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Agency

Great Lakes National
Program Office
536 South Clark Street
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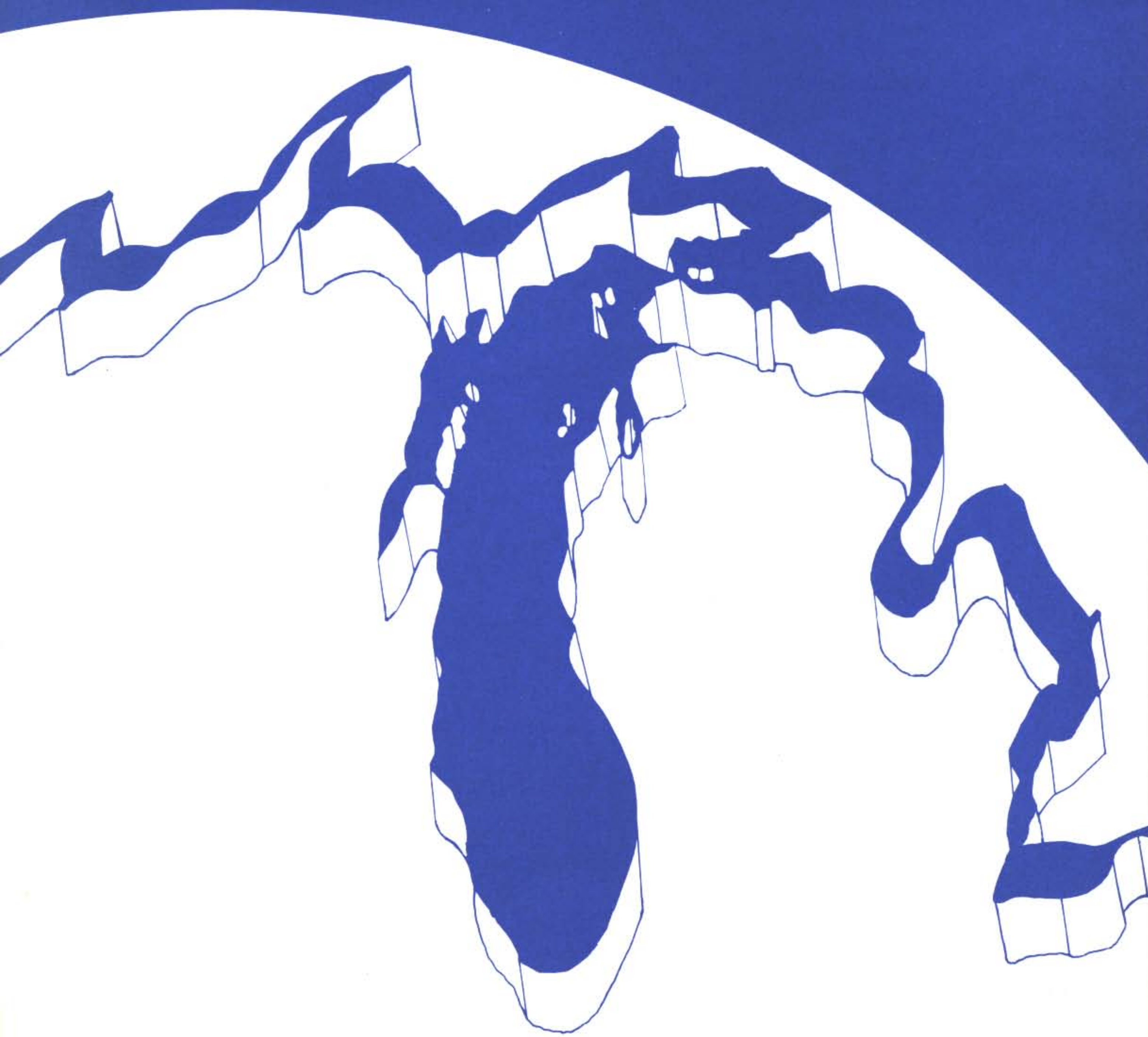
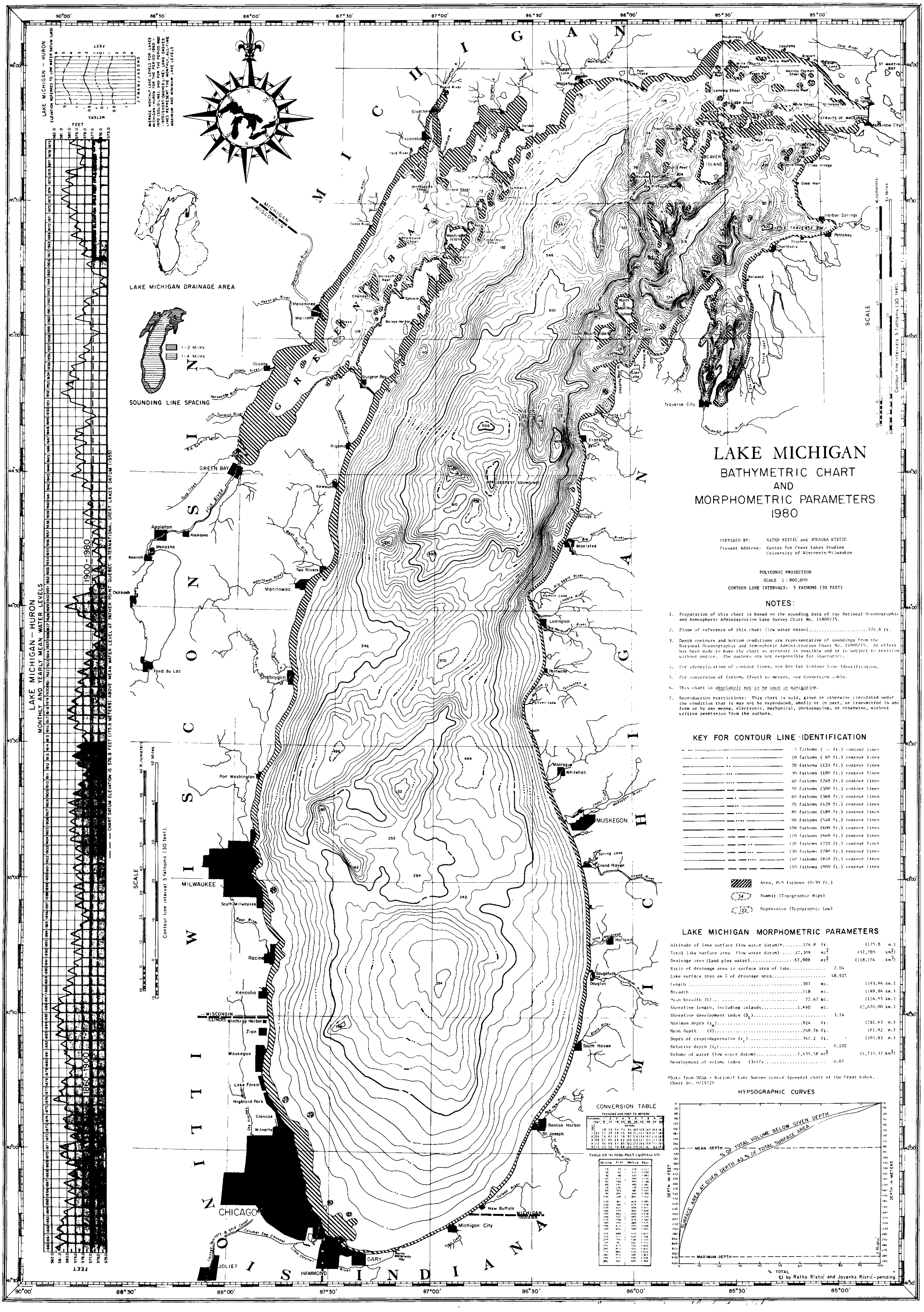
EPA

Lake Michigan Intensive Survey 1976-1977 - Management Report




LAKE MICHIGAN
BATHYMETRIC CHART
AND
MORPHOMETRIC PARAMETERS
1980
PREPARED BY: RATKO RISTIĆ and JOVANKA RISTIC
Present Address: Center for Great Lakes Studies
University of Wisconsin-Milwaukee
POLYCONIC PROJECTION
SCALE 1 : 800,000
CONTOUR LINE INTERVALS: 5 FATHOMS (30 FEET)
NOTES:
1. Preparation of this chart is based on the sounding data of the National Oceanographic and Atmospheric Administration Lake Survey Chart No. 14900/75.
2. Plane of reference of this chart (low water datum)........................576.8 ft.
3. Depth contours and bottom conditions are representative of soundings from the National Oceanographic and Atmospheric Administration Chart No. 14900/75. An effort has been made to make the chart as accurate as possible and it is subject to revision without notice. The authors are not responsible for inaccuracy.
4. For identification of contour lines, see Key for Contour Line Identification.
5. For conversion of fathoms (feet) to meters, see Conversion table.
6. This chart is absolutely not to be used in navigation.
7. Reproduction restrictions: This chart is sold, given or otherwise circulated under the condition that it may not be reproduced, wholly or in part, or transmitted in any form or by any means, electronic, mechanical, photocopying, or otherwise, without written permission from the authors.
KEY FOR CONTOUR LINE IDENTIFICATION
10 fathoms (60 ft.) contour lines
20 fathoms (120 ft.) contour lines
30 fathoms (180 ft.) contour lines
40 fathoms (240 ft.) contour lines
50 fathoms (300 ft.) contour lines
60 fathoms (360 ft.) contour lines
70 fathoms (420 ft.) contour lines
80 fathoms (480 ft.) contour lines
90 fathoms (540 ft.) contour lines
100 fathoms (600 ft.) contour lines
110 fathoms (660 ft.) contour lines
120 fathoms (720 ft.) contour lines
130 fathoms (780 ft.) contour lines
140 fathoms (840 ft.) contour lines
150 fathoms (900 ft.) contour lines
Area, 0-5 fathoms (0-30 ft.)
Summit (Topographic High)
Depression (Topographic Low)
LAKE MICHIGAN MORPHOMETRIC PARAMETERS
Altitude of lake surface (low water datum)*........576.8 ft. (175.8 m.)
Total lake surface area (low water datum) ......22,309 mi² (57,780 km²)
Drainage area (land plus water)..................67,909 mi² (118,104 km²)
Ratio of drainage area to surface area of lake.............. 2.04
Lake surface area as % of drainage area.................... 48.92%
Length...307 mi. (493.96 km.)
Breadth..118 mi. (189.86 km.)
Mean breadth (b)................................ 72.67 mi. (116.93 km.)
Shoreline length, including islands..............1,660 mi. (2,670.00 km.)
Shoreline development index (D_L)............................ 3.14
Maximum depth (z_m)...............................924 ft. (281.63 m.)
Mean depth (z̄)....................................268.76 ft. (81.92 m.)
Depth of cryptodepression (z_c)...................347.2 ft. (105.83 m.)
Relative depth (z_r).. 0.10%
Volume of water (low water datum)................1,135.58 mi³ (4,731.37 km³)
Development of volume index (3z̄)/z........................ 0.87
*Data from NOAA - National Lake Survey Center (general chart of the Great Lakes, Chart No. 0/1972)
HYPSOGRAPHIC CURVES
MEAN DEPTH
MAXIMUM DEPTH
% OF TOTAL VOLUME BELOW GIVEN DEPTH
% OF TOTAL SURFACE AREA
SURFACE AREA AT GIVEN DEPTH AS % OF TOTAL SURFACE AREA
DEPTH IN FEET
DEPTH IN METERS
% TOTAL
© by Ratko Ristić and Jovanka Ristić-pending
CONVERSION TABLE
FATHOMS AND FEET TO METERS
TABLE OF METERS-FEET EQUIVALENTS
LAKE MICHIGAN - HURON
MONTHLY AND YEARLY MEAN WATER LEVELS
1900-1980
1860-1900
CHART DATUM ELEVATION IS 576.8 FEET (175.8 METERS) ABOVE MEAN WATER LEVEL AT FATHER POINT QUEBEC INTERNATIONAL GREAT LAKES DATUM (1955)
FEET
LAKE MICHIGAN DRAINAGE AREA
SOUNDING LINE SPACING
1-2 Miles
1-4 Miles
MICHIGAN
WISCONSIN
ILLINOIS
INDIANA
GREEN BAY
DEEPEST SOUNDING
CHICAGO
MILWAUKEE
MUSKEGON
GARY
HAMMOND
JOLIET
BEAVER ISLAND
STRAITS OF MACKINAC
SCALE
Contour line interval 5 fathoms (30 feet)
Kilometers
Miles

LAKE MICHIGAN INTENSIVE SURVEY
1976-1977
MANAGEMENT REPORT

By

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AUGUST 1981

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FORWARD

The Great Lakes National Program Office (GLNPO) of the United States Environmental Protection Agency was established in Region V, Chicago to focus attention on the significant and complex natural resource represented by the Great Lakes.

GLNPO implements a multi-media environmental management program drawing on a wide range of expertise represented by Universities, private firms, State, Federal, and Canadian Governmental Agencies and the International Joint Commission. The goal of the GLNPO program is to develop programs, practices and technology necessary for a better understanding of the Great Lakes Basin Ecosystem and to eliminate or reduce to the maximum extent practicable the discharge of pollutants into the Great Lakes system. The Office also coordinates U.S. action in fulfillment of the Great Lakes Water Quality Agreement of 1978 between Canada and the United States of America.

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INTRODUCTION

During 1976 and 1977, the Great Lakes National Program Office (GLNPO) of the United States Environmental Protection Agency (USEPA) conducted an intensive survey of the Lake Michigan in order to determine the trophic status of the lake, changes or trends in water quality since previous surveys and to establish a data base to support the developme .t of predictive mathematical simulations which can be used to predict the effects of remedial programs, particularly phosphorus removal.

A complete description of this study and the results of the study including methodology is available in EPA document No. 905/4-80-003A LAKE MICHIGAN INTENSIVE SURVEY 1976-1977 (Rockwell et al 1980b). A microfiche copy of the intensive survey data base available in STORET is attached inside the back cover of the report.

The purpose of this executive summary is to summarize and discuss the major findings of the study and to update those findings in light of additional data that became available during or after the report writing process.

The appendices to this report contain abbreviated descriptions of the survey including station locations, parameters, analytical methods, quality control and the roles of other organizations which participated in or contributed to the study. Table 1 gives a brief summary of survey results for the southern basin in 1976 and 1977.

TABLE I

Averages of the Southern Basin Cruises
1976-1977
(Means of two layer volume weighted cruise values)

Southern Basin

	1976	1977
Water Temp. °C	8.9	7.4
Secchi (m)	4.4	5.4
Conductivity 25°C (umhos/cm)	274	276
Total Kjeldahl Nitrogen	.164	.158
Total Alkalinity	107	107
Turbidity (TU)	1.8	0.9
Ammonia (ug/l)	7.2	5.2
Nitrite + Nitrate	.226	.243
Total Phosphorus (ug/l)	8.0	5.6
Primary Productivity mg C/m^3/hr	4.9	3.9
Calcium	35.5	---
Magnesium	11.0	---
Sodium	4.7	---
Potassium	1.07	---
Chloride	8.09	8.19
Sulfate	21.1	22.3*
Fluoride	0.10	---
Dissolved Reactive Silica	1.13	0.94
Chlorophyll "a"	1.69	1.45

Units are mg/l unless otherwise noted. These are gross averages used to characterize the lake in simple terms. They include substantial variance in both time and space. For more precise information the reader is referred to the full technical report Rockwell et. al. (1980b) and Bartone and Schelske (1979) who reported on 1976 data separately.
* Arithmetic average of selected sampling sites in Indiana Nearshore Study.

CONCLUSIONS

ANNUAL VARIABILITY

Phosphorus is considered the principal limiting nutrient in Lake Michigan. Phosphorus concentrations were dramatically deceased over the winter between 1976 and 1977 throughout the entire southern basin resulting in an improved trophic conditions evaluation in 1977.

- Total phosphorus concentration decreased from 8 ug/l during 1976 to 5.6 ug/l during 1977 in the open waters of the southern basin. Substantial reductions also occurred at nearshore stations.

- Turbidity decreased from an average of 1.8 HTU during 1976 to 0.9 HTU in 1977.

- Transparency, as measured by secchi disk, increased from 4.4 meters during 1976 to 5.4 meters in 1977.

- Seasonal surface water nitrate depletion decreased from 0.17 mg/l during 1976 to 0.11 mg/l during 1977.

- Nitrate + Nitrite concentration averages increased from .226 mg/l in 1976 to .243 mg/l in 1977.

- Epilimnetic phytoplankton populations decreased from 4300 organisms/ml during 1976 to 3400 organisms/ml during 1977.

- Chlorophyll "a" concentrations decreased from 1.69 ug/l during 1976 to 1.45 ug/l during 1977.

- Primary productivity at the 5 meter depth decreased from 4.9 mg/C/m^3/hr during 1976 to 3.9 mg C/m^3/hr during 1977.

- Seasonal measurements of average dissolved reactive silica (DRS) concentrations in the surface water were higher throughout 1977 than during 1976. This can imply less utilization by diatoms in the nearshore surface water.

• Hypolimnetic dissolved reactive silica concentrations were lower during 1977 than during 1976 at deep water stations (depth greater than 80m). Volume weighted reactive silica decreased in the summary averages (Table 1) from 1.13 to .94 mg/l which indicated a loss of frustules to the sediments or bottom most layers of water.

All of these changes are consistent with an improvement in the trophic status of the lake.

An indication of trophic status which is not consistent with these improvements is that some species of green and blue-algae usually associated with deteriorating systems appear to have increased throughout the southern basin since 1962-63. However, their numbers were fewer in 1977 than in 1976 probably in response to the phosphorus reduction. There is also an apparent increase in phytoflagellates during the 1962-63 to 1976-77 period. The phytoplankton population in the southern basin indicate that the system suffers from cultural nutrient enrichment. This is illustrated by the marked shift from diatoms to blue-green algae which accompanied severe dissolved reactive silica concentration depletion in the surface waters at open lake stations sites (>80 meters deep) in both years and the marked increase of blue-green algae in the eastern zone of transect one.

PHOSPHORUS

Phosphorus concentrations in Lake Michigan can vary sharply from year to year. Fish and Wildlife Service data in an area between Milwaukee and Ludington averaged 16 ug/l during 1961 and the 1962-63 FWPCA study found 6-7 ug/l in the same area. During the early seventies the University of Wisconsin found concentrations of 8 to 9 ug/l along a transect between Milwaukee and Lundington. Our study found levels of around 7 ug/l in 1976 with a sharp decline to around 5 ug/l in 1977. In the entire southern basin total phosphorus concentrations declined from 8.0 $\pm$ 0.8 in 1976 to 5.6 $\pm$ 0.8 in 1977 (Figure 1). Eighty-five percent of the southern basin stations showed a reduction in total phosphorus concentrations between 1976 and 1977. Total dissolved phosphorus also decreased at 92 percent of the stations from a median of 3 ug/l in 1976 to below detectable limits in 1977.

Only a small portion of the southern basin lake-wide phosphorus decrease can be attributed to load reductions. Phosphorus loadings to Lake Michigan from industrial, municipal, atomospheric and tributary sources were 6566

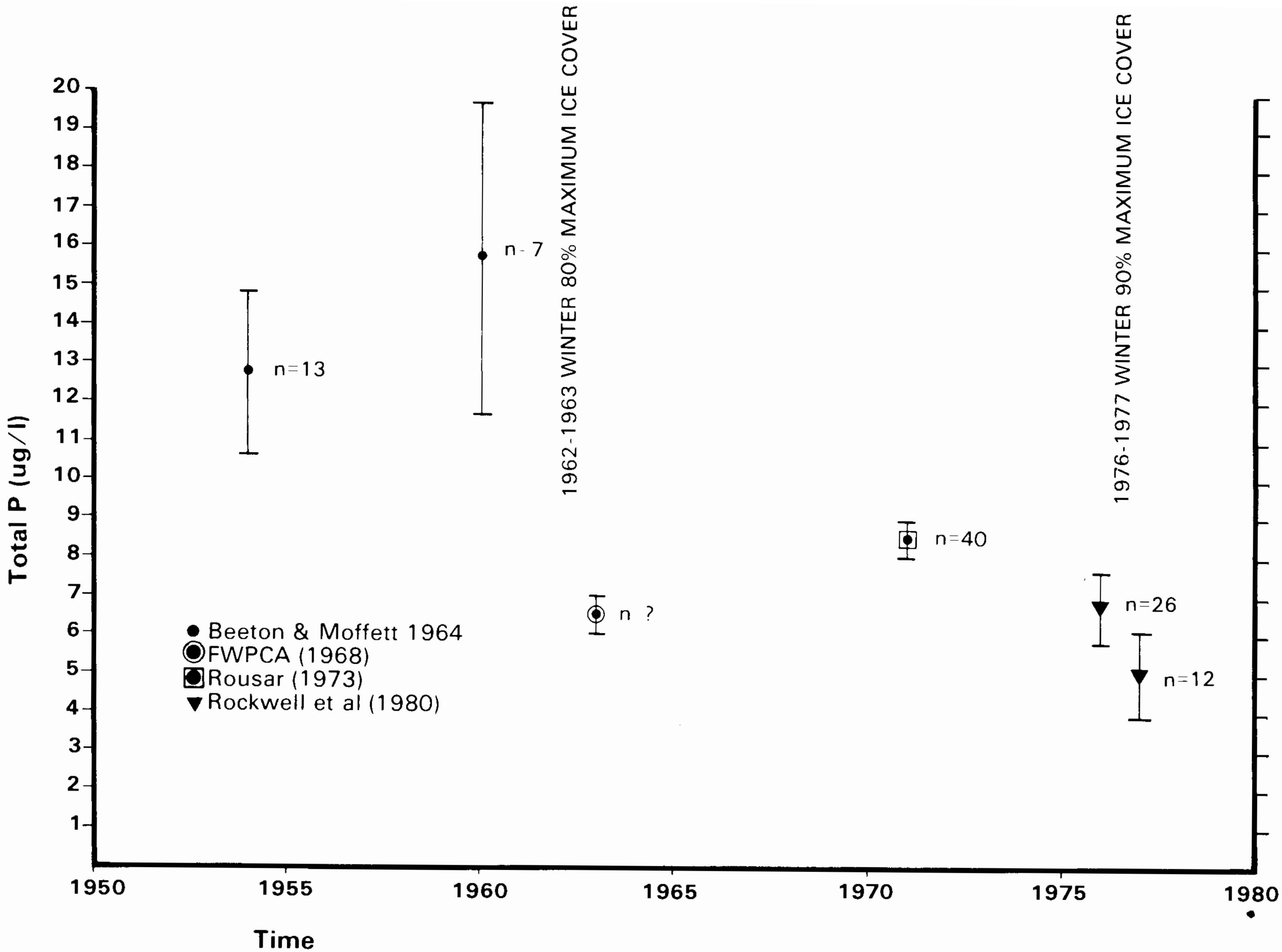

Figure 1

Total Phosphorous
Open Lake Area
Between Milwaukee and Ludington

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metric tons in 1976 and 4666 metric tons during 1977 (IJC, GLWQB, 1978a) a difference of 1900 metric tons. A 1.0 ug/l annual decrease in total phosphorus corresponds to a annual loss of 5000 metric tons loading (Chapra and Sonzogni, 1979). Assuming the southern basin reduction of 2.4 ug/l in one year is representative of the entire lake, a reduction of 12,000 metric tons would be required to produce this annual decline for the lake. Thus, 15 percent or less of the change in phosphorus can be attributed to reduction in loading.

WINTER EFFECTS

One explanation of this large and apparently natural decrease in total phosphorus may be the severity of the intervening winter. An abnormally large amount and duration of ice cover occurred during the winter of 1976-77. The onset of freezing conditions was 30 days earlier than normal. The maximum ice extent was 58 days longer than normal. The beginning of early ice decay started 4 days later than normal (Quinn *et al* 1978). Quinn summarized the weather and ice condition for the winter of 1976-1977.

> "The winter of 1976-77 was the fifth coldest in the past 200 years. Record-breaking low temperatures from mid-October to mid-February, associated with an upper air pressure pattern consisting of a strong ridge in the westerly flow over North America, resulted in extraordinary ice cover on the Great Lakes. Ice was produced almost simultaneously in various shallow protected areas of the Great Lakes in early December. The progression of early winter, mid-winter, and maximum ice extent was from 4 to 5 weeks earlier than normal. At the time of maximum ice extent in early February, Lake Superior was approximately 89 percent, Lake Erie 100 percent, and Lake Ontario approximately 38 percent. Spring breakup started in late February in the southern part of the Great Lakes region and in early March in the northen part. The bulk of ice cover was gone by the fourth week of April."

There are three mechanisms by which abnormal ice cover could affect the trophic status of the lake.

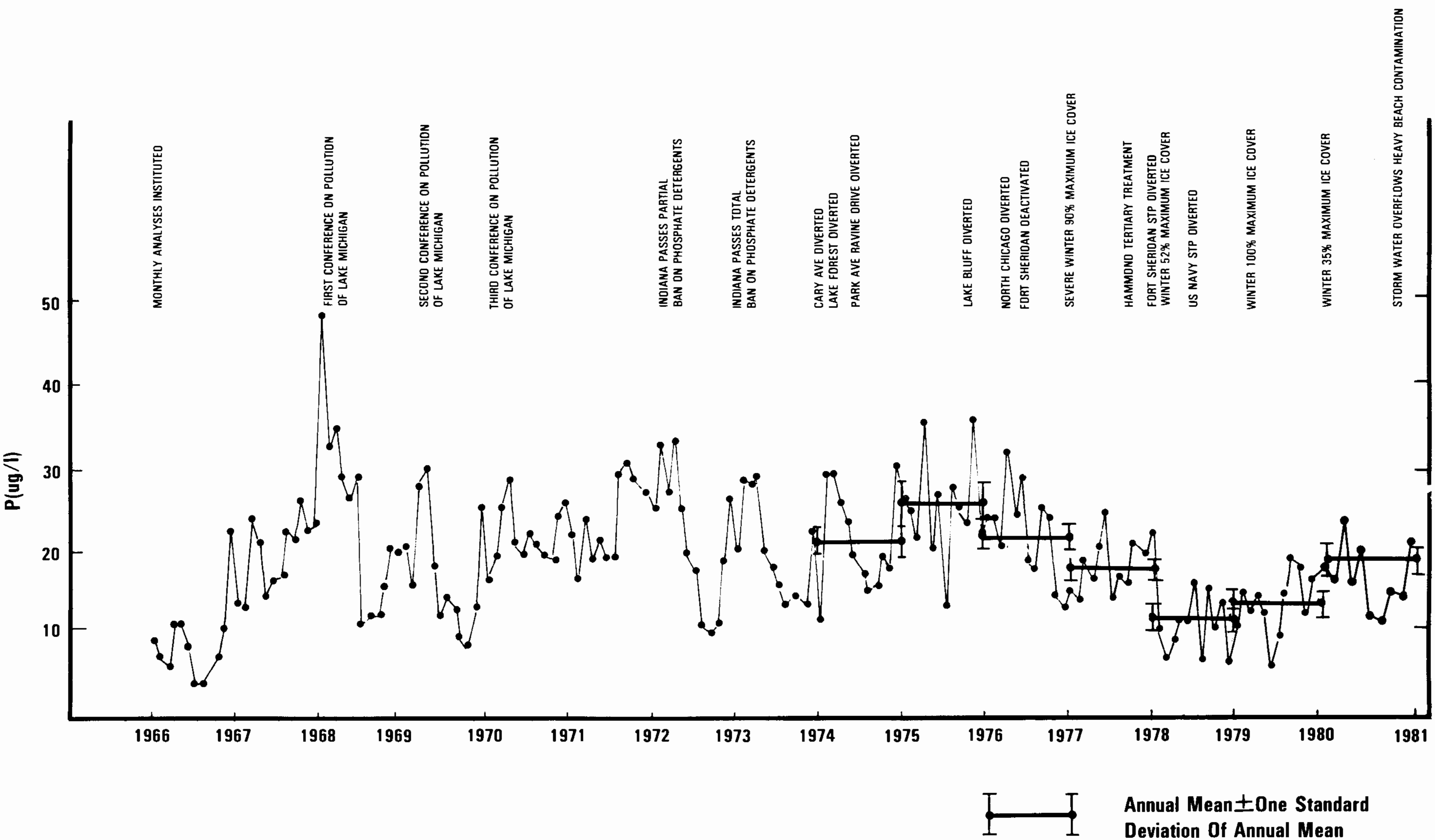
a. It could delay the thermal cycle of the lake. Thermal stratification with a discernible epilimnion, thermocline, and hypolimnion appears to have been delayed by the cold winter in 1977. The extent of thermal stratification on the May 25-June 2, 1976 cruises was about the same as observed on the June 15-21, 1977 cruise. The epilimnetic waters in 1977 were about 3-4°C cooler than in 1976 throughout the stratified season.

b. The ice cover would insulate the water mass from prevailing winds which are responsible for mixing. This would increase sedimentation in the lake. Resuspension of sediments would also be curtailed during ice cover in areas that are normally stirred up by winds (Rodgers 1980). That increased sedimentation of suspended material occurred between 1976 and 1977 is suggested by mean turbidity values which decreased from 1.8 ± .3 HTU in 1976 to 0.9 ± .1 HTU in 1977. This change occurred during the period between cruises ending in 1976 and starting in 1977.

c. Ice, particularly snow covered ice, would reduce the amount of light reaching the lake. This would inhibit biological productivity under the ice.

The loss of phosphorus between 1976 and 1977, should not be necessarily considered permanent. Such a comparatively large phosphorus deposition in the southern basin (up to $7.345 \cdot 10^3$ metric tons) would result in upper sediment layers being more highly enriched. This phosphorus is nearly twice the estimated 1976 loadings of total phosphorus to the southern basin ($3.797 \cdot 10^3$ MTs). Presumably this phosphorus could become a loading source when ther is subsequent resuspension during trubulent periods or via chemical or biological recycling (Rodgers 1980).

The winters of 1976-77 and 1978-79 were also more severe than normal. Data from Chicago's South Water Filtration Plant indicate that total phosphorus concentration was even lower during 1978 and 1979 averaging 12.1 ± 1.4 ug/l and 13.6 ± 1.1 ug/l respectively versus an average of 18.3 ± 1.0 ug/l during 1977 (Figure 2). During 1976, before the first severe winter, phosphorus concentration at this intake averaged 22.4 ± 1.6 ug/l (Figure 2). This plant's water intake is influenced by nearshore conditions. However, since one intake is 3 km offshore and is used when nearshore waters deteriorate, the plant's water seems to also reflect lake conditions. The decrease in nearshore total phosphorus in 1976-1978 noted at the plant was also found by the City of Chicago and Illinois EPA (Lake Michigan Water Quality Report 1979, 1980) at sampling points located 10 km to 30 km offshore near Chicago. If cold winters with extensive ice cover depress phosphorus levels during the following year, then mild winters with little ice cover may result in relatively higher concentrations during the following year. This appears to be the case after the relatively mild winter of 1979-80. Phosphorus concentrations at the Chicago water intake increased from an annual average of 13.6 ± 1.1 ug/l during 1979 to 16.7 ± 1.2 ug/l during 1980 (Jan-Oct).



South Water Filtration Plant
Chicago Water Purification Division
From Seasonal And Comprehensive Chemical Analysis
Total Phosphorus In parts Per Billion

figure 2

There is evidence that similar changes have occurred in the past. Phosphorus values in the entire southern basin averaged 13 ug/l (Beeton 1969) in 1960 and 1961. The winter of 1962-63 was severe, having an 80% maximum ice cover which was the most extensive recorded at that time (Assel, et al, 1979). Risley and Fuller (1965) reported total phosphorus values of 6-7 ug/l during 1963. Some of the 6-7 ug/l total phosphorus reduction may be due to winter effects in addition to differences related to station network, analytical methods and sampling strategies (Rousar and Beeton, 1973).

The apparent year-to-year variability of the Great Lakes phosphorus levels complicates any attempt to evaluate or predict the effectiveness of phosphorus control programs. Mathematical simulations of the biological cycles within the lakes have been very successful in predicting responses given initial spring conditions (Ditoro 1980) but do not predict the year-to-year variations very well. If this year-to-year variability can be explained by annual ice cover it will be possible to overcome this deficiency. If the annual variability of phosphorus can be related to an observable variable such as ice cover, the effects of meterological conditions may be separable from the effects of remedial programs. Thus, the effects of remedial programs can be predicted and measured with improved confidence.

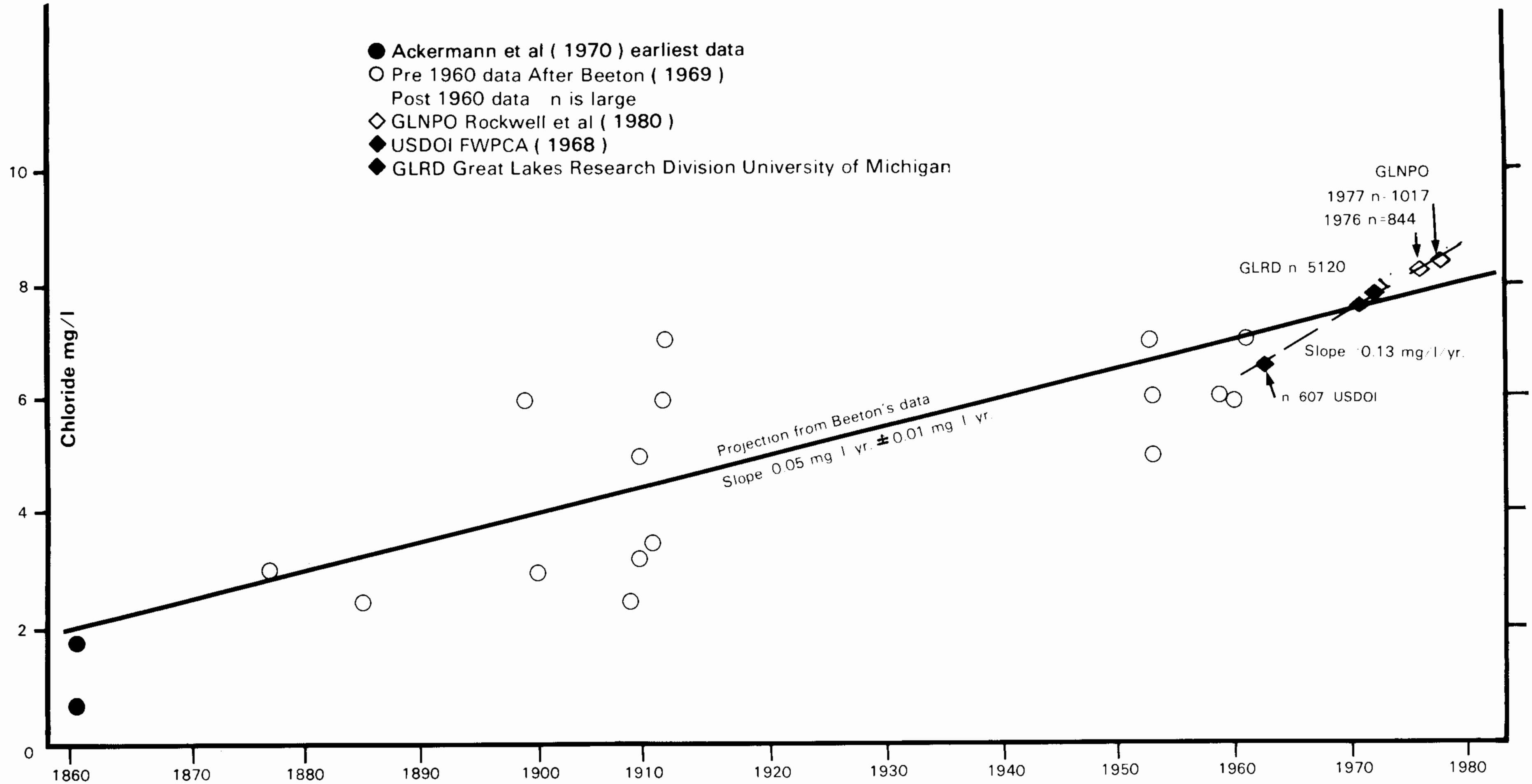
ACCUMULATION OF TOTAL DISSOLVED SOLIDS

Conservative ions, primarily chloride, sulfate and sodium are accumulating in Lake Michigan. Of these, chloride is accumulating at an increasing rate. During 1976 the mean concentration of chloride in the open waters of the southern basin was 8.09 mg/l and during 1977 it was 8.19 mg/l resulting in an annual increase of 0.10 mg/l (Table 1, and Figure 3). Sulfate concentration has increased to 21.1 and is accumulating at a rate between 0.11 to 0.17 mg/l per year. The sulfate concentration in Lake Michigan has risen 15 mg/l, the most of any conservative ion since 1877 (Figure 4).

CHLORIDES

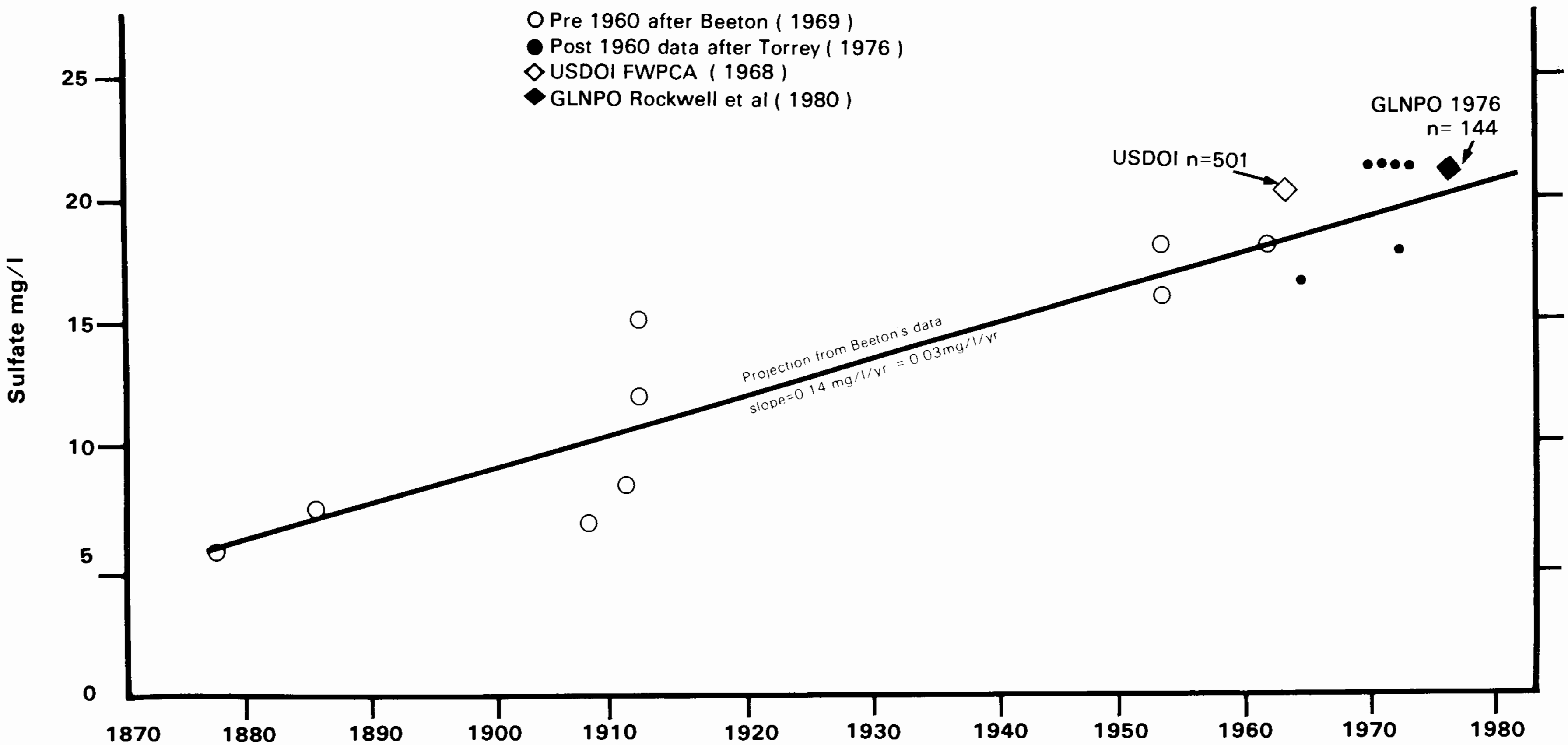
Increases in conservative ion concentrations have been noted in Lake Michigan water going back to the 1800's (Beeton, 1965). Concentration increases of chloride, sodium plus potassium, sulfate, and total dissolved solids have increased steadily over the years. As potassium concentrations seem to be in equilibrium around 1 mg/l (Torrey, 1976; Dobson, 1976), the increase in sodium plus potassium must be due to sodium.

Before the extensive growth of population and industrial development of the Lake Michigan drainage basin, chloride concentration in the 1860's was around 1.2 ± .3 mg/l (Ackerman et al, 1970). The level may have represented an equilibrium concentration, however, the data are limited and sampling locations not identified. By the turn of the century, chloride concentrations had increased to 3.0 mg/l (Ackerman et al, 1970) in the southern basin near Chicago. FWPCA (1968) observed mean chloride



Lake Michigan
Chloride Trends

Figure 3



Lake Michigan
Sulfate Trends

Figure 4

concentration of 6.5 mg/l at deep water stations in 1962-63. Chloride concentrations during 1976 and 1977 were 8.1 and 8.2 mg/l respectively. The rate of increase between 1962 and 1977 averaged 0.13 mg/l/yr (Figure 3). The rate of increase appears to be accelerating from 0.05 mg/l/yr (1860-1960), using Beeton (1969) data, to a current rate between 0.10 mg/l/yr to 0.13 mg/l/yr (Figure 3).

The rate of chloride accumulation in the open lake between 1962 and 1976 would correspond to loadings between 8.3 x 10^5 and 10.2 x 10^5 metric tons/yr. The volume of Lake Michigan's annual discharge is about 1% of the total volume of the lake (4900 km^3) (Torrey, 1976), and discharge concentrations ranged between 7 to 8 mg/l. The annual load of chloride discharged is between 3.4 x 10^5 and 3.9 x 10^5 metric tons. The increased annual chloride burden for Lake Michigan would be about 5.5 x 10^5.

The total tributary chloride load to Lake Michigan's basin was 7.1 x 10^5 metric tons during 1976 (IJC GLBC, 1978a). Point-source estimates for chloride discharged directly to the lake was 2.0 x 10^5 metric tons in 1976 (IJC, GLBC, 1978a). Atmospheric loading of chloride is estimated at 0.83 x 10^5 metric tons per year (Andern et al, 1977). The sum of these estimates (9.9 x 10^5 metric tons) falls within the limits of observed increases in ambient concentrations of chloride.

In 1972-73, salts used for road deicing throughout Lake Michigan's drainage basin amounted to 4.45 x 10^5 metric tons as chloride (Doneth, 1975). Assuming that this load level has not decreased, that it represents a stable proportion of the total load, and that most of this chloride eventually reaches the lake; deicing compounds could account for 40 to 45 percent of the annual load. (Municipal and industrial treatment processes used to reduce phosphorus and industrial wastes frequently produce chloride salts and also contribute to increase loadings of chloride.)

SULFATES

Southern basin sulfate concentration averaged 21.1 mg/l in 1976. This value is 30 to 35 percent higher than the mean concentrations of 16 to 18 mg/l (Beeton and Moffett, 1964) observed in 1954-55 in the southern and northern basins and 5 percent higher than the mean concentration of 20 mg/l (FWPCA, 1968) observed in 1962-1963. Atmospheric dry input of sulfate could be as high as 50 percent of the total load (785 MT.) (Sievering et al, 1979) and may be a possible explanation for the slightly higher epilimnetic sulfate concentrations observed. In the nearshore records of water filtration plants the accumulation of sulfates appears to be accelerating (Rockwell et al, 1980b). Tributary as well as atmospheric sources impact these zones. A recent source of additional sulfate ions is from the use of low phosphate detergents. These detergents contain about twice as much sulfate by weight in their builders as high phosphate detergents (Fuchs 1978).

The proximity of the urban-industrial area along the southern shore of Lake Michgian appears to contribute to the slightly higher sulfate concentrations in the southern basin (Figure 5). Based upon climatological data, emissions of a reactive pollutant such as SO_2 in the Chicago urban-industrial area would be expected to oxidize to sulfates and impact north and east of Chicago. Ozone, another reactive pollutant, has had maximum recorded values near Waukegan, Illinois (Illinois Annual Air Quality Reports, 1976, 1977, 1978, 1979). The conversion of SO_2 to sulfates may be reflected in higher sulfate water concentrations offshore from Waukegan and in the southern basin nearshore zones. An increasing atmospheric sulfate level is expected due to long range transport of SO_2 from higher stacks heights which were put in place during the past decade and from slightly increasing total SO_2 emission loads within the Ohio River Basin-11.5 million tons in 1970 to 12.8 million tons in 1975 (Stukel and Keenan, 1980).

The increasing levels of chlorides and sulfates will not threaten drinking water standards (at 250 mg/l) even during the next several centuries unless current loadings are increased dramatically. The biological consequences of increased dissolved solid levels are unknown. Higher levels create ever expanding habitat for brackish algal forms. Some new marine algal forms have adapted to lake conditions and are now frequently observed in the nearshore zones of Lake Michigan e.g. <u>Bangia atropurpurea</u>, a red attached algae.

SODIUM

There is evidence however that increased levels of sodium favor the growth of blue-green algae. Sodium concentrations averaged 4.8 mg/l in 1976-1977. These values were about 20 to 40 percent higher than the averages observed by FWPCA (3.9-4.0 mg/l) during in 1962-63 and by Beeton and Moffett during 1954-55 (3.3 to 3.4 mg/l).

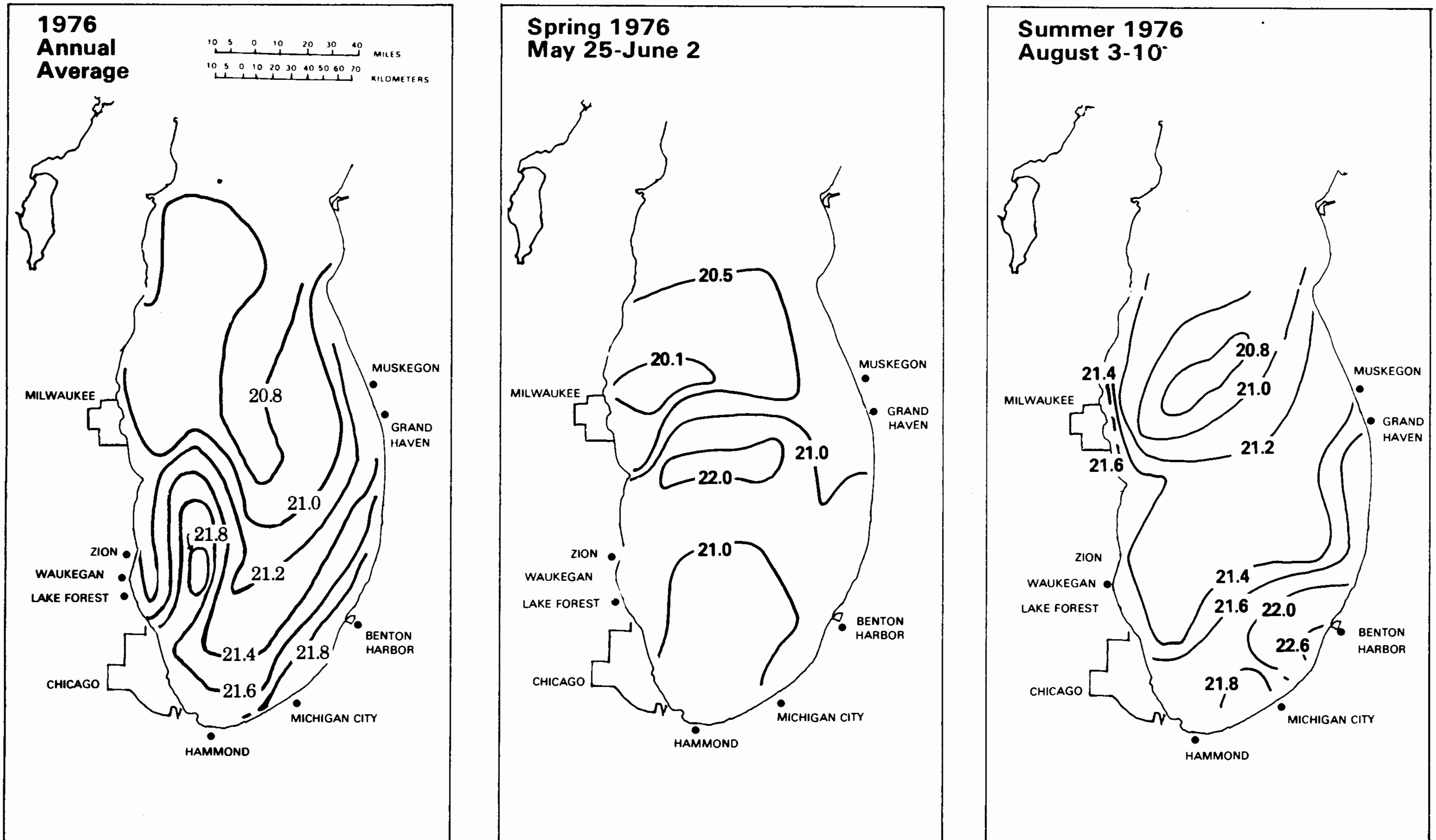
BLUE-GREEN ALGAE - FOOD CHAIN CONCERNS

Makarewicz and Baybutt (In Press) observed an increase in relative abundance of blue-green algae. In their data base, blue-greens (principally <u>Gomphosphaeria</u> and <u>Oscillatoria</u>) appeared and increased once annual sodium concentrations averaged 4.6 ug/l.

Several species of blue-green algae require sodium, frequently at concentrations at 4 to 5 mg/l or higher (Allen, 1952; Kratz and Myers, 1955; Allen and Arnon, 1955). There is a large body of circumstantial evidence which suggests that increase monovalent ion concentrations (particularly sodium and potassium) may favor the development of blue-greens (Provasoli, 1969). That sodium, potassium, and other ions can enhance the uptake of phosphate by blue-greens has been demonstrated by Jensen <u>et al</u> (1976). Anticipated discharges of salt will ultimately increase chloride ion concentrations from the current 8 mg/l to over 19 mg/l (Richardson, 1980). If sodium increases proportionately, then ultimate sodium ions levels could be greater than 10 mg/l throughout the lake.

figure 5

Distribution Of Sulfate In mg/l



Blue-green algae constituted 19.5% of the phytoplankton in the samples collected during 1976 compared to 14.2% of the phytoplankton in the 1977 samples. Furthermore, blue-green algae increased in absolute numbers and in percentage of phytoplankton in the south eastern portion of the southern basin. Eutrophication commonly enhances the growth and abundance of filamentous green or blue-green algae. Blue-green algae in particular can form mats of colonial single cells or rafts of filaments which become too large to be efficiently retained by grazers. The extracellular sheath associated with the blue-green algae may be toxic or noxious, further reducing the acceptablility of these phytoplankton food resources for grazers (Brooks, 1969; Arnold, 1971).

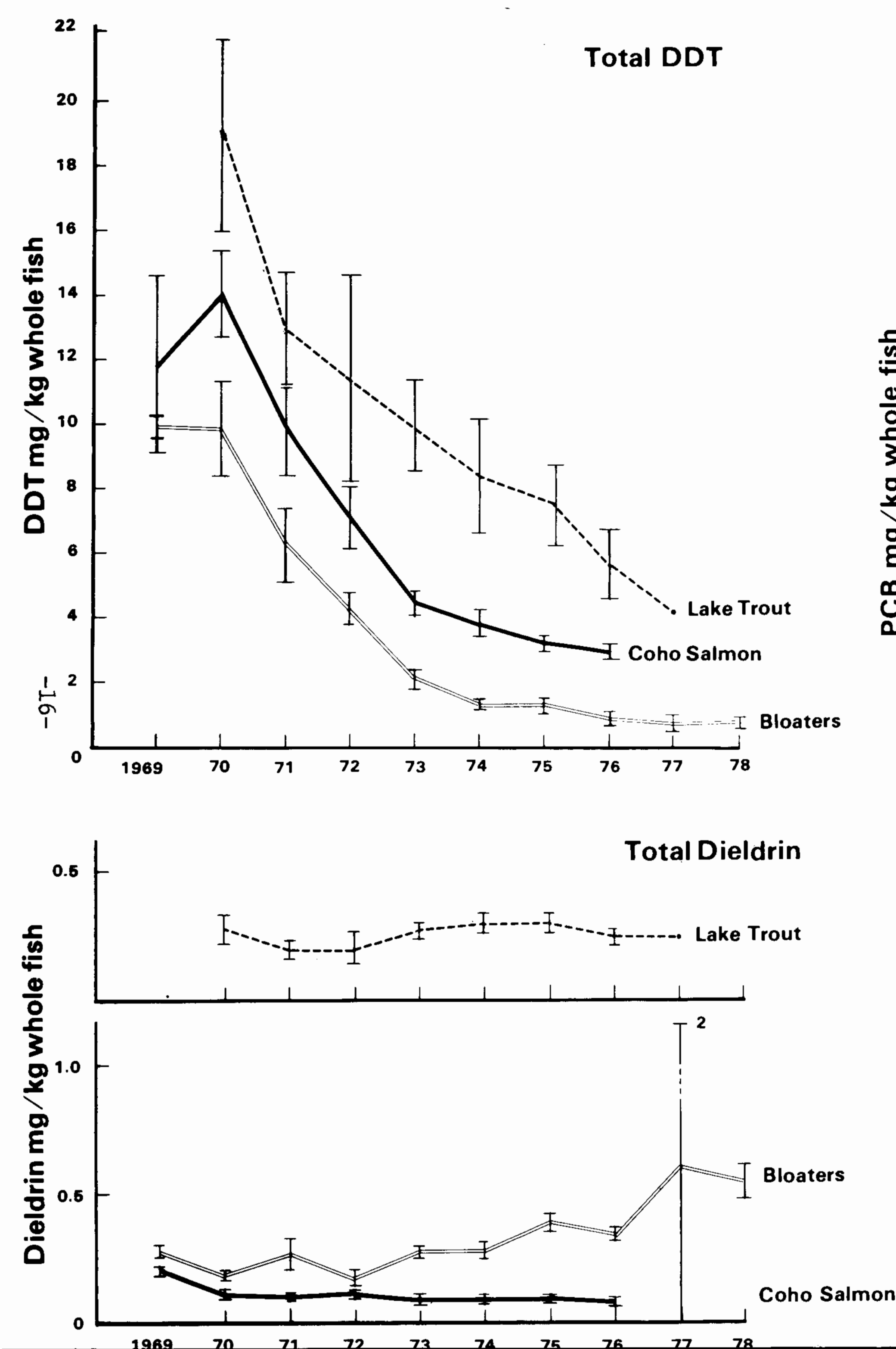
Increased blue-green algae domination, possibly resulting from higher sodium levels, will reduce the quality if not, the quantity of the food supply available to support game fish. It is not known to what extent this would affect game fish populations. If the food supply is a critical controlling factor, then the effect could be very severe. If not the effect could be minor. Lake Erie, which has a sodium concentration ranging between 7-12 mg/l and is heavily dominated by blue-green algae, has an apparently thriving fish population. (Lake Erie, however, is far more biologically productive than Lake Michigan with 3 to 6 times higher phosphorus concentrations so that the food supply is more abundant and therefore capable of absorbing loss of quality caused by blue-green domination.)

The Lake Michigan sports fishery has been described as one of the most exciting in the world and is valued at many million of dollars each year. If, as a result of increased sodium concentrations and reduced phosphorus concentrations, blue-green algae dominance of the phytoplankton increases; it would decrease the quality of the food supply. This could conceivably lead to reduction or even a collapse of the sports fishery.

TOXIC ORGANIC SUBSTANCES

The concentration of DDT found in Lake Michigan trout during 1970 was 19 mg/kg on a whole fish basis. During 1976 the concentration of DDT in Lake Michigan trout was 6 mg/kg. In coho salmon the concentration dropped from 10 mg/kg in 1970 to less than 1 mg/kg in 1976 (See Figure 6). These figures represent significant progress toward the solution of the environmental problem which has the most direct impact on man and on man's use of the Great Lakes, i.e. contamination by synthetic organic compounds or toxic substances.

Toxic organic substances such as DDT and PCB bioaccumulate through the food chain and have been found to have severe effects on mammals and birds which are at the top of the food chain. The effects of PCB on man are well documented. The United States Food and Drug Admininstration has established limits on the concentrations of these substances in fish for the protection of public health. As a result the consumption of fish from Lake Michigan is severely restricted and interstate sale of trout and coho salmon is forbidden.



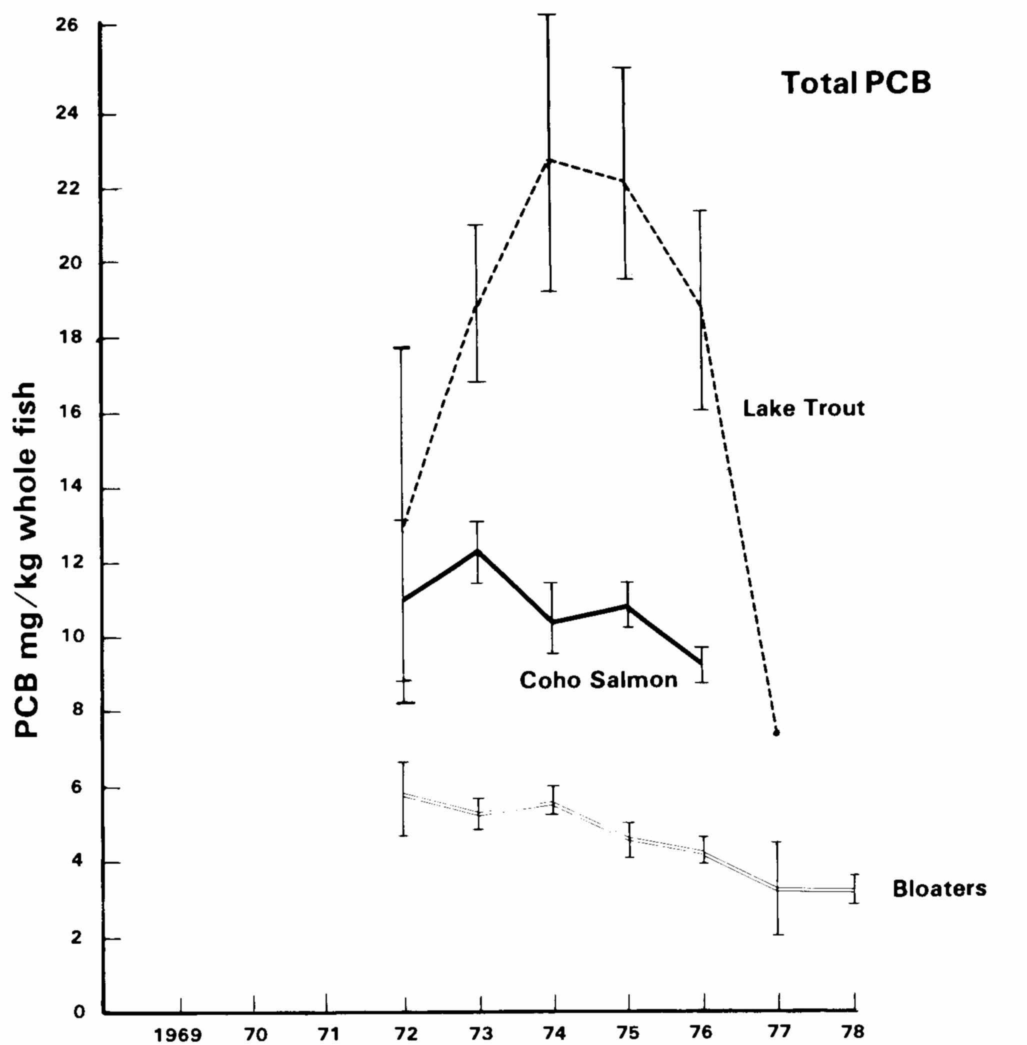
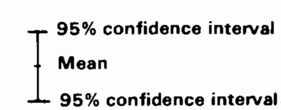


figure 6

Mean Concentrations of Chlorinated Hydrocarbons in Fish from Eastern Lake Michigan (USFWS Data Ann Arbor)

1977 Data from Columbia National Fishery Research Laboratory Based on One or Two Samples



The public has been advised not to consume more than one meal per week. Children and pregnant women are advised to avoid these species altogether. PCB is now found throughout the environment. It is in the air, the water, the soil and has been found in all parts of the globe. [It has been found that eating one meal of Lake Michigan trout is equivalent to breathing the air and drinking the water for a period of more than five years of exposure potential to PCB (Sonzogni and Swain 1980).]

It has been estimated that 80%-90% of the PCBs reaching the lake come by way of atmospheric fallout (Murphy 1977). They get into the atmosphere when materials containing PCBs are incinerated or escape from land fills via gas vapor (Andren et al, 1977). The problem of PCB contamination in Lake Michigan fish should eventually dissipate, but, it could take longer than the dissipation of DDT because PCB is far more widely distributed in the environment and appears to be easily merged into the atmosphere.

PCB concentrations were slightly lower in 1976 than in previous years for all three species tested; coho salmon, brown trout, and chub. In 1977 the Michigan Department of Natural Resources reported that coho salmon showed a decrease in PCB concentration, as compared to 1976 data, with values ranging between 2.4 to 5.04 for whole fish samples. (In 1978 the Illinois Department of Conservation detected 2.68 ppm PCB concentrations in lake trout fillets). This would appear to be the start of a downward trend, however, the Indiana Stream Pollution Control Board in 1977 found in 77 lake trout fillets an average of 16.75 ppm PCBs. Values ranged from 5.55 to 45.3 ppm. Although the manufacture of PCBs in the United States has ceased and their use has been restricted, the lack of quality assurance in these above tests places in doubt the establishment of any definite downward trends in PCB concentrations in fish. The incorporation of effective quality control measures in these tests would help to rectify this problem.

DDT levels in bloater chubs appear to have bottomed out at a low level which represents a decrease of more than 90% since 1969 (Figure 6). Total dieldrin in bloaters chubs appear to be increasing to levels (Figure 6) that are about twice the FDA levels for fillets and the 1978 U.S.-Canada Water Quality Agreement level (IJC-GLWQB, 1978b).

Monitoring for toxic substances has been severely restricted by a lack of reliable laboratory analysis capability. Analysing for these compounds in lake water is a "state of the art" undertaking because of the very low concentrations in the water,and a reliable method was not developed until 1980. Concentrations of many compounds in fish and sediments, however, are much higher so that detecting them is much easier.

HEAVY METALS

Concentrations of heavy metals in Lake Michigan are substantially below water quality standards or International Agreement objectives. This indicates that there is not a significant trace metal problem in Lake Michigan as far as water concentrations are concerned, but there could be through bioaccumulation. Of 1040 analyses of lake water concentrates including quality assurance replicates, there were a total of 12 analyses above the Great Lakes Water Quality Agreement of 1978 objectives. Table 2 summarizes the results and compares them with these International Joint Commission objectives.

ATMOSPHERIC DEPOSITION

Annual loading of twelve aerosol constituents to the southern basin were estimated from one site (Station 6). A comparison of minimum dry deposition loadings to estimates of wet atmospheric loading and surface run-off inputs shows that the atmospheric inputs by dry loading are at least 60 percent of the total lead input, 30 percent of the total zinc input, 20 percent of the total iron input and probably well over half the total sulfate and nitrate input (Sievering et al 1979). Phosphorus dry input is about equal to wet deposition. Total phosphorus atmospheric loads were estimated at about 16% of the total phosphorus loads in 1976 (Eisenreich et al 1980).

LONG TERM NEARSHORE IMPROVEMENTS ILLINOIS-INDIANA

There have been gradual improvements in nearshore conditions in the Illinois and Indiana nearshore zone (Rockwell et al 1980a). These changes appear to be linked to remedial programs which resulted in the diversion of twelve municipal plants and one industry in Lake County, Illinois in the years 1973 through 1978; Indiana's phosphate detergent ban in 1972 and 1973; and pollution abatement programs undertaken by northwest Indiana industries and municipalities during the 1970's. Gradually improving water quality is reflected in the decline in total coliform counts along the north shore (Figure 7) and in reduction of chemicals used for water purification at the south water filtration plant (Figure 8).

TROPHIC STATUS

Figure 9 compares the trophic status of Lake Michigan during 1976 with its trophic status during 1977. The improved trophic conditions are reflected in the substantially narrower mesotrophic nearshore zones during 1977.

TABLE 2
LAKE MICHIGAN JULY - AUGUST 1977
SUMMARY OF METALS DATA FROM WATER SAMPLES
(all values in ug/l)

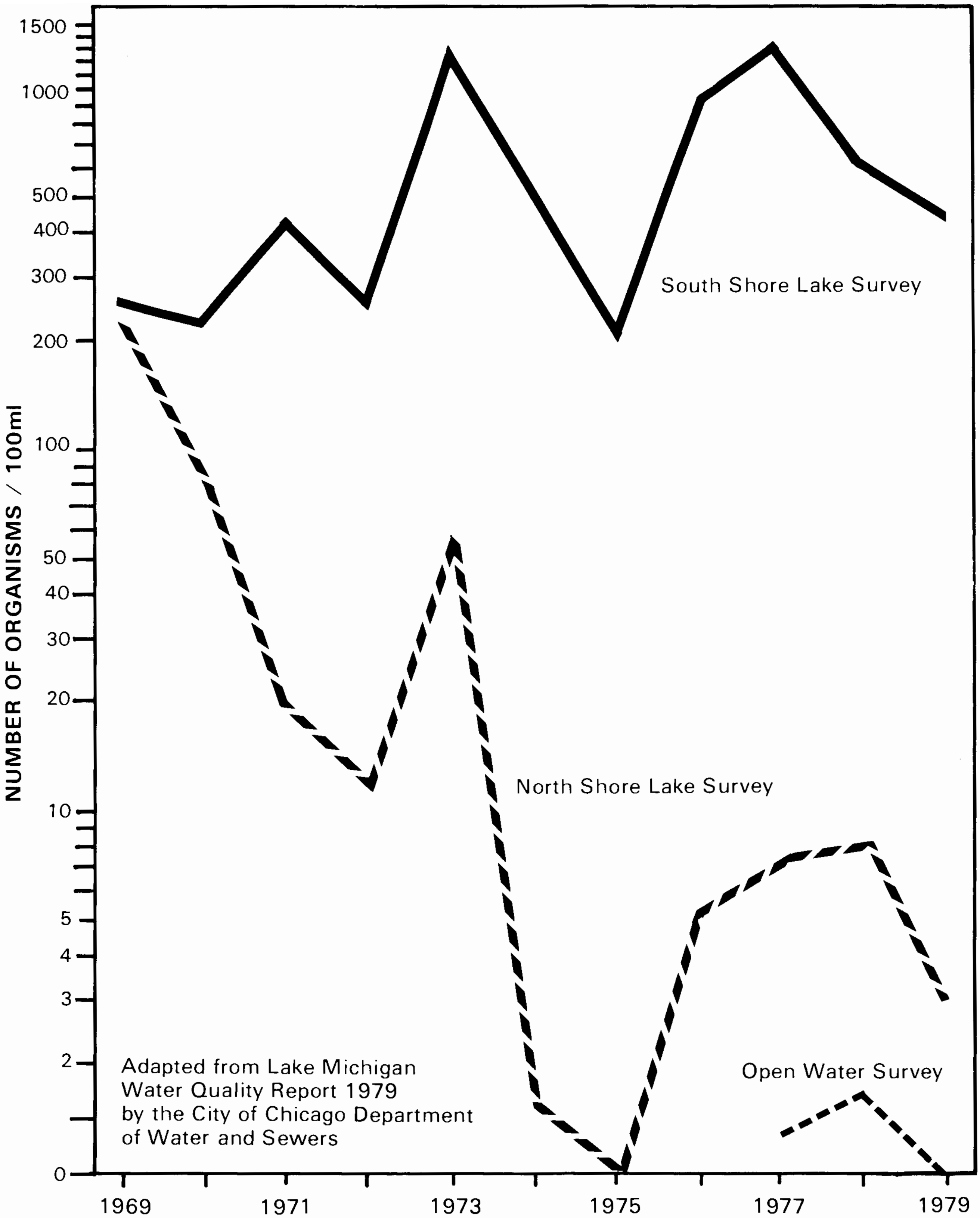
PARAMETER	TOTAL NUMBER OF SAMPLES	NO. SAMPLES LESS THAN INSTRUMENT RESPONSE LEVEL	INSTRUMENT LIMIT OF DETECTABILITY LESS THAN VALUES	MAX.	MEAN*	MIN	STAND. DEVIATION	DETECTION LIMIT**	IJC OBJECTIVE 1978
Arsenic	11	11	2	<2	<2	<2	---	2	50
Barium	102	0	1	40	12	8	4.2	1	---
Beryllium	102	102	2	<2	<2	<2	---	2	---
Cadmium	103	101	2	4	<2	<2	---	2	0.2
Cobalt	102	99	1	2	<1	<1	---	1	---
Copper	102	15	1	9	1.8	<1	1.3	7.5	5
Lead	102	50	6	19	6.6	<6	9.3	9	25
Manganese	103	81	1	8	<1	<1	---	1	---
Molybdenum	106	22	1	4	2.4	<1	1.2	2.2	---
Nickel	102	92	5	13	<5	<5	---	7.2	25
Silver	104	98	3	7	<3	<3	---	3	30
Vanadium	101	95	10	25	<10	<10	---	10	---
Zinc	38	1	3	20	11	<3	3.4	11	30

1976 & 1977 (all values in mg/l)

PARAMETER	TOTAL NUMBER OF SAMPLES	NO. SAMPLES LESS THAN INSTRUMENT RESPONSE LEVEL	INSTRUMENT LIMIT OF DETECTABILITY LESS THAN VALUES	MAX.	MEAN*	MIN	STAND. DEVIATION	DETECTION LIMIT**	IJC OBJECTIVE 1978
Calcium	549	0	.1	46.5	34.9	20.7	2.2	0.5	---
Magnesium	550	0	.1	14.9	10.8	7.8	0.9	0.1	---
Potassium	794	0	.01	2.4	1.1	0.9	0.1	0.01	---
Sodium	550	0	.1	13.9	4.8	3.3	0.7	1.5	---
Fluoride	258	0	.1	0.114	0.102	0.07	0.004	0.1	1.20

*Values below the detection limit were arbitarily assigned a value of 1/2 the detection limit for purposes of calculating the mean.

**Detection limit = mean of blanks + 2 standard deviations of mean.



Total Coliform

Figure 7

Figure 8

Chicago Water Purification Division
South Water Filtration Plant
Dosage Pounds/Millions Gallons/Year

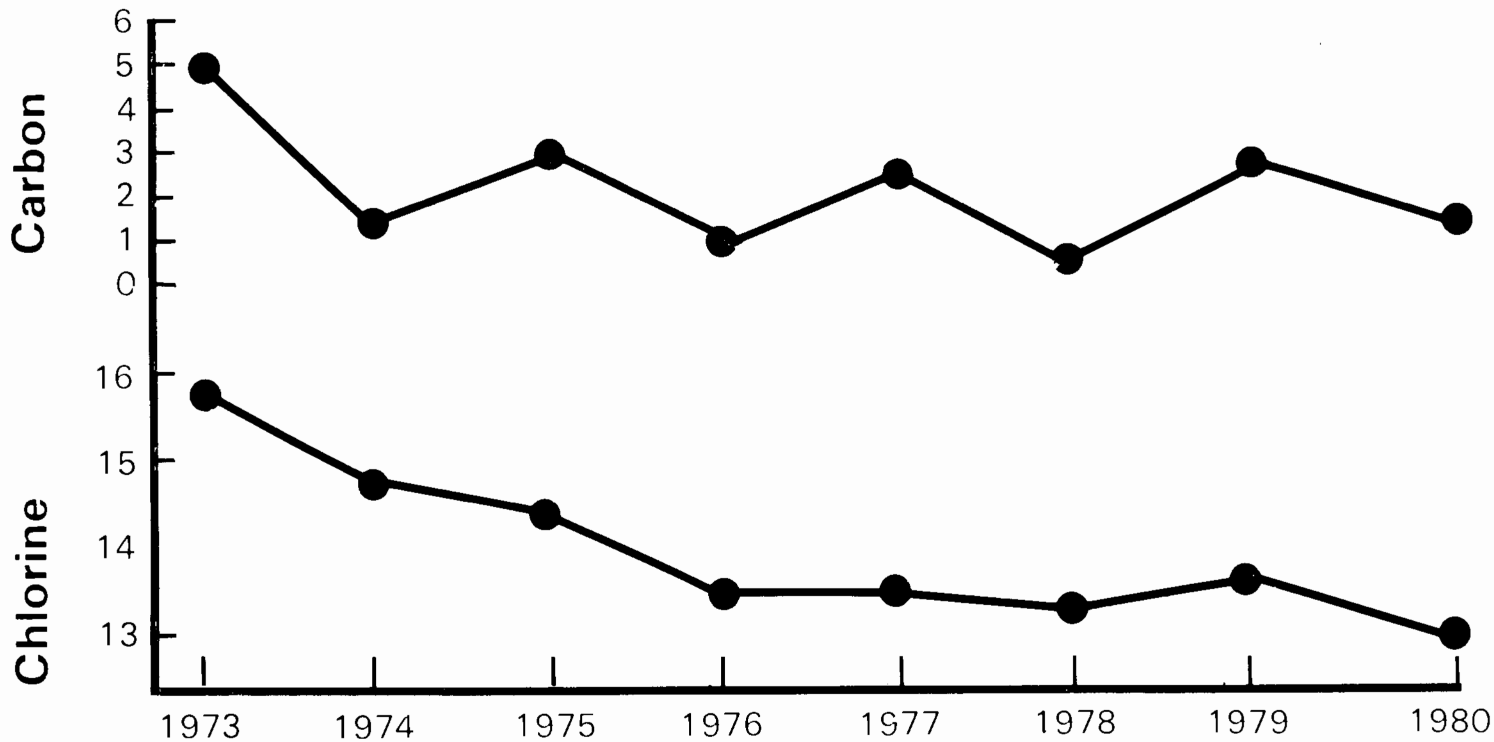
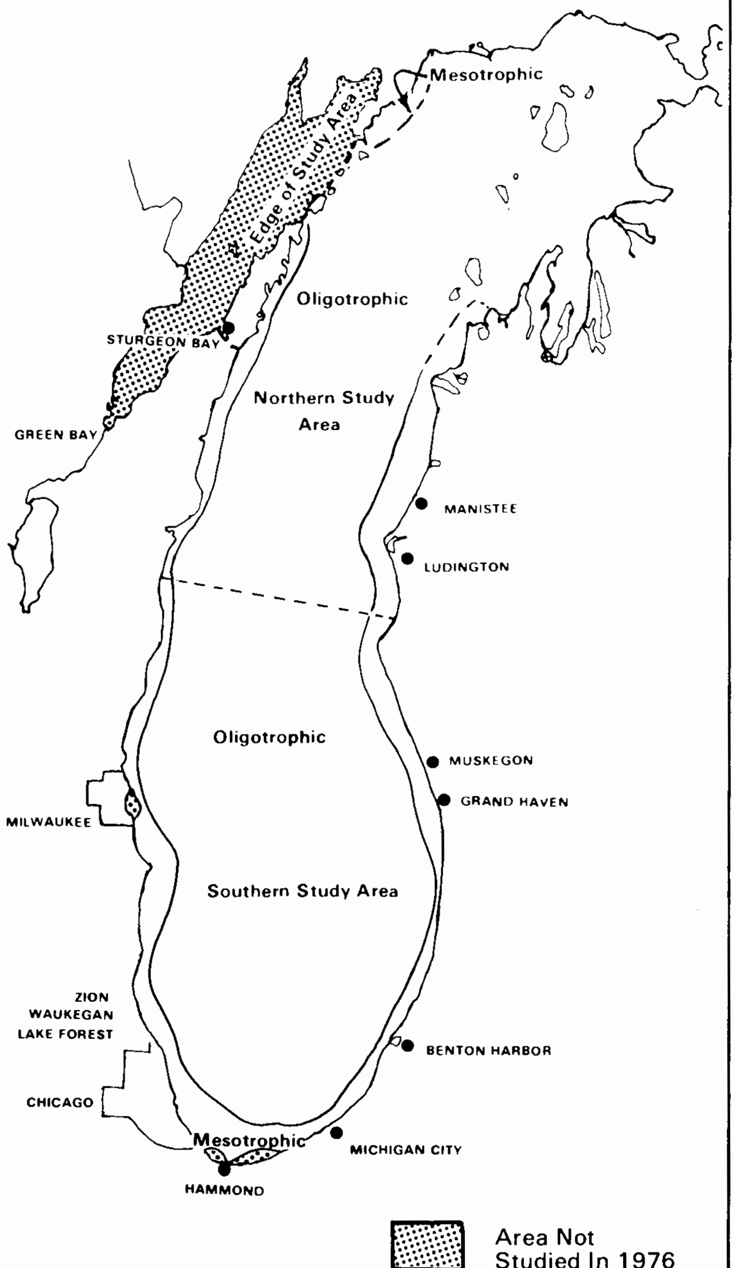


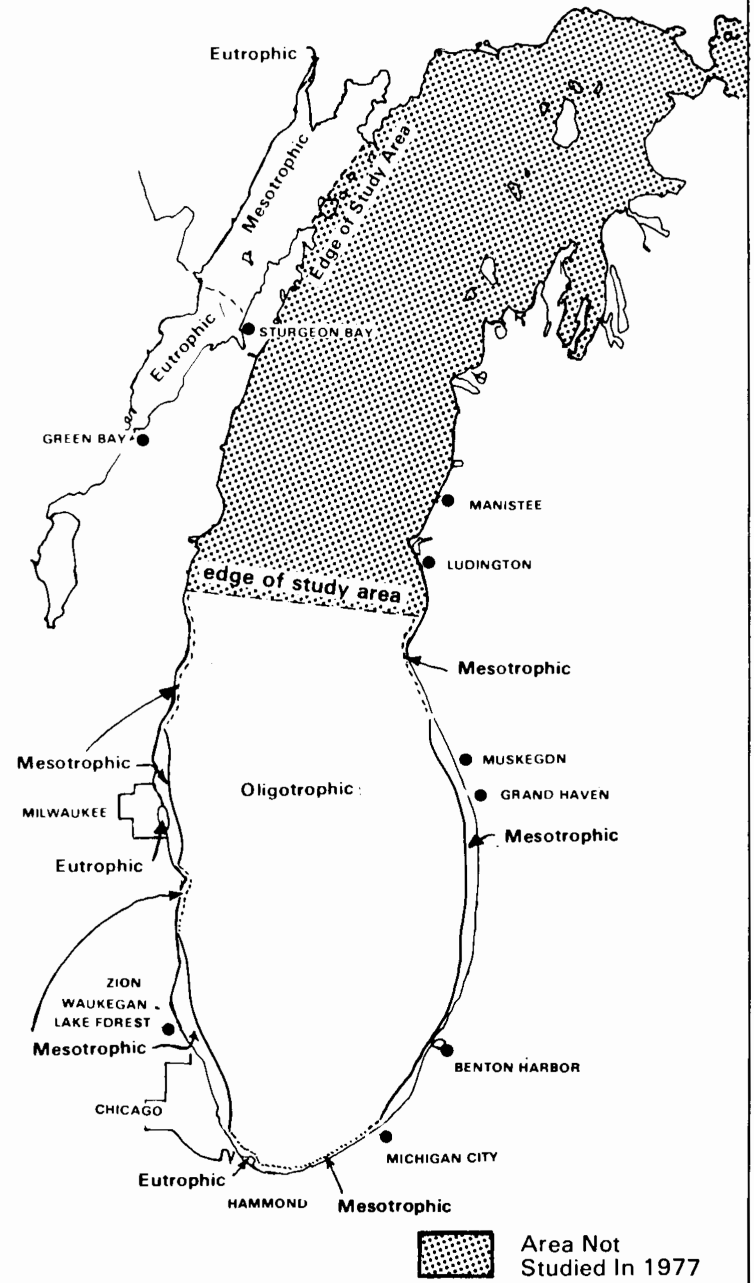
Figure 9

Lake Michigan
Estimated Trophic Status



Study Area Involved Open Lake Monitoring In Northern And Southern Basins.

1976



Study Areas Included Nearshore Zones At Milwaukee, Chicago. Calumet And Green Bay. Open Lake Monitoring In Southern Basin Only.

1977

Many different systems have been developed for characterizing the trophic status of lakes. Systems based on empirical observations from many different water bodies have been derived. The systems most applicable to the Great Lakes were developed by the IJC Upper Lake Reference Group (1976), Dobson (1976) and Rast and Lee (1978). These systems were used to evaluate Lake Michigan. Although these systems are an improvement over the purely subjective judgment previously used to define the trophic state of the lakes, they do not entirely agree with each other. Further, the processes of eutrophication which these systems attempt to quantify are not linear and not monotonic. Table 3 provides a summary of the trophic status indicator values, which were developed for total phosphorus, chlorophyll "a", and secchi depth by each observer. Table 3 also contains trophic status indicator transition values for aerobic heterotrophs which have been proposed by the Great Lakes Research and Surveillance staff and which may be used together with each of the previous systems, to expand their indicator categories to include microbiology (Rockwell et al 1980b).

The evaluation for Lake Michigan was developed by applying all three systems to data for each station and applying the consensus or most prevalent result for each year. Improved conditions during 1977 are reflected by the narrow mesotrophic zones along the shore lines. Eutrophic zones shown are Milwaukee and Indiana Harbor Canal in 1977 are the results of near shore studies conducted during that year and undoubtedly existed during 1976 also.

U.S.E.P.A. RESPONSES

The response of the Great Lakes National Program Office (GLNPO) to the 1976-1977 intensive field year has been an on-going process. The GLNPO monitoring program has moved to include a search for toxic chemicals which may be bioaccumulating in fish and sediments. This programs seeks to pinpoint sources of Great Lakes toxics via harbor and tributary monitoring. Programs to compute actual loadings of pollutants to the Great Lakes have been a part of the GLNPO program for several years. However, these loading programs have recently expanded through high flow monitoring to more accurately determine tributary loads and atmospheric inputs into the lakes.

SPECIFIC RESPONSES

TECHNICAL ASSESSMENT TEAMS (TAT)

The Great Lakes intensive survey on Lake Michigan in 1976-1977 collected more data on this lake's water quality than ever before in history. Processing that information and interpreting its significance required an extensive dedication of time and agency personnel - two commodities in short supply due to resource constraints and the necessity to have timely enough data interpretation actually effect control programs.

TABLE 3

ENRICHMENT PROBLEM RELATIONSHIPS APPLIED ON LAKE MICHIGAN DATA

	Oligotrophic Mesotrophic Indicator Transition Values	Mesotrophic-Eutrophic Indicator Transition Values
H.H. Dobson Systems (1976)		
Summer Total Phosphorus (ug/l)	8	19
Chlorophyll "a" (ug/l)	2	5
Secchi Depth (meters)	6	3
IJC		
The Waters of Lake Huron & Lake Superior[1]		
Upper Lakes Reference Group (1976) - Volume I		
Total Phosphorus (ug/l)	6.5	14.1
Chlorophyll "a" (ug/l)	2.4	7.8
Secchi Depth (meters)	8.6	2.9
Rast and Lee (1978)		
Annual Total Phosphorus (ug/l)	10	20
Summer Mean Epilimnetic Chlorophyll "a" (ug/l)	2	6
Secchi Depth (meters)	4.6	2.7
Surveillance & Research Staff		
Aerobic Heterotrophs		
Aerobic Heterotrophs - nearshore (<15 meters or <3 kilometers)	120	2000
Aerobic Heterotrophs - offshore (>15 meters and >3 kilometers)	20	200

[1]Estimates of the mid-range of each parameter were made from page 128 of the report "The Waters of Lake Huron and Lake Superior".

During 1980 and 1981, GLNPO assembled TAT's for Lake Erie and Lake Huron to help prepare reports directed to the scientific community, governmental decision makers, and the public-at-large based upon intensive field year efforts. U.S. universities, particularly the sea-grant universities, have developed research programs on the Great Lakes involving well recognized scientists. During FY 1980, direct grants were made to Ohio State University's Center for Lake Erie Area Research and to the University of Michigan's Great Lakes Research Division to provide assistance in data evaluation, coordination of reports, report writing and technical editing. These teams will be teams will be responsible for data from the 1978-1979 intensive field years on Lake Erie and the 1980 intensive field year on Lake Huron.

PROGRAM DESIGN EVALUATION

To date the selection of station networks and the frequency of cruises necessary for an intensive year of monitoring on the Great Lakes has been based on best judgment. Actual implementation may be less than required due to weather conditions or financial resource constraints. However, field work imposes a limitation on discovery of spacial variability and meteorological variability. To better understand the sufficiency of sampling networks and frequencies, open lake eutrophication simulations were developed and are underway using Lake Michigan's 1976-1977 data base. Lake Erie will be evaluated in a similar manner if the Lake Michigan simulations meet expectations.

The open lake eutrophication simulations require a minimum number of stations and sampling cruises to assure a sufficient data base for their verification and operation. The verified model can be used to determine the adequacy of the station network and cruise schedule. It can also be used to project long term changes in chlorophyll "a" levels dependent on various remedial program strategies such as phosphorus controls.

One unexpected finding of the intensive survey of Lake Michigan in 1976-1977 was the rapid and large change in lake chemistry apparently brought on by the extensive ice cover resulting from the severe winter. Lake chemistry changes exceeded expectations, by far. Lake simulations will be modified to include a capability to vary spring lake concentrations based on winter meteorological conditions.

MONITORING RESPONSES

ANNUAL LAKE ERIE PROGRAM

One lake has been selected for annual programs by the GLNPO, Lake Erie, since it is the most eutrophic as well as the smallest of the the Great Lakes. Due to its relatively small size, lake conditions here could change more rapidly than in the other lakes due to loading changes. Lake Erie has a filling time of 2.5 years for the entire lake, while the filling time for Lake Michigan is estimated at 100 years. The first GLNPO annual program for Lake Erie was funded in 1980. It includes a limited number of open lake stations to provide an estimate of annual trophic conditions and to determine the extent, severity, and duration of dissolved oxygen depletion in the central basin. This annual program also monitors nearshore conditions by quantative measurements of cladophora growth.

TRIBUTARY HIGH FLOW LOADS

To improve annual estimates of nutrients and metals loadings to the Great Lakes, 12 high flow events on each major tributary are monitored in addition to regular monthly surveys. This program provides more accurate estimates of the annual tributary loads to the Great Lakes. Loading data is very important in modeling simulations of eutrophication responses to various phosphorus management strategies.

ATMOSPHERIC DEPOSITION

The atmosphere has been found to be a significant source of many chemicals. In the southern basin of Lake Michigan atmospheric loads of anthropogenically derived trace elements (lead, zinc, and iron), nutrients (nitrate and phosphate), and a conservative ion (sulfate) are found to be a large percentage of the individual total loads for these substances (Sievering et al 1979). To improve estimates of atmospheric contributions, GLNPO has instituted a network of 40 bulk and wet atmospheric deposition sampling sites along the shorelines and on some islands within the Great Lakes. In addition to their primarily function to provide information on nutrients, metals and toxic substances, these sites will collect information to support the requirements of the National Acid Rain monitoring program.

INVESTIGATION OF NEW POTENTIAL PROBLEMS

The 1976-1977 Lake Michigan field work, as well as the report from a grant to study the fifty year phytoplankton record from the City of Chicago's water filtration intakes, focused attention on sodium inputs to the the lake as a potential critical nutrient controlling the growth rates of some blue-green algae in Lake Michigan waters.

New waste control processes and road salting programs contribute sodium to the basin. The concentration of sodium in Lake Michigan varies between 4 and 5 mg/l. Laboratory experiments with sodium concentrations levels above 5 mg/l have resulted in some species of blue-green algae thriving. Concentration of 4 mg/l to 5 mg/l sodium may be a critical threshold above which blue-green algae are found to have a competative advantage over other forms of algae. Should this situation hold in the waters of Lake Michigan, it would alter the composition of the food base for zooplankton and, eventually fish. The nature and severity of this potential shift to blue-green algae is not known. However, this preliminary information would suggest a study of controls on the use of salt in road deicing and industrial processes so as to protect the lake against deterioration of its food chain at the most fundamental level.

HARBOR SEDIMENT PROGRAM

Toxic substances are being introduced into the environment from many sources. Secondary compounds from these toxicants are often formed in the environment. Some of these secondary compounds are more hazardous than the primary chemicals from which they came. River, harbor, and lake sediments collect pollutants. Under some circumstances sediments may release the pollutants they have collected. To identify "hot spots" where toxic substance have accumulated, GLNPO has initiated a harbor sediment program. This program will seek out contaminated sediments in 19 harbors in 1981, searching for a wide range of toxic compounds in the sediments. With this information harbor sediment dredging activities will then be reviewed to evaluate the desirability of depositing any contaminated sediments found in the harbors in the adjacent lake.

FISH FLESH CONTAMINANT PROGRAM

Bioaccumulation of toxic contaminants has been shown to present significant health hazards to man, even though the contaminant levels are may be low in the environment. Since fish are near the top of the aquatic food chain and are consumed by man, GLNPO has undertaken an extensive program to search for a wide range of chemicals in fish flesh (Table 4).

During the 1970's, the use of DDT was banned and PCB's were greatly restricted. The fish monitoring program has tracked the response to these actions and is used to assess the effectiveness of the remedial programs designed to limit the exposure of the biological and physical environment to these chemicals.

The fish program is directed at both open lake game fish and at near-shore areas. It is used in conjunction with findings from the sediment program to identify areas where bioaccumulation of toxics substances is occuring.

INTENSIVE GREAT LAKE SURVEILLANCE

The regular intensive surveys of the Great Lakes will continue in the Lake Ontario basin in 1981-82. GLNPO will implement intensive nearshore studies in the Niagara River area, Rochester embayment, and the Oswego area. These areas have been identified as water quality problem areas. The studies will determine compliance with state water quality standards and International Agreement objectives. Canadian agencies will conduct the intensive survey of Lake Ontario open waters.

STATE MONITORING GRANTS

Funds have been made available to monitor the Great Lakes bordering the State of Michigan over a five year period. Work involves fish monitoring for toxic substances, tributary monitoring, water intake monitoring and verification, and nearshore studies at selected problem areas.

TABLE 4

CHEMICALS MONITORED IN FISH FLESH

Contaminants monitored --- (Lipid content determined on all samples)

(a) All samples:

Organics	Metals
DDT and Metabolites	Arsenic
Aldrin/Dieldrin	Cadmium
PCBs	Copper
Mirex (Lake Ontario only)	Lead
Chlordane (α , γ , oxy)	Chromium
Heptachlor	Mercury
Heptachlor Epoxide	Zinc

(b) Selected samples will be scanned for organics and metals using best available methods. The organic scans involving acid, base, and neutral extraction should include, but not necessarily be limited to:

Endrin	Trichlorophenol
Kepone	Pentachlorophenol
Lindane	Tetrachlorophenol
Methoxychlor	Tetrachloroethylene
Toxaphene	Chlorinated Styrenes (Octa & Poly)
Dichlorobenzenes	Hexachlorobutadiene
Trichlorobenzene	B-BHC (Benezene Hexachloride) (BHC 1, 2, 3, 4, 5, 6-Hexachlorocyclohexane)
(HCBD) Tetrachlorobenzene	Polybrominated Biphenyls
Pentachlorobenzene	Chlorinated Terphenyls
Hexachlorobenzene	Polynuclear Aromatic Hydrocarbons
p - Bromoanisole	
Chlorinated Naphthaline	
Methylnaphthalene	

WATER INTAKE PROGRAMS

Water intakes are in the nearshore zone and provide permanent monitoring posts. Several sites have been selected on the Great Lakes to provide a minimun amount of weekly data year round. These sites can link together the intensive year efforts. They will provide some detection of major trends in the nearshore areas where they are located.

RECOMMENDATIONS

Toxics in the environment have become the most significant threat to man's enjoyment of available fishing resources in the Great Lakes. More importantly, bioaccumulation of a wide range of known organic and inorganic contaminants has been shown to be a significant health hazard to man and predators at the top of the aquatic food chain. During the seventies production bans were placed on DDT and PCB. A fish monitoring program is required to track the effect that bans have on ambient levels of toxics in fish flesh. The program should also attempt to identify additional compounds that are bioaccumulating in Great Lakes's fishes.

Toxics also accumulate in sediments. Secondary compounds can form in sediments from toxic introduced into the environment. To identify geographical "hot spots" toxic substance accumulation, a harbor sediment program is recommended. This program should be coordinated with the fish flesh monitoring to enable remedial program resources to be directed to curtail and to clean up hazardous substances which effect food resources and the public health.

The fish and harbor sediment monitoring programs will provide identification of potential industrial and municipal sources of hazardous substances. This information can be used to modify National Pollutant Discharge Elimination System (NPDES) permits to curtail or eliminate sources of toxicants which may pass into the Great Lakes.

Nutrient loads to the Great Lakes have not been quantified adequately by the previous tributary and atmospheric monitoring programs. Mathematical simulations of lake responses to various phosphorus removal strategies are based on mass balance equations and observed concentrations in the lake. The mass balance equation is made up of terms involving inputs from tributaries, atmospheric sources, point source discharges, and sediments, as well as outputs from the lake. Accurate estimates of the inputs are required for the models to successfully predict responses within the required ranges so as to measure alternative remedial program effectiveness.

The annual variability of ambient phosphorus concentrations within the lake has significance for the design of lake monitoring programs. The present strategy, which calls for intensive surveys during two of every nine years, is based on the assumption that significant changes occur slowly over a period of years. The magnitude of the observed decrease in total phosphorus which occurred during the 1976-77 winter raised the issue of what is an appropriate long-term nutrient monitoring strategy. Since meterological conditions during the 1976-77 winter significantly altered this aspect of Lake Michigan's chemistry and since total phosphorus concentrations during the ice-out period determine in large part the annual limnological response of the system, the current monitoring strategy is inadequate. There appears to be sufficient evidence that this type of concentration change is not unique to Lake Michigan and occurs in the other Great Lakes (Rockwell, 1981). Thus, proper interpretation of long term trends requires annual determinations of the ice-out conditions on each of the Great Lakes.

Within the intensive field year program observed changes occurring between cruises indicate the need for biweekly or weekly monitoring at selected sites. These stations should be monitored to characterize shorter term phenomena, such as phytoplankton succession or nutrient cycling, and to increase our knowledge of the biological processess essential to controlling eutrophication responses of the ecosystem. Less frequent monitoring can miss some aquatic species or short lived blooms. Knowledge of these events are useful in characterization of the lakes biological status. However, the intensive monitoring completed during 1977 at a single deep water station showed that during a twenty-four hour period the hour-to-hour variability was not statistically significant. Thus, the assumption that a cross-lake transect completed within one day is synophic, is reasonable, provided a storm does not occur.

Variable sedimentation rates during winter appear to be the most probable mechanism for the rapid changes in total phosphorus concentrations observed during the 1976-77 field years on Lake Michigan. Lake models need to be enhanced to account for sediment transport, deposition, and resuspension processes. To successfully incorporate these mechanisms and their relationships to winter meterological conditions, studies of winter sedimentation rates in deep lakes are required.

Increasing levels of chloride and sulfate concentrations will not threaten drinking water standards during the next several centuries unless loads are dramatically increased. However, increasing concentrations of these conservative ions are making possible an ever expanding habitat for marine algal forms. Some new marine algal forms have been observed in the nearshore zones of Lake Michigan as well as in other more eutrophic Great Lakes. Furthermore, increasing sodium concentrations in Lake Michigan may permit certain blue-green algae species to grow more rapidly and selectively replace more desirable zooplankton food sources during the summer. Studies of sodium and other conservative ion effects on phytoplankton in the southern basin of Lake Michigan need to be undertaken. Control options to restrict chloride and sodium inputs from road de-icing and industrial processes should be investigated.

In summary our recommendations are:

(1) Toxic monitoring programs should continue to be implemented to determine effectiveness of remedial activities. These programs include

a) Fish flesh monitoring of game fish in the open lake and at river mouth collection sites.

b) Harbor sediment monitoring at selected sites to detect high concentrations of toxic contaminants.

c) Toxics monitoring in the water column at selected sites to determine existing background levels.

(2) The nutrient monitoring strategy should be modified to improve the ability to predict long term effects of alternate phosphorus control remedial programs. This modification should involve

a) High flow event monitoring twelve times per year at selected major tributaries.

b) Improved and expanded atmospheric load monitoring at selected sites along the shore lines and on islands within the Great Lakes.

c) Determining spring ice-out conditions at selected sites on each of the Great Lakes each year.

d) Adding weekly to biweekly monitoring at selected intensive field year sites.

e) Conducting limited mid-winter surveys after an intensive Great Lake field year.

(3) Expansion of current knowledge in several significant new problem areas is recommended:

a) Studies of sodium and conservative ion effects on phytoplankton in the southern Lake Michigan Basin should be initiated.

b) Studies of winter sedimentation processes and incorporation of sediment transport, deposition and resuspension processes into new or existing lake modes should be undertaken.

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APPENDIX A

DESCRIPTION OF SURVEY

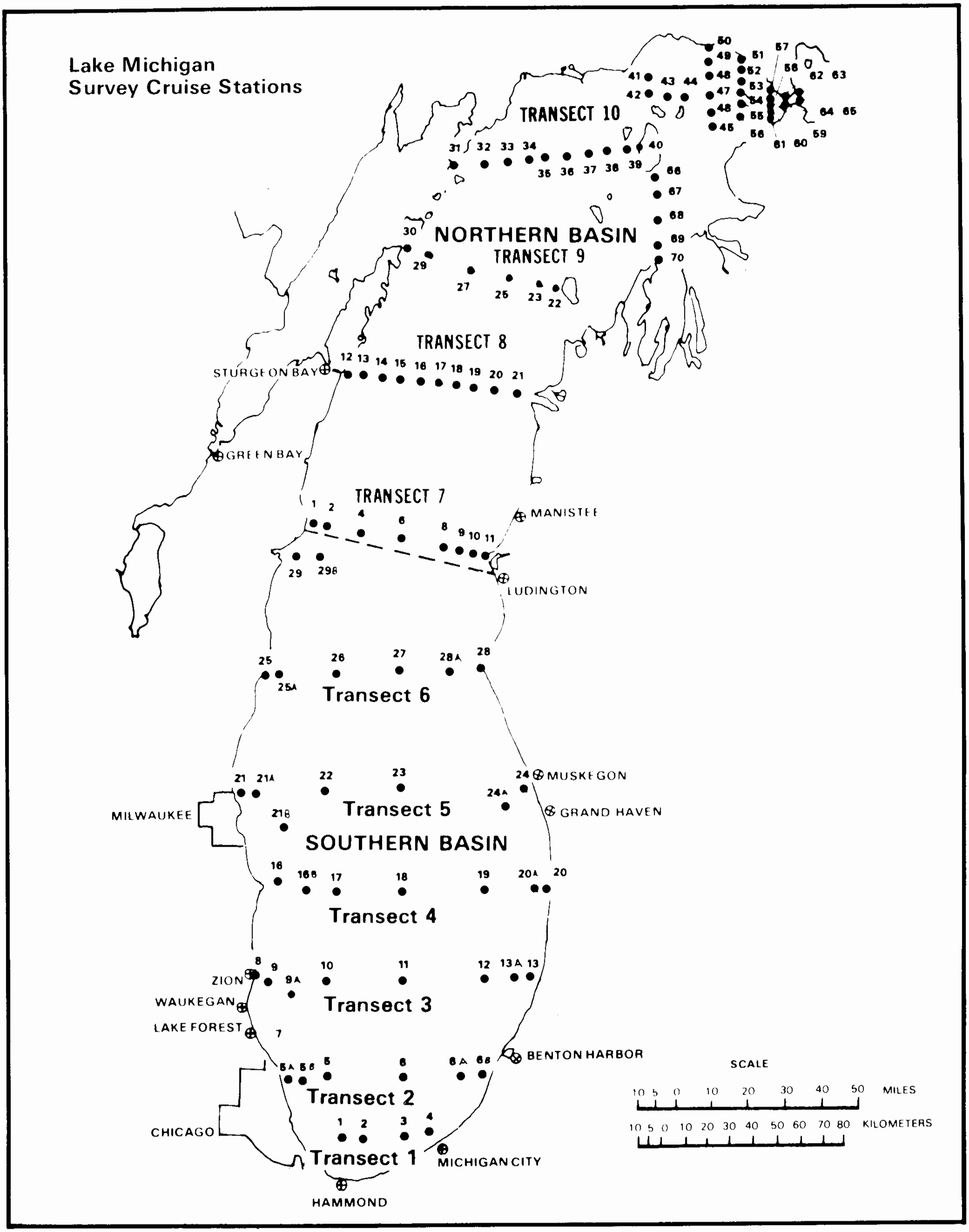
Figure A-1 shows the station locations and schedules for cruise conducted on the main lake. The station were selected to provide complete coverage of the main lake and representative coverage of nearshore zones which were not in problem areas. Figure A-2 shows locations of stations used in nearshore studies in problem areas which were conducted during 1977. Separate reports on these nearshore studies are being prepared. The actual location of many of the stations was selected because data from these points are available from older studies primarily the 1962-63 study of Lake Michigan conducted by the U.S. Public Health Service.

Depth Selection. During the first four cruises of 1976, each station was sampled when possible, at 2, 5, 10, 20, 50, 100 meters, and 1 meter above the bottom. Throughout the rest of 1976 and during 1977 additional samples were taken from thermally stratified stations at mid thermocline, 5M above and 5M below mid thermocline. Any of the fixed depths above that were within 3M of the thermocline depths were deleted (Figure A-3).

Table A-1, A-2 and A-3 list the analyses performed on each cruise. and the rationale for the parameters used to index the trophic state of Lake Michigan.

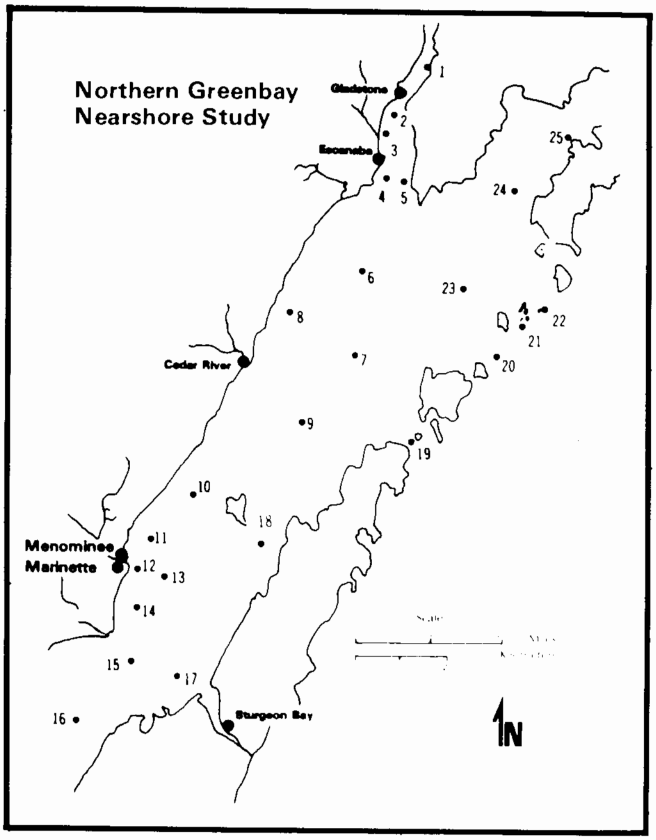
Figure A-4 illustrates the sample processing performed on the USEPA monitoring vessel Roger R. Simons and Figure A-5 shows the sampling processing on board the University of Michigan vessel Laurentian.

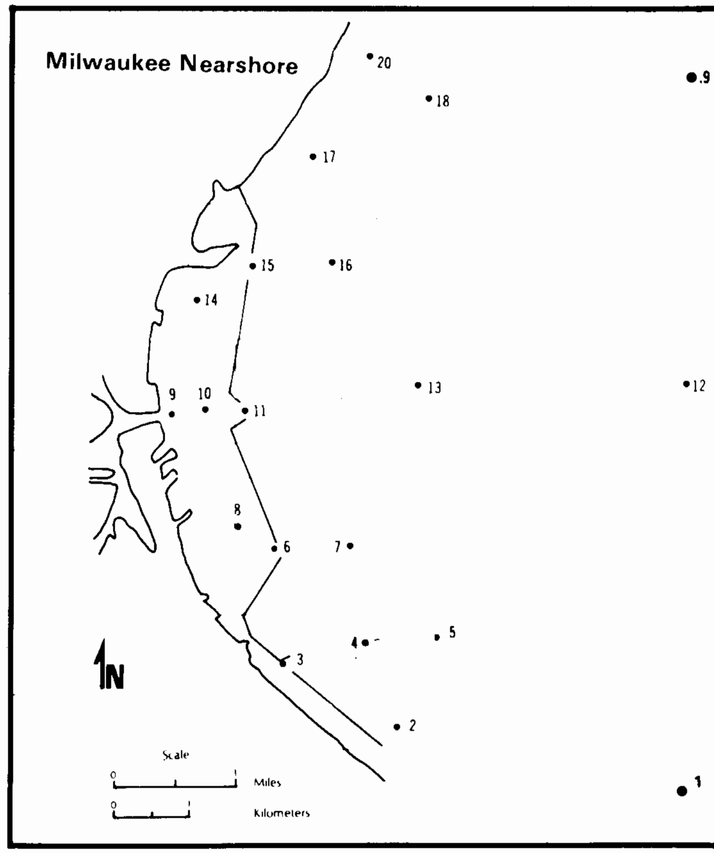
Figure A-1

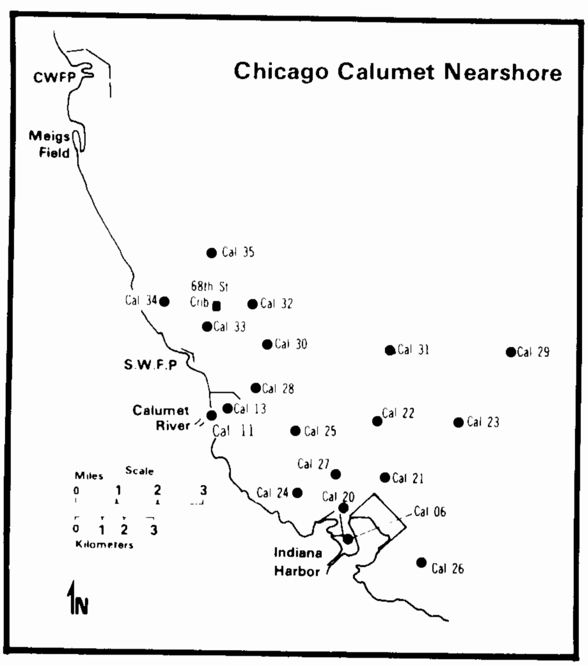


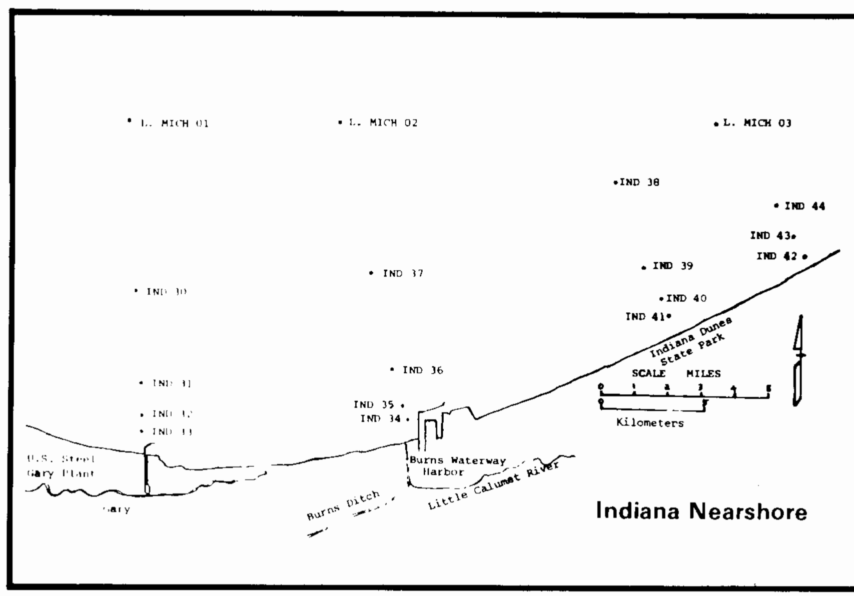
Lake Michigan
Survey Cruise Stations
TRANSECT 10
NORTHERN BASIN
TRANSECT 9
TRANSECT 8
STURGEON BAY
GREEN BAY
TRANSECT 7
MANISTEE
LUDINGTON
Transect 6
MUSKEGON
GRAND HAVEN
MILWAUKEE
Transect 5
SOUTHERN BASIN
Transect 4
ZION
WAUKEGAN
LAKE FOREST
Transect 3
BENTON HARBOR
CHICAGO
Transect 2
Transect 1
MICHIGAN CITY
HAMMOND
SCALE
10 5 0 10 20 30 40 50 MILES
10 5 0 10 20 30 40 50 60 70 80 KILOMETERS

Figure A-2









Lake Michigan
Nearshore Survey
Cruise Stations

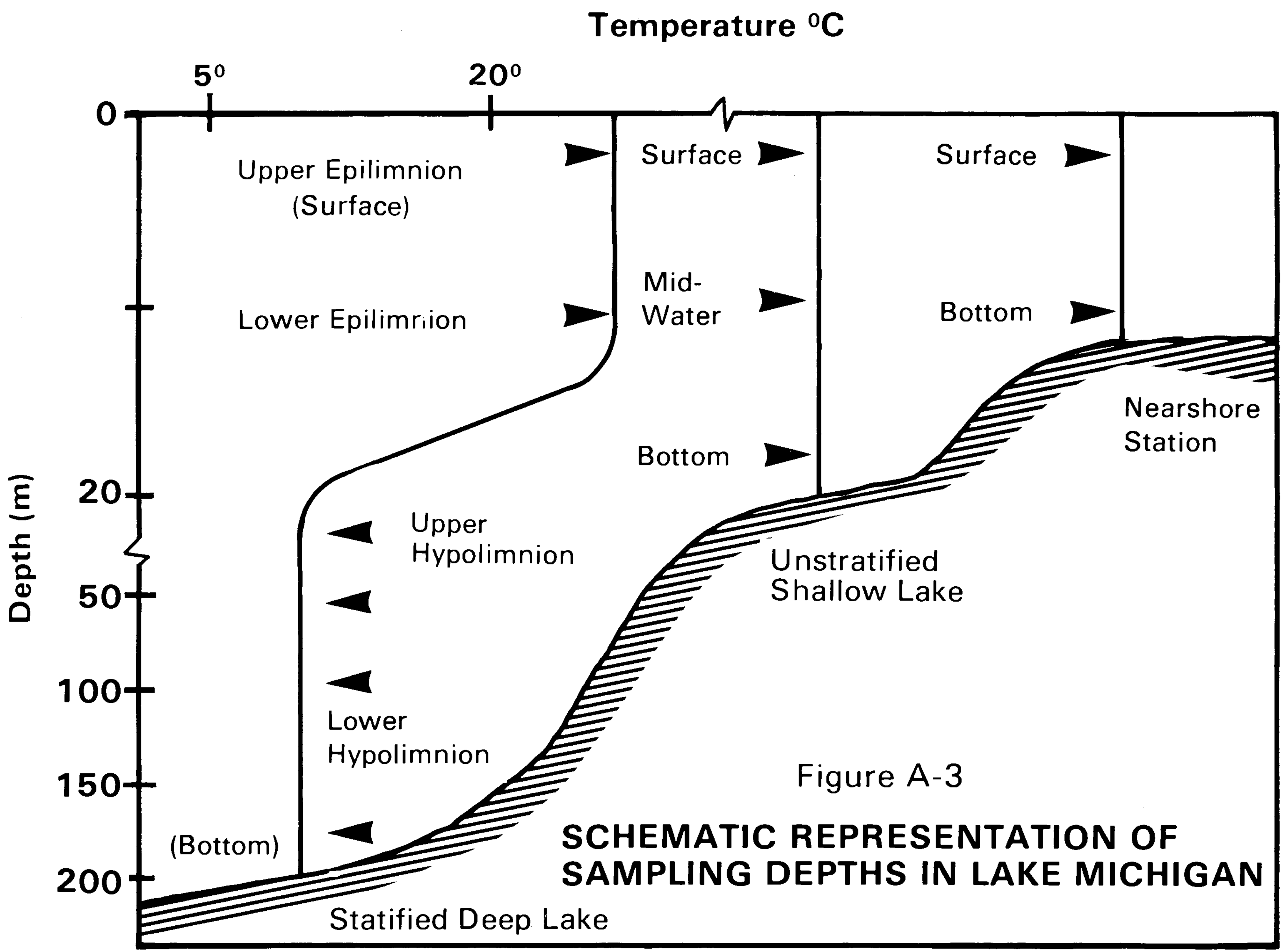


Figure A-3

SCHEMATIC REPRESENTATION OF SAMPLING DEPTHS IN LAKE MICHIGAN

TABLE A-1

PARAMETERS MEASURED BY GLNPO

in 1976-1977

Parameter	STORET	Cruises	Stations	Depths	Sample
Air Temperature	00020	All	All	--	Shaded from Sun
Wind Speed	00035	All	All	--	Onsite meas.
Wind Direction	00040	All	All	--	Onsite meas.
Secchi Depth	00078	All	All	--	Onsite observ.
Wave Height	70222	All	All	--	Onsite observ.
Water Temperature	00010	All	All	All	Niskin, EBT
Optical Transmittance	00074	All	All	cont.	EBT
Turbidity	00076	All	All	All	Niskin-PEC
Specific Conductance	00095	All	All	All	Niskin-PEC
pH	00400	All	All	All	Niskin-PEC
Total Alkalinity	00410	All	All	All	Niskin-PEC
Suspended Solids	00530	Selected	All	All	Niskin-PEC-petri di
Total Ammonia Nitrogen	00610	All[1]	All	All	Niskin-PEC
Total Kjeldahl Nitrogen	00625	Selected	All	All	Niskin-125 PE(S)
Total Nitrate + Nitrite	00630	All[1]	All	All	Niskin-PEC
Total Phosphorus	00665	All[1]	All	All	Niskin-125 PE(S)
Total Dissolved Phosphorus	00666	All[1]	All	All	Niskin-PEC-125 PE(S
Dissolved Orthophosphate	00671	All[1]	All	All	Niskin-PEC-125 PE
Total Cyanide	00720	Selected	Select	All	Niskin-250 PE (A)
Metals		Selected	All	5M	Niskin-PE (N)
Total Chloride	00940	Selected	All	All	Niskin-125 PE
Total Sulfate	00945	Selected	All	All	Niskin-125 PE
Total Fluoride	00951	Selected	Select	All	Niskin-125 PE
Dissolved Reactive Silica	00955	All[1]	All	All	Niskin-PEC-125 PE
Total Arsenic	01002	Sed-77	Select	5M	Niskin-PE (N)
Fecal Coliform	31616	Selected	All	Selected	ZoBell Sampler
Total Plate Count	31749	Selected	All	Selected	ZoBell Sampler
Chlorophyll "a" fluor.	32209	Selected	All	All	Niskin-PEC
Pheophytin "a" fluor.	32213	Selected	All	All	Niskin-PEC
Total Phenolics	32730	Selected	All	All	Niskin-250 PE (A)
Primary Productivity	70990	Selected	All	5M	Niskin-BOD bottles
Aesthetics		All where applicable			
Phytoplankton		Selected	All	All	Niskin PE 960
Zooplankton		Open lake	All	Integrated	Net #6 PE 960

EBT= Electric bathythermograph/transmissometer
PEC= Polyethylene Cubitainer, one gallon or 2 1/2 gallon
PE = Polyethylene, preceding number indicates volume in mls.
(A)= 10 ml/l NaOH (1.0N) added as preservative
(S)= 1 ml/l concentrated sulfuric acid added as preservative
(N)= 5 ml/l concentrated nitric acid added as preservative
(L)= 5 ml/l Lugols
[1]Nutrients 610, 630, 665, 666, 671 & 955 not run on metal cruises

TABLE A-2

SELECTED CRUISE PARAMETERS MEASURED BY GLNPO

in 1976-1977

	Southern open lake survey #1 1976	Southern open lake survey #2 1976	Southern open lake survey #3 1976	South to North survey and Southern open lake survey #4 1976	Southern open lake survey #5 1976	Southern lake survey #6 & #8 1976	Southern open lake survey #7 1976	Milwaukee nearshore survey #1	Milwaukee nearshore survey #2	Chicago nearshore survey #1	Chicago nearshore survey #2	24 hr. station 6 #1 & #2	24 hr. station 6 #3	Southern open lake survey #1 1977	Southern open lake survey #2, #3, & #4 1977	Indiana nearshore survey #1	Indiana nearshore survey #2 & #3	Green Bay survey #2	Green Bay survey #3
Suspended Solids	-	-	-	-	-	-	+	+	+	+	-	-	-	-	-	-	-	-	-
Total Kjeldahl Nitrogen	+	+	+	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+
Total Cyanide	-	-	-	-	-	-	-	+	-	+	-	-	-	-	-	-	-	-	-
Metals*	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Chloride	+	+	+	+	+	+	+	-	+	-	+	+	+	+	+	+	+	+	+
Total Sulfate	+	+	+	+	+	+	+	-	+	-	+	-	-	-	-	-	+	+	+
Total Fluoride	+	-	+	-	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-
Total Arsenic*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fecal Coliform	+	+	+	+	+	+	+	+	+	+	+	-	-	-	+	+	+	-	+
Total Plate Count	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+
Chlorophyll "a" fluor.	+	+	+	-	-	-	-	+	+	+	+	+	+	-	+	+	+	+	+
Pheophytin "a" fluor.	+	+	+	-	-	-	-	+	+	+	+	+	+	-	+	+	+	+	+
Total Phenolics	-	-	-	-	-	-	-	+	-	+	-	-	-	-	-	-	-	-	-
Primary Productivity	-	-	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	-	-

*Sampled on the 1977 metal cruises.

TABLE A-3

SYSTEM OF PARAMETERS USED TO INDEX THE TROPHIC

STATE OF LAKE MICHIGAN

Physical Measurements

Temperature: ... exerts control on biological activities; identifies location of thermocline

pH: ... affects biological activity; may reflect rate of photosynthesis

Conductivity: ... a meausre of dissolved material that will conduct an electrical current

Transmissibility: ... an indicator of concentration of suspended solids

Wind Direction & Velocity, Estimate of Wave Height and Period: ... important factors in mixing lake water

Water Chemistry

Dissolved Oxygen: ... depletion of oxygen, particularly in the hypolimnion beneath the thermocline, limits higher life forms

Alkalinity: ... buffer to control pH; a measure of calcium bicarbonate in lake (an alternative nutrient for algae)

Soluble Reactive Phosphorus: phosphorus is currently considered to be primary cause of eutrophication as a nutrient of phytoplankton - form of phosphorus instantly (most readily) available to phytoplankton

Total Dissolved Phophorus: form of phosphorus available to phytoplankton over a period of time (twenty days).

Total Phosphorus: form of phosphorus used in trophic evaluation system to measure all the phosphorus in the environment

Ammonia: ... indicator of nitrogen concentration, breaks down to nitrate/ nitrite, indicator of relatively recent pollution

Nitrate + Nitrite: ... nitrogen is a primary nutrient of phytoplankton

Biological Parameters

Plankton: ... species of phyto- and zooplankton present, and their relative abundance may also indicate state of eutrophication

Primary Productivity: water sample (containing phytoplankton) obtained on station, $NaCO_3$ tagged with radioactive carbon added, sample incubated and cells filtered on shipboard, ^{14}C in cells counted on mainland ... primary productivity is rate of incorporation of inorganic carbon into molecules of living cells (increase of biomass); another indicator of state of eutrophication

Aerobic Heterotrophs & Coliforms: heterotrophic bacteria require complex organic compounds of nitrogen and carbon for their metabolic synthesis and thus are very sensitive to minute changes of fluctuations in nutrient concentrations. Coliform are indicators of organic loadings especially nearshore. Both are indicators of the nutrition status of lakes

Chlorophyll "a": ... measurement of these pigments can provide insight into relative amount of standing crop of algae, results to be correlated with primary productivity study and phytoplankton study

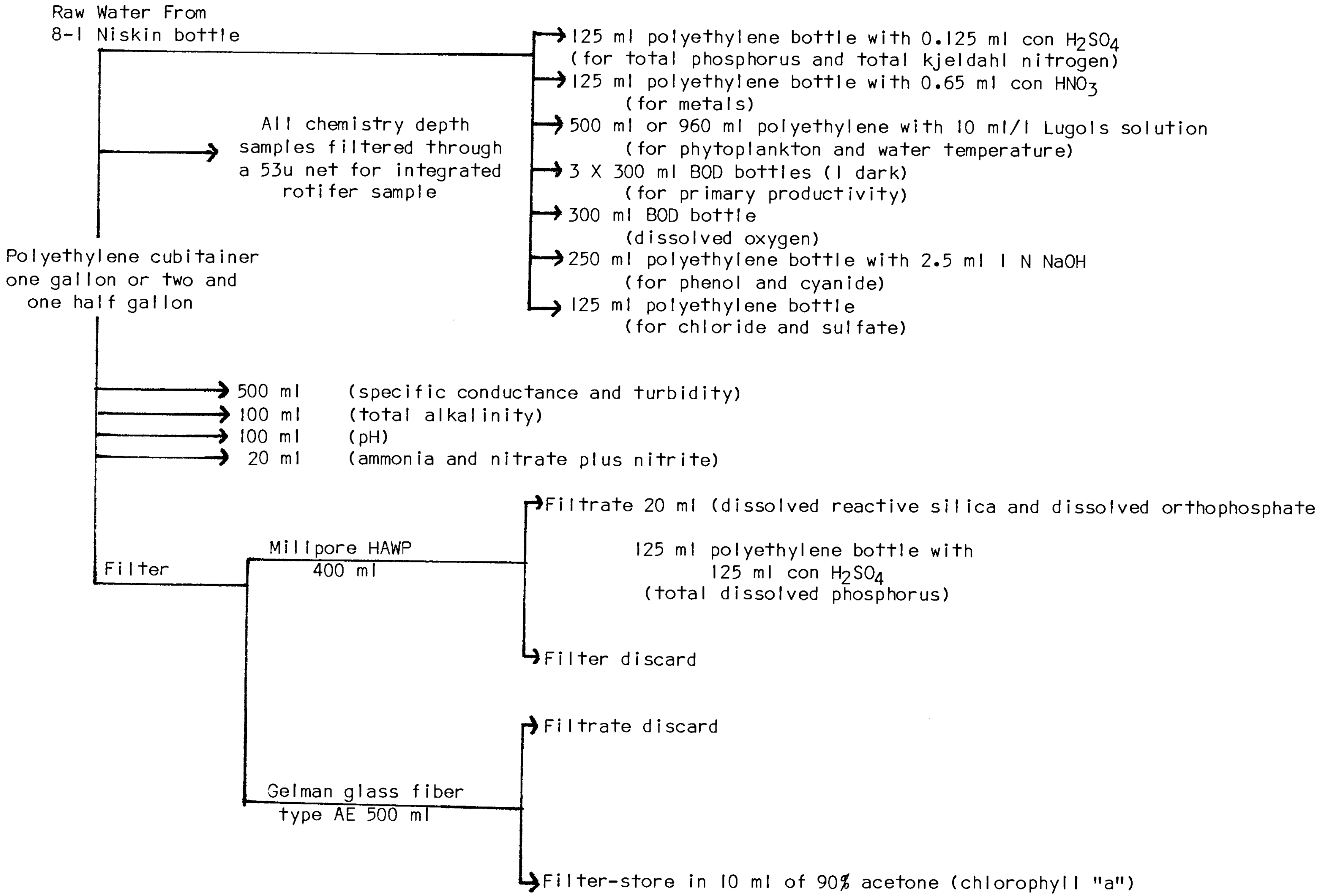


Figure A-4
Flow chart illustrating sample processing on EPA monitoring vessel.

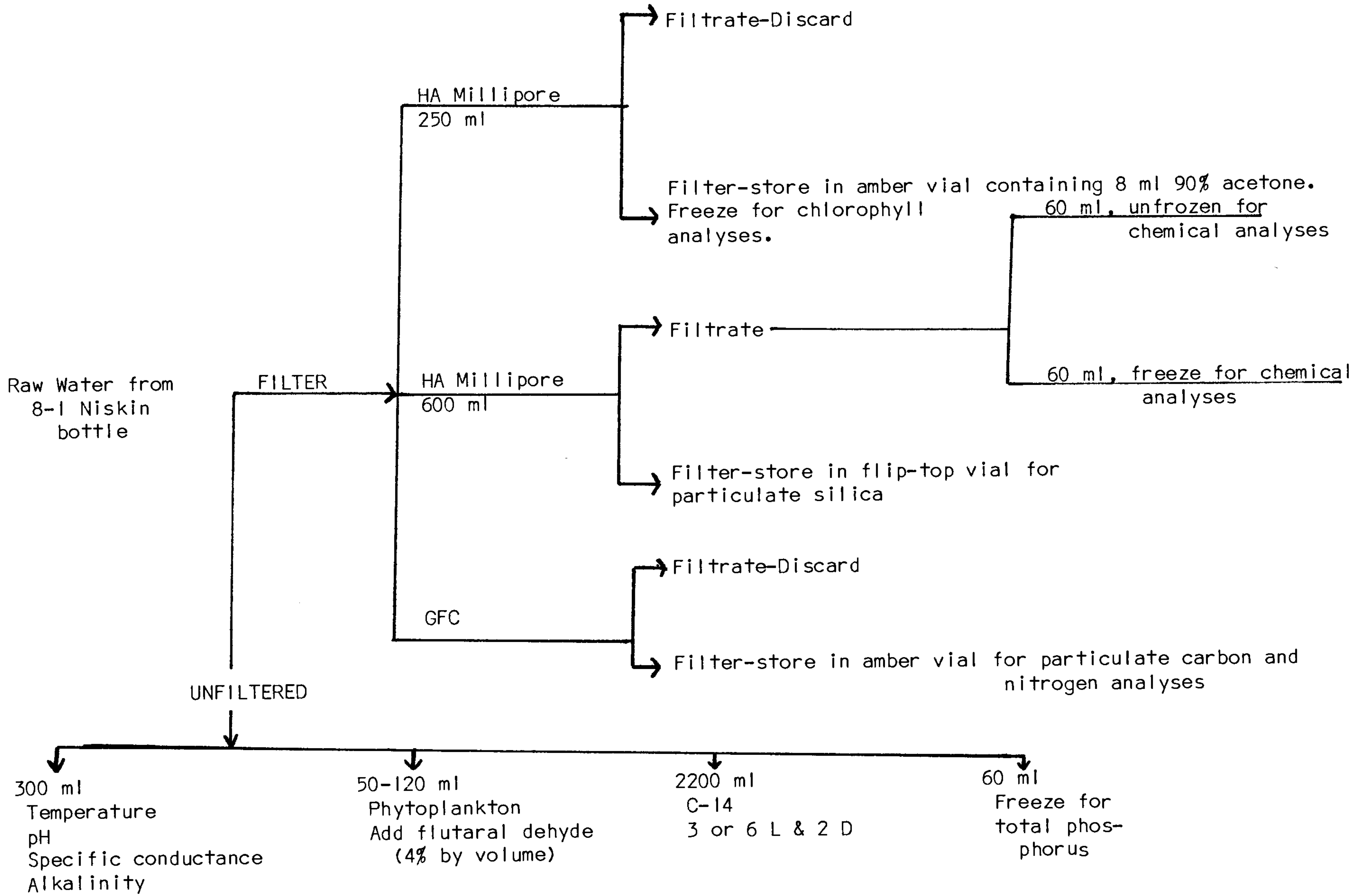


FIG. A-5 Flow chart illustrating sample processing for study of northern Lake Michigan.

APPENDIX B

QUALITY ASSURANCE USED BY GLNPO

Data quality assurance, evaluation , and control were achieved by the following techniques. A maximum permissible shelf life was indicated for each analysis, and no data were taken from samples whose shelf life exceeded this value. New bottles, rinsed once with sample, were used for all chemical samples. With every 20 samples or less, a pair of known stable reference samples (one near the top of the analytical working range and one near the bottom) and a reagent blank were analyzed. The reagent blanks were collected in the sample bottles from the reagent water source and treated thereafter like the other samples. Allowable deviation of the reference samples and reagent blanks from the true values was expressed as A+Bx where x is the true value and A and B are constants determined from a representative sampling. Exceeding this allowable deviation resulted in the deletion of the data for samples associated with these reference samples. With every 20 samples or less, duplicate samples were collected. Each of these two samplings (Niskin bottles) were split into separate sample bottles to give a total of four subsamples for the chemistry analyes. The differences between the four subsamples were then used to establish the variability arising from small changes in time or location in Lake Michigan and in laboratory analyses. The samples for duplication were selected at random (Table B-1).

The Quality Assurance program included check standards, reagent blanks, duplicate samples, split samples and performance evaluation samples (unknowns).

Two check standards prepared from reagent materials were normally analyzed with every 10 to 20 samples (Table B-2). These check standards were analytical checks as apposed to sampling checks, i.e. they were not carried through the sampling and preservation procedures.

TABLE B-1

GLNPO
DIFFERENCES BETWEEN SPLIT SAMPLE ANALYSES
SOUTHERN LAKE MICHIGAN

Parameter mg/l*	Number of Splits	Mean Absolute Value of Differences	Standard Deviation Of Differences
		1976	
Turbidity (HTU)	214	0.031	0.59
Specific Conductance (umhos/cm)	210	0.15	1.12
pH (SU)	218	0.0096	0.089
Total Alkalinity	208	0.29	1.20
Suspended Solids	144	0.038	1.39
Total Ammonia (ug/l)	136	1.323	0.138
Total Nitrate + Nitrite	180	0.0067	0.054
Total Phosphorus (ug/l)	254	1.221	0.095
Calcium	74	0.084	0.88
Magnesium	74	0.018	0.19
Potassium	110	0.0011	0.058
Sodium	76	0.022	0.18
Total Chloride	200	0.020	0.29
Total Sulfate	200	0.016	0.64
Total Fluoride	40	0.00028	0.0014
Dissolved Reactive Silica	208	0.015	0.075

(contd.) TABLE B-1

1977

Turbidity (HTU)	222	0.019	0.17
Specific Conductance (umhos/cm)	224	0.094	0.76
pH (SU)	224	0.0067	0.044
Total Alkalinity	224	0.076	0.84
Suspended Solids	30	0.043	0.30
Total Ammonia-N	202	0.00012	0.0013
Total Kjeldahl-N	222	0.0038	0.055
Total Nitrate + Nitrite	214	0.0014	0.0078
Total Phosphorus	200	0.00040	0.0034
Total Chloride	206	0.035	0.26
Total Sulfate	34	0.044	0.67
Dissolved Reactive Silica	224	0.00094	0.028
Chlorophyll "a" (ug/l)	136	0.016	0.71
Pheophytin (ug/l)	134	0.12	0.14

*Unless Otherwise noted.

TABLE B-2

GLNPO Shipboard Check Standard & Reagent Blank* Summary

1976

Parameter	Concentration	Number	Mean Found	Standard Deviation
Total Alkalinity mg/l	100	13	98.2	1.240
Total Alkalinity mg/l	80	14	80.14	1.724
Specific Conductivity umho/cm	293.3	26	291.73	2.017
Specific Conductivity umho/cm	245.0	22	244.77	0.712
Specific Conductivity umho/cm	196.5	4	196.50	0.577
Ammonia N mg/l	0.044	217	0.04430	0.00161
Ammonia N mg/l	0.02940	217	0.03003	0.00222
Ammonia N mg/l	0.01470	5	0.01580	0.00045
Ortho Phosphate P mg/l	0.0079	239	0.00792	0.00095
Ortho Phosphate P mg/l	0.0021	240	0.0021	0.00082
Silica SiO_2 mg/l	2.14	186	2.215	0.0276
Silica SiO_2 mg/l	1.07	186	1.120	0.0288
Nitrate + Nitrite N mg/1	0.72	166	73.0169	0.0313
Nitrate + Nitrite N mg/l	0.21	165	22.0715	0.0092

*all reagents blanks in 1976 were less than or equal to the following values. Ammonia - N 0.003 mg/l, Ortho Phosphate - P. 0.002 mg/l, SiO_2 0.03 mg/l, NO_3 + NO_2-N 0.01 mg/l.

1977

Parameter	Concentration	Number	Mean Found	Standard Deviation
Turbidity JTU	reagent blank	137	0.184	0.085
pH SU.	9.18	117	9.06	0.096
pH SU.	7.01	124	6.99	0.041
pH SU.	reagent blank	122	5.41	0.549

(contd.) TABLE B-2

Shipboard Check Standard & Reagent Blank Summary

1977

Parameter	Concentration	Number	Mean Found	Standard Deviation
Total Alkalinity mg/l	100	135	100.22	0.87
Total Alkalinity mg/l	80	135	80.40	0.87
Total Alkalinity mg/l	reagent blank	136	1.06	0.46
Specific Conductivity umho/cm	293.3	131	291.7	1.48
Specific Conductivity uhmo/cm	196.5	133	196.4	1.69
Specific Conductivity uhmo/cm	reagent blank	136	1.2	0.53
Ammonia-N mg/l	0.044	253	0.0444	0.00218
Ammonia-N mg/l	0.0147	248	0.0152	0.00203
Ammonia-N mg/l	reagent blank	250	0.00029	0.00075
Ortho Phosphate-P mg/l	0.0393	256	0.0388	0.00189
Ortho Phosphate-P mg/l	0.0210	252	0.0207	0.00140
Ortho Phosphate-P mg/l	reagent blank	256	0.0004	0.00056
Silica SiO_2 mg/l	4.28	258	4.259	0.078
Silica SiO_2 mg/l	2.14	260	2.139	0.051
Silica SiO_2 mg/l	reagent blank	262	0.0052	0.015
Nitrate + Nitrite-N mg/l	0.72	254	0.721	0.0159
Nitrate + Nitrite-N mg/l	0.21	252	0.209	0.0083
Nitrate + Nitrite-N mg/l	reagent blank	242	0.0000	0.0019

Reagent water was prepared onboard with a Millipore Milli-Q reagent grade water system. The system contained a carbon cartridge, demineralizer cartridges, a 0.2 u final membrane filter, and a 10 megohm-cm indicator light. Feed water to the system was obtained from the onboard portable water supply and was deionized with a high capacity hose-nipple cartridges prior to feeding the Milli-Q system.

Performance evaluation samples were provided as unknowns by EPA Region V Quality Assurance Office (Table B-3).

Sucessive duplicate ZoBell samples for total aerobic heterotrophs were collected at the same locations as the chemistry duplicates. A distilled water suitability and detergent toxicity test for microbiology was determined on the shipboard de-ionized water and distilled water used in this study. Media used were recorded as to date of reception, lot number (including lot number of Rosolic acid used in m-FC media), date the media container was opened, and pH checked. Coliform colony verification (on at least 10 percent of samples), sterility and air controls on the media, and sterility controls on the filter funnels and buffered dilution water were performed and recorded. Lot numbers also kept on the membrane filters. Daily temperature readings on the incubators, autoclave, and water bath were recorded. The pH meter and balance were checked for accuracy on a regular basis.

Volume Weighting Calculation. The two-layer volume weighted average was determined by the equation TLVWA= $(M_1 V_1 + M_2 V_2)/(V_1 + V_2)$

M_1= mean of all samples in the upper twenty meters.

M_2= mean of all samples in the below twenty meters.

V_1= volume of water in the upper twenty meters.
South Basin 574.3 km^3
North Basin 423.4 km^3

V_2= volume of water below twenty meters
South Basin 1795.1 km^3
North Basin 2003.6 km^3

TABLE B-3

Upper Lake Reference Group Performance
Standards Run During USEPA 1977 Cruises

	Number of Analyses	Mean	Standard Deviation	True or Value Accepted
Nitrate + Nitrite Nitrogen mg/l				
Standard #1	19	0.3232	0.0067	0.32
Standard #2	19	0.4047	0.0077	0.40
Ammonia Nitrogen mg/l				
Standard #1	19	0.0117	0.0016	0.011
Standard #2	19	0.0187	0.0018	0.018
Orthophosphate as P mg/l				
Standard #1	19	0.0031	0.0006	0.004
Standard #2	19	0.0057	0.0008	0.007
Dissolved Reactive Silica as SiO_2 mg/l				
Standard #1	12	0.751	0.014	0.76
Standard #2	12	0.851	0.018	0.86
Standard #3	8	2.38	0.087	2.47
Standard #4	8	2.41	0.039	2.52
Standard #5	4	1.28	0.015	1.35
Standard #6	4	1.46	0.026	1.52

The computation was developed to estimate average lake concentrations. With the exclusion of the dense station network in the Straits of Mackinac comparison of means and standard errors computed using TLVWA with computer volume weighted calculations (Yiu, 1978) gave similar statistic results for total phosphorus and temperature. This comparison would suggest that TLVWA results can be used for other parameters which are more uniformly distributed and that the station network and sample depth were well chosen for characterization of lake water quality. The layering of the lake at 20 meters has been shown to be representative of the epilimnetic layer (Bartone & Schelske, 1979 and Rodgers, 1980) for both 1976 and 1977.

Twenty-Four Hour Surveillance

Three 24-hour surveys were conducted on June 9-10, August 18-19, and September 6-7, 1977 at a open lake station (L. Mich. 6) in the southern basin. The unique aspect of these monitoring efforts was regular two-hour sampling at one lake position for approximately 24 hours. Table B-4 contains the results by depth for these visits.

Note that the variability over a 24 hour period for all parameters was very low compared to the variability with depth and the variability between 24 hour periods. This is particularly true in the epilimnion and the hypolimnion. The somewhat higher variability in the thermocline and near bottom layers can be attributed to the internal wave structure of the thermocline and to small errors in the depth of the samples respectively. This low hour-to-hour variability is significant because it indicates that diurnal variability is not important in the open waters of Lake Michigan for the parameters measured. Stations collected over a 24 hour period therefore, can be considered to be reasonably synoptic for these parameters. This conclusion would not apply if a storm or major weather change occurred during the period.

TABLE B-4

Station L. MICH 06 24-Hour Surveys 1977

Depth M	Turbidity TU	Water Temp °C	Conductivity Micromhs/cm at 25°C	PH	Tot ALK mg/l	Total NH_3-N ug/l	TKN-N mg/l	Tot NO_2+NO_3-N mg/l	Total P ug/l	Chloride mg/l	Diss. Reactive Silica mg/l	Aerobic Heterotrophs	Chlorophyll a ug/l	Secchi Depth meters
								Survey#1 6/9 - 10/77						
2	(11) .58±.03	(11)12.4±.1	(11)278±.4	(11)8.35±.01	(11)108±.2	(11)2.1±0.1	(11)0.16±.011	(11)0.195±.002	(11)4.4±0.4	(6)8.50±.03	(11)0.50±.010	(11)12± 3	(11)0.83±.04	(7)6.5±0.3
5	(11) .67±.04	(11)12.4±.1	(11)279±.3	(11)8.34±.01	(11)108±.2	(11)2.3±0.2	(11)0.16±.005	(11)0.195±.001	(11)4.0±0.2	(8)8.55±.02	(11)0.50±.009	(6)12± 1	(11)0.91±.06	
12	(11) .59±.03	(11)12.1±.2	(11)279±.2	(11)8.35±.01	(11)108±.2	(11)2.0±0.0	(11)0.16±.006	(11)0.195±.002	(11)4.8±0.3	(7)8.53±.03	(11)0.51±.013	(6)16± 6	(11)1.03±.04	
20	(11) .56±.02	(11)11.8±.1	(11)278±.2	(11)8.35±.01	(11)108±.2	(11)2.0±0.0	(11)0.15±.007	(11)0.195±.002	(11)4.1±0.3	(7)8.50±.04	(11)0.54±.010	(6)23± 4	(11)1.11±.02	
25	(11) .61±.03	(11)11.2±.2	(11)278±.3	(11)8.35±.01	(11)108±.2	(11)2.0±0.0	(11)0.15±.008	(11)0.196±.002	(11)4.3±0.3	(5)8.42±.02	(11)0.56±.009	(7)28± 7	(11)1.12±.07	
30	(11) .60±.03	(11) 8.6±.4	(11)277±.2	(11)8.32±.01	(11)108±.2	(11)2.2±0.1	(11)0.16±.007	(11)0.200±.002	(11)4.3±0.4	(8)8.40±.03	(11)0.63±.013	(6)24± 1	(11)1.37±.16	
40	(11) .79±.03	(11) 4.9±.1	(11)277±.2	(11)8.15±.01	(11)108±.2	(11)4.9±0.4	(11)0.14±.007	(11)0.218±.002	(11)4.5±0.3	(9)8.23±.05	(11)0.87±.016	(6)18± 3	(10)1.92±.09	
55-64	(11)1.10±.05	(11) 4.6±.1	(11)278±.0	(11)8.10±.01	(11)108±.2	(11)6.6±0.3	(11)0.15±.008	(11)0.226±.002	(11)5.9±0.7	(6)8.26±.01	(11)1.03±.009	(6)14± 3	(11)1.71±.11	
								Survey#2 8/18 -19/77						
2	(12) .65±.04	(12)21.2±.1	(12)271±.3	(12)8.59±.02	(12)108±.2	(12)2.3±0.2	(12)0.18±0.01	(12)0.140±.002	(12)3.2±0.2	(11)8.27±.02	(12)0.22±.002		(12)0.76±.04	(7)5.7±0.3
5	(12) .67±.02	(12)21.0±.0	(12)271±.2	(12)8.56±.01	(12)108±.1	(12)2.3±0.1	(12)0.19±0.01	(12)0.139±.001	(12)3.5±0.2	(12)8.28±.02	(12)0.22±.002		(12)0.72±.05	
10	(12) .65±.02	(12)21.0±.0	(12)271±.2	(12)8.57±.01	(12)108±.1	(12)2.3±0.1	(12)0.18±0.01	(12)0.141±.001	(12)3.9±0.2	(12)8.29±.02	(12)0.23±.003	(8) 1± 0	(11)0.81±.06	
17	(12) .66±.02	(12)17.8±.3	(12)274±.4	(12)8.52±.01	(12)109±.3	(12)5.9±0.6	(12)0.17±0.01	(12)0.157±.001	(12)4.2±0.3	(12)8.28±.01	(12)0.23±.002		(11)0.94±.06	
22	(12) .75±.03	(12)13.4±.5	(12)277±.4	(12)8.38±.01	(12)110±.2	(12)12.5±0.5	(12)0.18±0.01	(12)0.189±.003	(12)4.4±0.2	(12)8.30±.02	(12)0.36±.028	(11) 8± 3	(11)1.00±.07	
27	(12) .79±.03	(11) 6.0±.1	(11)279±.3	(11)8.04±.01	(11)111±.1	(11)2.5±0.2	(11)0.14±0.02	(11)0.265±.002	(11)4.5±0.2	(11)8.21±.01	(11)1.26±.007		(10)0.85±.06	
40	(12) .92±.02	(12) 5.6±.1	(12)279±.2	(12)8.03±.01	(12)111±.1	(12)2.7±0.2	(12)0.16±0.01	(12)0.264±.001	(12)5.1±0.3	(12)8.23±.02	(12)1.30±.007		(11)0.90±.08	
65	(12)1.26±.19	(12) 5.6±.1	(12)279±.2	(12)8.02±.01	(12)111±.2	(12)3.0±0.2	(12)0.19±0.02	(12)0.266±.001	(12)9.3±2.2	(12)8.20±.02	(12)1.31±.005	(11) 26±11	(11)0.73±.07	
								Survey#3 9/6 - 7/77						
2	(12)1.21±.02	(12)21.0±.1	(12)268±.3	(12)8.46±.01	(12)105±.3	(12)2.6±0.2	(12)0.14±.007	(12)0.114±.001	(12)3.0±0.0	(12)8.35±.03	(12)0.21±.002	(6) 3±1		(7)4.2±0.2
5	(12)1.28±.02	(12)21.0±.0	(12)268±.1	(12)8.46±.01	(12)105±.1	(12)2.2±0.1	(12)0.15±.005	(12)0.114±.001	(12)3.4±0.2	(12)8.37±.03	(12)0.21±.003			
10	(12)1.32±.02	(12)20.9±.0	(12)268±.1	(12)8.46±.01	(12)105±.2	(12)2.3±0.2	(12)0.16±.014	(12)0.114±.001	(12)3.4±0.3	(12)8.36±.02	(12)0.21±.003	(6) 4±1		
15-20	(15)1.29±.03	(14)20.2±.3	(15)269±.4	(15)8.43±.01	(15)106±.3	(15)5.5±0.8	(15)0.14±.005	(15)0.120±.002	(15)3.2±0.1	(15)8.41±.02	(15)0.23±.008	(3) 15±5		
25	(12)1.25±.03	(11)15.8±.4	(12)276±.3	(12)8.32±.02	(12)108±.4	(12)13.2±0.6	(12)0.14±.005	(12)0.158±.005	(12)4.7±0.9	(12)8.51±.04	(12)0.46±.030	(3) 27±12		
30	(9)1.27±.03	(9) 9.4±.7	(9)279±.3	(9)8.13±.04	(9)110±.3	(9)5.7±1.1	(9)0.12±.010	(9)0.230±.007	(9)4.0±0.3	(9)8.30±.05	(9)0.94±.080			
55	(12)0.77±.03	(12) 6.1±.2	(12)280±.2	(12)7.98±.01	(12)110±.3	(12)2.2±0.1	(12)0.11±.009	(12)0.263±.001	(12)4.4±0.4	(12)8.26±.02	(12)1.38±.007			
64	(12)0.72±.02	(12) 5.8±.2	(12)280±.2	(12)7.97±.01	(12)110±.2	(12)2.1±0.1	(12)0.11±.009	(12)0.263±.001	(12)4.2±0.2	(12)8.25±.02	(12)1.40±.006	(6) 4±1		

NOTE: (number of samples at depth
mean value ± standard error of mean

APPENDIX C

ORGANIZATIONS INVOLVED

A number of organizations, other than Great Lakes National Program Office (GLNPO), participated or made significant contributions to the 1976-1977 survey of Lake Michigan. The authors wish to acknowledge the roles of these agencies in the study.

Great Lakes National Program Office (GLNPO)

The GLNPO conducted 12 open lake cruises during 1976 and 1977 on the southern basin of Lake Michigan. A special study was made to determine locations of heavy metal concentrations in the entire Lake during 1976 and 1977 by GLNPO. Nearshore studies were conducted in four areas; Chicago-Calumet, Indiana, Milwaukee, and Green Bay.

University of Michigan, Great Lakes Research Division (GLRD)

GLRD conducted five open lake cruises during 1976 in the northern half of Lake Michigan and nearshore studies in 1977. In addition staff of GLRD provided phytoplankton and zooplankton analyses for nearshore studies under grants from the U.S. EPA. Separate reports are in press for the northern basin and the plankton analysis of Green Bay and Indiana nearshore studies. Stoermer and Stevenson (1979) and Stoermer and Tuckman (1979) are available phytoplankton reports for Green Bay and the Indiana nearshore study respectively.

Michigan Department of Natural Resources (MDNR)

The MDNR conducted the first of the three nearshore surveys in Green Bay during 1977 under a grant from the U.S. EPA. Results can be found in Limnological Survey of Nearshore Waters of Lake Michigan 1976. EPA Grant R005146011. David Kenage, William Creal, and Robert Bash. In Press USEPA Grosse Ile, Michigan 48138.

National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce - Great Lakes Environmental Research Laboratory (GLERL) conducted current metering studies in the southern basin, in the transition zone between Green Bay and Lake Michigan. U.S. EPA provided ship support to deploy and recover the current meters.

Governors State University (GSU) - Conducted a study of atmospheric loading to the lake from the Chicago metropolitan area, with grants and ship support from U.S. EPA. Sievering et al (1979) is a report on this work.

University of Wisconsin (U.W.) - Conducted studies of dry atmospheric fallout to the southern basin during regular GLNPO cruises.

National Atmospheric and Space Administration (NASA) - Made several remote sensing overflights of the southern basin to demonstrate and develop remote sensing applications to water quality monitoring. Water samples were collected by GLNPO to calibrate remote sensing outputs with actual in-lake conditions (ground truth).

Argonne National Laboratory (ANL), U.S. Department of Energy - Studied sedimentation rates in the southern basin with ship support from GLNPO.

Wisconsin Department of Natural Resources (DNR) - Compiled biological and chemical monitoring data applicable to the southern half of Green Bay, under a grant from GLNPO.

Cities of Milwaukee, Chicago, Grand Rapids, Manitowoc and South Haven - located on Lake Michigan provided data or sent samples from their public water filtration plants.

Fish and Wildlife Service - Great Lakes Laboratory, Ann Arbor, Michigan and Columbia National Fish Laboratory, Columbia, Missouri provided toxic contaminate data in fish flesh from eastern Lake Michigan.

State University of New York at Brockport - Analyzed long term phytoplankton and chemical data from the Chicago Water Filtration system under a grant from GLNPO. Makarewicz and Baybutt (in press Torrey Botanical Bulletin) are two reports on this work.

APPENDIX D

MICROFICHE - LAKE MICHIGAN

INTENSIVE SURVEY DATA 1976-1977

MICROFICHE ATTACHED TO INSIDE BACK COVER

Errata — Units for nearshore primary productivity are milligrams /m^3/hr