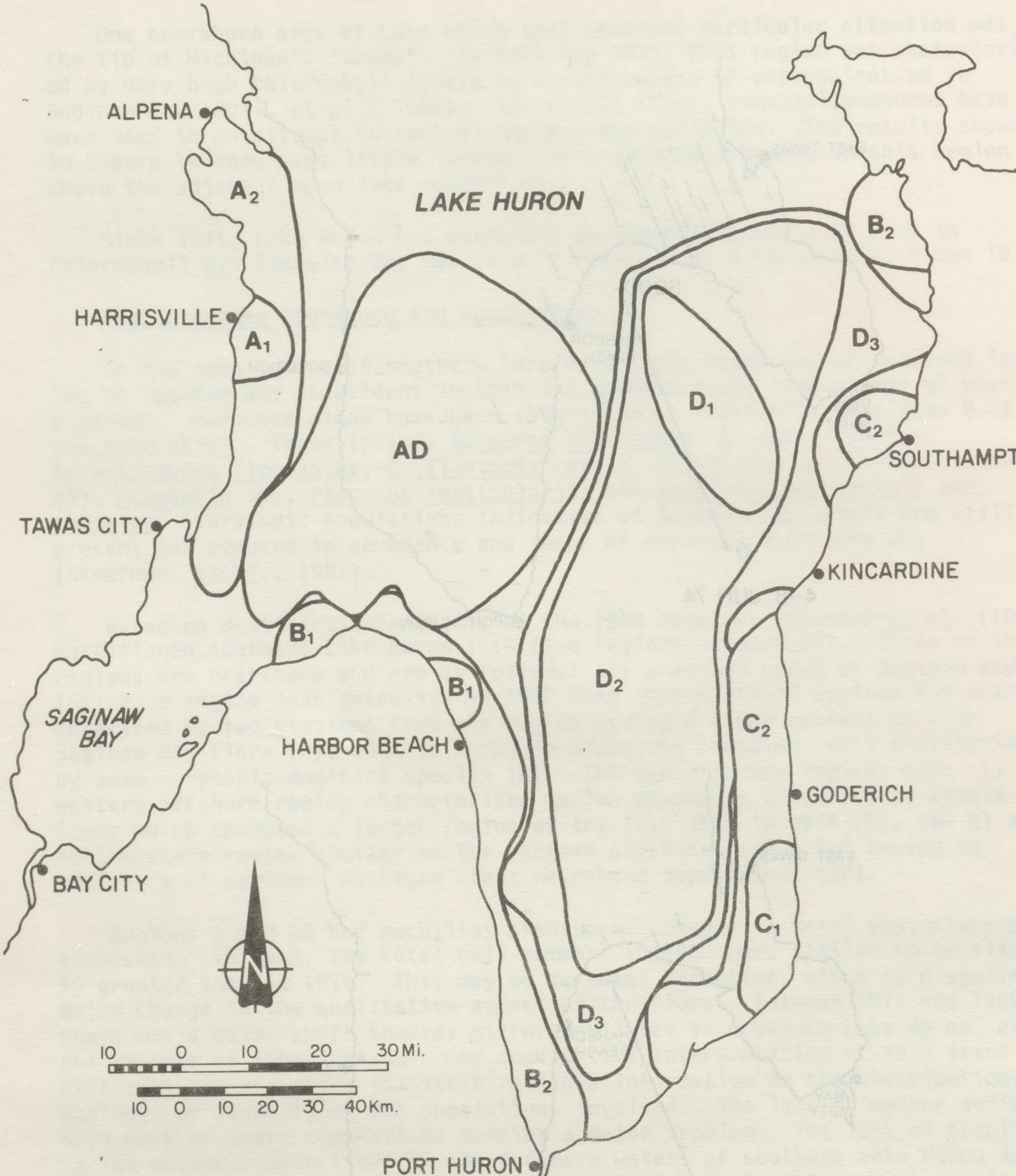


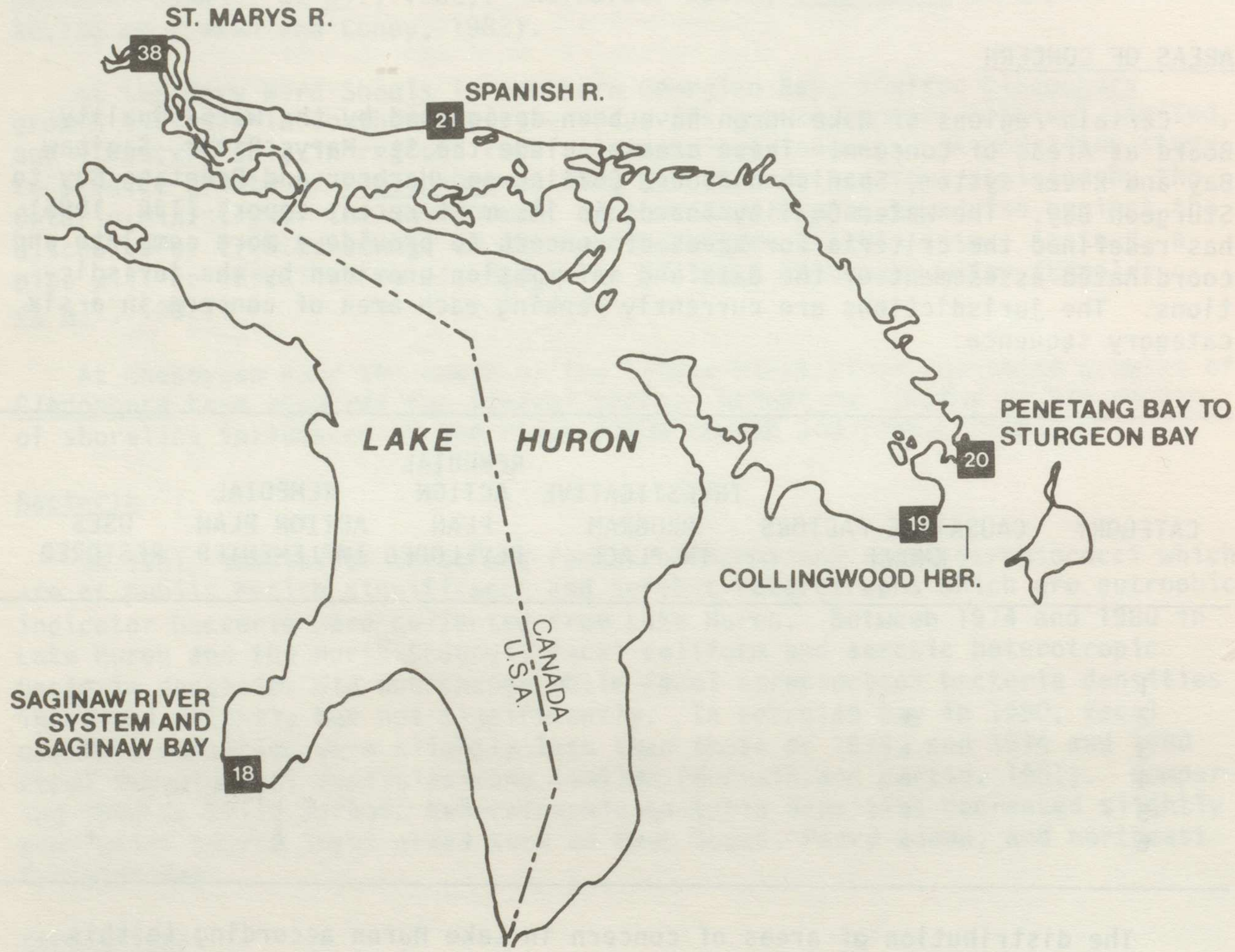
FIGURE 21 SUMMARY OF ZONES OF SIMILAR PHYTOPLANKTON ABUNDANCE AND SPECIES COMPOSITION IN SOUTHERN LAKE HURON DURING 1980 BASED ON MULTIVARIATE STATISTICAL COMPARISONS

shore where it decomposes, impairing the quality of beaches used for recreational purposes (Auer, et al., 1982).

For the most part, the remote shoreline of Lake Huron is devoid of attached filamentous algae even though physical requirements for growth are favourable. This is because phosphorus levels, and/or possibly halide levels in the case of Bangia, are too low to support basin wide growth. Instead, the algae occur locally in association with natural or anthropogenic nutrient sources, where the level of enrichment and general degradation in water quality is reflected in the type and amount of algae present. For example, a first sign of phosphorus enrichment is an increase in the distribution of Ulothrix, followed in order of increasing perturbation by fringing Cladophora, submerged Cladophora, and finally problem growths of submerged Cladophora. This sequential occurrence of Ulothrix and Cladophora in relation to phosphorus supply has application as a management tool since nearshore trophic status can be evaluated rapidly and at low cost by visually documenting the presence/absence and abundance of these highly conspicuous forms. (Although Bangia is not strictly limited by phosphorus availability in Lake Huron, its occurrence is still a clear sign of advanced degradation of water quality). The Thirty Thousand Islands of eastern Georgian Bay are the greatest concentration of islands and potential habitat for attached filamentous algae in the world. Problem growths of submerged Cladophora annually inundate miles of physically similar shoreline in Lakes Ontario and Erie, a direct consequence of phosphorus enrichment. Georgian Bay, therefore, should be monitored closely for any signs of change since even a minor increase in phosphorus concentration may have disproportionately large environmental consequences (i.e. an increase in open lake total phosphorus concentration of only 1 µg/L may be sufficient to initiate basin wide growth of Cladophora) (Jackson and Hamdy, 1982).

It is apparent that attached filamentous algae bioaccumulate (10^3 to 10^5) a variety of elements primarily in proportion to environmental supply in water. The internal concentrations attained show a similar pattern for Ulothrix as well as for Cladophora (i.e. N, Ca >Al, Fe, Mg, P >Mn >Zn >Pb, Cu >As, Cr, Ni >Co >Cd, Se >Sb >Hg). Differences between algae, however, are apparent in their capacity to concentrate certain elements. In particular, and consistent with algal distributional patterns, Ulothrix appears to have a competitive advantage over both forms of Cladophora at sequestering phosphorus in dilute and turbulent nearshore waters, while fringing Cladophora may have a similar competitive advantage over submerged Cladophora (no comparable data are available for Bangia, although the alga's limited distribution tends to indicate a relatively high requirement for phosphorus). Elevated internal concentrations of certain trace elements (As, Cd, Cu, Ni, Pb, Zn) at remote sites in eastern Georgian Bay indicate that metals in 'Shield' runoff water are impacting nearshore biota, at least at the primary trophic level.

Nuisance Cladophora growth has occurred at Port Sanilac, Harbor Beach, Port Hope, Cheboygan, St. Ignace, eastern Georgian Bay, and Goderich. It has been reported at Port Huron, Lexington, Alpena, Sarnia, Kettle Point, Stoney Point, Grand Bend, Bayfield, Point Clark, Kincardine, Douglas Point, Southampton, Tobermory, the eastern Bruce Peninsula, Wiarton, Owen Sound, Little Current, Manitoulin Island, Mary Ward Shoal in southern Georgian Bay, eastern Saginaw Bay and Blind River. The areas of nuisance growth of Cladophora are usually, though not always, associated with point discharges of phosphorus



MAP REF. NO.	AREA OF CONCERN	JURISDICTION	CATEGORY
18	Saginaw River/Saginaw Bay	MI	3
19	Collingwood Harbour	ON	4
20	Penetang Bay/Sturgeon Bay	ON	2
21	Spanish River Mouth	ON	3
38	St. Marys River	ON/MI	4/3

FIGURE 22 AREAS OF CONCERN IN LAKE HURON

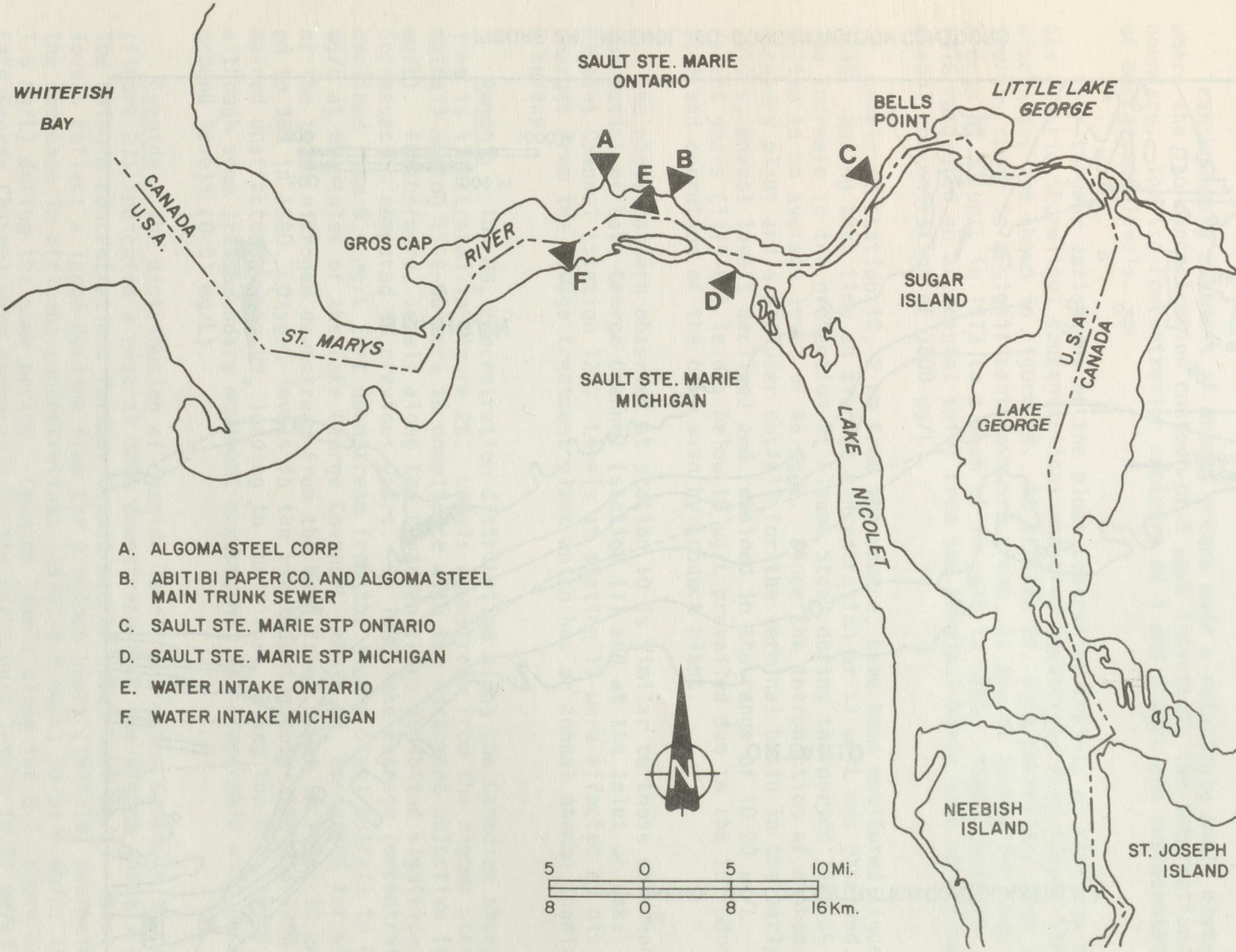


FIGURE 23 ST. MARYS RIVER - MUNICIPAL INTAKES, OUTFALLS AND INDUSTRIAL WASTE DISCHARGES

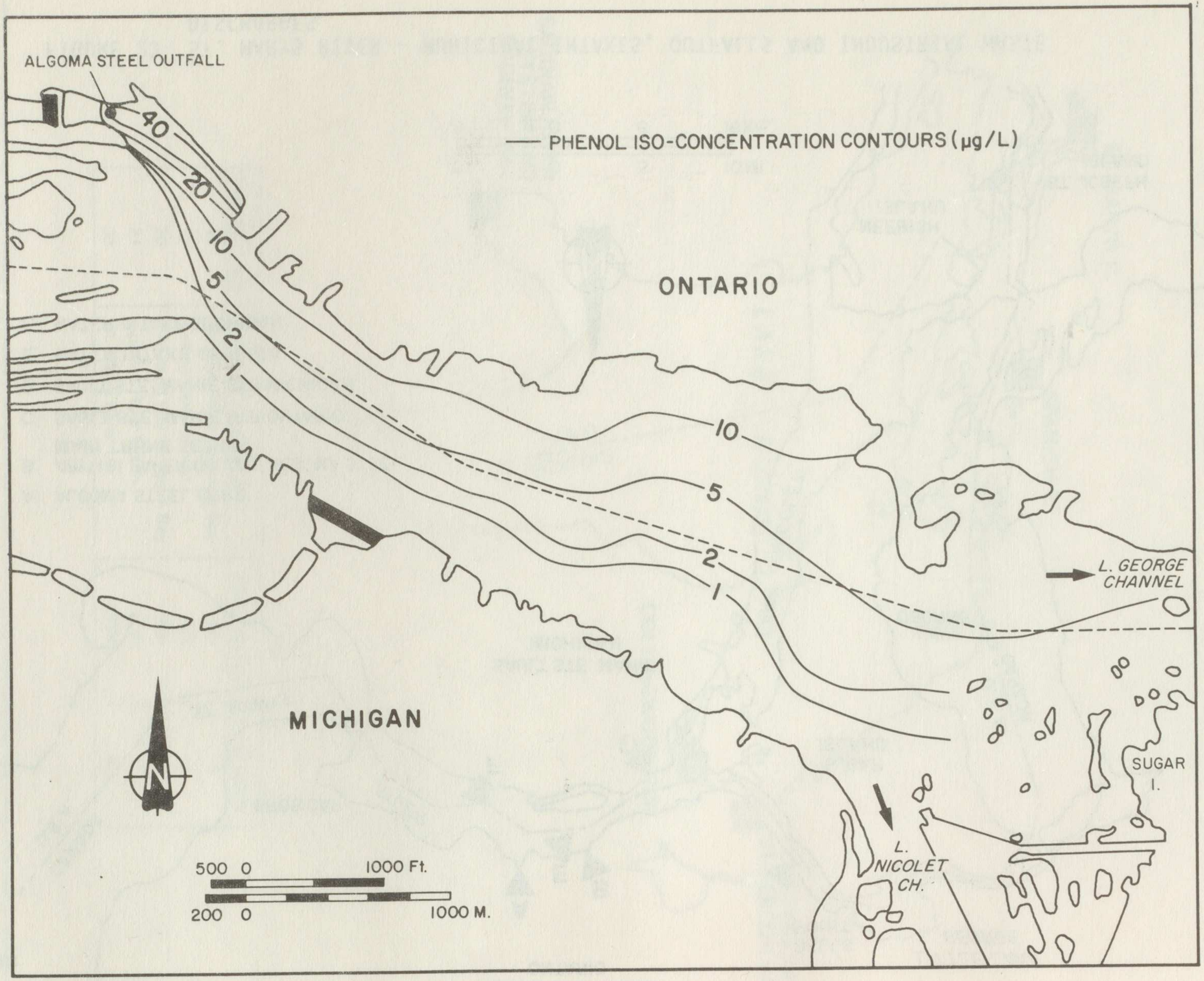


FIGURE 24 PHENOL ISO-CONCENTRATION CONTOURS

Power Canal, tend to confine the contaminants to the Ontario shoreline of the river. The Agreement objectives for phenol in public water supplies is 1 µg/L and this is exceeded at the Sault Ste. Marie, Ontario municipal water intake.

Transboundary movement of phenol occurs over a relatively small distance where the iso-concentration contour of 5 µg/L intersects the international boundary. The iso-concentration contours of 1 and 2 µg/L are representative of background levels.

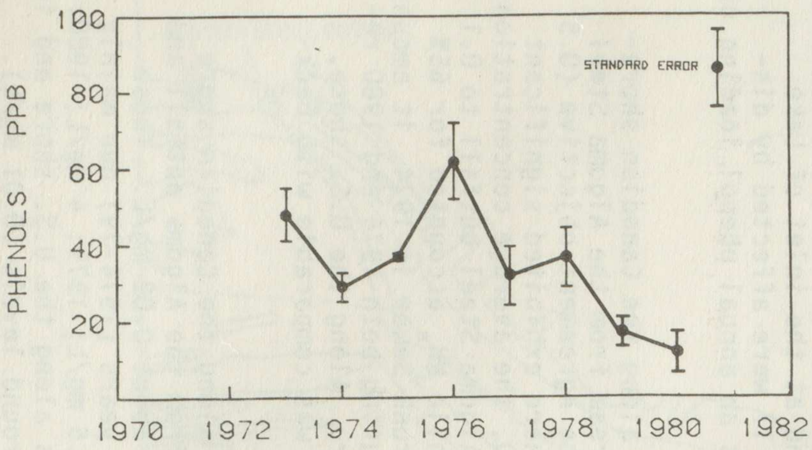
Year-to-year variations of the plume centreline (mainly at stations near the Ontario shoreline) concentrations measured downstream from Algoma Steel discharges are shown in Figure 25. At station 29, 300m downstream from the source, there is a significant downward trend, as phenol levels declined from a mean of 50 µg/L in 1973 to a mean of 15 µg/L in 1980. High levels in 1976 reflected an accidental spill from the terminal basin with an effluent phenol concentration of 3800 µg/L.

Levels at station 10, 3 km from the source, have been monitored since 1948. During that time an average concentration of 14 µg/L was observed. The increase in the production at Algoma Steel during the period 1965-69 resulted in an average level of 46 µg/L. Since the introduction of a phenol recovery plant and a diffuser outfall for the terminal basin in the early 1970's, phenol levels declined and remained in the range of 10-20 µg/L. In recent years (1979-80) levels below 10 µg/L prevailed due to the introduction and operation of the coke oven by-product plant.

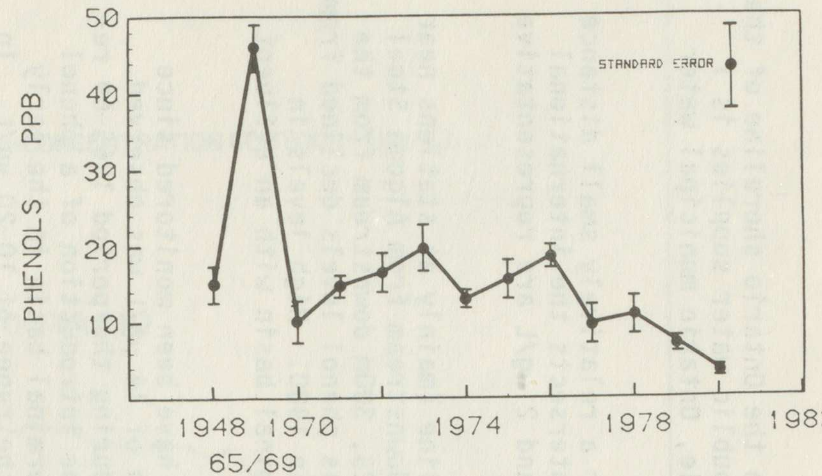
The above pattern observed at station 10 is similar to those observed at the outlet of Lake George Channel (station 17) and at the inlet of Lake Nicolet Channel (station 12). Levels at station 17 were affected by discharges from the sewage treatment plant which has an annual phenol loading of 7 kg/day.

<u>Ammonia</u> - The NH_3 concentration distribution along the Canadian shoreline is illustrated in Figure 26. Levels downstream from the Algoma Steel outfall during 1979-80 were in compliance with the Agreement objective (0.5 mg/L). Furthermore, levels along the Canadian shore exhibited significant decreases as compared to previous years. In 1980, the average concentration declined from 0.4 mg/L just downstream from the Algoma Steel outfall to 0.1 mg/L at the inlet of the Lake George Channel. While NH_3 accounted for 65% of the total nitrogen downstream from the Main Trunk Sewer in 1974, it amounted to 38% in 1980. Oxygen levels in the river during both 1974 and 1980 remained unaffected by the NH_3 loading to the river. Along the U.S. shore, although some transboundary movement occurs, NH_3 was comparable with background levels (0.01 mg/L).

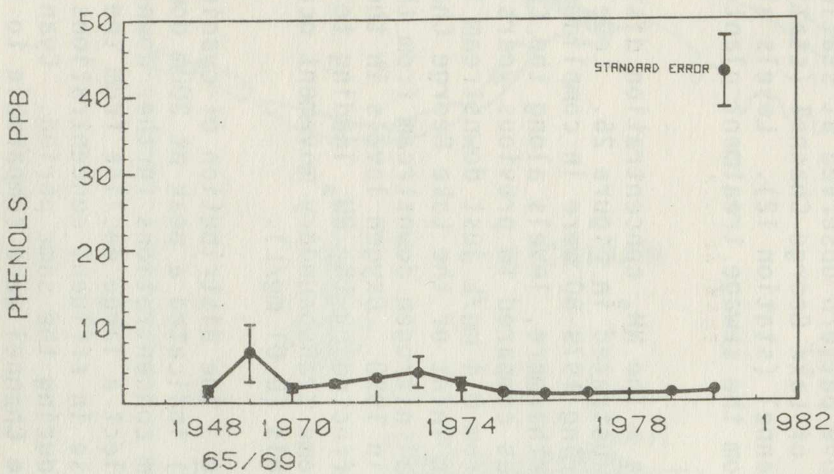
<u>Cyanide</u> - The distribution of cyanide levels along the Canadian shore (Figure 27) indicated a peak at 300m downstream from the Algoma outfall and low uniform concentrations further downstream of about 0.02 mg/L. These levels reflect a large decline from the previous years (1974-79) due mainly to the decrease in effluent concentrations (1974: 8.5 mg/L; 1979: 4 mg/L; 1980: 1.5 mg/L) during the same period. Cyanide levels along the U.S. shore and in Lake George Channel were comparable to the background levels (0.01 mg/L).



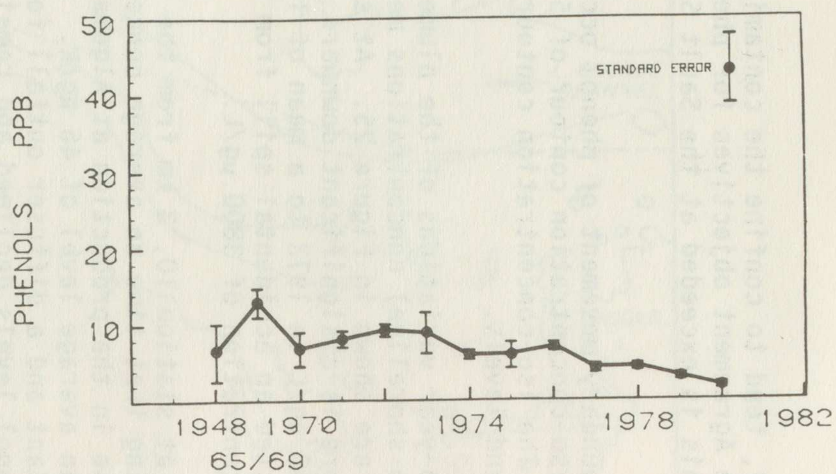
STN # 29 (300 M. DOWNSTREAM FROM ALGOMA OUTFALL)



STN # 10 (3200 M. DOWNSTREAM FROM ALGOMA OUTFALL)



STN # 12 (LAKE NICOLET CHANNEL)



STN # 17 (LAKE GEORGE CHANNEL)

FIGURE 25 YEARLY TRENDS FOR PHENOL LEVELS

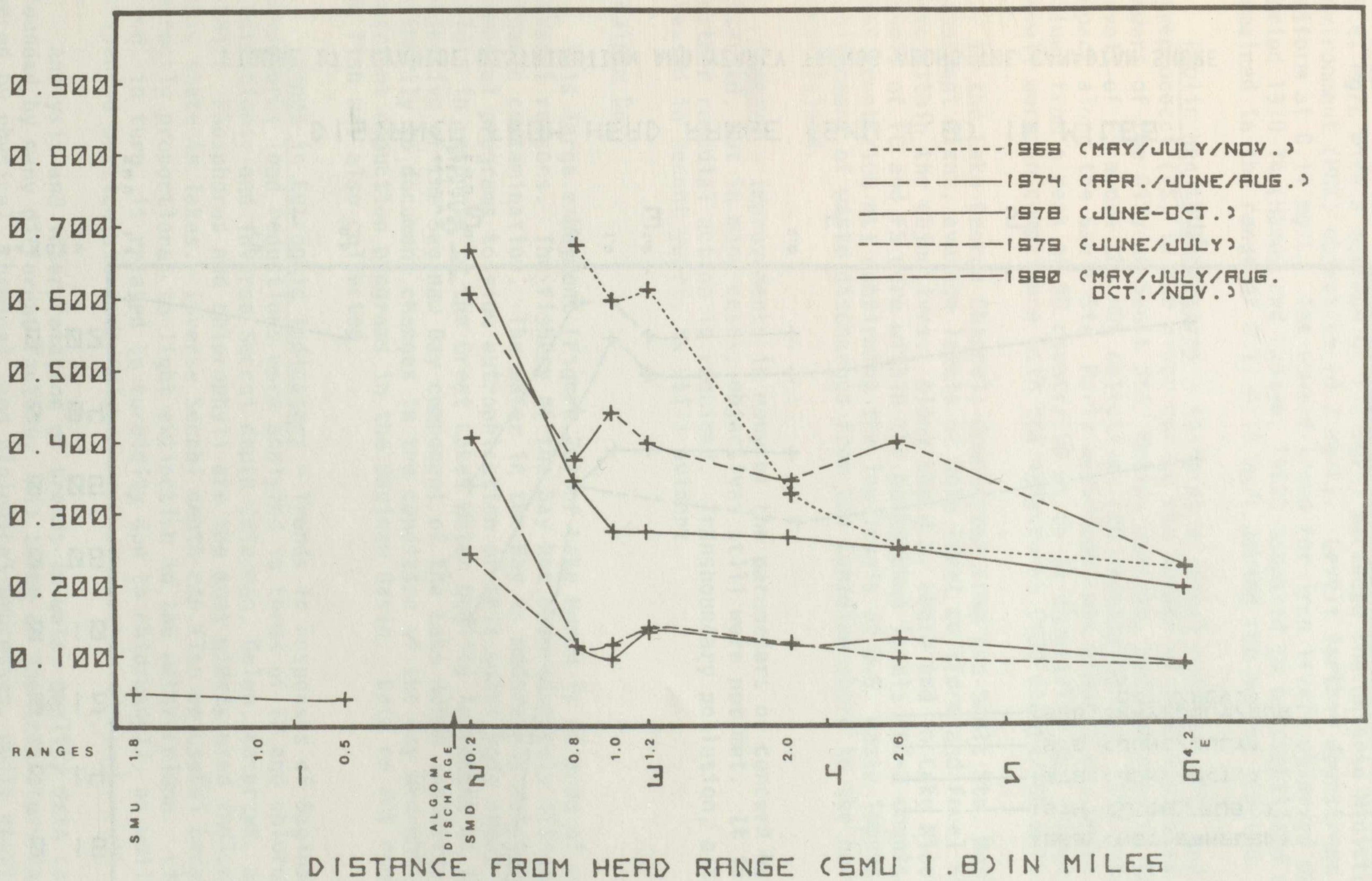


FIGURE 26 AMMONIA DISTRIBUTION AND YEARLY TRENDS ALONG THE CANADIAN SHORE

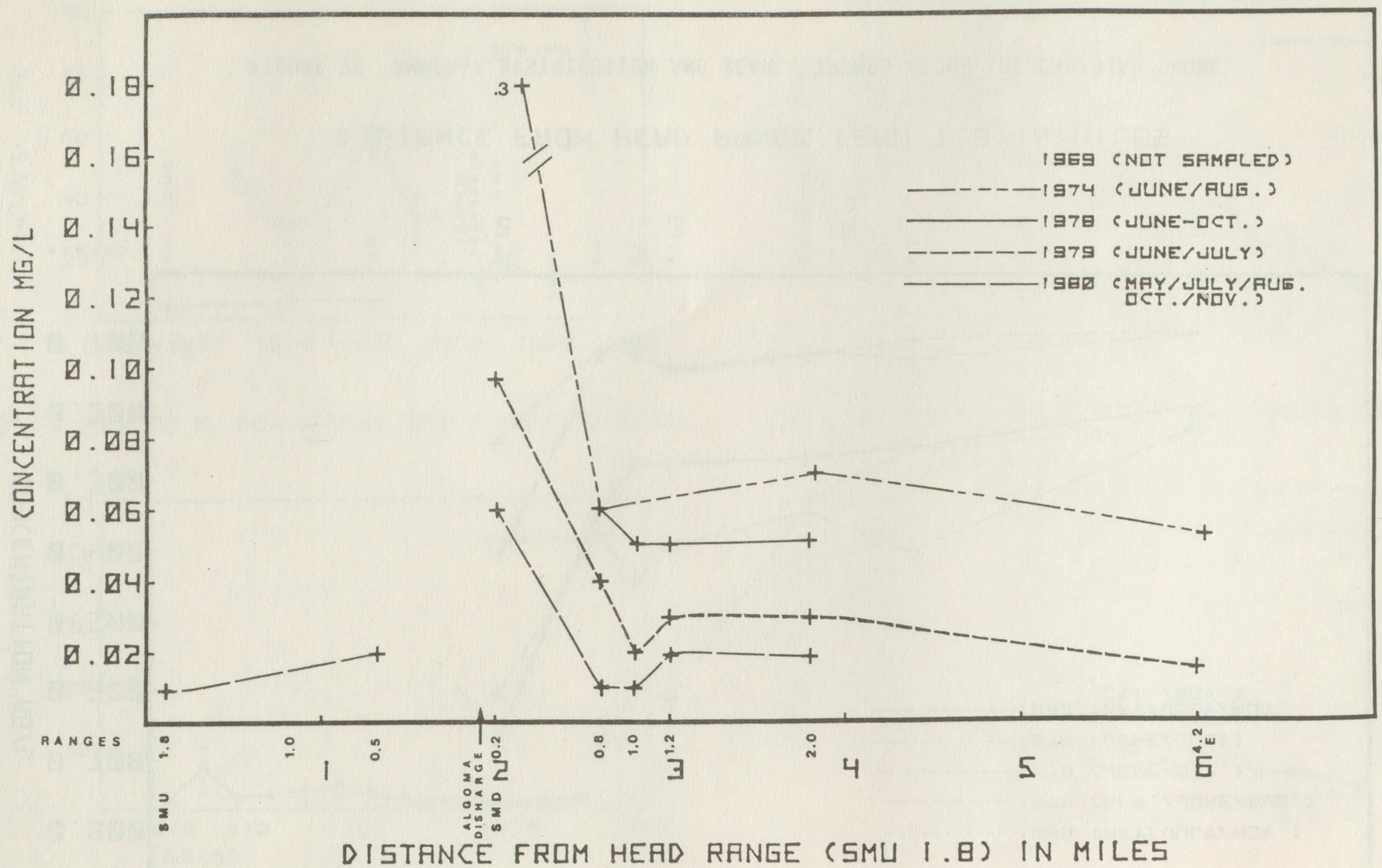


FIGURE 27 CYANIDE DISTRIBUTION AND YEARLY TRENDS ALONG THE CANADIAN SHORE

Iron - Average levels of total iron at 300 m from the Terminal Basins (0.41 mg/L with a maximum of 1.0 mg/L) exceeded the Ontario Ministry of the Environment (MOE) objective (0.3 mg/L). Levels farther downstream remained uniform at 0.11 mg/L. The upward trend for iron levels observed during the period 1970-74 (Hamdy and Lahaye, 1982) appeared to be stabilized as levels remained in the range of 0.11-0.15 mg/L during the period 1976-80.

Public Health Indicators - Analyses of fecal coliform (FC) and fecal streptococci (FS) in the river during the summer of 1980 indicated that storm sewers of the City of Sault Ste. Marie, Ontario, had contributed to elevated levels of FS above the MOE objectives (20 counts/100 mL). The extent of the impact along the Sault Ste. Marie waterfront was about 3 km, where levels declined from a peak of 50 counts/100 mL to 36 counts/100 mL. Fecal coliform levels were in compliance with the objectives (100 counts/100 mL).

In the Lake George Channel, downstream from the Sault Ste. Marie Sewage Treatment Plant, average levels of both fecal coliform and fecal streptococci were within the objectives. Along the U.S. shore and in Lake Nicolet Channel, levels of FC and FS were within the background levels (FC=3 counts/100 mL, FS=4 counts/100 mL) confirming the low levels of U.S. waste inputs and the confinement of waste discharges from the Canadian shore to the north side of Sugar Island.

Summary - Improvements in many of the parameters of concern have been observed, but in many cases, objectives still were not met. It is clear that further remedial action is required. Transboundary pollution, although decreased in recent years, is still evident.

Saginaw Bay

This large embayment (Figure 28) of Lake Huron is an area of concern for several reasons. The fishery of the Bay has been adversely affected by organic contamination. The water in the Bay is moderately eutrophic. Remedial programs to slow eutrophication of this water body began in the early 1970's in response to the Great Lakes Water Quality Agreement of 1972. The objective of the Saginaw Bay component of the Lake Huron Intensive Plan was primarily to document changes in the condition of the Bay brought about by nutrient reduction programs in the Saginaw Basin. Data on PCB contamination in fish was also collected.

Trends in Eutrophic Indicators - Trends in responses of Saginaw Bay to phosphorus load reductions were analyzed in terms of TP and chlorophyll *a* concentrations, and inverse Secchi depth (Bierman, Dolan, Kasprzyk, and Clark, 1984). Phosphorus and chlorophyll are the most widely used indicators of trophic state in lakes. Inverse Secchi depth can also be useful because it is directly proportional to light extinction in the water column. Light extinction, in turn, is related to turbidity due to chlorophyll, as well as other suspended particulate materials.

Analysis and interpretation of trends in water quality data can be confounded by many different factors. All three of the indicators can be influenced by physical, chemical, and biological processes, quite apart from effects due to phosphorus loadings. For example, water exchange between Saginaw Bay and Lake Huron proper influences the magnitude and timing of dilution of

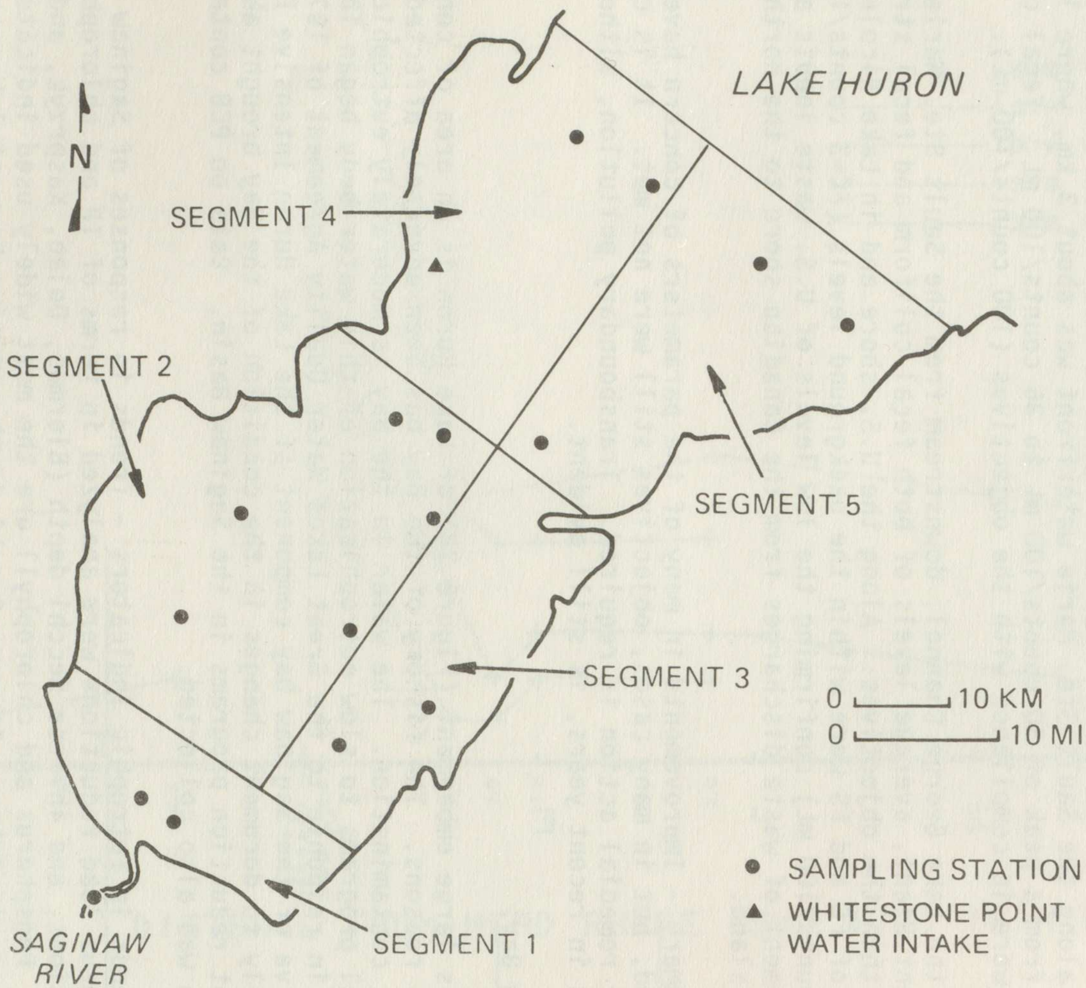


FIGURE 28 SAMPLING LOCATIONS IN SAGINAW BAY

the Saginaw River input loadings. Sediment-water exchanges, especially due to resuspension from wind-induced wave action, can directly influence phosphorus concentration and inverse Secchi depth, and can indirectly influence chlorophyll concentration through changes in phosphorus supply rate and alteration of the underwater light environment. Incident solar radiation and water temperature can strongly influence the amount of chlorophyll that is actually produced from a given amount of nutrients. All of these factors are stochastic in nature, and can be expected to vary from year to year. Accordingly, it is not always possible to identify statistically meaningful trends. Furthermore, it is not always possible to conclude that any trends observed were actually the result of phosphorus loading reductions.

Another important consideration in trend analysis of water quality data is the identification of appropriate space and time scales. With regard to spatial scale, the present analyses were conducted separately for the inner and outer portions of the Bay. This segmentation was useful because these portions tended to be dominated by different processes, and their water quality characteristics tended to be somewhat distinct. The inner Bay was directly influenced by loading from the Saginaw River, and contained the most seriously degraded water in the Bay. The outer Bay was more strongly influenced by exchanges with the oligotrophic waters of Lake Huron.

With regard to temporal scale, data were aggregated into operationally-defined spring (April-June) and fall (August-October) seasons. These seasons were consistent with the characteristic hydrological and productivity cycles observed in the Bay. Data for the spring tended to reflect the consequences of high and variable input loadings due to snowmelt and peak runoff, and colder temperatures. Data for the fall tended to reflect the consequences of lower and reasonably stable input loadings, and higher temperatures. These two seasons tended to be uncoupled in the Bay because they were generally separated by a period of very rapid hydraulic flushing prior to establishment of a stable summer-fall circulation pattern (Bierman and Dolan, 1981).

When analysis of variance was conducted on sampling results aggregated in this manner, a simple linear decrease over the study period (1974-80) was found only for chlorophyll a concentration. This decrease was significant ($P < 0.01$) for both seasons, and in both spatial segments. No simple linear decreases were found for TP concentration or inverse Secchi depth.

Seasonal average values for the three indicators in the inner Bay are contained in Table 29. These values represent seasonal averages of the individual station medians for the given season, where the medians have been adjusted for the "station effect". It is clear that chlorophyll a concentration decreased substantially in a direct linear fashion. TP concentration and inverse Secchi depth both increased during the middle years, and then declined to values in 1980 that were somewhat lower than the 1974 values. The data suggested that chlorophyll a concentrations were not tightly coupled to either TP concentration or inverse Secchi depth. Seasonal average values for TP and chlorophyll a concentrations were never less than 24 µg/L and 8 µg/L, respectively. By generally accepted criteria, inner Saginaw Bay could still be classified as eutrophic over the entire study period.

TABLE 29

SEASONAL AVERAGE WATER QUALITY PARAMETERS FOR INNER SAGINAW BAY, 1974-1980

YEAR	TOTAL PHOSPHORUS CONCENTRATION µg/L		CHLOROPHYLL a CONCENTRATION µg/L		INVERSE SECCHI DEPTH (1/m)	
	SPRING	FALL	SPRING	FALL	SPRING	FALL
1974	30.5	29.3	20.6	29.1	0.92	1.05
1975	35.4	27.3	19.5	19.9	0.77	0.89
1976	41.2	40.9	18.6	26.4	1.28	1.19
1977	-	-	-	-	0.72	1.28
1978	47.3	34.8	14.0	14.0	1.02	1.07
1979	37.3	27.7	8.1	12.4	0.92	1.05
1980	26.8	24.8	12.2	12.2	0.86	0.86

TABLE 30

PERCENT DECREASES IN SELECTED WATER QUALITY PARAMETERS IN SAGINAW BAY, 1974-1980[1]

PARAMETER	SPRING	FALL
Total Phosphorus Concentration		
Inner Bay	1	14
Outer Bay	51	0
Chloropyll a Concentration		
Inner Bay	53	61
Outer Bay	53	0
Inverse Secchi Depth		
Inner Bay	0	17
Outer Bay	26	0

Decrease in Annual Total Phosphorus Load = 56%
Decrease in Annual Dissolved Ortho-Phosphorus Load = 72%

[1]Determined from the respective regression curves.

Results of all trend analyses for phosphorus loads and the three indicators in both the inner and outer Bay are summarized in Table 30. Results are expressed in terms of per cent decreases in each quantity over the study period, as determined from the respective regression curves. The most notable feature of the results was the disproportionate response of TP and chlorophyll a concentrations in the inner Bay. TP concentrations decreased by only 1% and 14% in the spring and fall, respectively, while chlorophyll a concentrations decreased by 53% and 61% in the same seasons. The corresponding decreases for inverse Secchi depth were 0% and 17%. Thus it appeared that chlorophyll a concentrations in the inner Bay were uncoupled from TP concentration and inverse Secchi depth. Instead chlorophyll a appeared to be coupled only to the external phosphorus loadings. The reduction in phosphorus loadings did not appear to have any substantial effect on TP concentration or on inverse Secchi depth.

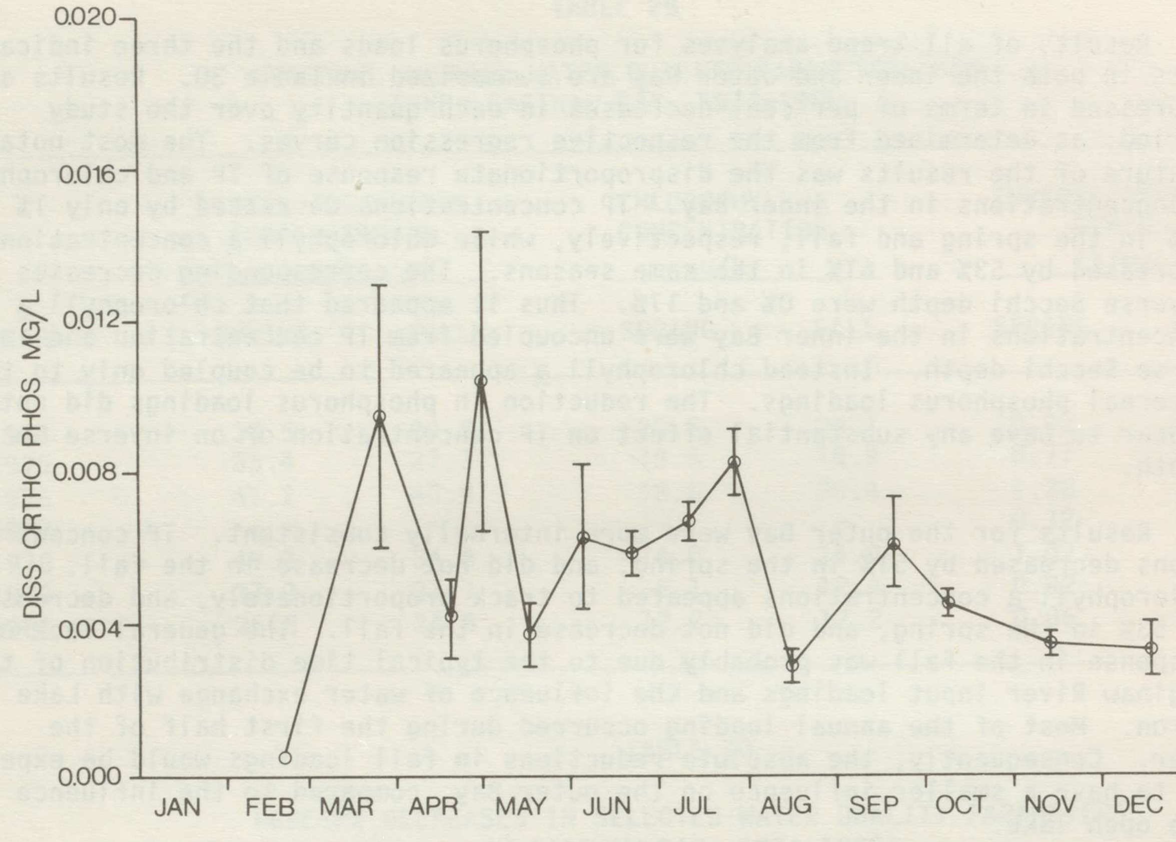
Results for the outer Bay were more internally consistent. TP concentrations decreased by 51% in the spring, and did not decrease in the fall. Chlorophyll a concentrations appeared to track proportionately, and decreased by 53% in the spring, and did not decrease in the fall. The general lack of response in the fall was probably due to the typical time distribution of the Saginaw River input loadings and the influence of water exchange with Lake Huron. Most of the annual loading occurred during the first half of the year. Consequently, the absolute reductions in fall loadings would be expected to have a smaller influence on the outer Bay, compared to the influence of the open lake.

Changes in Free Nutrient Resources - As discussed previously, a substantial decrease in TP load to Saginaw Bay occurred over the period 1974-1980. In Saginaw Bay itself, the concentrations of TP have responded slowly to this dramatic decrease, probably due to resuspension of total phosphorus from nutrient rich sediments (Dolan and Bierman, 1983). However, since a large part of the phosphorus removed by municipal wastewater treatment plants is (SRP) and the form of phosphorus affected by the detergent ban is P_2O_5 which contributes to SRP, the SRP levels in the bay responded much more positively (Figure 29).

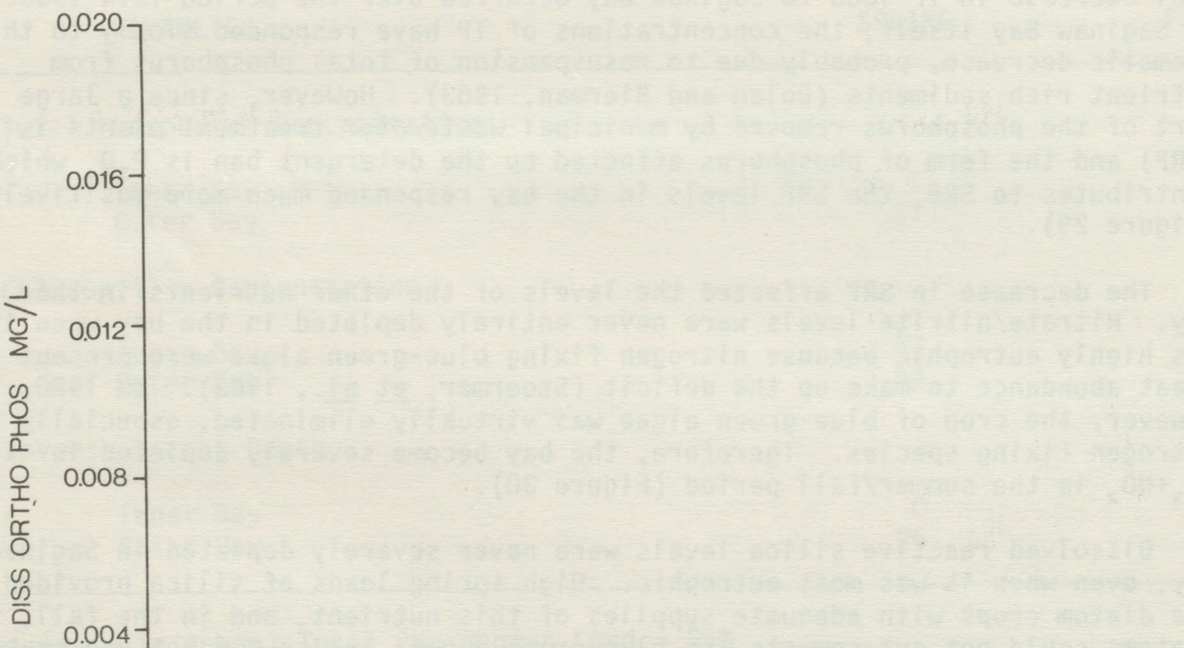
The decrease in SRP affected the levels of the other nutrients in the bay. Nitrate/nitrite levels were never entirely depleted in the bay when it was highly eutrophic because nitrogen fixing blue-green algae were present in great abundance to make up the deficit (Stoermer, et al., 1982). In 1980, however, the crop of blue-green algae was virtually eliminated, especially the nitrogen fixing species. Therefore, the bay become severely depleted in NO_3+NO_2 in the summer/fall period (Figure 30).

Dissolved reactive silica levels were never severely depleted in Saginaw Bay, even when it was most eutrophic. High spring loads of silica provided the diatom crops with adequate supplies of this nutrient, and in the fall, the diatoms could not out-compete the blue-green algae, and so did not use much silica (Dolan, Griesmer, and McNaught, 1984). With the lack of blue-green algae in 1980, however, fall diatom populations experienced good growth and fully depleted the dissolved reative silica in the bay (Figure 31). Thus, the levels of all three primary nutrients for phytoplankton in Saginaw Bay have decreased substantially.

FIGURE 29 1974 AND 1980 ORTHO-PHOSPHATE CONCENTRATIONS IN SAGINAW BAY

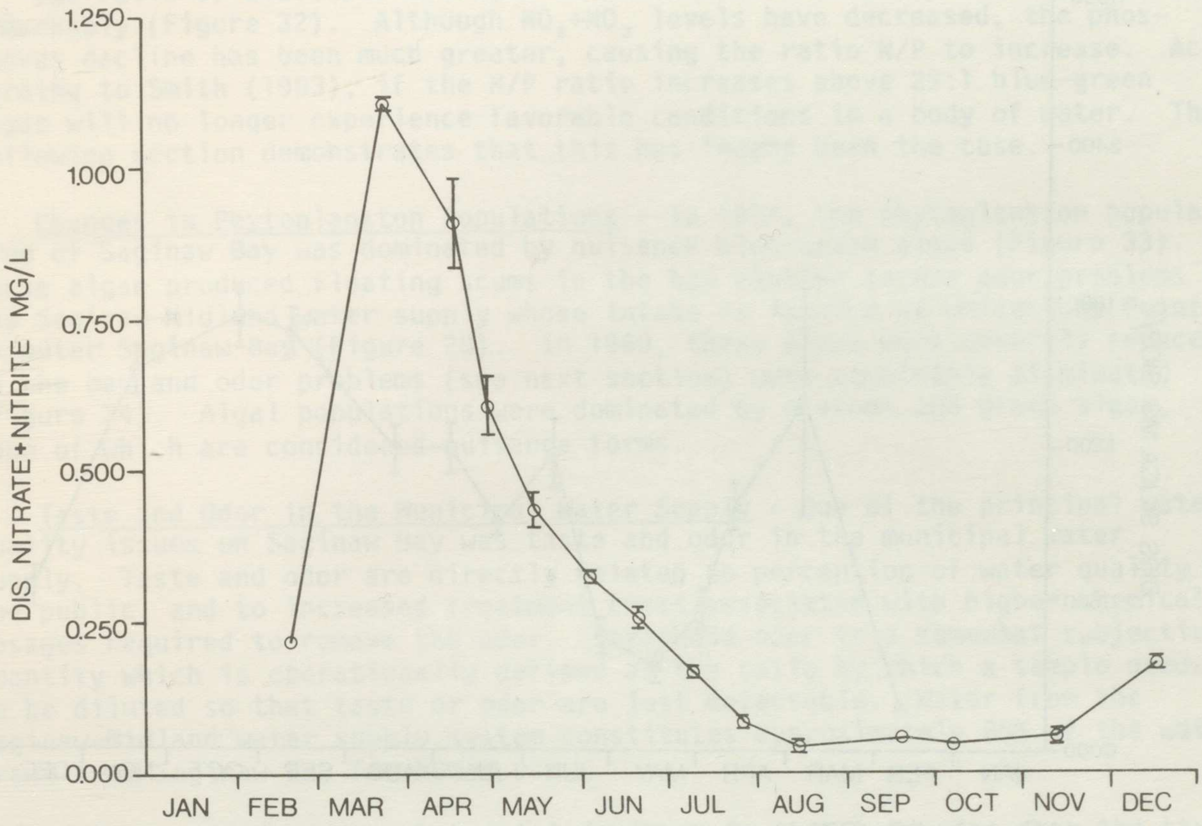


Segment 2, 1974

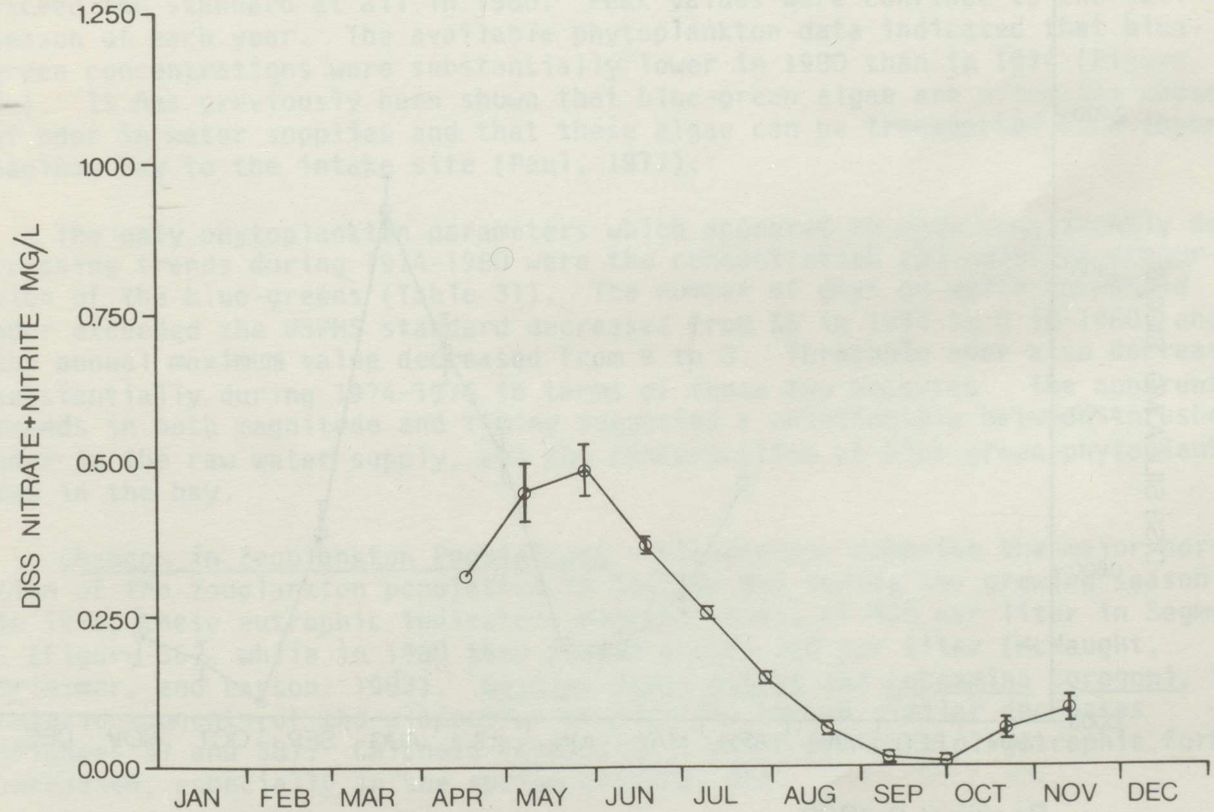


Segment 2, 1980

FIGURE 30 1974 AND 1980 NITRATE-NITRITE CONCENTRATIONS IN SAGINAW BAY

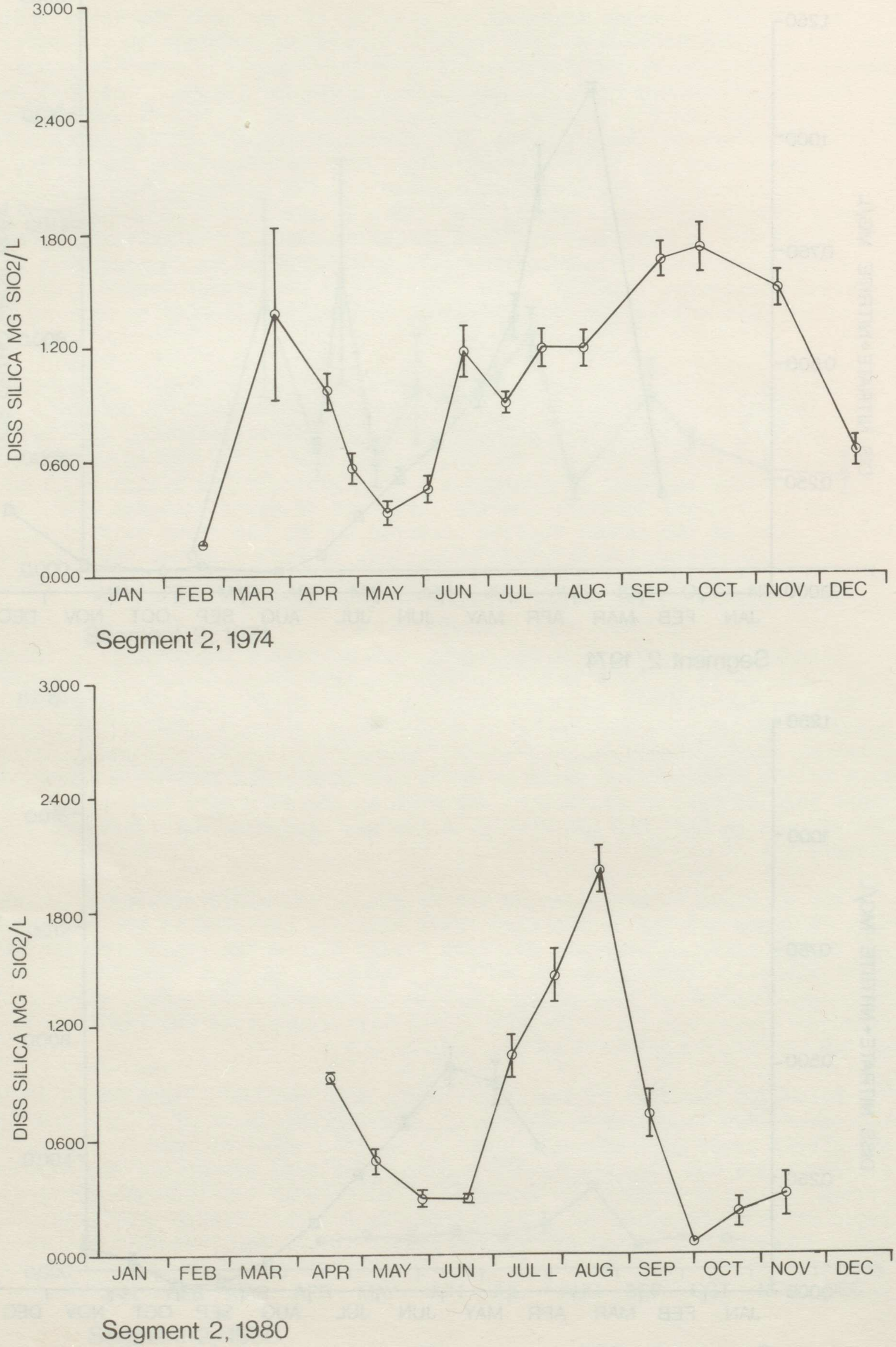


Segment 2, 1974



Segment 2, 1980

FIGURE 31 1974 AND 1980 DISSOLVED SILICA CONCENTRATIONS IN SAGINAW BAY



The ratio of available nitrogen to phosphorus in Saginaw Bay has increased remarkably (Figure 32). Although NO_3+NO_2 levels have decreased, the phosphorus decline has been much greater, causing the ratio N/P to increase. According to Smith (1983), if the N/P ratio increases above 29:1 blue-green algae will no longer experience favorable conditions in a body of water. The following section demonstrates that this has indeed been the case.

Changes in Phytoplankton Populations - In 1974, the phytoplankton population of Saginaw Bay was dominated by nuisance blue-green algae (Figure 33). These algae produced floating scums in the bay causing severe odor problems in the Saginaw-Midland water supply whose intake is located at Whitestone Point, in outer Saginaw Bay (Figure 28). In 1980, these algae were severely reduced in the bay and odor problems (see next section) were completely eliminated (Figure 34). Algal populations were dominated by diatoms and green algae, none of which are considered nuisance forms.

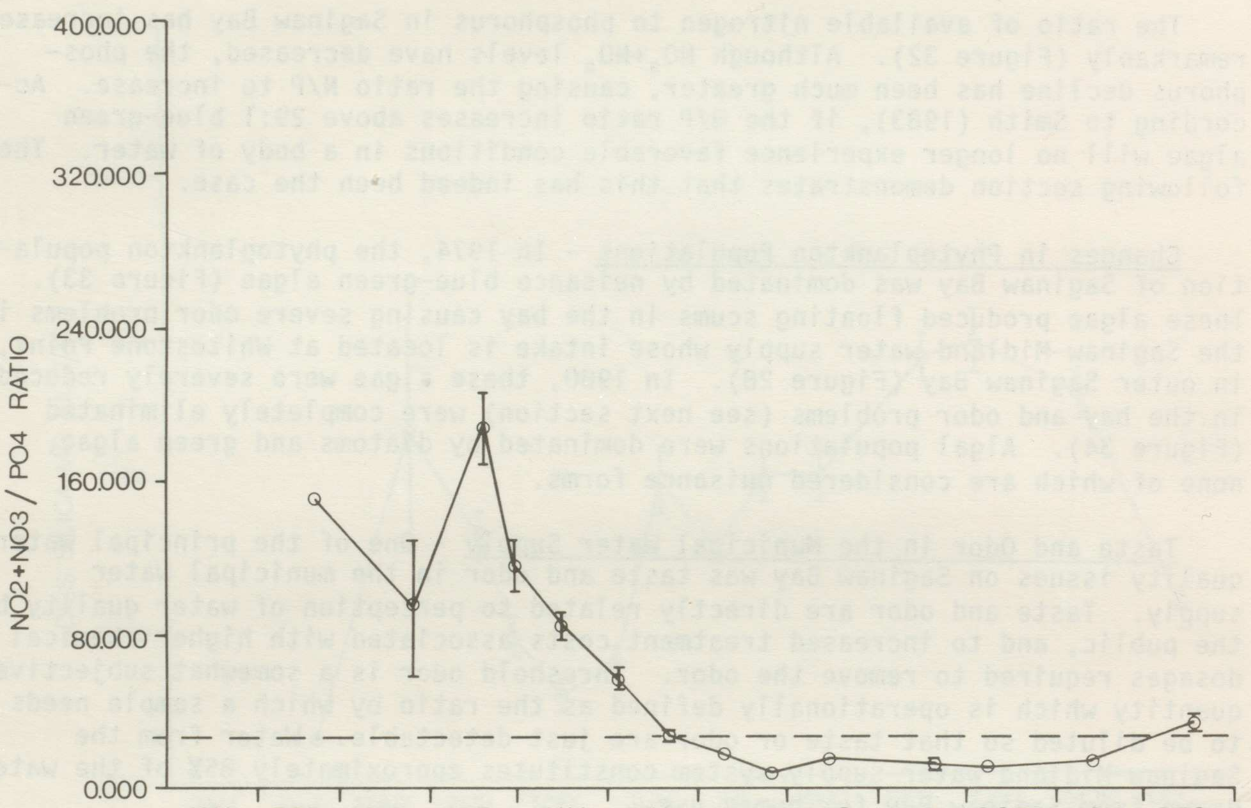
Taste and Odor in the Municipal Water Supply - One of the principal water quality issues on Saginaw Bay was taste and odor in the municipal water supply. Taste and odor are directly related to perception of water quality by the public, and to increased treatment costs associated with higher chemical dosages required to remove the odor. Threshold odor is a somewhat subjective quantity which is operationally defined as the ratio by which a sample needs to be diluted so that taste or odor are just detectable. Water from the Saginaw-Midland water supply system constitutes approximately 85% of the water drawn from Saginaw Bay for human use.

Analysis indicated a substantial decrease in threshold odor over the study period. Threshold odor exceeded the United States Public Health Service (USPHS) standard of three for an extended period during 1974, but did not exceed the standard at all in 1980. Peak values were confined to the fall season of each year. The available phytoplankton data indicated that blue-green concentrations were substantially lower in 1980 than in 1974 (Figure 35). It has previously been shown that blue-green algae are often the cause of odor in water supplies and that these algae can be transported from inner Saginaw Bay to the intake site (Paul, 1977).

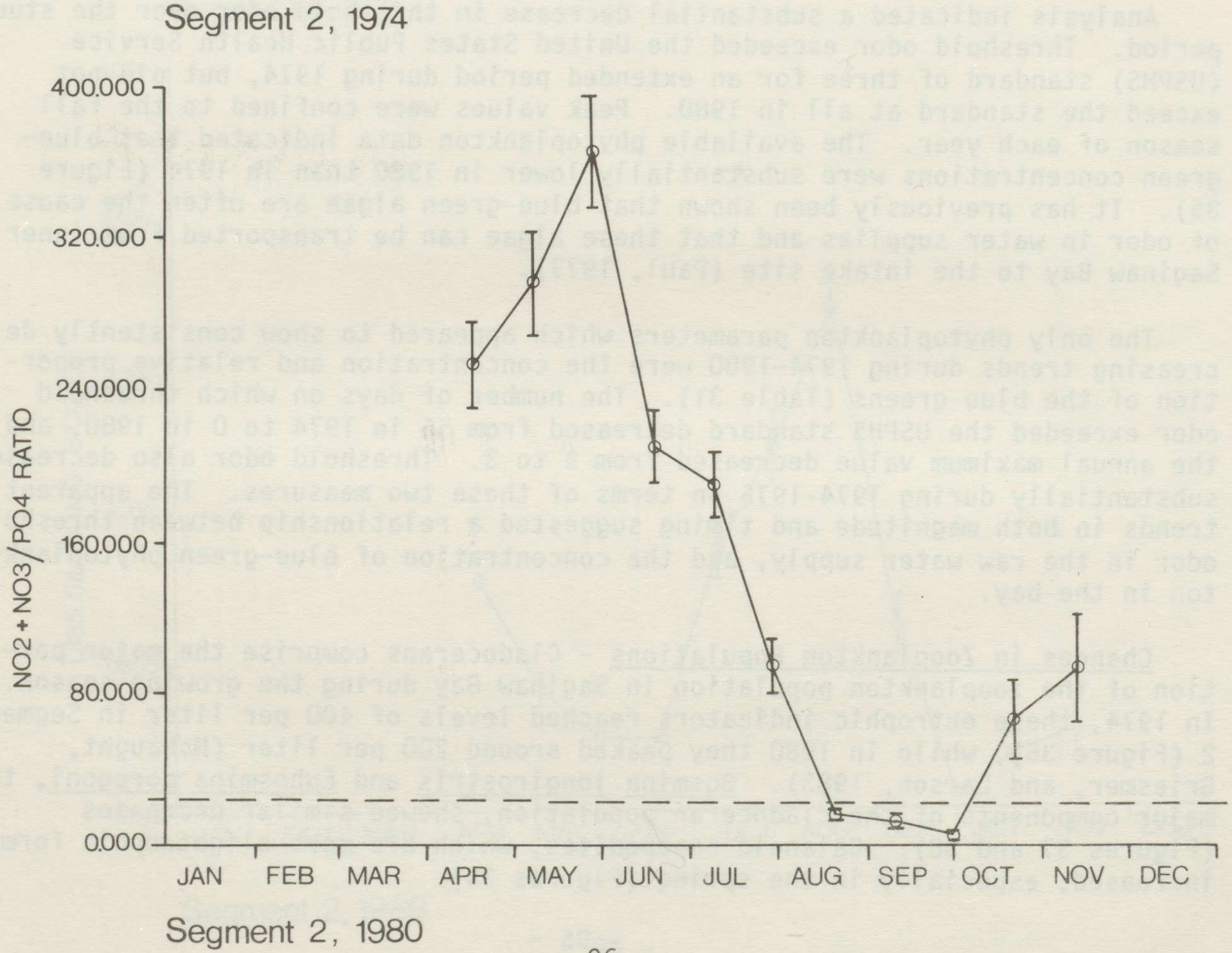
The only phytoplankton parameters which appeared to show consistently decreasing trends during 1974-1980 were the concentration and relative proportion of the blue-greens (Table 31). The number of days on which threshold odor exceeded the USPHS standard decreased from 56 in 1974 to 0 in 1980, and the annual maximum value decreased from 9 to 3. Threshold odor also decreased substantially during 1974-1976 in terms of these two measures. The apparent trends in both magnitude and timing suggested a relationship between threshold odor in the raw water supply, and the concentration of blue-green phytoplankton in the bay.

Changes in Zooplankton Populations - Cladocerans comprise the major portion of the zooplankton population in Saginaw Bay during the growing season. In 1974, these eutrophic indicators reached levels of 400 per liter in Segment 2 (Figure 36), while in 1980 they peaked around 200 per liter (McNaught, Griesmer, and Larson, 1983). Bosmina longirostris and Eubosmina coregoni, the major components of the cladoceran population, showed similar decreases (Figures 37 and 38). Calanoid copepodites, which are more oligotrophic forms, increased, especially in the spring (Figures 39).

FIGURE 32 1974 AND 1980 N/P RATIOS CONCENTRATIONS IN SAGINAW BAY



Segment 2, 1974



Segment 2, 1980

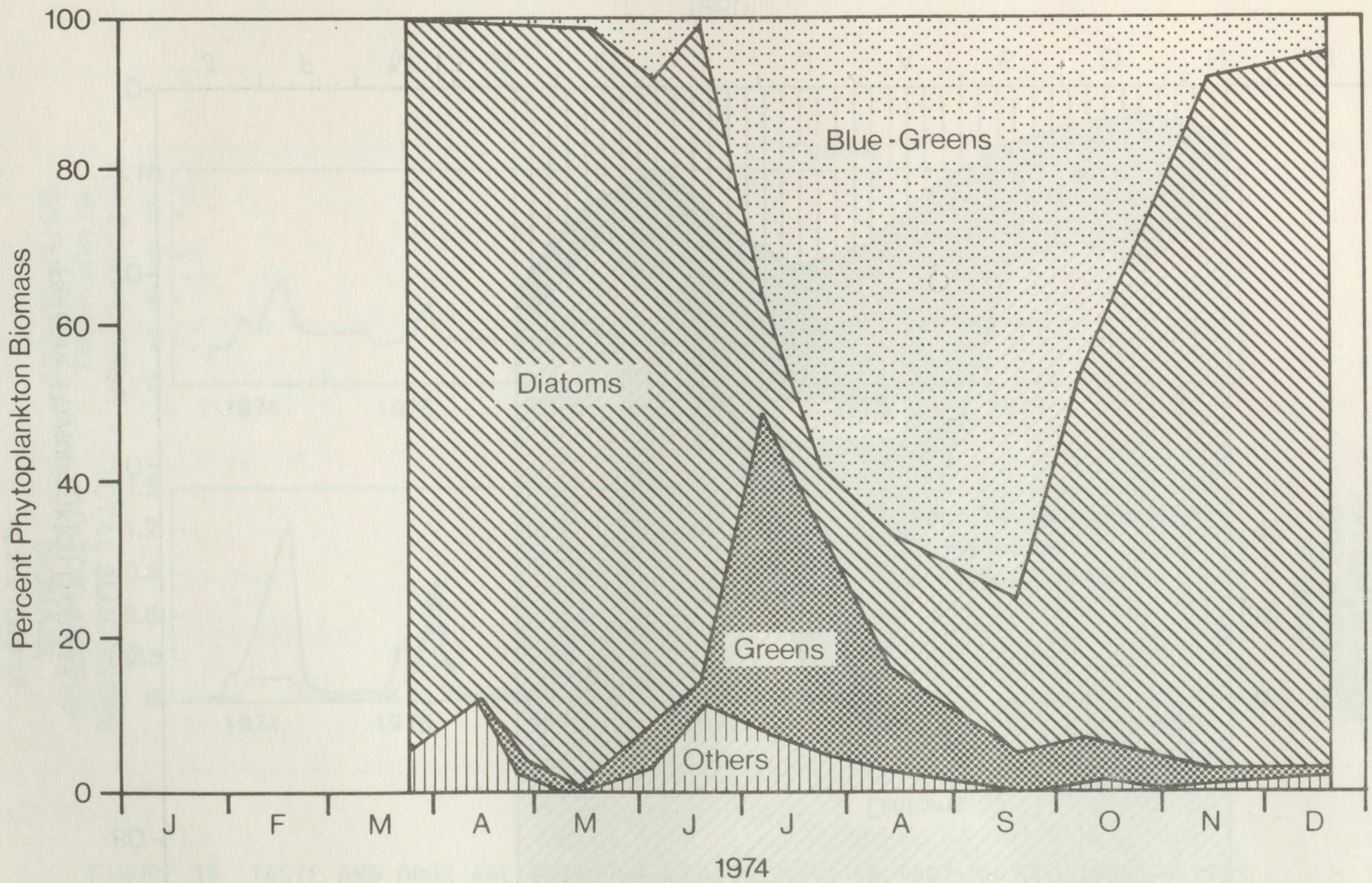


FIGURE 33 COMPOSITION OF PHYTOPLANKTON CROP VS. TIME FOR INNER SAGINAW BAY, 1974

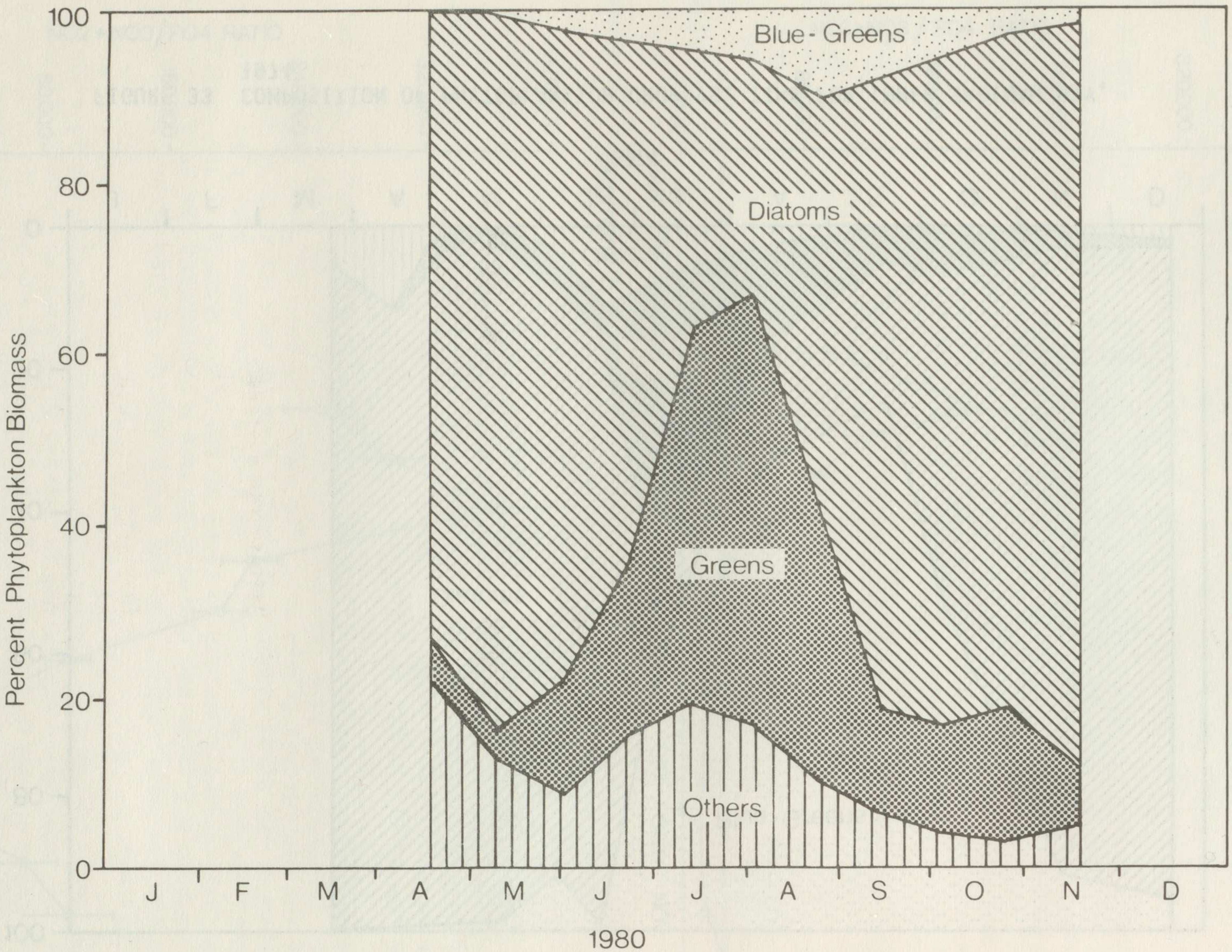


FIGURE 34 COMPOSITION OF PHYTOPLANKTON CROP VS. TIME FOR INNER SAGINAW BAY, 1980

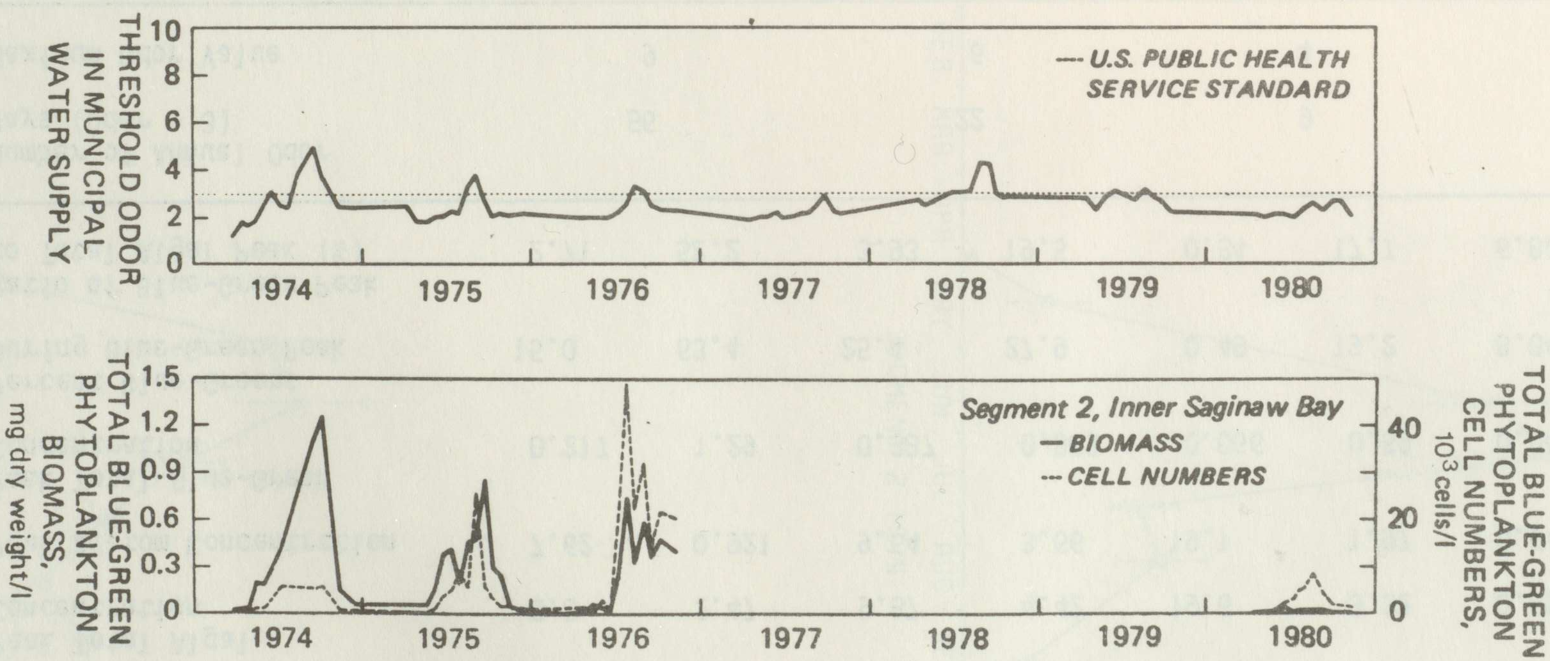


FIGURE 35 TASTE AND ODOR AND PHYTOPLANKTON BIOMASS IN SAGINAW BAY WATER WASTES

TABLE 31

SEASONAL PHYTOPLANKTON CONCENTRATIONS IN SEGMENT 2, INNER SAGINAW BAY

PARAMETER	CONCENTRATION, mg DRY WEIGHT/L							
	1974		1975		1976		1980	
	SPRING	FALL	SPRING	FALL	SPRING	FALL	SPRING	FALL
Peak Total Algal Concentration	8.0	2.47	9.87	4.42	19.6	3.32	0.630	1.39
Peak Diatom Concentration	7.62	0.921	9.64	3.66	19.1	1.97	0.541	1.30
Peak Total Blue-Green Concentration	0.217	1.29	0.387	0.863	0.066	0.59	0.043	0.027
Percent Blue-Greens During Blue-Green Peak	15.0	63.4	25.4	27.9	0.49	19.2	8.04	5.46
Ratio of Blue-Green Peak to Total Algal Peak (%)	2.71	52.2	3.93	19.5	0.34	17.7	6.82	1.94
Number of Annual Odor Days (Odor > 3)	56		22		9		0	
Maximum Odor Value	9		6		4		3	

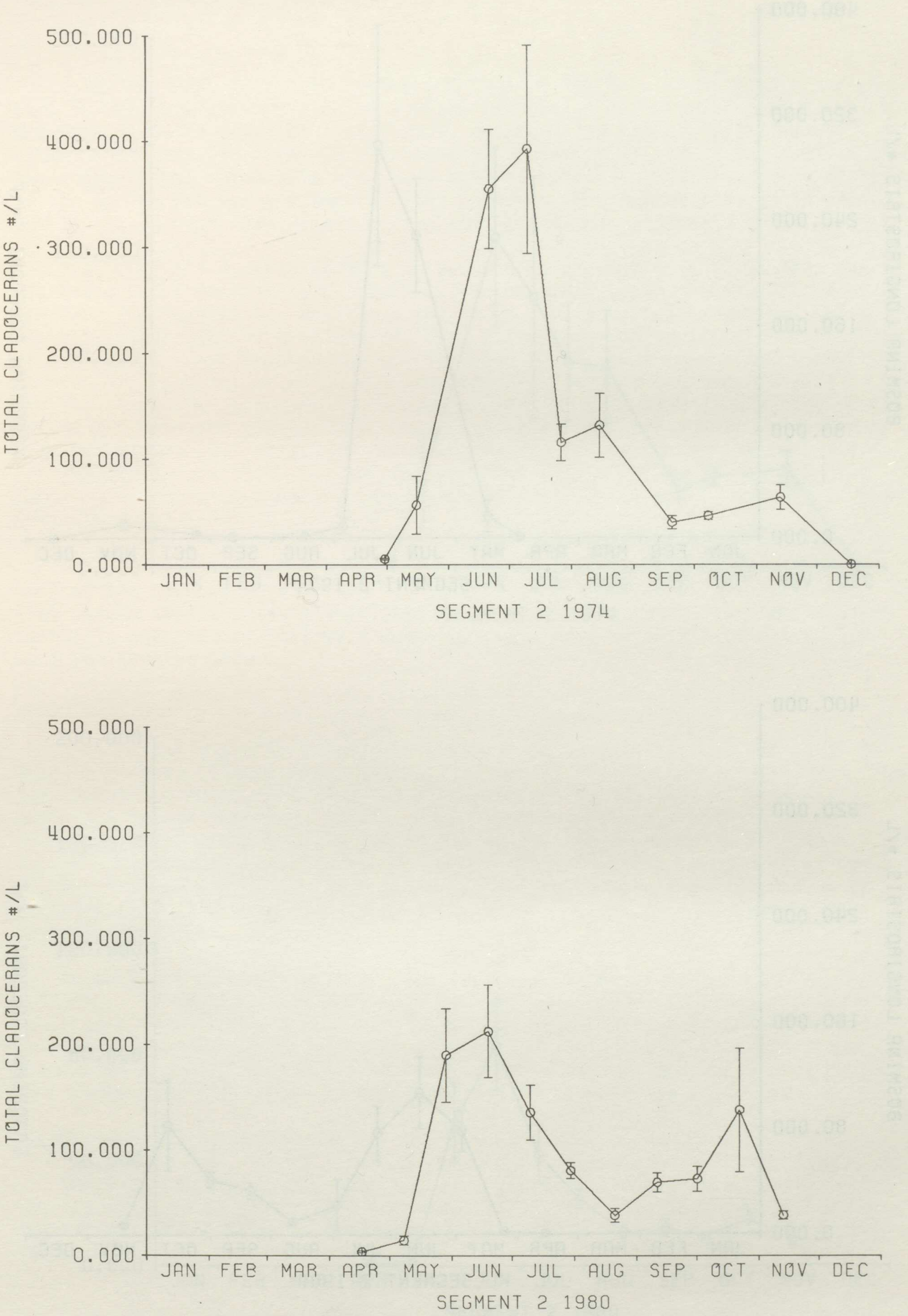
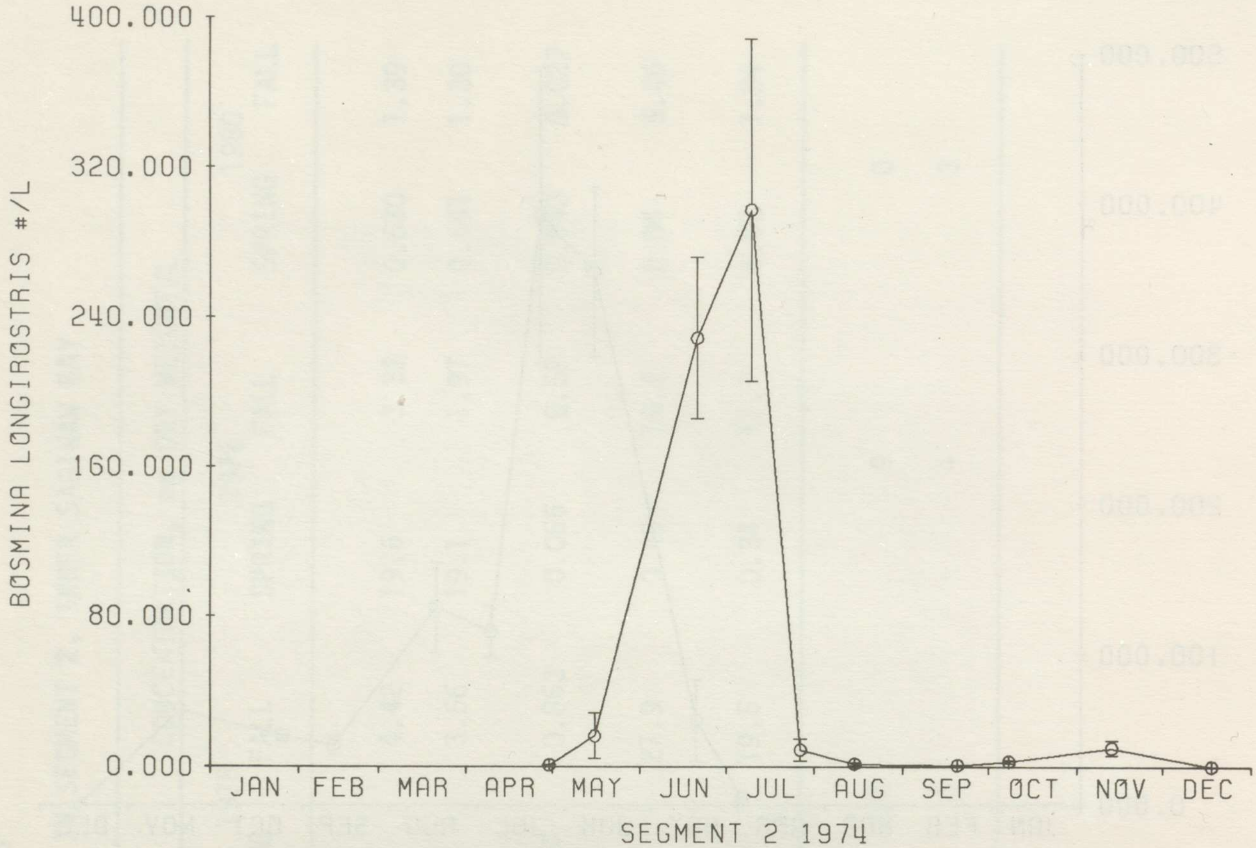


FIGURE 36 1974 AND 1980 ZOOPLANKTON NUMBERS IN SAGINAW BAY



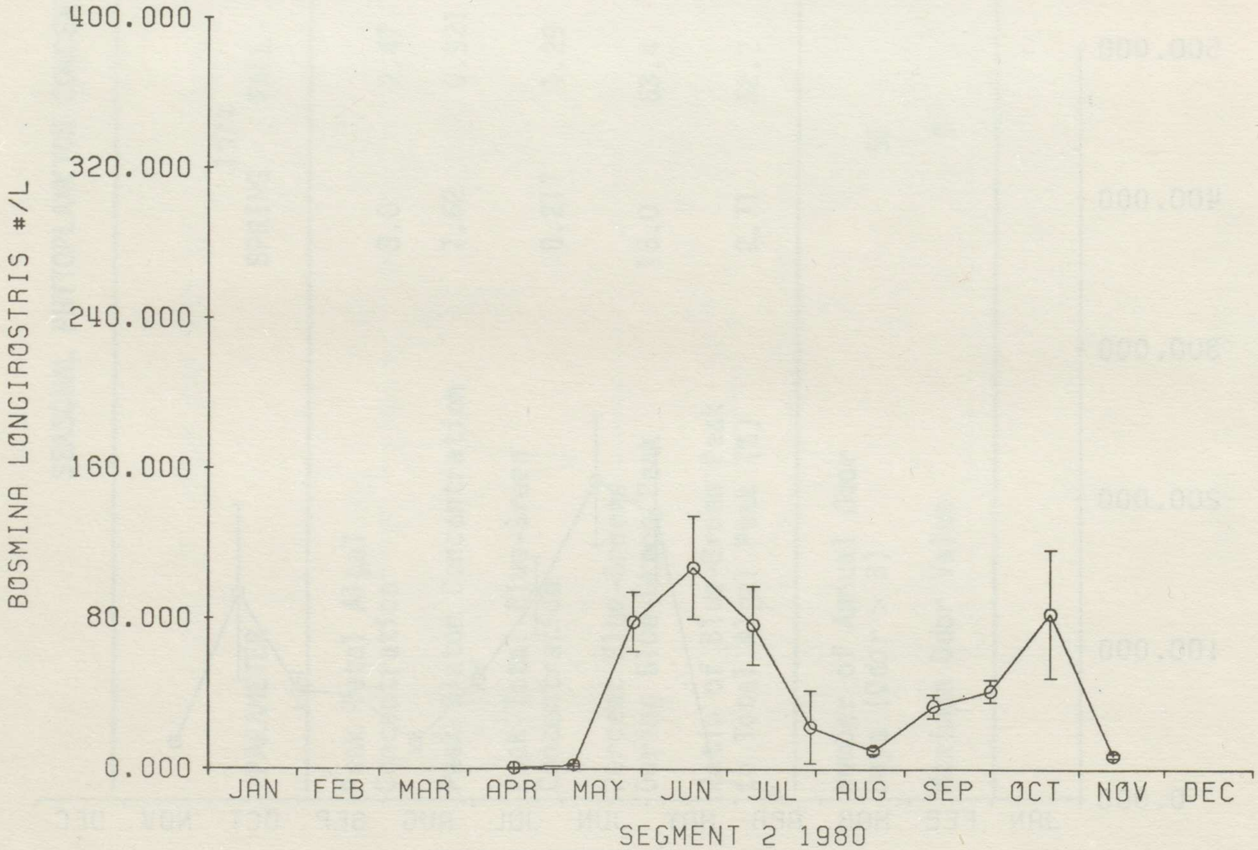


FIGURE 37 1974 AND 1980 ZOOPLANKTON NUMBERS IN SAGINAW BAY

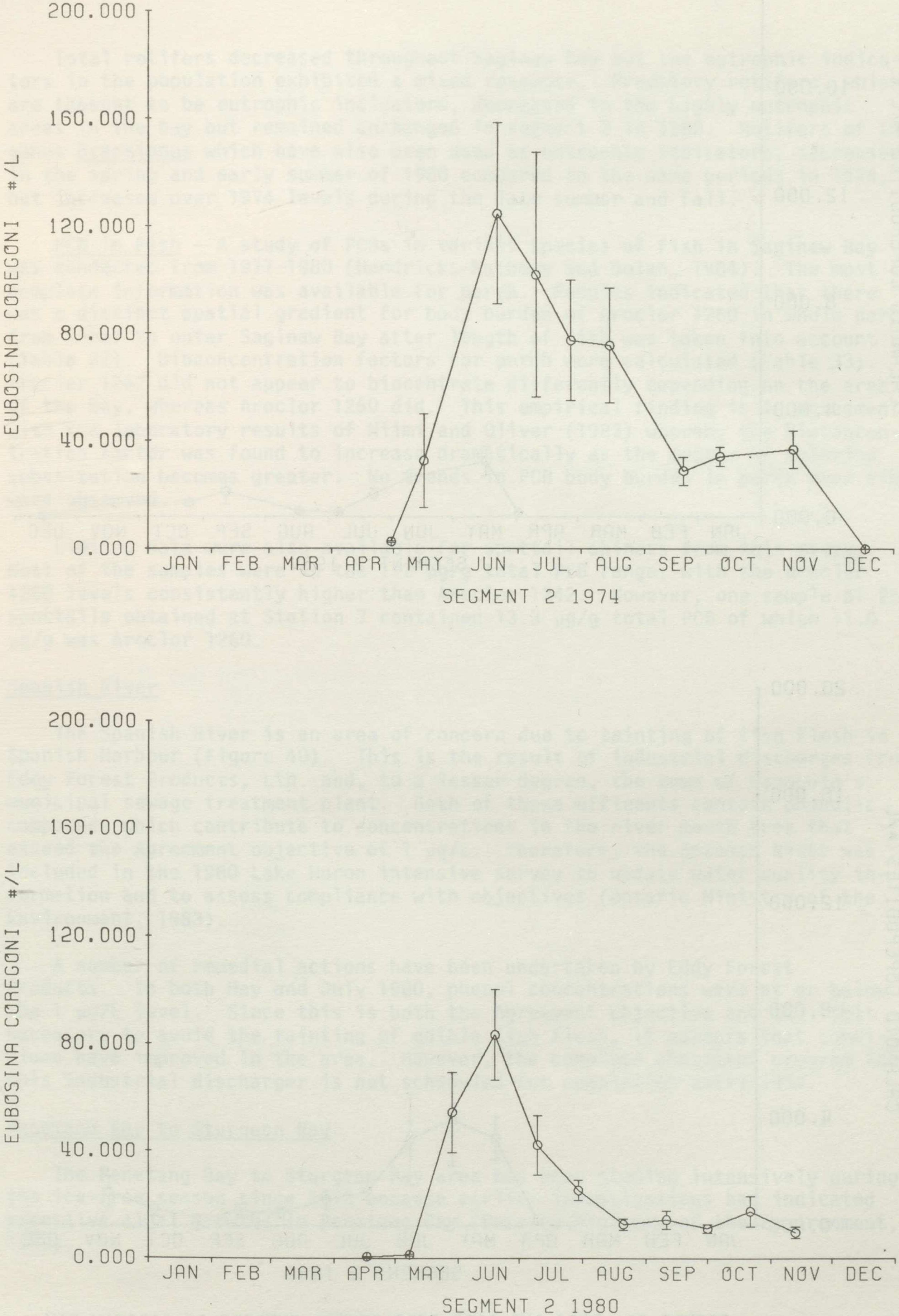


FIGURE 38 1974 AND 1980 ZOOPLANKTON NUMBERS IN SAGINAW BAY

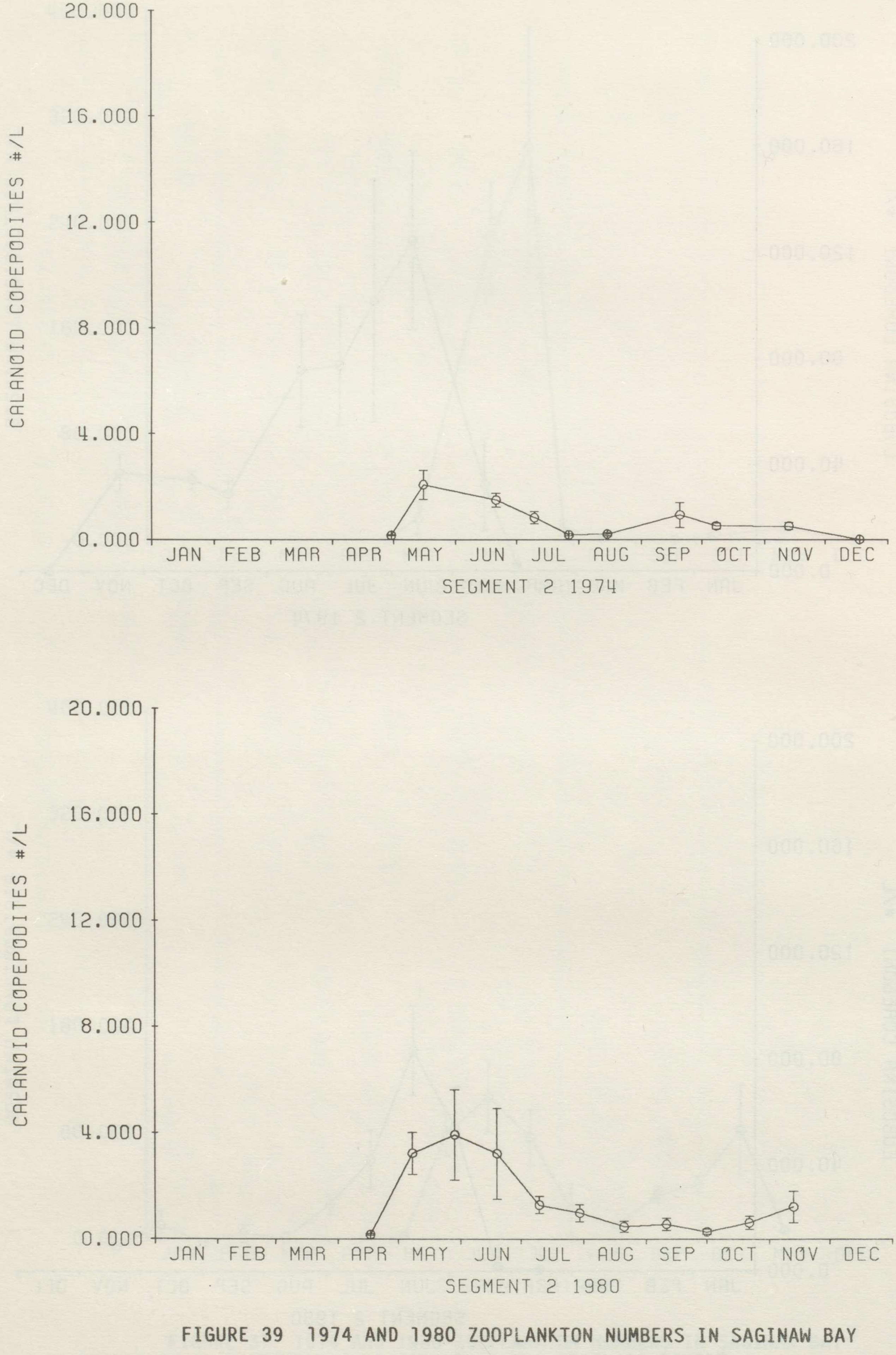


FIGURE 39 1974 AND 1980 ZOOPLANKTON NUMBERS IN SAGINAW BAY

Total rotifers decreased throughout Saginaw Bay but the eutrophic indicators in the population exhibited a mixed response. Predatory rotifers, which are thought to be eutrophic indicators, decreased in the highly eutrophic areas in the bay but remained unchanged in segment 2 in 1980. Rotifers of the genus Brachionus which have also been used as eutrophic indicators, decreased in the spring and early summer of 1980 compared to the same periods in 1974, but increased over 1974 levels during the late summer and fall.

PCB in Fish - A study of PCBs in various species of fish in Saginaw Bay was conducted from 1977-1980 (Hendricks-Mathews and Dolan, 1984). The most complete information was available for perch. Results indicated that there was a distinct spatial gradient for body burden of Aroclor 1260 in whole perch from inner to outer Saginaw Bay after length of fish was taken into account (Table 32). Bioconcentration factors for perch were calculated (Table 33). Aroclor 1242 did not appear to biocentrate differently depending on the area of the bay, whereas Aroclor 1260 did. This empirical finding is in agreement with the laboratory results of Niimi and Oliver (1983) whereby the bioconcentration factor was found to increase dramatically as the degree of chlorine substitution becomes greater. No trends in PCB body burden in perch over time were observed.

Limited data were also available for spottail shiners from this study. Most of the samples were in the 1-2 µg/g total PCB range, with the Aroclor 1260 levels consistently higher than Aroclor 1242. However, one sample of 25 spottails obtained at Station 7 contained 13.3 µg/g total PCB of which 11.0 µg/g was Aroclor 1260.

Spanish River

The Spanish River is an area of concern due to tainting of fish flesh in Spanish Harbour (Figure 40). This is the result of industrial discharges from Eddy Forest Products, Ltd. and, to a lesser degree, the town of Espanola's municipal sewage treatment plant. Both of these effluents contain phenolic compounds which contribute to concentrations in the river mouth area that exceed the Agreement objective of 1 µg/L. Therefore, the Spanish River was included in the 1980 Lake Huron intensive survey to update water quality information and to assess compliance with objectives (Ontario Ministry of the Environment, 1983).

A number of remedial actions have been undertaken by Eddy Forest Products. In both May and July 1980, phenol concentrations were at or below the 1 µg/L level. Since this is both the Agreement objective and the limit necessary to avoid the tainting of edible fish flesh, it appears that conditions have improved in the area. However, the complete abatement program for this industrial discharger is not scheduled for completion until 1984.

Penetang Bay to Sturgeon Bay

The Penetang Bay to Sturgeon Bay area has been studied intensively during the ice-free season since 1973 because earlier investigations had indicated excessive algal growths in Penetang Bay (Ontario Ministry of the Environment, 1983).

TABLE 32

PAIRWISE COMPARISONS FOR PERCH PCB BODY BURDEN CAUGHT AT DIFFERENT STATIONS, 1977-1980

STATION NUMBER	LENGTH ADJUSTED MEAN AROCLOR 1260	STATIONS DIFFERING SIGNIFICANTLY FROM EACH OTHER*
7	1.29 µg/g	26 and 53
26	1.53 µg/g	all but 47
29	1.23 µg/g	26 and 53
47	1.21 µg/g	none
53	0.98 µg/g	all but 47

Grand mean = 1.24 µg/g Aroclor 1260

*α = 0.05

TABLE 33

BIOCONCENTRATION FACTORS (BCFs) FOR A1242, A1260 AND TPCB IN SAGINAW BAY YELLOW PERCH, 1977-1980

	BIOCONCENTRATION FACTORS*		
SEGMENT	A1242	A1260	TPCB
1	47390	60700	53600
2	50750	93850	72350
3	48820	109380	78900
4	44300	130770	95580
5	48040	119660	88890

*Based on concentrations of A1242 and A1260 in total water as reported by Richardson _et al_., 1983.

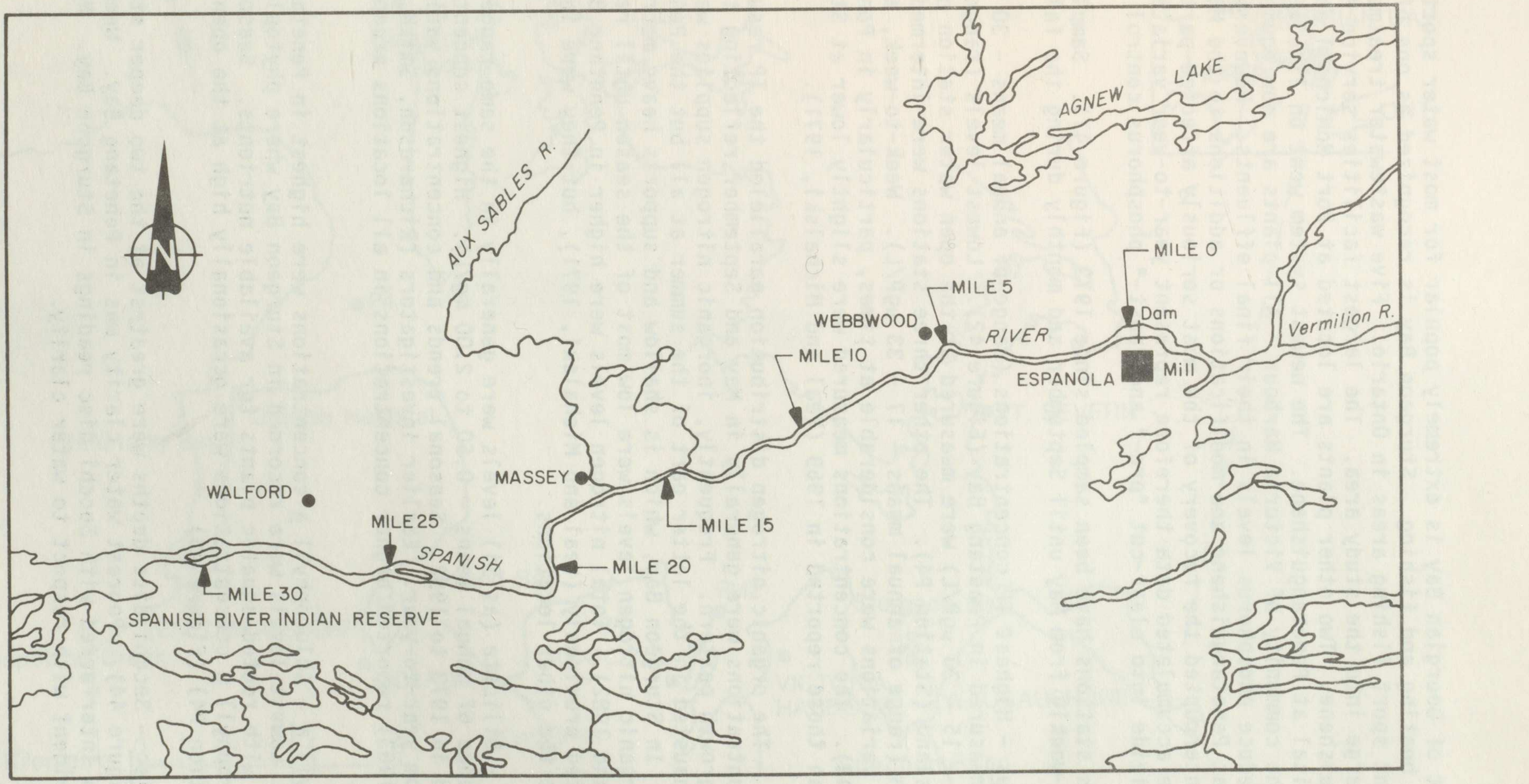


FIGURE 40 THE LOWER SPANISH RIVER

This part of Georgian Bay is extremely popular for most water sports, particularly boating and fishing. Sturgeon Bay is recognized as one of the most important sport fishing areas in Ontario. Five wastewater treatment plants discharge into the study area. The largest facilities service Midland and Penetanguishene. Two other plants are located at Port McNicholl and the Ontario Hospital at Penetanguishene. The newest system went on line in 1983 and serves the community of Victoria Harbour. All plants are now equipped to chemically reduce phosphorus levels in their final effluents. However, plant overloading at Penetanguishene and modifications or additions to the Midland plant have interrupted the recovery of the most seriously affected parts of the bay. The accumulated data therefore represent year-to-year variation only and do not divide into clear-cut "pre-" and "post-" phosphorus control periods.

Five main stations have been sampled since 1973 (Figure 41). Samples were collected bi-weekly from May until September and monthly during the fall.

Phosphorus - Highest TP concentrations (range of annual means - 30 to 49 µgP/L) were measured in Penetang Bay (Figure 42). Lowest levels (range of annual means - 15 - 20 µgP/L) were measured at the open water station near Beausoleil Island (Station P4). The other three stations were intermediate in concentration (range of annual means - 17 - 33 µgP/L). Week-to-week, and year-to-year variations were considerable at times, particularly in Penetang Bay (Figure 43). The concentrations measured were slightly lower at Stations P1 and P4 than those reported in 1969 (Veal and Michalski, 1971).

Nitrogen - The organic nitrogen distribution paralleled the TP results. Highest concentrations were generally in May and September reflecting the bi-modal algal growth pattern. Frequently, inorganic nitrogen supplies were virtually exhausted in the latter part of the summer at all but the Penetang Bay station. In Sturgeon Bay, which is shallow and supports heavy macrophyte growths, inorganic nitrogen levels were low most of the season until recent years (1981 and 1982). Total nitrogen levels were higher in Penetang Bay than levels reported previously (Veal and Michalski, 1971), but they were in the same range at the other locations.

Silicate - Silicate (as Si) levels were generally in the same range at all locations (range of annual means - 0.50 to 2.00 mg/L). Highest concentrations were measured in 1973 to 1982. Seasonal trends and concentrations varied considerably from year-to-year. Earlier investigators (Richardson, Smith, and Wethington, 1983) reported higher concentrations in all locations except Sturgeon Bay.

Chlorophyll a - Chlorophyll a concentrations were highest in Penetang Bay (Figure 44). Lowest levels were recorded in Sturgeon Bay where phytoplankton must compete with rooted aquatic plants for available nutrients. Seasonal maximum chlorophyll a concentrations were occasionally high at the open water station (Station P4) (Figure 45).

Secchi Disc - Secchi disc depths were greatest at the two deeper stations, P4 and M1 (Figure 44). Poorest water clarity was in Penetang Bay. Weed growths often interferred with Secchi disc readings in Sturgeon Bay. No trends are evident with respect to water clarity.

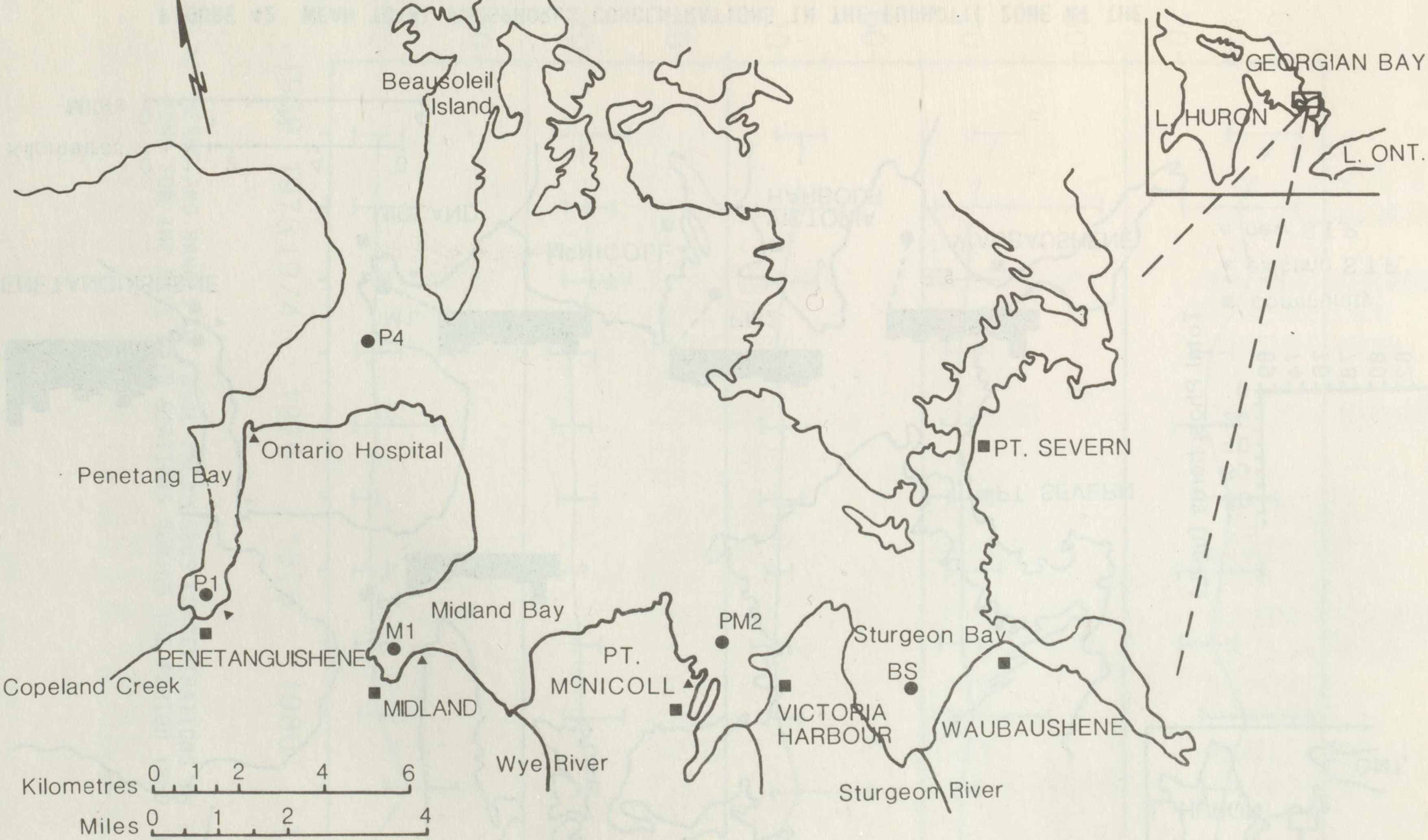


FIGURE 41 MAP OF THE PENETANGUISHENE-WAUBAUSHENE AREA

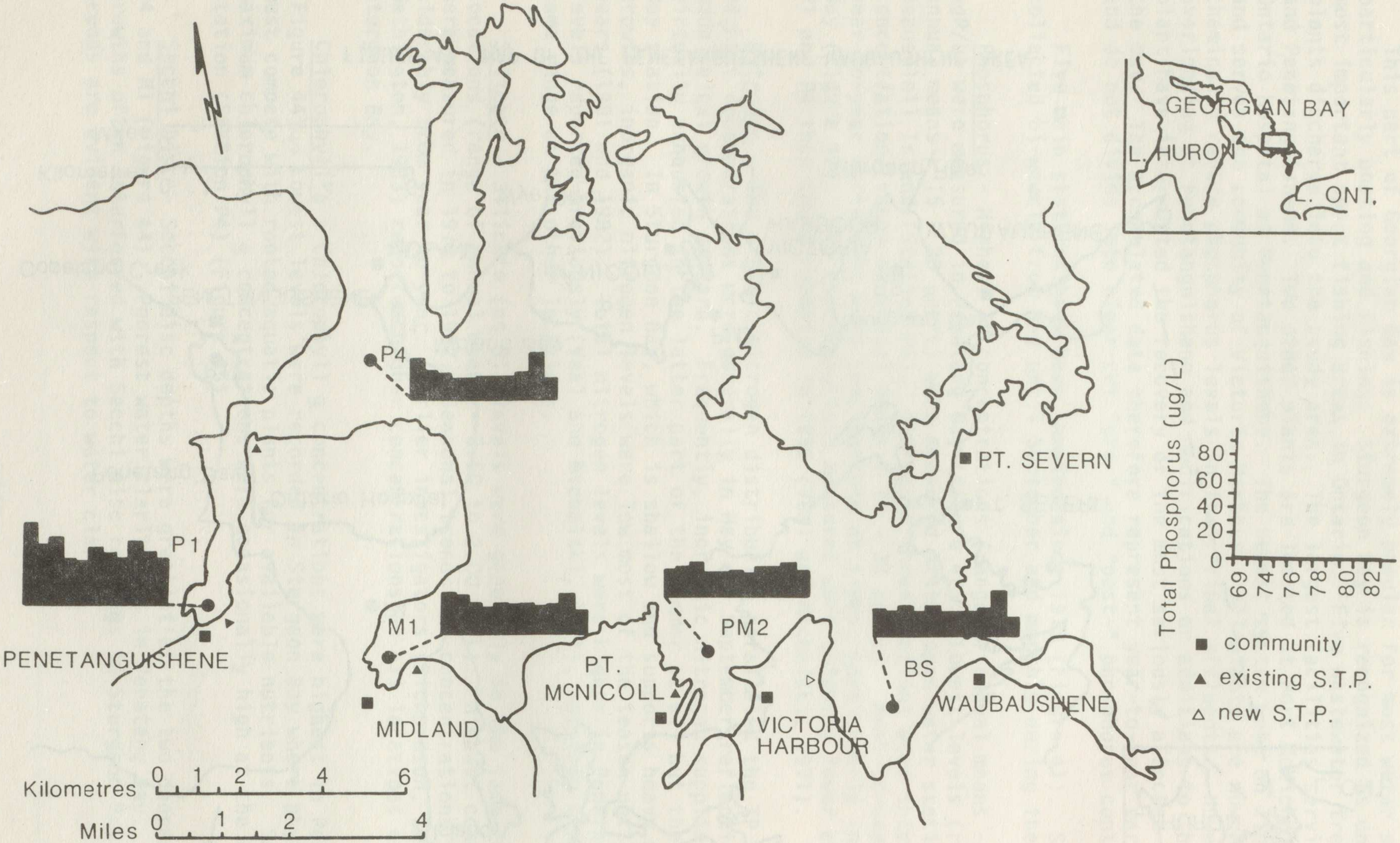


FIGURE 42 MEAN TOTAL PHOSPHORUS CONCENTRATIONS IN THE EUPHOTIC ZONE AT THE FIVE MAIN STATIONS DURING THE PERIOD 1969, 1973-1982

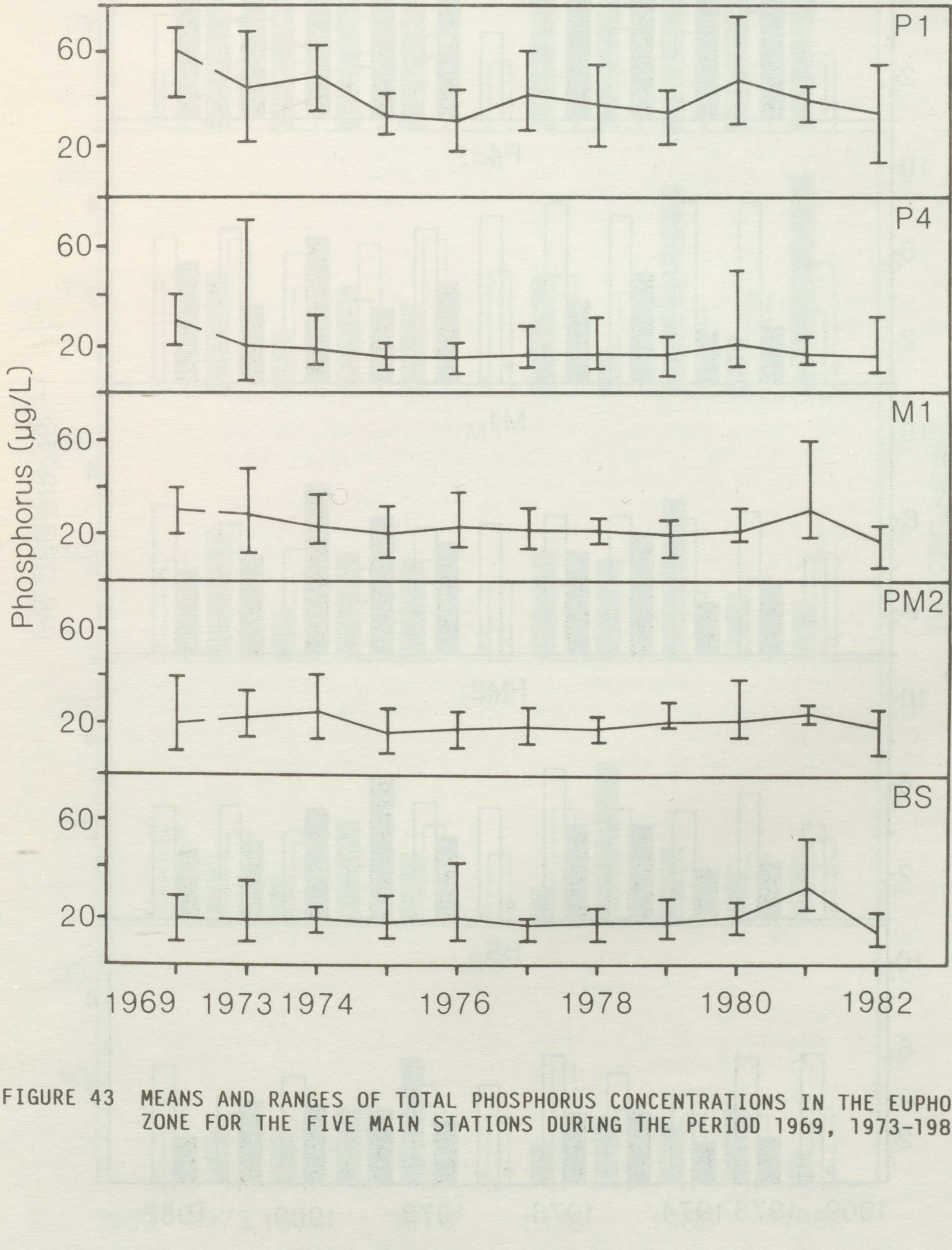


FIGURE 43 MEANS AND RANGES OF TOTAL PHOSPHORUS CONCENTRATIONS IN THE EUPHOTIC ZONE FOR THE FIVE MAIN STATIONS DURING THE PERIOD 1969, 1973-1982

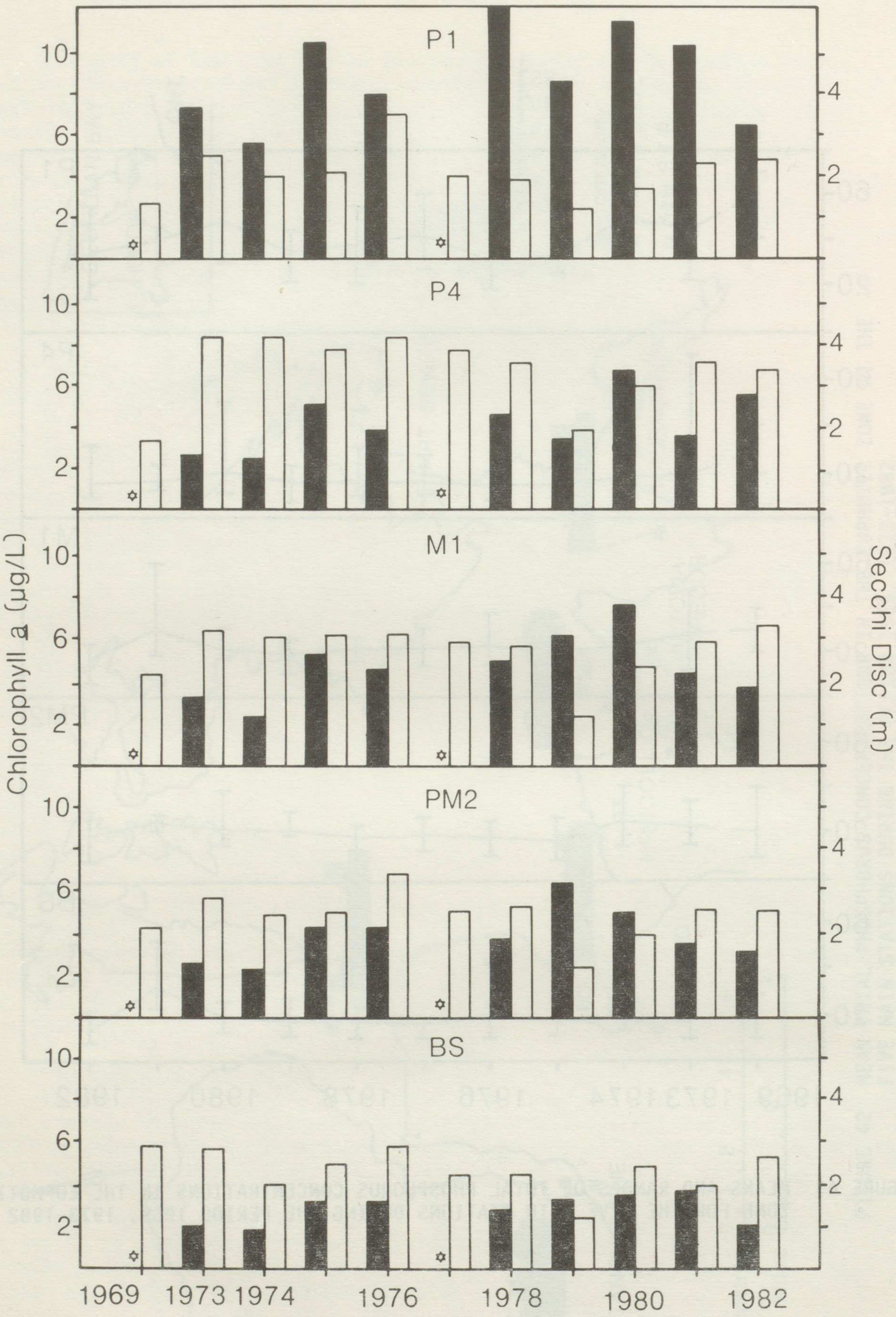


FIGURE 44 MEAN CHLOROPHYLL a CONCENTRATIONS IN THE EUPHOTIC ZONE (BLACK) AND MEAN SECCHI DISC DEPTHS (WHITE) AT THE FIVE MAIN STATIONS FOR THE PERIOD 1969, 1973-1982

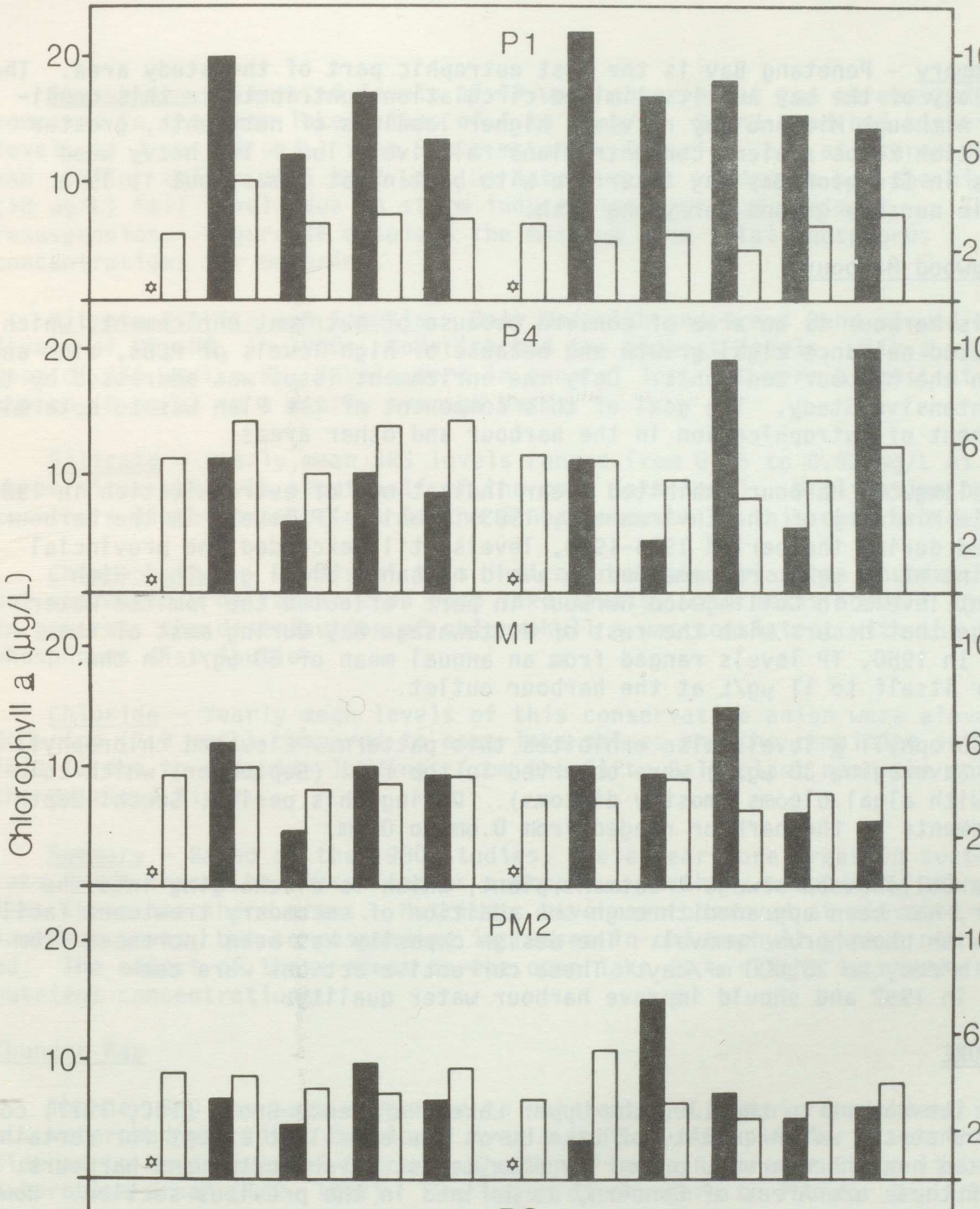


FIGURE 45 MAXIMUM CHLOROPHYLL a CONCENTRATIONS IN THE EUPHOTIC ZONE (BLACK) AND MAXIMUM SECCHI DISC DEPTHS (WHITE) AT THE FIVE MAIN STATIONS FOR THE PERIOD 1969, 1973-1982

Summary - Penetang Bay is the most eutrophic part of the study area. The morphology of the bay and its limited circulation contribute to this condition. Although Midland Bay receives higher loadings of nutrients, greater circulation keeps ambient concentrations relatively low. The heavy weed growths in Sturgeon Bay may interfere with boating at times, but it is a valuable nursery ground for young fish.

Collingwood Harbour

This harbour is an area of concern because of nutrient enrichment, which has caused nuisance algal growth and because of high levels of PCBs, zinc and lead in the harbour sediments. Only the enrichment issue was addressed by the 1980 Intensive Study. The goal of this component of the Plan was to determine the extent of eutrophication in the harbour and other areas.

Collingwood Harbour exhibited clear indications of eutrophication in 1980 (Ontario Ministry of the Environment, 1983). While TP levels in the harbour declined during the period 1974-1980, levels still exceeded the provincial guideline of 20 µg/L recommended to avoid nuisance algal growth. High nutrient levels in Collingwood Harbour in part reflected the limited water exchange that occurs with the rest of Nottawasaga Bay during most of the year. In 1980, TP levels ranged from an annual mean of 60 µg/L in the harbour itself to 11 µg/L at the harbour outlet.

Chlorophyll a levels also exhibited this pattern. Elevated chlorophyll a levels (averaging 30 µg/L) were observed in the fall (September) which coincided with algal blooms (mostly diatoms). During this period, Secchi depth measurements in the harbour ranged from 0.6m to 0.9m.

The Collingwood sewage treatment plant, which is discharging into the harbour, has been upgraded through the addition of secondary treatment facilities with phosphorus removal. The design capacity has been increased from 19,000 m^3/day to 25,000 m^3/day. These corrective actions were completed in 1982 and should improve harbour water quality.

NEARSHORE

In its report to the IJC, the Upper Lakes Reference Group (IJC, 1977) concluded that the water quality of Lake Huron was excellent except for certain localized nearshore areas, primarily embayments, river mouths and harbours. Many of these are Areas of Concern, as defined in the previous section. However, certain nearshore regions, while not severely degraded, showed signs of eutrophication. These areas, which include the southeastern shore of Lake Huron, Nottawasaga Bay in Ontario and Thunder Bay in Michigan, were the subjects of special studies in 1980.

Southeastern Lake Huron

A total of 56 sampling sites were divided among three nearshore regions in southeastern Lake Huron: Grand Bend-Ausable River, Goderich-Maitland River, and Southampton-Saugeen River (Ontario Ministry of the Environment, 1983). Three synoptic cruises were carried out at Southampton and Goderich in late June, late August and mid October/early November. Only the two summer cruises were conducted at Grand Bend due to a severe storm.

Phosphorus - Elevated levels of TP were observed at the three study sites compared to the open lake values of 4 to 5 µg/L. Grand Bend had higher levels in June (10 µg/L) than Southampton or Goderich, but all three sites had similar values of 5 to 7 µg/L by late summer. Goderich had the highest (18 µg/L) fall levels due to storm-induced loadings and sediment resuspension. Figure 46 displays the maximum mean total phosphorus concentrations for Goderich.

Nitrate-Nitrite and Ammonia - Only Goderich and Grand Bend showed elevated levels of NO_3+NO_2 in 1980. Goderich had the highest levels, with a yearly mean of 355 µg/L. NH_3 levels were in general low, but were highest at Southampton (8 µg/L) on a yearly average basis.

Silicate - Yearly mean SRS levels ranged from 0.35 to 0.52 mg/L at the three sites which is about half of the open lake level. Utilization by nearshore diatom populations is the probable cause of this observed decrease.

Chlorophyll *a* - Levels of this indicator of phytoplankton abundance were not appreciably different than open lake levels, with means about 1 µg/L. In general, the distribution of chlorophyll *a* was consistent with the total phosphorus distribution.

Chloride - Yearly mean levels of this conservative anion were elevated at Goderich (7.3 mg/L) compared to open lake values and the remaining sites. This is due to chloride loadings from the Sifto Salt plant near the mouth of the Maitland River.

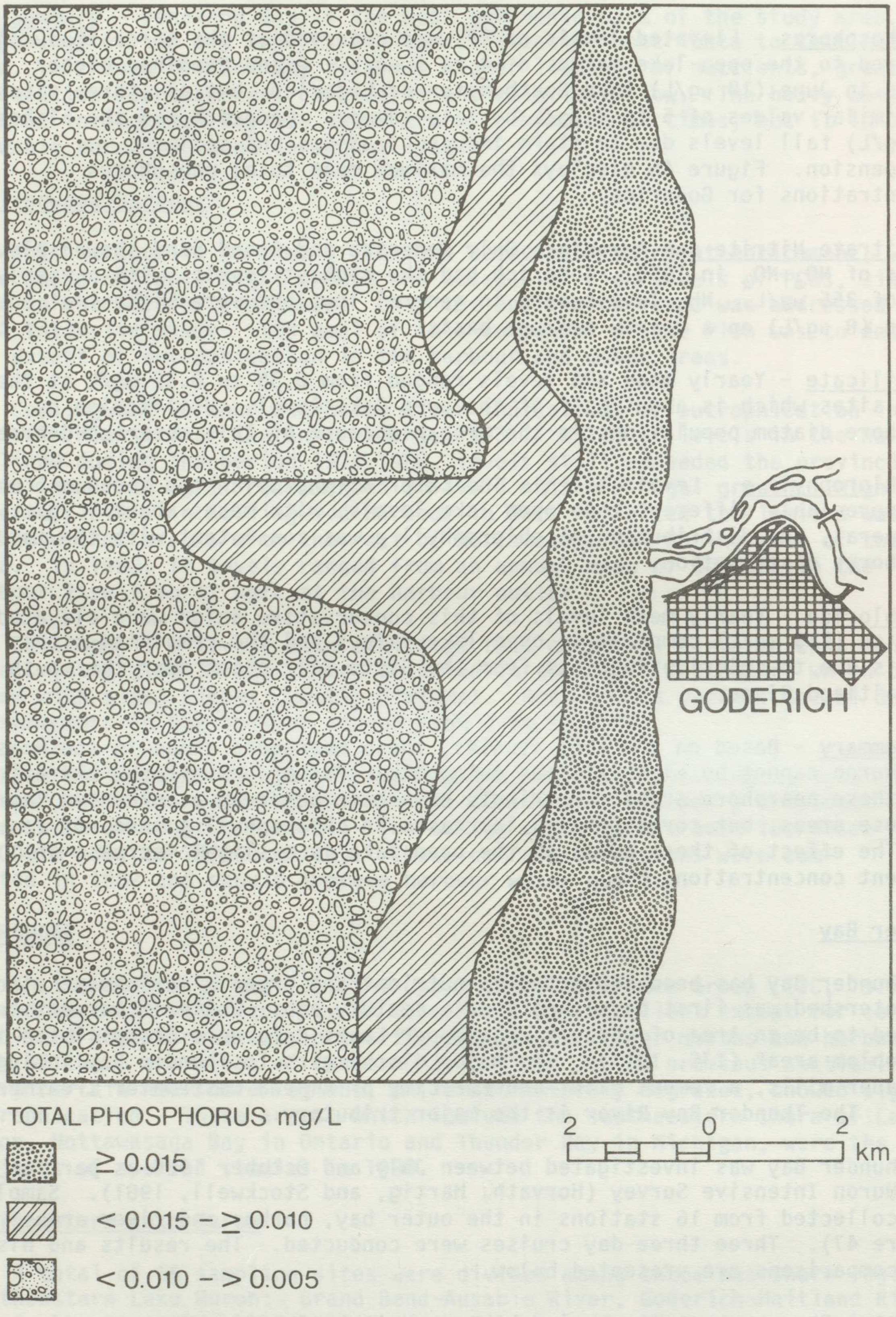
Summary - Based on the 1980 studies, these nearshore areas in southeastern Lake Huron cannot be classified as eutrophic. Rather, mesotrophy characterizes these nearshore areas. Nutrients have been observed at elevated levels in these areas, but corresponding increases in chlorophyll *a* have not resulted. The effect of these areas on the open lake is a slight increase in nutrient concentrations.

Thunder Bay

Thunder Bay has been subjected to nutrient and organic enrichment since its watershed was first developed over a century ago. While it was not considered to be an Area of Concern, the Upper Lakes Reference Group listed it as a "problem area" (IJC, 1977). The major dischargers to Thunder Bay include two paper mills, a cement plant and the City of Alpena wastewater treatment plant. The Thunder Bay River is the major tributary.

Thunder Bay was investigated between July and October 1980 as part of the Lake Huron Intensive Survey (Horvath, Hartig, and Stockwell, 1981). Samples were collected from 16 stations in the outer bay, harbor and river areas (Figure 47). Three three-day cruises were conducted. The results and historical comparisons are presented below.

Total Phosphorus - The period of record is 1968-1980. Concentrations in the river have decreased substantially (<30 µg/L) from the high levels (>100 µg/L) recorded in the late 1960's. Harbor and bay concentrations in 1980 were slightly lower than those observed during the late 1960's. The



TOTAL PHOSPHORUS mg/L

≥ 0.015

< 0.015 − ≥ 0.010

< 0.010 − > 0.005

FIGURE 46 PHOSPHORUS CONCENTRATIONS IN THE GODERICH AREA

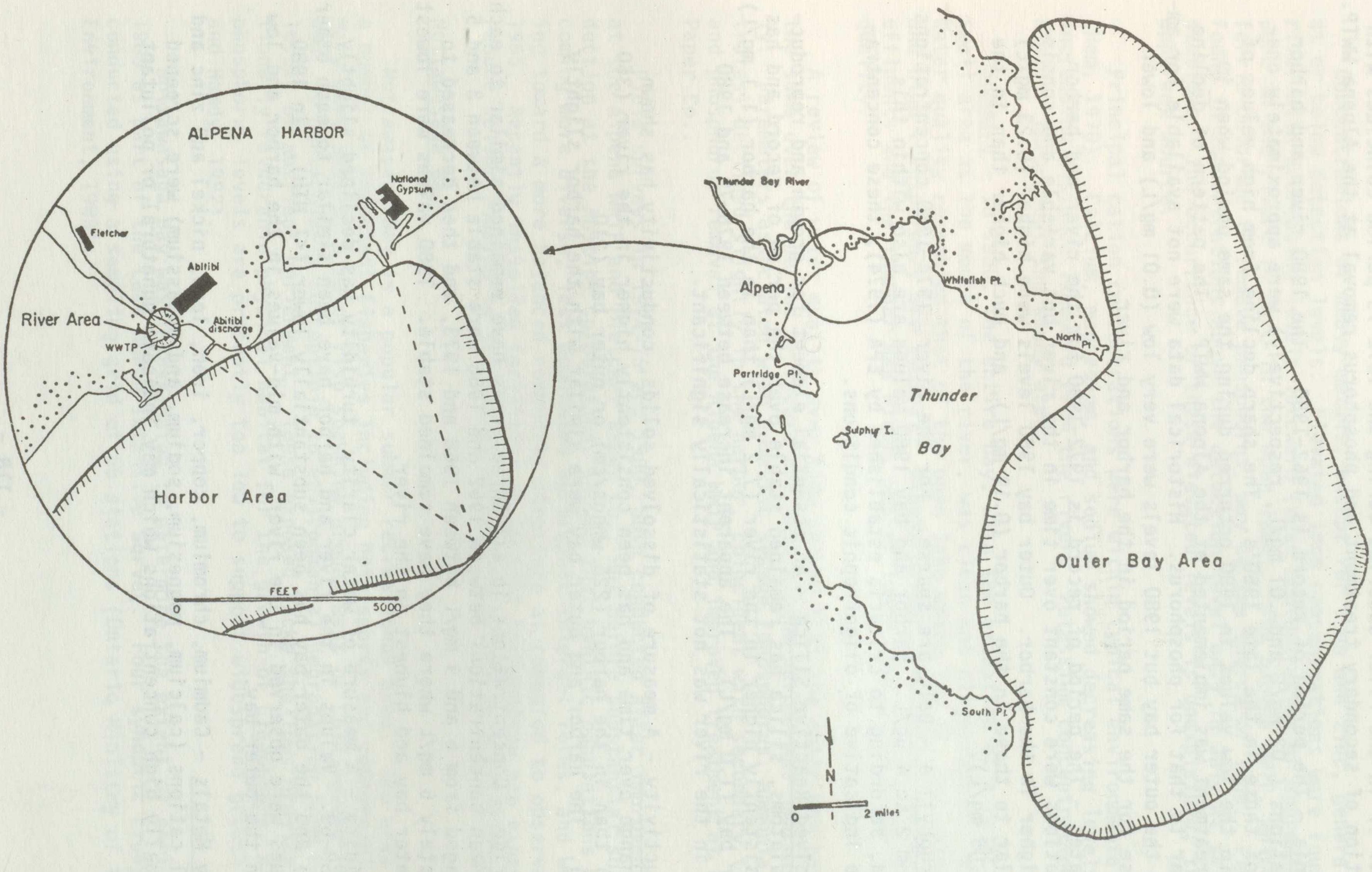


FIGURE 47 THUNDER BAY, ALPENA HARBOR, AND THE THREE AREAS (OUTER BAY, ALPENA HARBOR, AND THE RIVER) WHERE HISTORICAL WATER QUALITY CONDITIONS ARE COMPARED

decline of TP in the river observed during the 1972-75 period coincides with installation of secondary treatment and phosphorus removal at the Alpena WWTP.

Ammonia - The period of record is 1962-1980. The 1980 river and harbor concentrations (.02 mg/L and .01 mg/L, respectively) were approximately one-quarter of those in the late 1960's. The sharp decline from high values of 1968-69 to the low values in 1980 occurred during the same period when improved treatment was implemented at the Alpena WWTP. The pattern of decline is similar to that for phosphorus. Historical data were not available for ammonia in the outer bay but 1980 levels were very low (0.01 mg/L) and lower than those for the same period in the harbor and river.

Nitrates - The period of record is 1972-1980 for the river and harbor. Concentrations were constant over time in the river but variable and consistently higher in the harbor. Outer bay 1980 levels were higher (0.23 mg/L) but similar to those in the harbor (0.19 mg/L), and much higher than in the river (0.05 mg/L).

Chlorophyll a - Data are sparse. For the river, 1974-1980 concentrations range from 2 to 4 μg/L. Harbor and bay 1980 values are also within this range and, according to criteria established by EPA (1974), these concentrations are indicative of oligotrophic conditions.

Dissolved Reactive Silica - An essential element for growth and reproduction of diatoms, silica has remained stable over the period of record and has been consistently higher in the river (7.2 mg/L) than in the harbor (1.1 mg/L) and outer bay (1.0 mg/L). The apparent increase between 1978-79 and 1980 observed in the river was not statistically significant.

Conductivity - A measure of dissolved solids, conductivity has shown little change over time and has been consistently higher in the river (350 μmhos/cm) than in the harbor (225 μmhos/cm) or outer bay (210 μmhos/cm). The harbor and outer bay were similar with the harbor slightly higher.

Chloride - Concentrations in all three areas have remained similar to each other. Mean concentrations between 1962 and 1966 were stable between 3 and 5 mg/L, ranged from 6 and 9 mg/L between 1968 and 1973, and then decreased to approximately 6 mg/L where they have remained stable. 1980 values were lowest in the outer bay and highest in the river.

Turbidity - A measure of water clarity, turbidity has declined slightly since 1968-69. Values in the river and harbor have been similar to each other (2-3 NTU) and the outer bay has been substantially lower (<1 NTU). In 1980, high values were observed in the river, with mid-values in the harbor and low values in the outer bay.

Heavy Metals - Cadmium, chromium, copper, iron, lead, nickel and zinc and principal cations (calcium, magnesium, sodium, and potassium) were screened for unusually high concentrations which may indicate unnatural or pollutant sources.

Concentrations of heavy metals, except for iron and zinc, generally were at or below detection levels. Elevated iron concentrations were found in the river with decreasing levels lakeward (mean concentration of approximately 280 µg/L in the river; 14 µg/L in the open lake). The Alpena WWTP, which uses ferric chloride to remove phosphorus, may be the source of iron. Zinc was found in concentrations above the detection level only in July at selected stations. The occurrence of these elevated levels is unexplained; there is no apparent source.

Principal cation concentrations were within typical environmental levels (Hem, 1970). Calcium, magnesium, and sodium showed decreasing levels with increasing distance lakeward from the river. Potassium concentrations were similar throughout the study area.

Summary - In 1980, the entire bay, with the exception of a relatively small area at the mouth of the river, was clean and oligotrophic. Overall bay water quality resembled that of the open lake where low TP, low chlorophyll a, and high transparency are typical. Alpena Harbor, influenced by wastewater effluents and the Thunder Bay River, was of lower, but still quite high, quality.

A review of water quality over time showed that the outer bay has remained the same over the period of record and that Alpena Harbor has improved slightly. Parameters associated with domestic sewage (phosphorus, ammonia, nitrates) declined slightly in the harbor, coincident with secondary treatment and phosphorus removal at the Alpena WWTP and improved treatment at Fletcher Paper Co..

Field surveys in 1974-75 and 1980, both conducted after improved treatment at the Alpena WWTP and Fletcher Paper Co., but before substantial solids reduction at the Abitibi Corporation, showed that benthic populations were becoming more diverse, less dominated by organic-tolerant forms, and were tending toward a more balanced community structure as compared to observations in 1965. Recently installed facilities at Abitibi Corporation are expected to reduce solids loading to the bay as operations become more efficient.

Nottawasaga Bay

Nottawasaga Bay is a popular summer recreational area. The area supports a number of important fisheries including both sports and commercial. The Mary Ward Shoals, a major fish spawning ground west of Collingwood (Figure 48), is particularly susceptible to environmental degradation from even minor levels of nutrient enrichment. These exposed rocky shallows provide an exceptionally favourable physical habitat for the growth of Cladophora; however, phosphorus levels are presently too low to support widespread growth (Jackson and Hamdy, 1982).

Nottawasaga Bay was investigated to determine the extent of enrichment in 1980 as part of the Lake Huron Intensive Survey. Four synoptic cruises were conducted using a sampling grid of 56 stations (Ontario Ministry of the Environment, 1983).

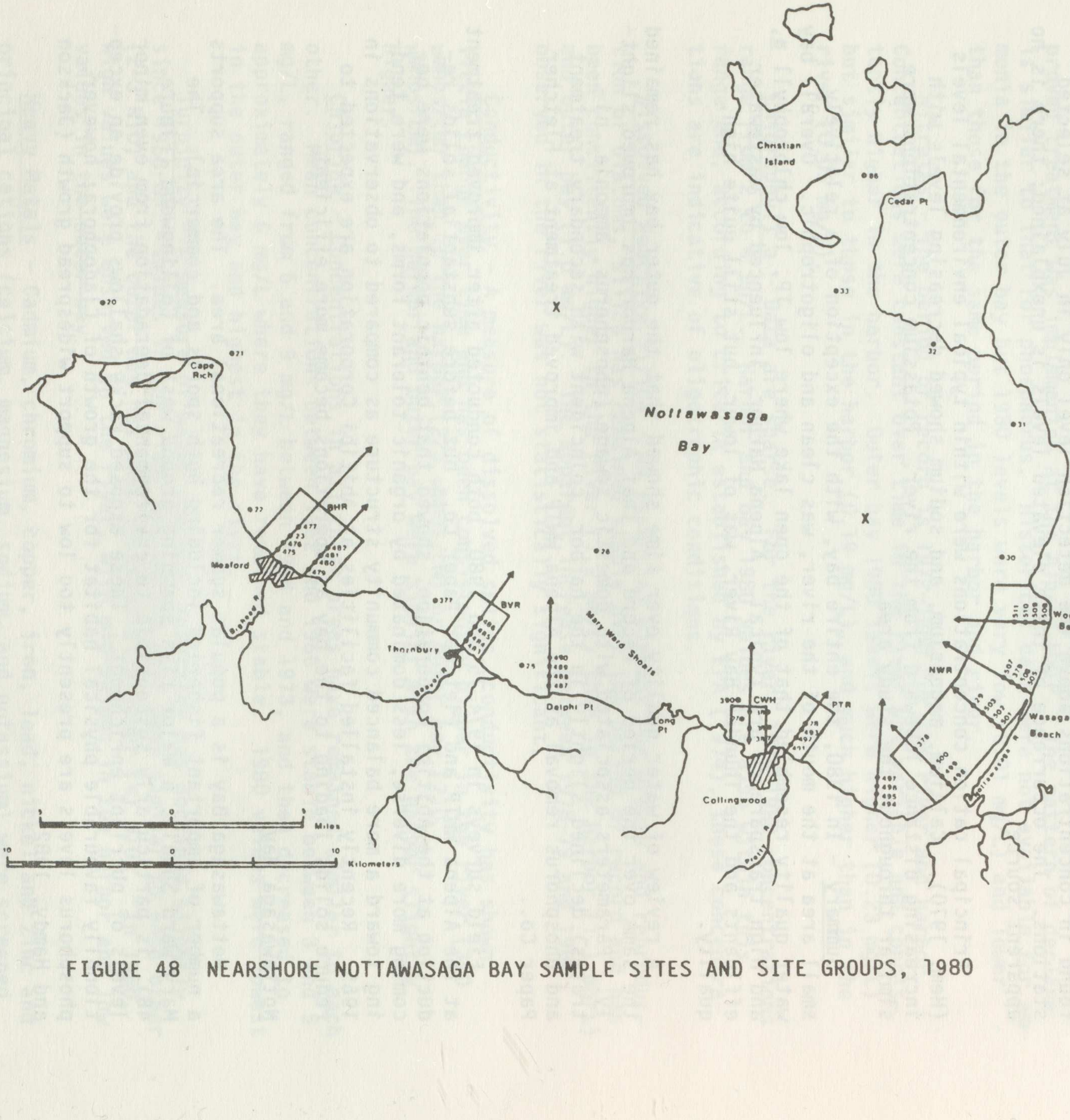


FIGURE 48 NEARSHORE NOTTAWASAGA BAY SAMPLE SITES AND SITE GROUPS, 1980

Phosphorus - Yearly mean concentrations of TP ranged from 4 to 6 μg/L in different areas of the bay, while mean levels of SRP ranged from 2 to 3 μg/L. This compares to levels of 4 and <1 μg/L in open Georgian Bay for TP and SRP, respectively.

Nitrogen - Yearly mean concentrations of NO_3+NO_2 ranged from 246 to 260 μg/L, showing little variation. NH_3, however, showed marked variation. Open Georgian Bay concentrations averaged about 2 μg/L while levels near Collingwood Harbour were about 18 μg/L. Also, other nearshore areas ranged from 10 to 12 μg/L.

Silicate - Yearly mean reactive silicate concentrations ranged from 0.50 to 0.66 mg/L which is about half of the open bay level. Little seasonal variation was observed.

Phytoplankton - Chlorophyll a levels were low during the study period, ranging from 0.87 μg/L near enriched areas to 0.54 μg/L at more remote sites. The dominant algal class at all 9 stations studied for phytoplankton was diatoms (Bacillariophyceae, Figure 49). Other classes comprised less than 15% of the observed assemblages. Minor quantities of the blue-green algae *Anabaena* and *Oscillatoria* and eutrophic diatom species suggest the influence of some nutrient enrichment. However, the bay, in general, has a trophic status more like open Lake Huron, than some of the more eutrophic areas of the Great Lakes.

Summary - Only two areas in Nottawasaga Bay showed clear signs of eutrophication: the mouth of Collingwood Harbour and the mouth of the Nottawasaga River. The affected area did not extend to the Mary Ward Shoals, a major fish spawning area. Oligotrophic conditions characterized open Nottawasaga Bay and most nearshore areas. The presence of bloom-forming blue-green algae is a cause for some concern, however, and warrants further surveillance.

Water Intake Monitoring

Three Ontario water intakes (Goderich, Grand Bend and Sarnia) (Figure 50), have been monitored weekly for phytoplankton since 1964 and phytoplankton and chemistry since 1976. Data of this type are useful in providing a long term record of year-round limnological conditions.

The phytoplankton community at these intakes was dominated primarily by diatoms with some development of blue-green and green crops in late summer. At Goderich and Sarnia, a steady increase in NO_3 nitrogen was observed since 1976 with a distinct spring peak. Silica concentrations followed a cyclical pattern with only a slight long term increase observed at Sarnia. No other chemical parameters were observed to have a trend with time.

A separate report (Hopkins, 1983) has documented the water quality at these three water supply intakes in southeastern Lake Huron covering the period 1976-1981. While the main intended use of intake data is for long-term trend analysis, the data can also be used for short-term (seasonal) evaluations of water quality. Relative to the 1980 surface data presented in this report (p. 120), the intake findings were comparable for most water quality indicators; only TP levels were appreciably different (i.e. intake levels

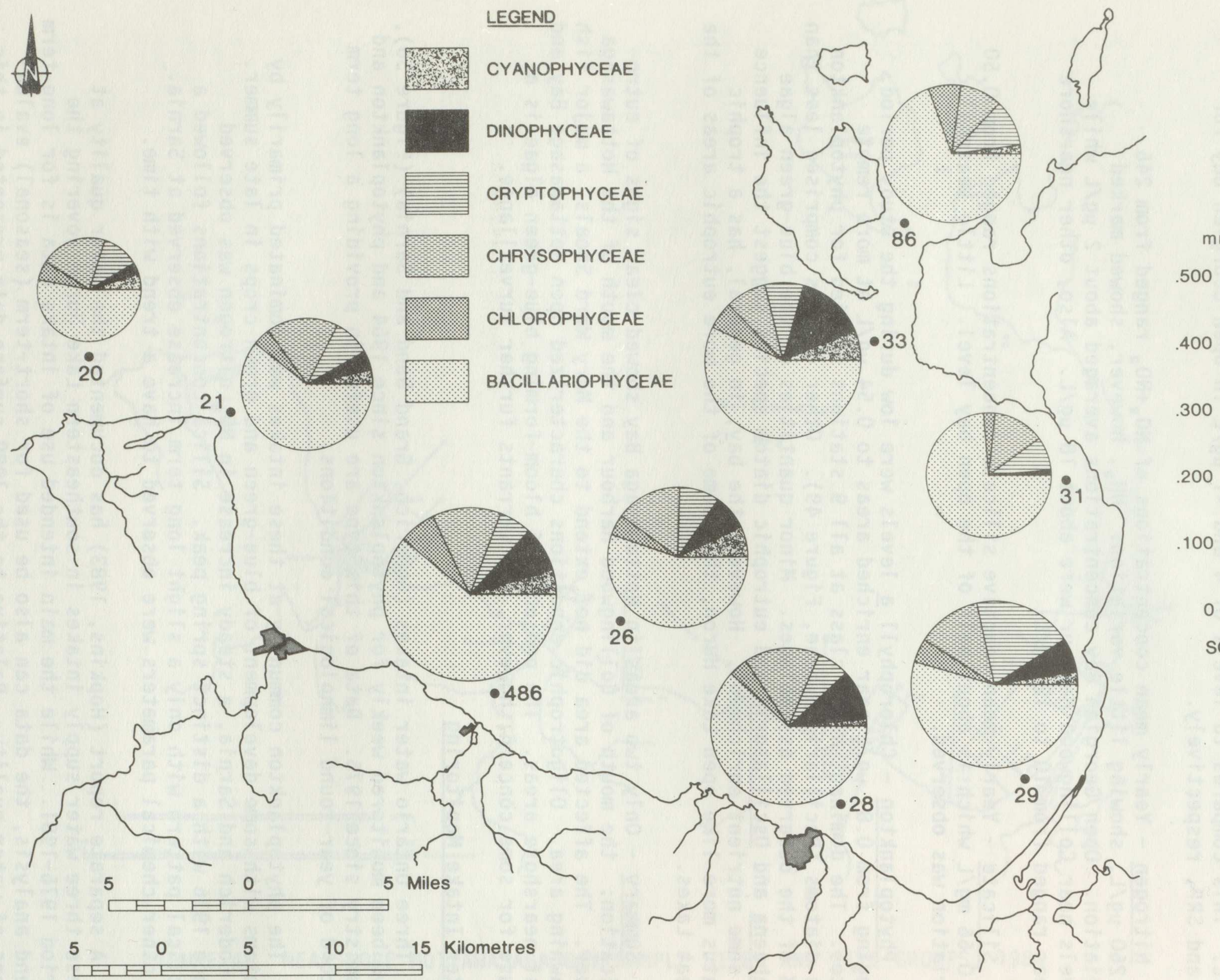


FIGURE 49 PHYTOPLANKTON DENSITIES AND TAXONOMIC COMPOSITION AT NINE NEARSHORE SITES IN NOTTAWASAGA BAY FOR THE ICE-FREE PERIOD (SPRING, SUMMER, FALL), 1980

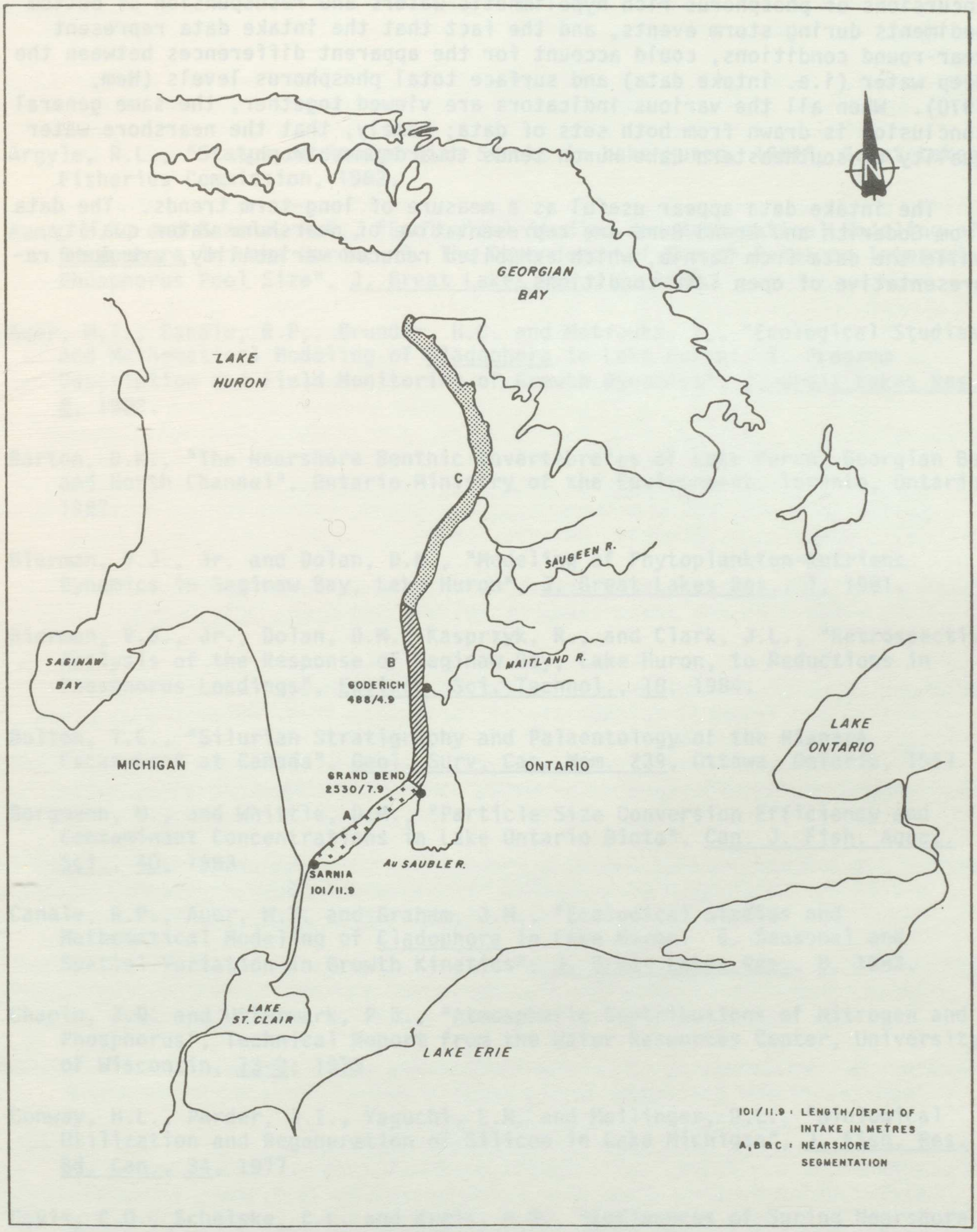


FIGURE 50 LOCATION OF THREE WATERWORKS MONITORING STATIONS IN SOUTHEASTERN LAKE HURON AND NEARSHORE SEGMENTATION AS REPORTED IN U.G.L. REF. GROUP (ANON 1977)

were about twice as high as surface values). Since the intake data reflect deeper water conditions, the higher TP levels are not particularly unusual. Incursions of phosphorus rich hypolimnetic waters and resuspension of bottom sediments during storm events, and the fact that the intake data represent year-round conditions, could account for the apparent differences between the deep water (i.e. intake data) and surface total phosphorus levels (Hem, 1970). When all the various indicators are viewed together, the same general conclusion is drawn from both sets of data; namely, that the nearshore water quality of southeastern Lake Huron tends towards mesotrophy.

The intake data appear useful as a measure of long-term trends. The data from Goderich and Grand Bend are representative of nearshore water quality, while the data from Sarnia, which exhibited reduced variability, are more representative of open lake conditions.

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