

LAKE MICHIGAN STUDY: SOME PRELIMINARY FINDINGS

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Great Lakes National Program
Region V, U.S. EPA
Chicago, IL

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14-00000

SUMMARY EVALUATION

The open waters of Lake Michigan are still slowly deteriorating. This is evidenced by reduced silica concentrations in the epilimnion, increased phytoplankton and zooplankton levels and the increasingly frequent appearance of stephanodiscus and other species of phytoplankton indicative of mesotrophic or eutrophic conditions. This enrichment has reached a stage where the waters must be considered more mesotrophic than oligotrophic. The enrichment now being observed is the result of the high rates of loading to which the Lake was subjected during the sixties and early seventies. It is known that it requires 10-20 years for the open waters of the Lake to come into equilibrium with nutrient loadings imposed upon it. Therefore, worsening conditions must be expected in the near future. In the open lake waters, the benefits of reduced phosphorus loadings will be to reduce the rate of eutrophication and may be reflected in terms of degradation that does not occur rather than actual improvement.

The abatement programs have produced positive improvements in local nearshore areas. Several beaches in Lake County, Illinois and north Chicago have been reopened for public bathing, the incidence of taste and odor problems at Chicago water intakes has decreased as a result of the industrial abatement programs in the Calumet area. (1) Further, cladophera is no longer the problem it was during the late sixties.

Average total phosphorus concentrations along the entire Indiana shoreline of Lake Michigan are the lowest in the entire southern basin. This seems to reflect the benefits of the 1973 Indiana detergent phosphate ban and phosphorus removal by municipal treatment which may have been implemented in recent years. Productivity as measured by chlorophyll in this nearshore zone, is lower than other similar areas, e.g., Green Bay and the eastern shoreline near river sources. This is expected since phosphorus generally controls phytoplankton production and standing crops in temperate lakes.

Chloride concentrations are accumulating more rapidly over the last ten years than ever before. The effects of higher chloride levels are not known, but there is a concern that higher chloride levels will encourage the growth of stephanodiscus and other filamentous algae. If this occurs, it may affect the cost of water filtration plant operation where plants draw their water from the nearshore zone.

Sulfate, which was increasing rapidly during the sixties, appears to have leveled off with virtually no increase since 1970 in the southern basin. This may be attributable to the discontinuation of sulfuric acid pickling by the steel industry and to reduced use of high sulfur fuels.

The concentration of DDT in Lake Michigan fish has decreased steadily since 1969. In 1976, it was down to approximately 10% of 1969 concentrations. This is the result of the ban on the use of DDT, and shows that even a persistent compound such as DDT will disappear if its source is eliminated. Figure 1.

PCB concentrations were slightly lower in 1976 than in previous years for all three species tested - coho salmon, brown trout, and chub. It is not certain if this is the start of a downward trend or a random perturbation of the data. PCB compounds are very similar to DDT. Their manufacture in the United States has ceased and their use has been restricted to sealed electrical components. Unfortunately PCBs were used for a great many things whereas DDT was used almost exclusively as a pesticide. This makes it far more difficult to eliminate the input of PCB compounds to the lake. It is now estimated that 80% - 90% of the PCBs reaching the lake come by way of atmospheric fallout. They get into the atmosphere when materials containing PCBs are incinerated. There is also evidence that PCB compounds escape from land fills through gas vents. There is no question that the problem of PCB contamination in Lake Michigan fish will eventually dissipate. It may have started already, but it is likely to be a much slower process than the dissipation of DDT which has gone down 90% in seven years.

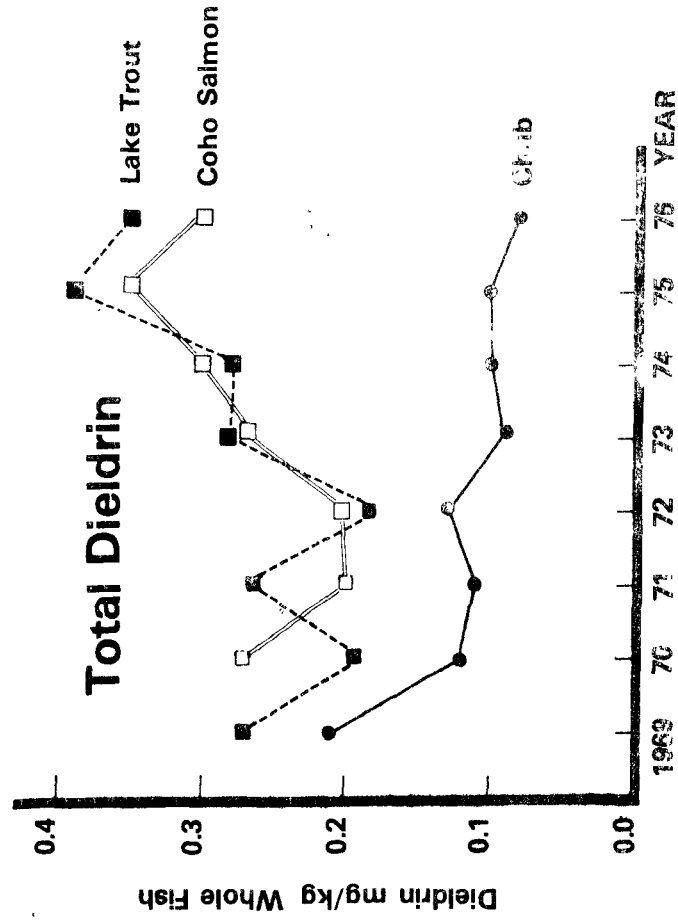
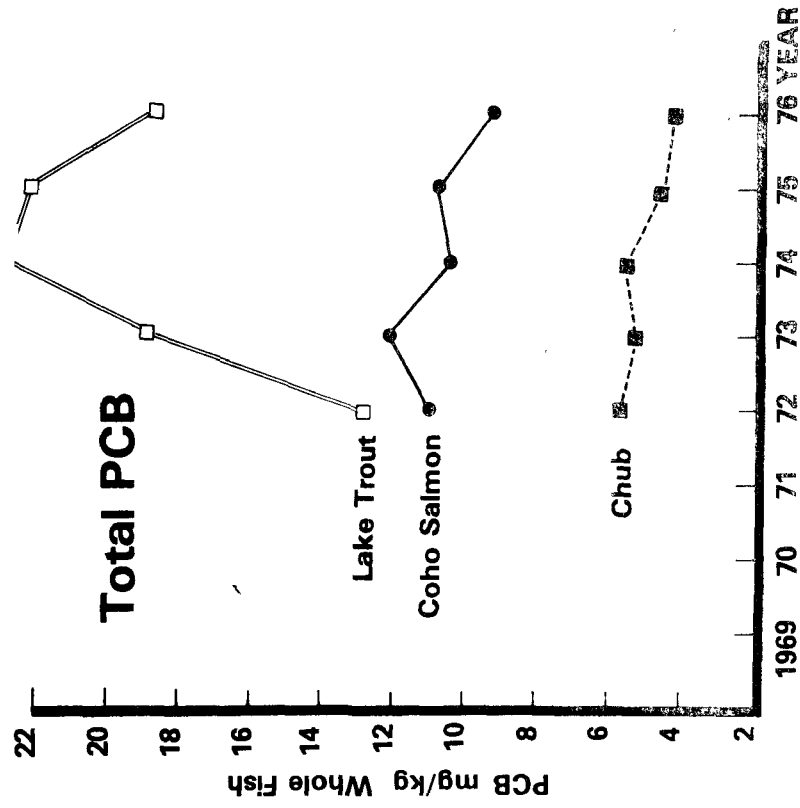
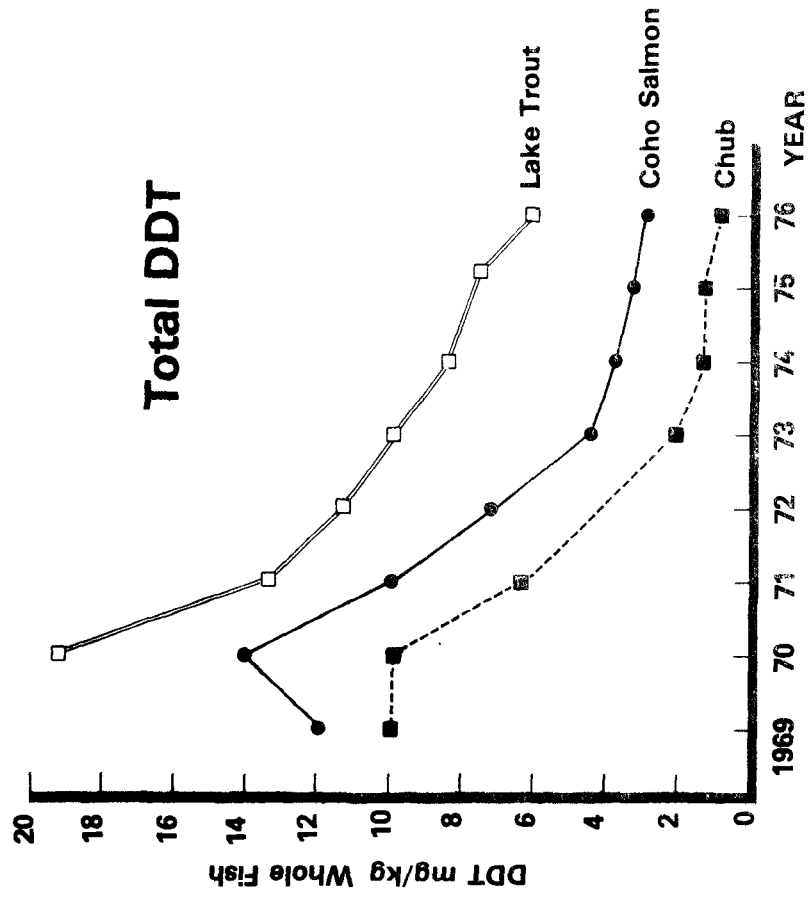


FIGURE 1

Mean concentrations of chlorinated hydrocarbons
in fish from Eastern Lake Michigan (US FWS DATA)

TROPHIC STATE

The definition of the trophic state of a lake is primarily a subjective process. There is general agreement that eutrophication is an aging process and that young or oligotrophic lakes are nutrient-poor and old or eutrophic lakes are nutrient-rich. Figure 2 summarizes some of the methods used to classify lakes.

Figure 3 characterizes the lake according to three criteria: Phytoplankton, chlorophyll a, and total phosphorus. These criteria indicate that the open waters of the southern basin are on the border between oligotrophy and mesotrophy. The nearshore waters are clearly mesotrophic. The open waters at the extreme southern end represented by Station 1 are definitely mesotrophic. The open waters in the transition area between the northern and southern basins of the Lake represented by Station 26 are still somewhat oligotrophic.

FIGURE 2
ENRICHMENT PROBLEM RELATIONSHIPS

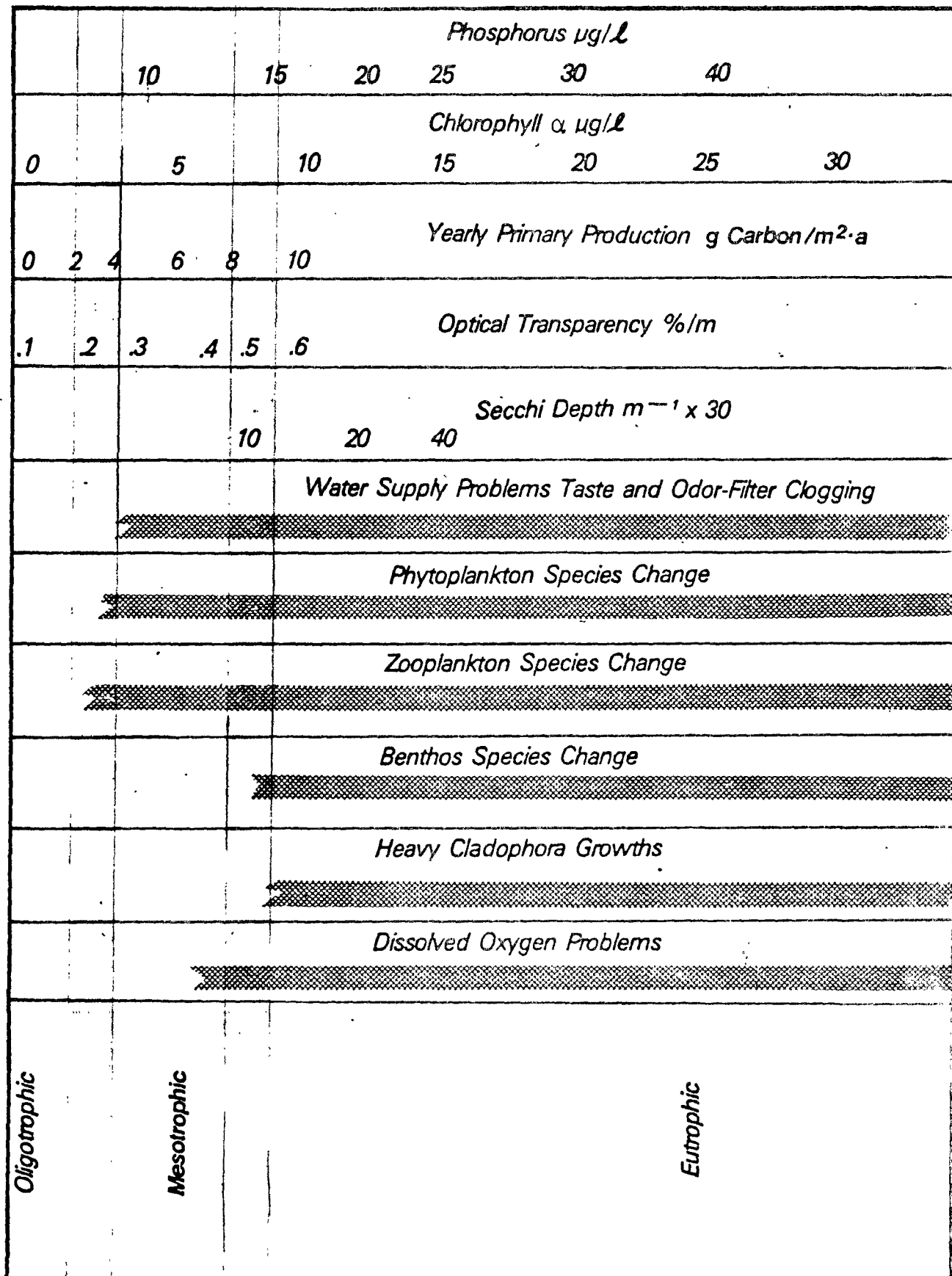


FIGURE 3

SUMMARY OF AVAILABLE BIOLOGICAL DATA FOR THE U.S. EPA-GLSB 1976 SAMPLING PROGRAM

Station #	Type	Depth Meters	PHYTOPLANKTON no./ml		ZOOPLANKTON no./Cm ³			CHLOROPHYLL A mg/m ³		TOTAL PHOSPHORUS ug/l	
			Avg.	Trophic Level	Avg.	<i>Microcrustacea</i> Trophic Level	<i>Rotifers</i> Trophic Level	Avg.	Trophic Level	Avg.	Trophic Level
26	open water	138	2048	O/M	6	M	M	212	0	6.8	O/M
18	open water	167	4340	M	21	M	M	139	O/M	7	O/M
6	open water	70	4116	M	10	M	M	110	0	6.5	O/M
<u>OPEN WATER STATION AVERAGES</u>											
			(3501)		(12)			(154)		(6.8)	
21	nearshore	13	5507	M	6	M	M/E	246	0	8.6	M
9	nearshore	37	4850	M	11	M	E	437	O/M	8.6	M
6a	nearshore	28	4437	M	7	M	M	204	0	8.6	M
<u>NEARSHORE STATION AVERAGES</u>											
			(4931)		(8)			(296)		(8.6)	
<u>SOUTHERN END</u>											
1		20	6687	M	12	M	M	143	M	7.3	O/M

Trophic Levels: 0 = Oligotrophic, M = Mesotrophic, E = Eutrophic

PHOSPHORUS

Phosphate phosphorus is one of the major nutrients required for plant nutrition and is utilized roughly in a ratio of 1 to 15 to 106 with nitrogen and carbon. Since it is the most easily controlled of the major nutrients needed for plant growth and usually in least supply, regulation of phosphorus is the primary means for controlling eutrophication.

Phosphates enter the lake from several major sources, point source discharges which include industrial, human and detergent contributions; tributary sources which include land drainage and agricultural sources; and atmospheric deposition.

This distribution of average total phosphorus concentrations in 1976 are shown in Figure 4. The changes in total phosphorus concentrations from inshore to offshore zones are consistent with important sources of total phosphorus to the lake. Important sources of total phosphorus loading to the lake are Green Bay, the northern suburbs of Chicago, the Benton Harbor area, the Grand Haven-Muskegon area, and the Ludington-Manistee area; conspicuous by its absence is the Indiana Harbor area.

Changes in the expected pattern in the Calumet-Indiana Harbor area may be due to the detergent phosphorus ban in the State of Indiana. Near-shore phosphorus concentration in Indiana waters are actually lower than in adjacent open-lake waters. This is remarkable in view of the major municipal discharges in the area some of which do not have adequate treatment facilities. The ammonia data, Figure 5, clearly shows the impact of these discharges. The fact that the phosphorus data does not show a similar impact is very significant and a strong indication that by controlling the sources of phosphorus we can slow or even reverse the eutrophication process.

Dissolved reactive phosphorus concentrations in the lake are almost invariably less than 2 $\mu\text{g/l}$ which is the limit of detectability of the analysis. Dissolved reactive phosphorus is the form of phosphorus actually used by phytoplankton for growth. Levels lower than 5 $\mu\text{g/l}$ indicate that there is no excess dissolved reactive phosphorus and that the organisms are continuously recycling it. This supports the belief that phosphorus is the controlling nutrient in Lake Michigan.

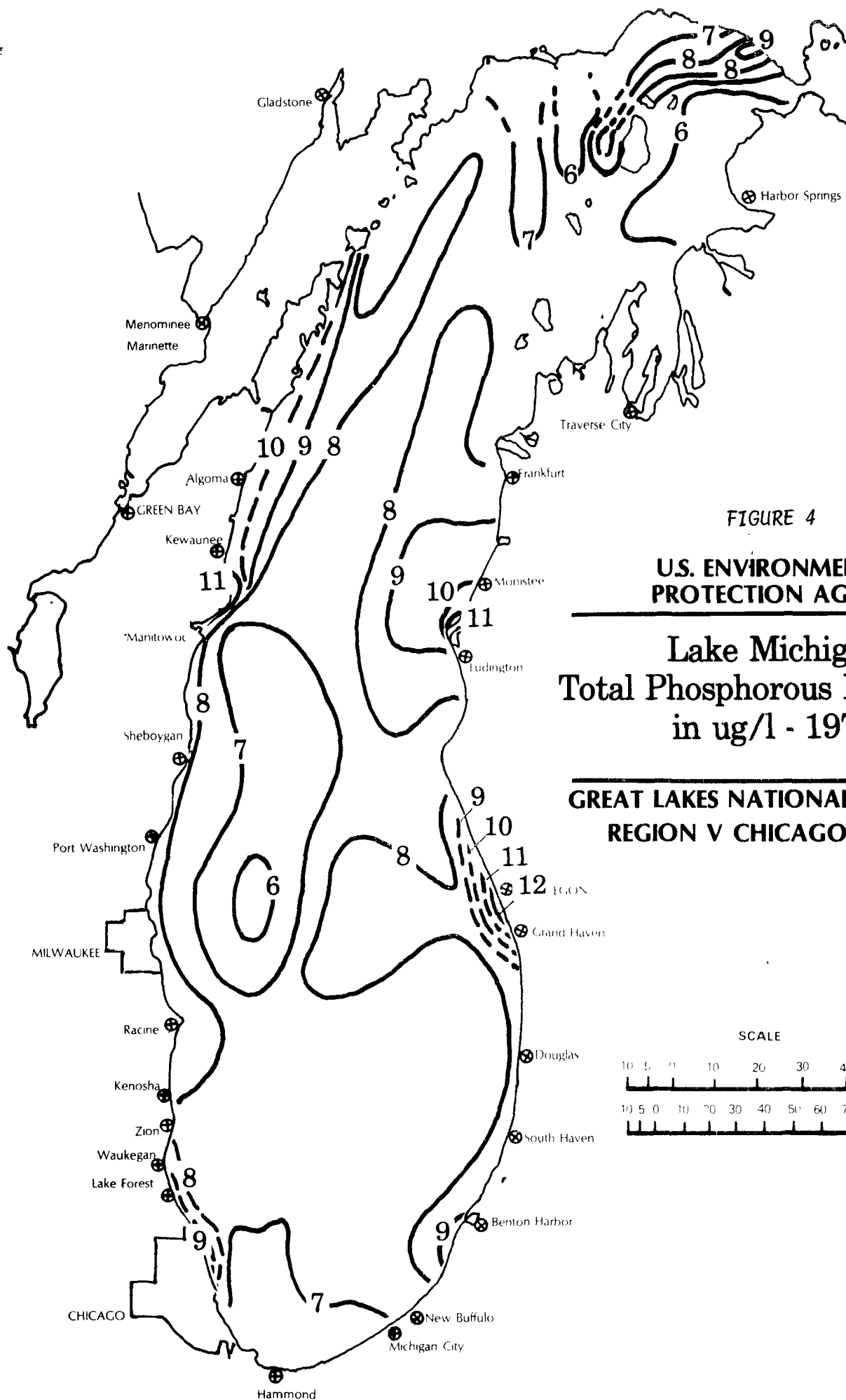


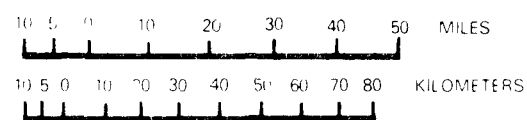
FIGURE 4

U.S. ENVIRONMENTAL
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Lake Michigan Total Phosphorous Distribution in ug/l - 1976

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SCALE



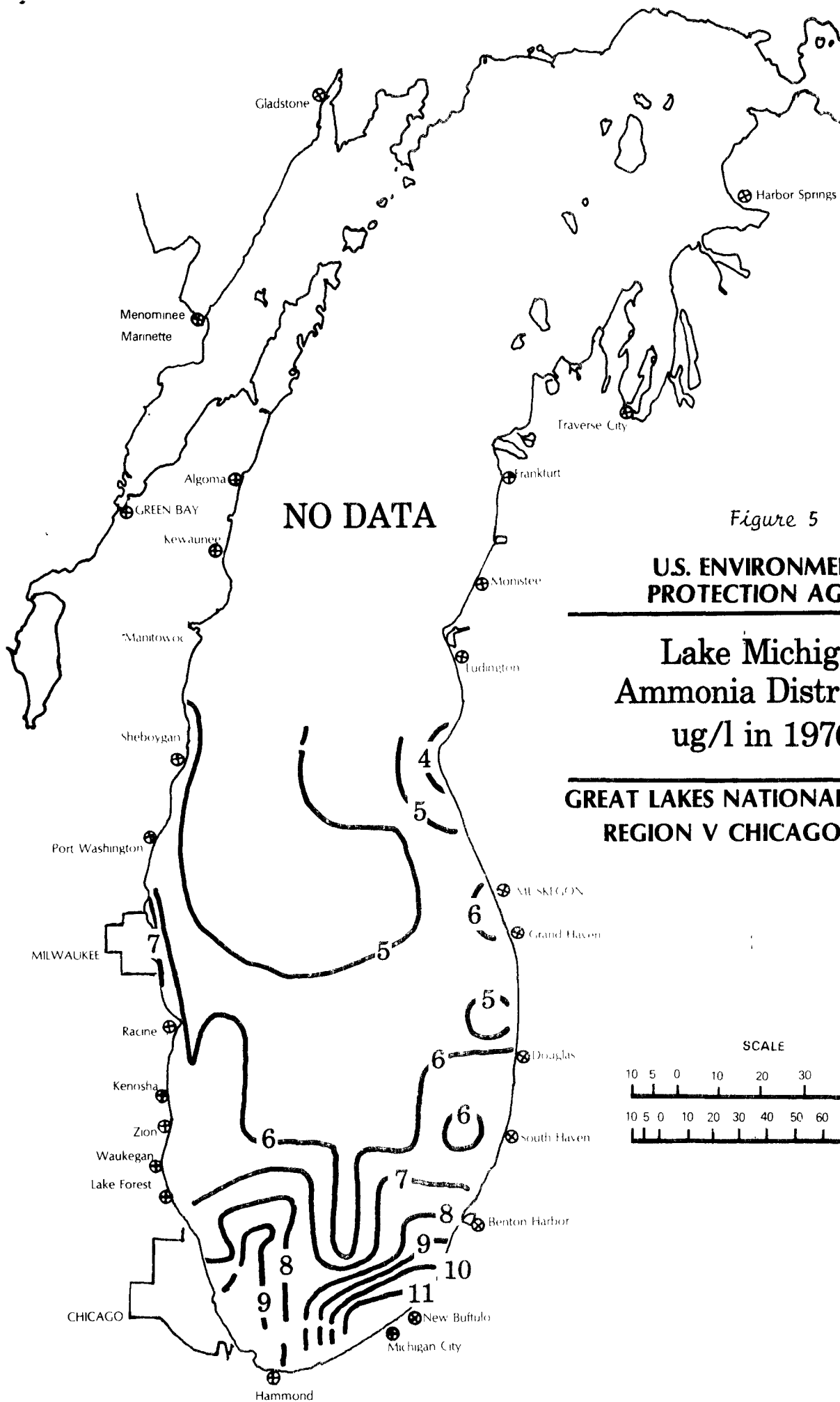
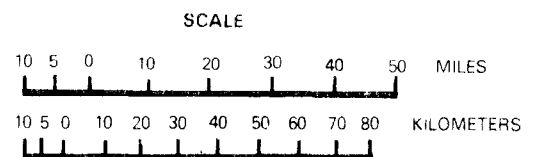


Figure 5

**U.S. ENVIRONMENTAL
PROTECTION AGENCY**

Lake Michigan Ammonia Distribution ug/l in 1976

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CHLOROPHYLL

Chlorophyll is the basic chemical compound in the photosynthetic process used by all plants to convert sunlight and nutrients into organic matter and oxygen. All algae contain chlorophyll and measuring this pigment can yield some insight into the amount of algae in the water. Algal production of chlorophyll varies from species to species and with environmental and nutritional factors. Biomass estimates based on chlorophyll measurements are relatively imprecise but form a major method for estimation of productivity and algal biomass.

The average chlorophyll α concentrations are shown in Figure 6. The maximum values occur nearshore south of the Green Bay outlet towards Manitowoc Wisconsin and North from Michigan City, Indiana to Manistee, Michigan.

Chlorophyll α concentrations along Indiana in the southernmost basin do not attain the high values found near other major tributaries. This may be linked to reduced phosphorus concentrations in the area resulting from the detergent phosphorus ban in Indiana, from turbidity that reduces photosynthesis of algae, or from possible toxic effects of industrial discharges in the area.

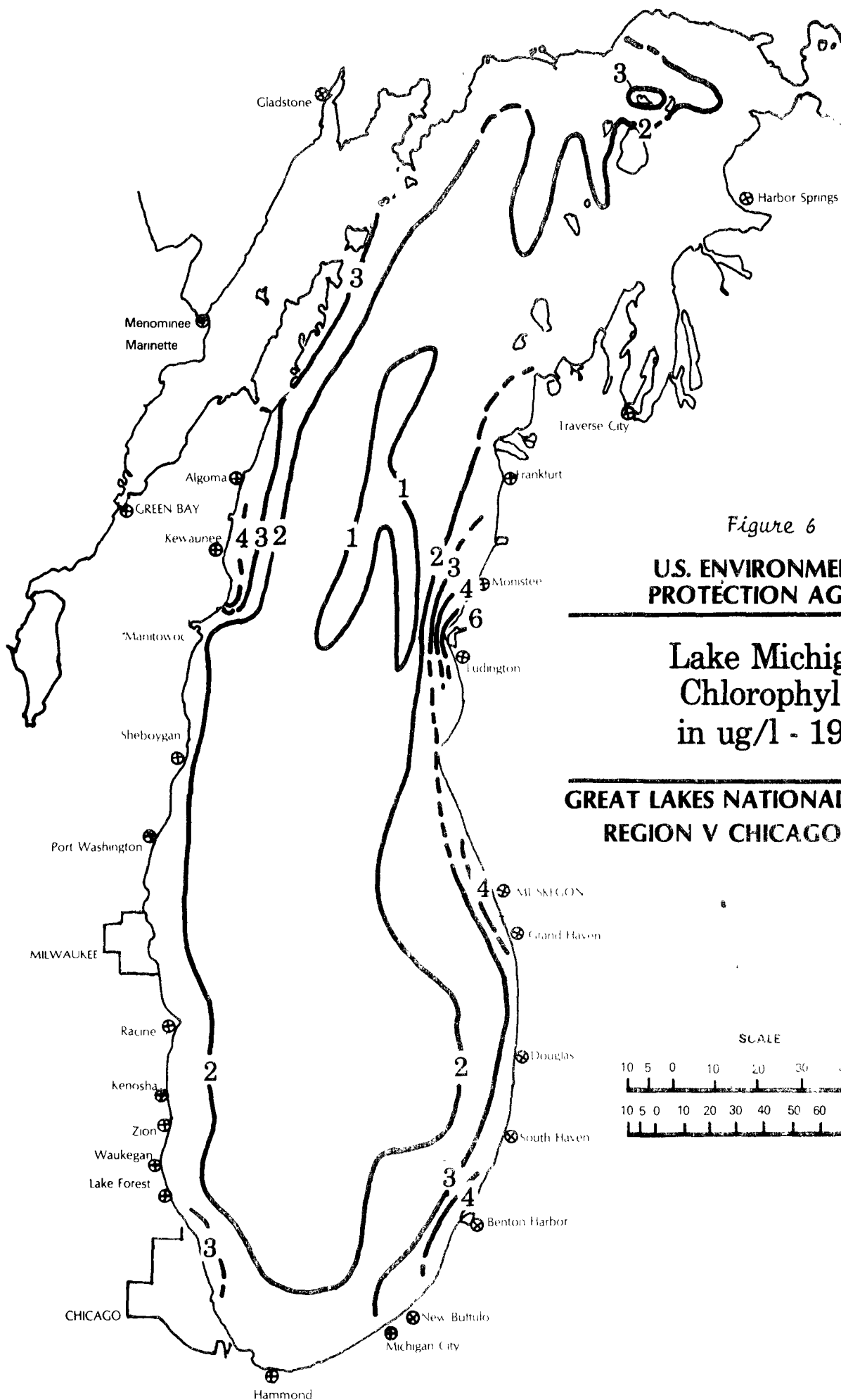


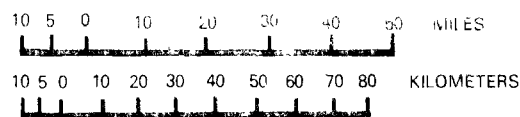
Figure 6

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PROTECTION AGENCY

Lake Michigan
Chlorophyll A
in ug/l - 1976

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SCALE



SILICA

Silica is essential to diatoms which incorporate it into their exoskeleton. If other nutrients and light are available, diatom populations will increase causing a reduction in silica concentrations. If this reduction becomes severe, the diatoms are less able to compete for nutrients and other, less desirable, algae may become dominant. This process appears to be occurring in Lake Michigan.

Figure 7 shows the vertical distribution of dissolved reactive silica at Station 26 on eight days between May 26 and October 8, 1976. During May, before stratification, the vertical silica distribution was virtually constant with a surface concentration of 1.21 mg/l. As the season progressed, the surface concentration of silica decreased steadily until it reached 0.27 mg/l in early August. Thereafter, it began to recover. Concentrations in the hypolimnion, and particularly near the bottom, increased steadily throughout the season reaching 2.76 mg/l during October. This clearly shows that silica settles toward the bottom with diatomaceous organisms. The total silica in the water column remains reasonably constant but the silica available in the epilimnion and the photic zone, where virtually all of the photosynthetic activity takes place, is greatly reduced.

Figure 8 compares the annual silica cycle in the surface waters at Lake Michigan for the years 1954, 1965 and 1976. It shows that there has been a significant decrease in silica available in surface waters since 1954. If this trend continues, it could lead to major changes in the phytoplankton species which are dominant in the lake.

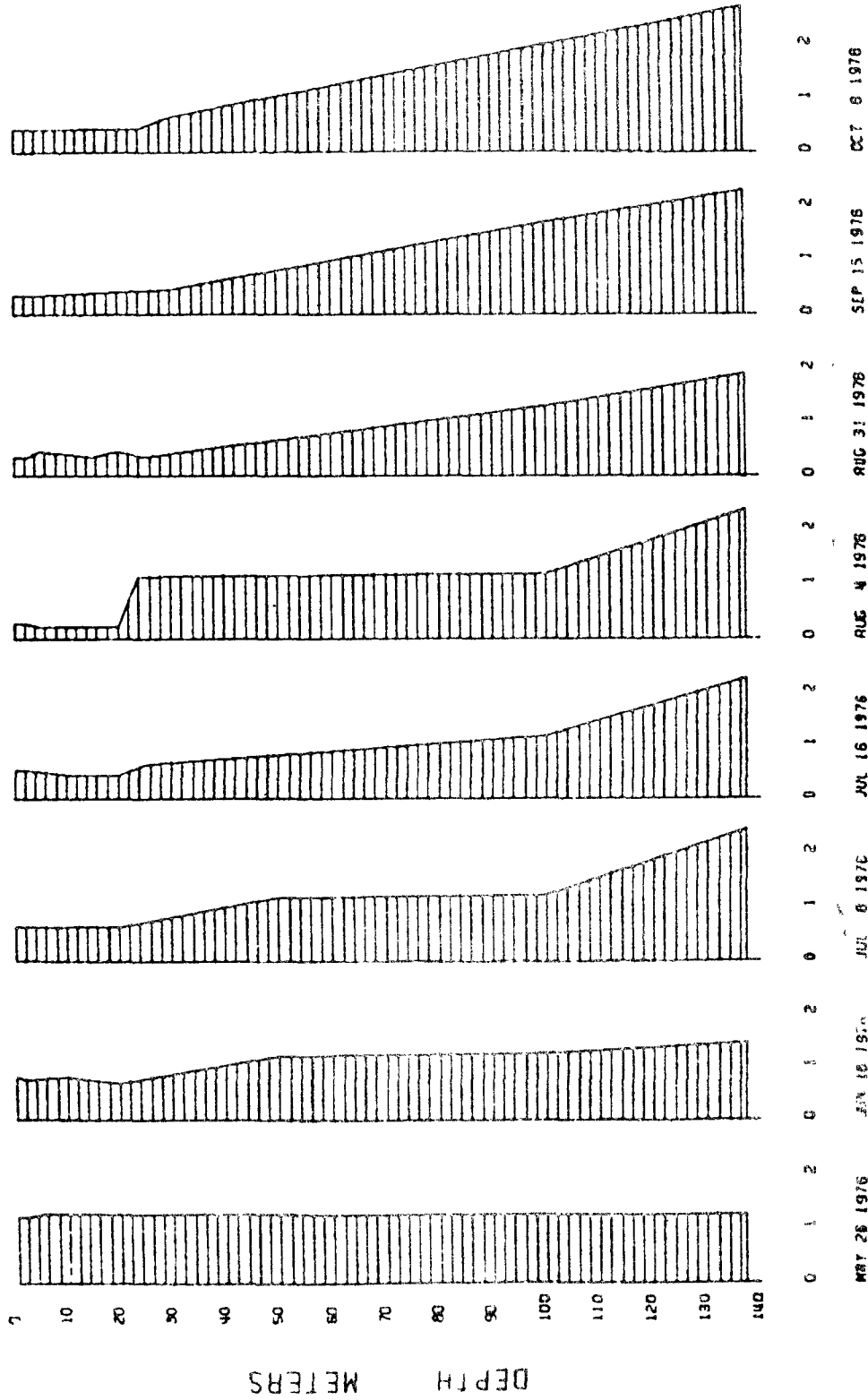


FIGURE 7

GREAT LAKES NATIONAL PROGRAM
STATION 26 SILICA DISTRIBUTION
U.S. ENVIRONMENTAL PROTECTION AGENCY Region V Chicago, Ill

STATION 26

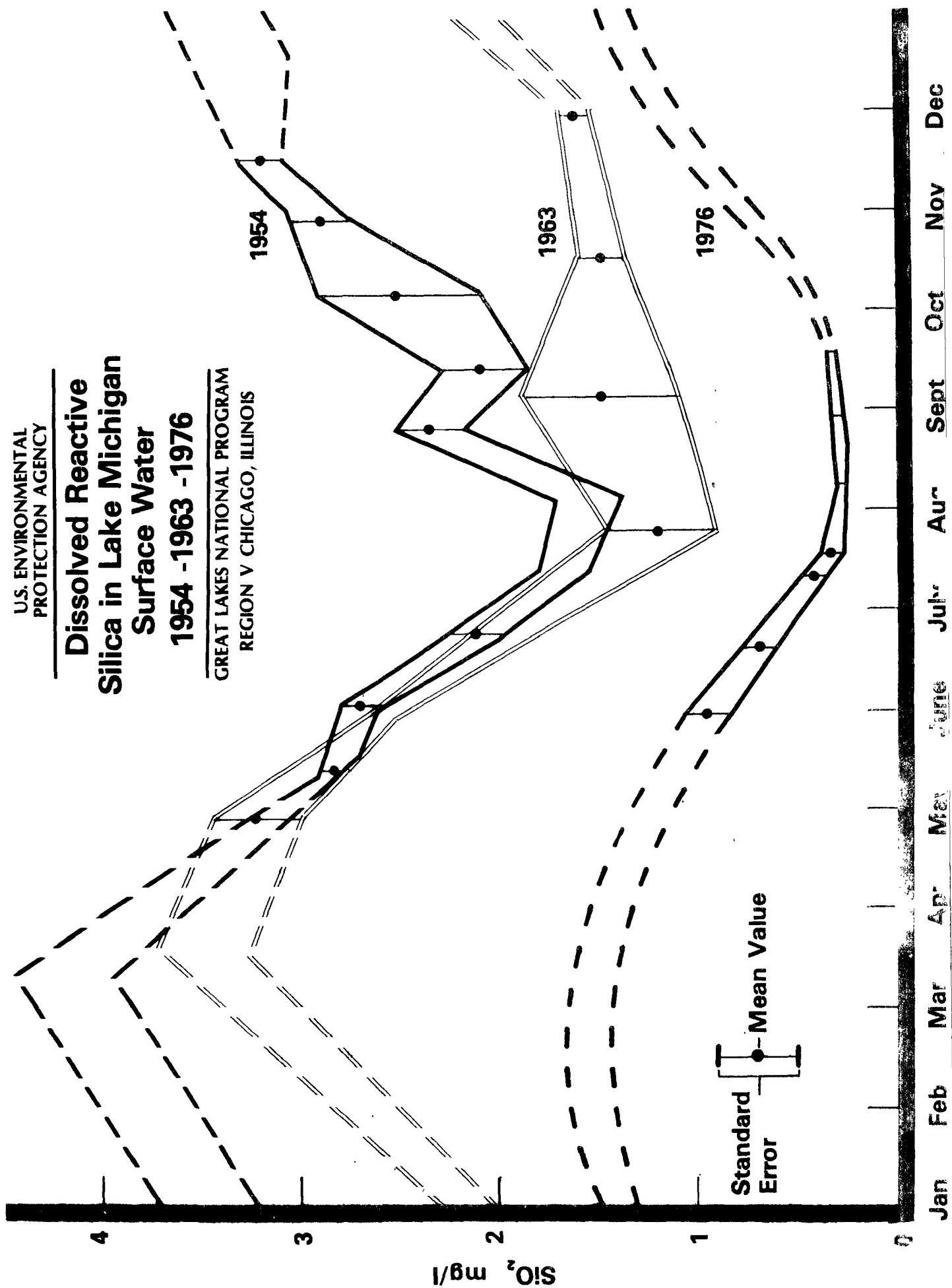
DISCUSS THE RELATIVE SILICA MG/L

Figure 8

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PROTECTION AGENCY

**Dissolved Reactive
Silica in Lake Michigan
Surface Water
1954 - 1963 - 1976**

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Chloride

Chloride compounds are associated with many of man's activities. Salt is used extensively for de-icing roadways in the winter. Industrial processes result in the discharge of brines. Chlorine is added to wastes to destroy bacteria and, recently, ferric chloride has been added to municipal waste water plants to remove phosphorus. As a result, the chloride ion can be used to measure cultural pollution, the added impact that modern man is making on the Lake.

Before the extensive population growth and industrial development of the Lake Michigan basin, chloride concentrations in Lake Michigan were around 1.0 mg/l.⁽³⁾ This represented an equilibrium concentration where the natural sources of chloride balanced the outflow from the Lake. These natural sources include weathering and erosion of rocks and soils, and atmospheric aerosols. The concentration increased, reaching 3.0 mg/l by 1910. The 1962-3 offshore samples of the lake averaged 6.5 mg/l, and the 1976 sampling of the entire Lake found an average of 7.9 mg/l. Figure 9 shows the distribution of mean chloride during 1976. From these observations, the rate of chloride accumulation over this period is about 0.11 mg/l/yr.

This accumulation rate is approximately four times that estimated during the period 1860 to 1910 (.025 mg/l/yr.), and greater than that estimated for the period 1910 to 1960 (.07 mg/l/yr.).

Supporting information is provided by nearshore water intake records. Nearshore time series data from three water filtration plants are shown in figure 10. The average annual rates of increase over the different time periods shown are $0.10 \pm .01$ mg/l at Milwaukee's Linwood Filtration plant, 0.12 ± 0.1 mg/l at Chicago's South Water Filtration Plant, and $0.15 \pm .01$ mg/l at Grand Rapids Lakeshore Filtration plant. Close inspection of these time series will show that the rate of accumulation since the 1960's is greater than the average rate during previous years.

Calculations of loading of chloride confirm the observed rates of increase of chloride concentration in the open lake. During the last 15 years the rate of increase ranged between 0.10 mg/l and 0.13 mg/l. These increases in concentration correspond to loadings of 900,000 and 1,050,000 metric tons of chlorides per year. During 1975 chloride loadings from rivers were estimated to be 775,000 metric tons. Point source estimates for direct discharge totaled 160,000 metric tons⁽⁵⁾ and atmospheric loading of chloride was estimated at 83,000 metric tons/year.⁽⁶⁾ The sum of these estimates, 1,018,000 metric tons/year, compares quite well with observed increases in lake concentrations.

Figure 11 compares 1963 chloride values with 1976 chloride values for 11 different open lake segments. The mean rate of accumulation over the thirteen year period is higher at the northern and southern ends of the lake than in the middle of the lake (segments E and D). This is because of the abatement of brine discharges from the Frankfort-Manistee area which caused higher concentrations during 1963. The

nearshore zone at Frankfort-Manistee is the only area of the lake where 1976 average chloride concentrations are less than 1963 concentrations. Figure 12 shows the distribution of chloride in Lake Michigan with the highest concentrations in the Southern basin and the Ludington Manistee area.

In 1972-1973, salts used for road deicing amounted to 445,000 metric tons as chloride (7). Assuming that chlorides are conservative and that ion exchange between chlorides and various soil types are minimal, most of the chloride used for deicing eventually reaches the Lake. This source of chloride could account for approximately 40% to 45% of the total current load. Other factors affecting modern loadings are the use of hydrochloric acid in steel manufacture, coagulation with chloride salts for phosphorus removal at municipal treatment plants and many industrial waste treatment processes which use chloride salts as coagulants.

The accelerating accumulation of chloride in Lake Michigan may lead to the current Lake chloride standards being violated in the next decade. State governments will be faced with the choice of taking action to reduce chloride loadings or altering their lake standards. The State of Indiana has recently proposed raising their standard from 10 mg/l to 15 mg/l. Illinois has a standard of 12 mg/l.

Although there is no doubt that the current levels of chloride concentrations are far below the drinking water standard of 250 mg/l set by the United States Public Health Service which is based on taste and not toxicity, there is the unpleasant possibility that future increases in chloride levels may lead to fundamental, probably irreversible, changes in the lake's natural biological systems. The extent, severity, and desirability of these changes and the chloride levels at which they will occur are not known. The chloride levels in Lake Erie are much higher than in Lake Michigan but the effects have been masked by the massive eutrophication that has taken place in that lake. The effects of increased chloride levels on a mesotrophic lake where phosphorus inputs are controlled is a subject for research which will be required for basic policy decisions.

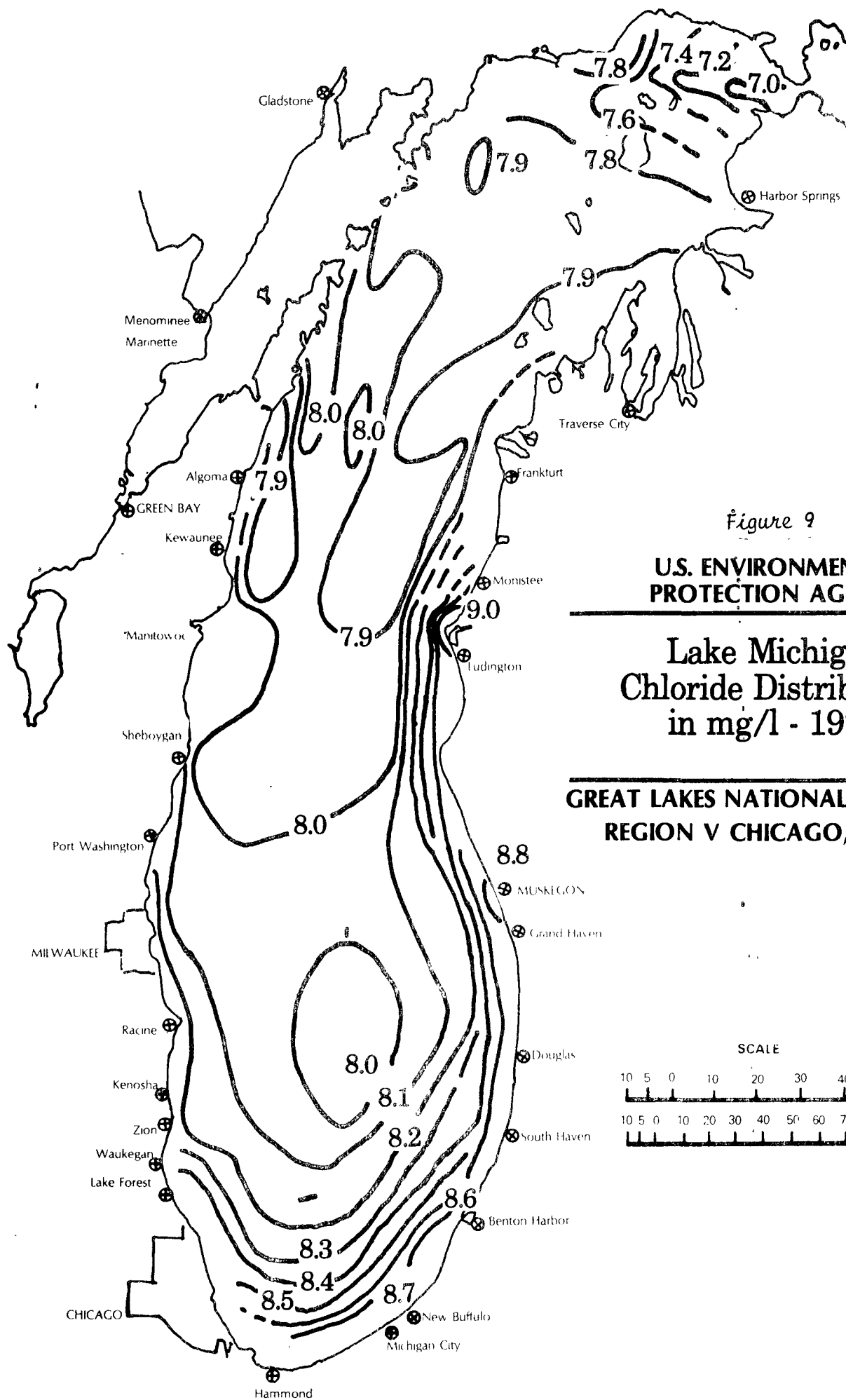
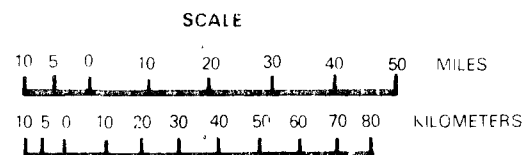


Figure 9

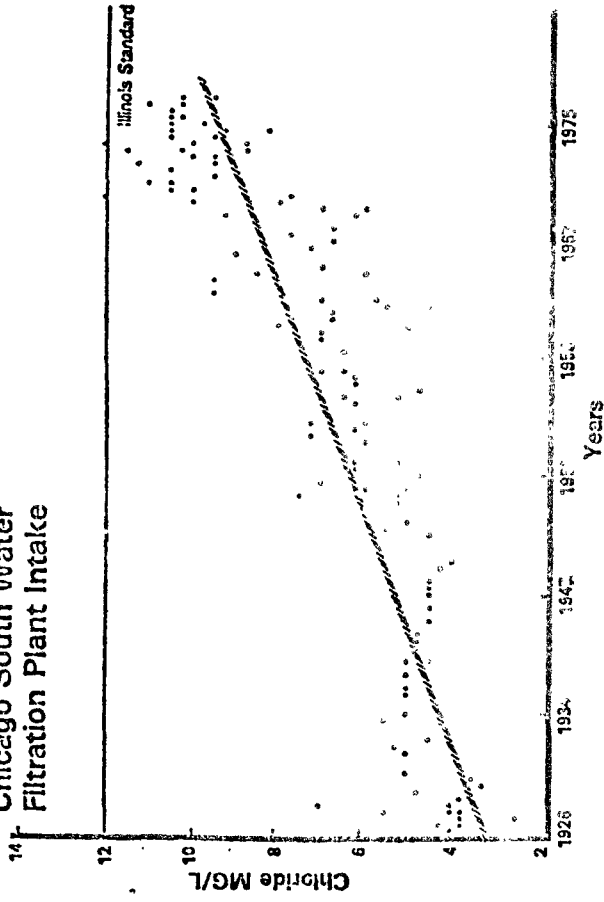
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Lake Michigan Chloride Distribution in mg/l - 1976

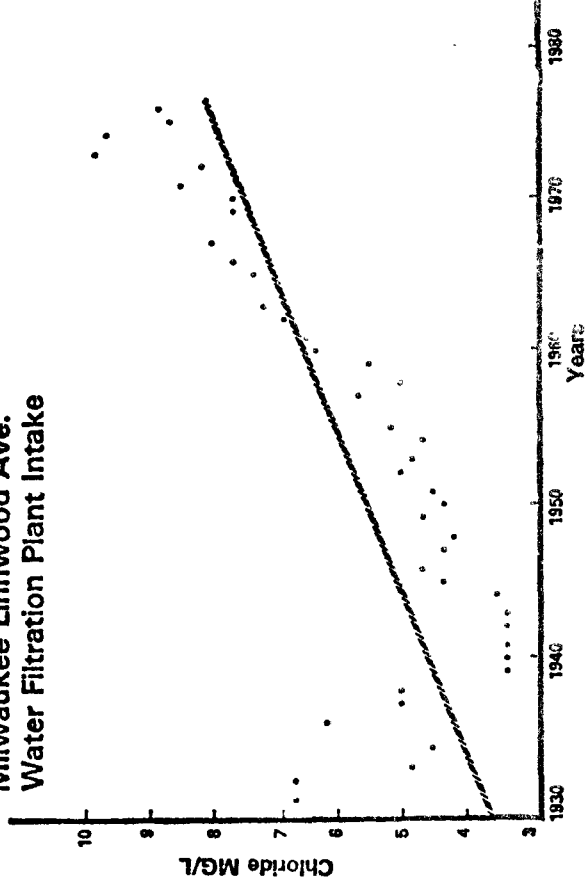
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Chicago South Water
Filtration Plant Intake



Milwaukee Linnwood Ave.
Water Filtration Plant Intake



Grand Rapids Lakeshore
Filtration Plant Intake

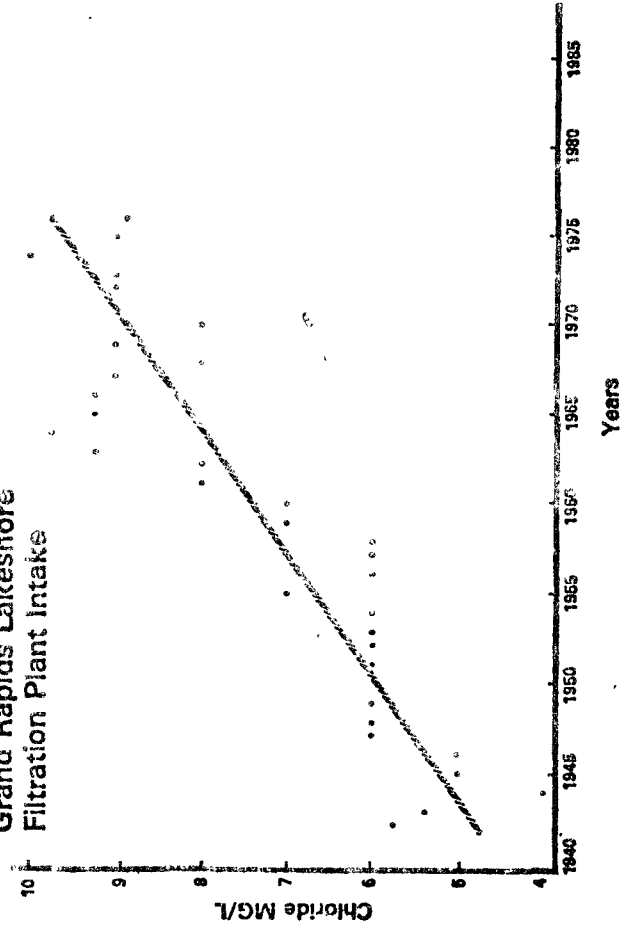
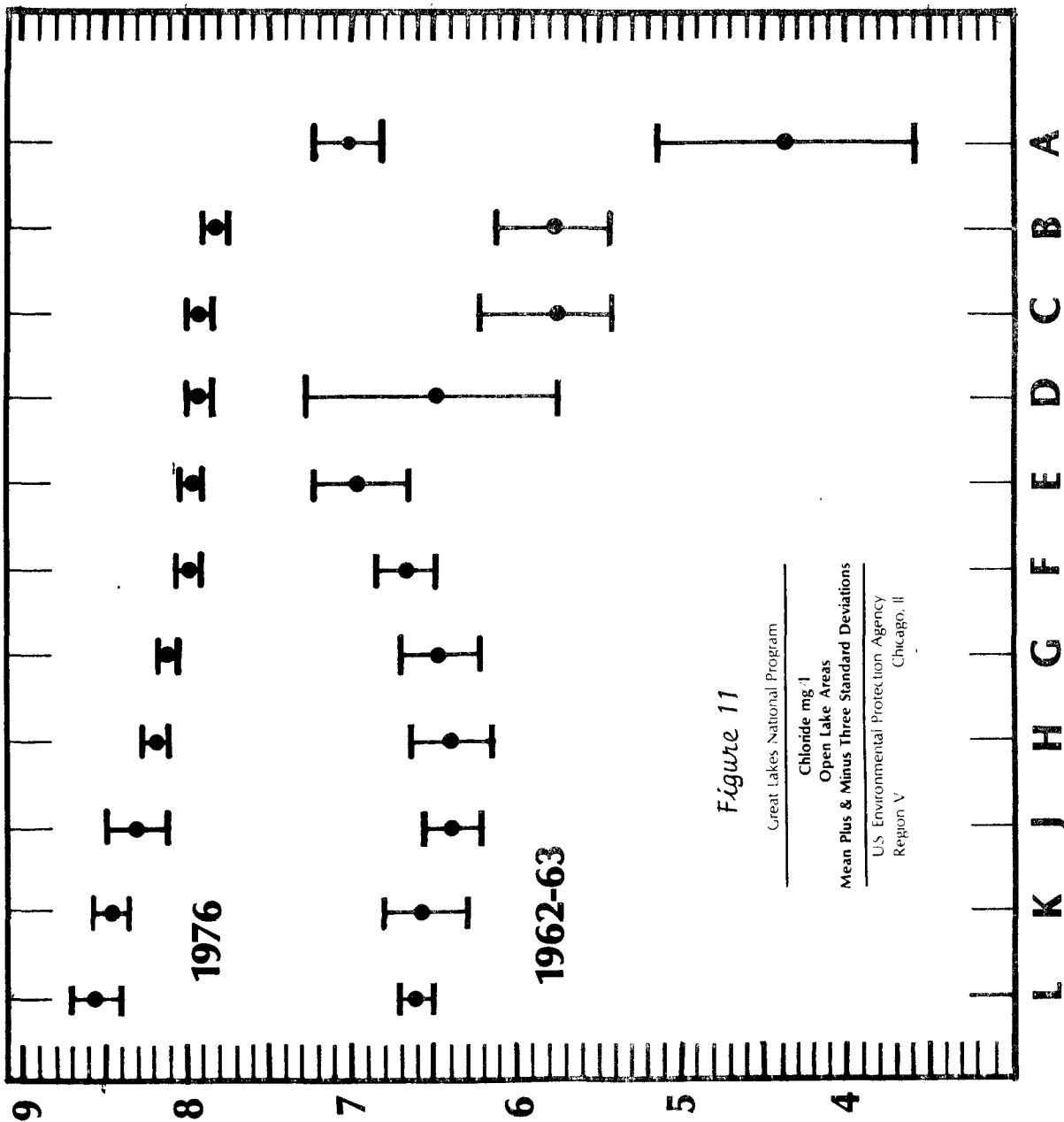
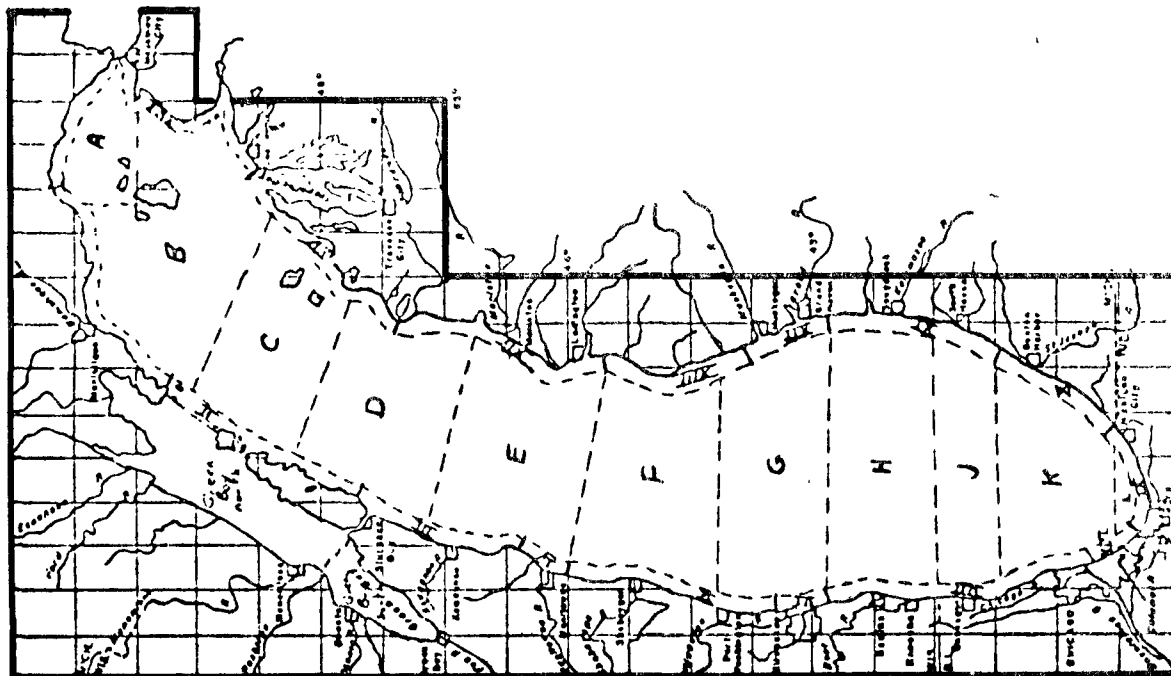


FIGURE 10

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LAKE MICHIGAN
CHLORIDE TRENDS

U.S. ENVIRONMENTAL PROTECTION AGENCY



- ° Pre 1960 data after Beeton
- x Post 1960 data after Torrey
- ⊙ Post 1960 n is large

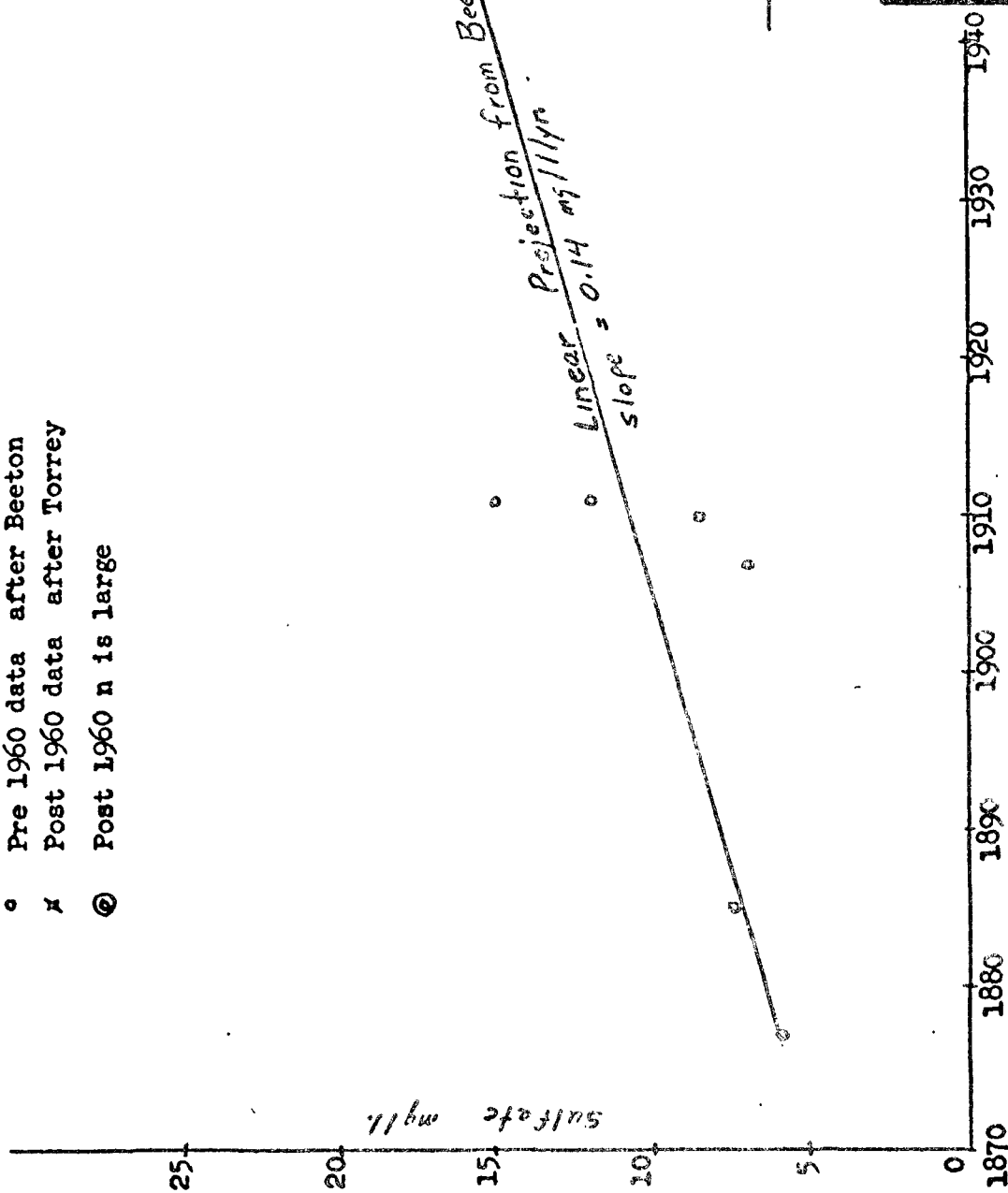


FIGURE 12

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LAKE MICHIGAN
SULFATE TRENDS

U.S. ENVIRONMENTAL PROTECTION AGENCY
Region V
Chicago 111

PLANKTON

Plankton are the small animal (zooplankton) and plant (phytoplankton) organisms that float or drift in the water at or near the surface and are incapable of sustained mobility in directions counter to the water currents. Diatoms are a major form of open water plankters and are dominant in oligotrophic waters of the Great Lakes. Plankton are a large part of the food chain base and as primary producers convert inorganic heterotrophic nutrients to organic matter. They use the energy of sunlight to metabolize inorganic nutrients and convert them to complex organic materials. Zooplankton and other herbivores graze upon the phytoplankton passing along the stored energy to higher organisms which in turn use the zooplankton as food.

Information of phytoplankton and zooplankton populations and species distribution has application in several areas. The kind of species and relative percentage of total population is important in characterization of a lake trophic status. These organisms are sensitive indicators of pollution and by their presence or absence can indicate toxic exposure to cultural discharge sources. Plankton often are a source of taste and odor problems and if present in large numbers increase costs of treatment at water filtration plants. Plankton blooms can permanently alter the habitat and cause extreme fluctuations in dissolved oxygen concentrations which can adversely effect living conditions for fish and other higher forms of aquatic life. Zooplankton are part of the food chain, feeding on bacteria and phytoplankton and are in turn consumed by fish. Since phytoplankton are the base of the food chain and widespread change in their composition can have a great impact on all of the biota in the lake.

SULFATE ($\text{SO}_4^{=}$)

Sulfate is a conservative ion which reflects sulfur inputs to the lake. Biochemical and chemical reactions in a well-aerated system such as Lake Michigan have little effect on the concentration of sulfate in the water. Thus it is useful in tracking man's impact on the environment.

Rising levels of sulfate in the nearshore zones create concern because additions of sulfide ($\text{S}^{=}$) from industrial sources demand large amounts of oxygen. This is because of the rapid oxidation of sulfide to sulfate and increased populations of sulfur-reducing bacteria.

Sulfate has many sources. Weathering and erosion of sulfur-containing minerals and soils remove sulfur from the watershed to the Lake. Human activities add sulfates via waste discharges from petrochemical, chemical, metal mining and refining, metal working and fabricating, and the pulp and paper processes.

The standard for sulfate in public water supplies, which is based on taste and laxative effects, is 250 mg/l, much higher than levels presently found in Lake Michigan.

The concentration of sulfate in Lake Michigan was increasing more rapidly than any other ion between 1900 and 1960 based on data compiled and published by Beeton. This data indicated an average rate of increase of 0.14 mg/l/yr. A comparison of the 1963 data with the 1976 data for open lake waters shows an average accumulation rate of 0.08 mg/l/yr (Figure 12). A close examination of this figure indicates that this increase may have leveled off completely in the early seventies. Averages of data collected in the southern basin varied between 20 mg/l and 22.7 mg/l with an overall average of about 21 mg/l. This compares with the 1976 average of 21.1 mg/l in the southern basin (Figure 13).

The water intake data (Figure 14) shows average rates of increase of 0.09 mg/l/yr at Milwaukee, 0.18 mg/l at Chicago south water filtration plant, and 0.31 mg/l/yr at Grand Rapids. Close examination of the Chicago data shows a leveling off around 1970 although this is not evident in the Milwaukee or Grand Rapids data.

Monitoring of the Calumet area (9) during 1965-1969 shows a dramatic decrease in sulfate loadings due to changes in steel making processes and effluent treatment. The change from pickling steel with sulfuric acid to hydrochloric acid and the use of deep well disposal for spent acids is a factor in this apparent decrease in sulfur accumulation at the southern tip of the lake. Another factor may be the reduced use of high sulfur fuels in the Chicago metropolitan area.

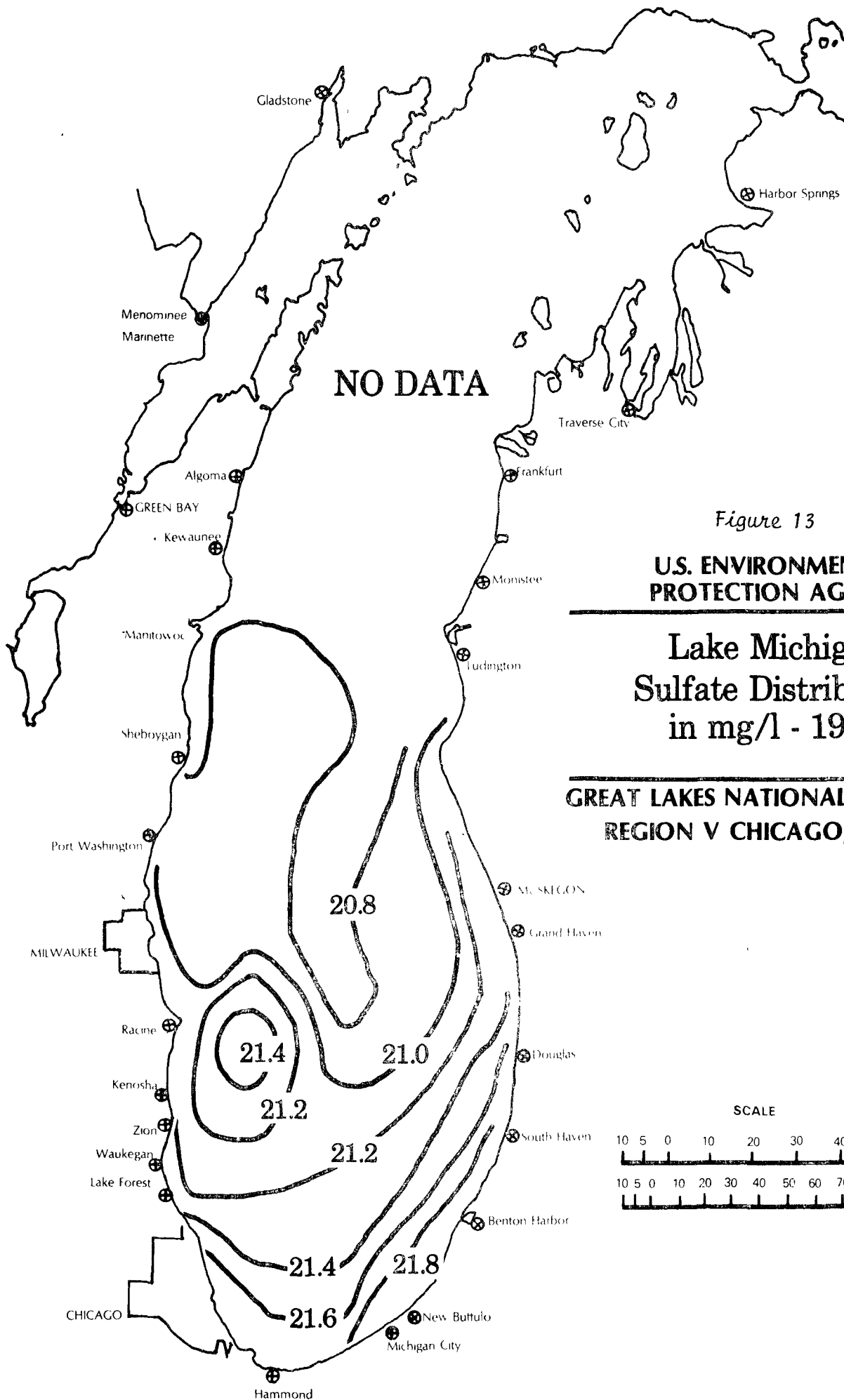
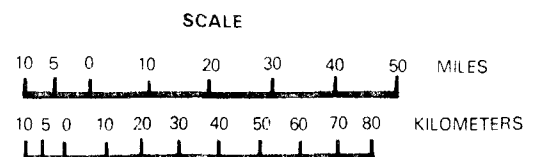


Figure 13

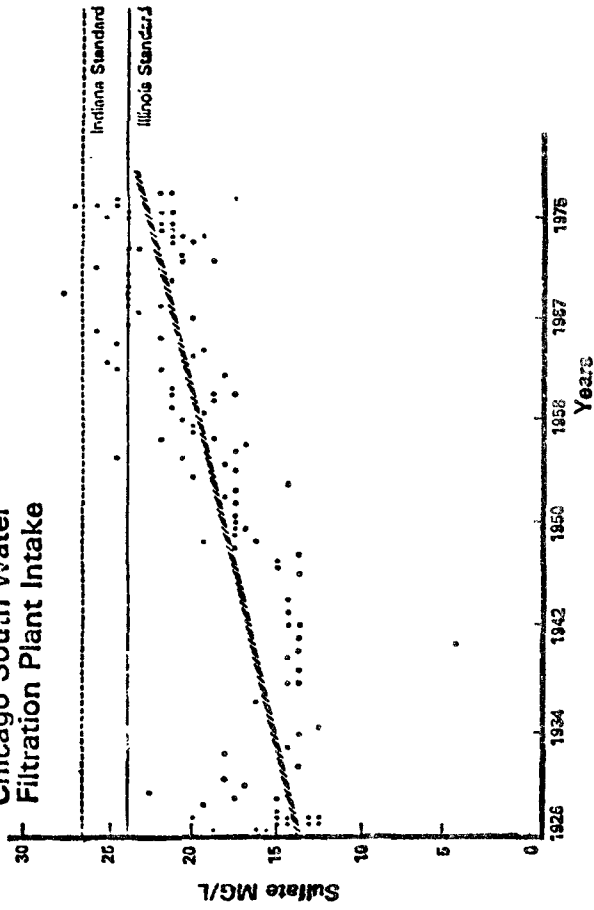
U.S. ENVIRONMENTAL
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Lake Michigan
Sulfate Distribution
in mg/l - 1976

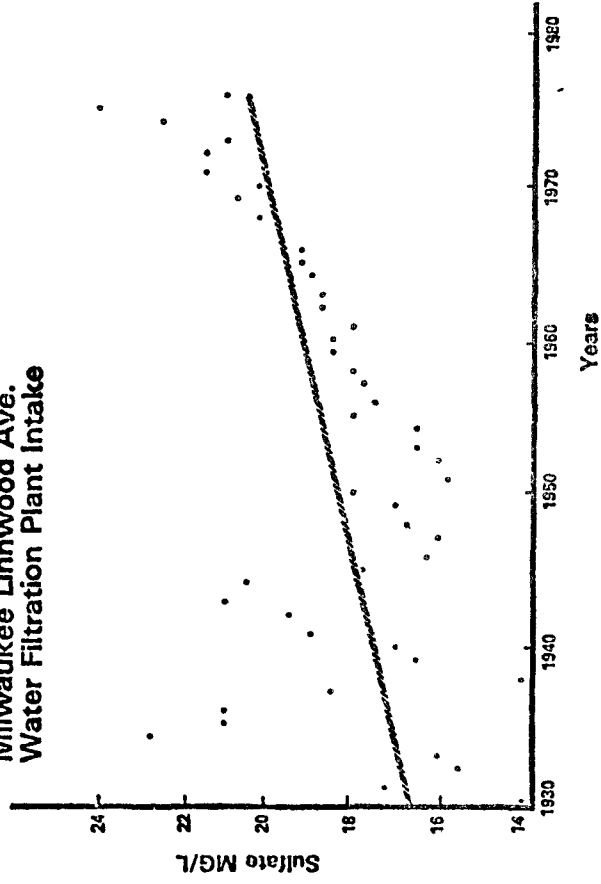
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REGION V CHICAGO, ILLINOIS



Chicago South Water
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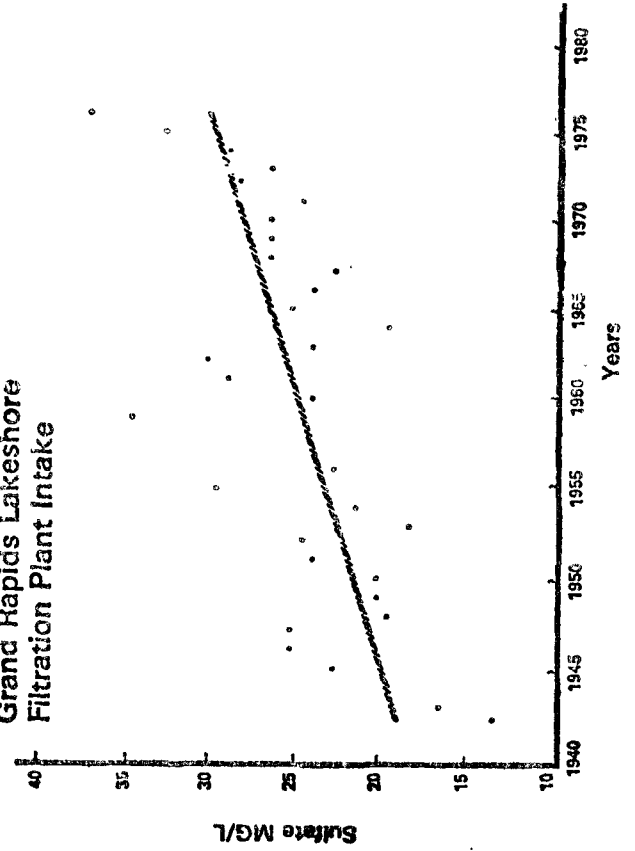


FIGURE 14

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LAKE MICHIGAN
SULFATE TRENDS

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