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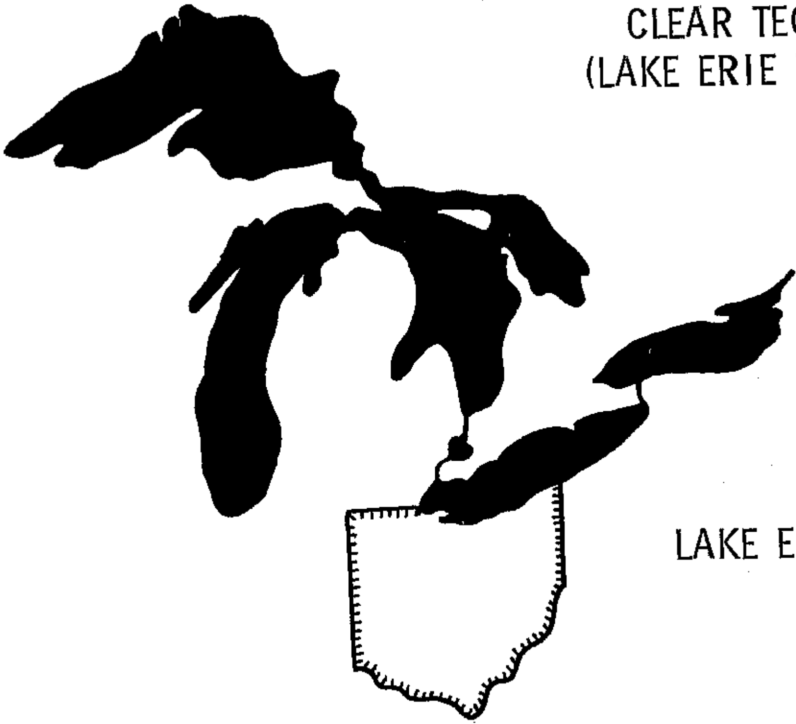
(LAKE ERIE TAT CONTRIBUTION NO. 27)



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LAKE ERIE INTENSIVE STUDY 1978-1979
MANAGEMENT REPORT

Prepared by

Lake Erie Technical Assessment Team

Prepared for

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PREFACE

Lake Erie has experienced several decades of acclerated eutrophication and toxic substances contamination. During the latter part of the 1960's remedial actions were planned and by the latter part of the 1970's, many of the plans were at least partially implemented. The first signs of lake recovery are now being observed through comprehensive monitoring programs. The intent of this report is to highlight the findings and conclusions of the 1978-1979 Lake Erie Intensive Study by placing them in perspective with earlier investigations and subsequent monitoring data from 1980 and 1981, where available. The primary function of this report is to provide management information in the form of a review of the lake's status and its trends and in the form of recommendations to insure continued improvements in the quality of its waters and biota.

Charles E. Herdendorf, Chairman

Lake Erie Technical Assessment Team

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INTRODUCTION

Objectives of Study

Lake Erie, as one of the Great Lakes of North America, represents a significant source of fresh surface water for the people of Canada and the United States. In recognition of the importance of this resource and the need to restore and maintain its water quality, the Canadian and United States governments entered into the Great Lakes Water Quality Agreement in 1972. The Agreement was reaffirmed in 1978 by further actions to enhance water quality in the Great Lakes Basin ecosytem.

These governments have mandated the International Joint Commission (IJC) task of coordinating the implementation of the Agreement. Recognizing the need for a uniform surveillance effort by both parties of the agreements and the cooperating state and provincial jurisdictions, the IJC formed and directed the Water Quality Board to develop an international surveillance plan. Work groups were established for each lake, with the responsibility for developing detailed plans.

The Lake Erie Work Group prepared a nine-year surveillance plan in 1977, which was designed to provide an understanding of the overall, long-range responses of the lake to pollution abatement efforts. This plan was eventually incorporated as part of the Great Lakes International Surveillance Plan (GLISP) developed by the Surveillance Subcommittee of the Water Quality Board. The general objectives established for this plan included:

1. To search for, monitor, and quantify violations of the existing Agreement objectives (general and specific), the IJC recommended objectives, and jurisdictional standards, criteria and objectives. Quantification will be in terms of severity, areal or volume extent, frequency, and duration, and will include sources.

2. To monitor local and whole lake response to abatement measures and to identify emerging problems.

3. To determine the cause-effect relationship between water quality and inputs in order to develop the appropriate remedial/preventative actions and predictions of the rate and extent of local/whole lake responses to alternative abatement proposals.

Within the context of these general objectives and considering the key issues specific to Lake Erie, the surveillance plan for Lake Erie additionally focused on:

1. Determining the long-term trophic state of the lake and determining to what degree remedial measures have affected improvements.

2. Assessing the presence, distribution, and impact by toxic substances.

3. Providing information to indicate the requirements for and direction of additional remedial programs, if necessary, to protect water uses.

The Lake Erie plan called for a two-year Intensive Study of main lake, nearshore and tributary conditions (1978 and 1979), followed by seven years of main lake monitoring (1980-1986). The overall objective of the Intensive Study was to provide information for a detailed assessment of inputs to the lake and the current condition of the lake. The intensive study was also designed to identify emerging problem areas, to detect changes in water quality on a broad geographic basis, and to provide information necessary for trend analyses. The study plan considered the seasonal nature of tributary inputs, lake circulation patterns, and nearshore-offshore gradients. The plan stressed linkages between the various components of the study in order to permit an adequate "whole lake" water quality assessment.

Organization of Data Collection and Analysis

Field investigations for the Intensive Study were initiated in January 1978 under the auspices of the IJC. Approximately 25 organizations collected data relevant to the effort (Table 1). Most components of the plan were implemented on schedule as the environmental protection, natural resource management, and the scientific research communities of the Great Lakes region embarked on the two-year study (Figure 1). Planning and implementation of the study was coordinated by the Lake Erie Work Group of the Surveillance Subcommittee. This subcommittee served the Implementation Committee of the IJC Great Lakes Water Quality Board. The Lake Erie Work Group was charged with the responsibility of monitoring the progress of field investigations and preparation of reports which analyze the results of these studies, and the production of a comprehensive assessment of the current status of Lake Erie.

TABLE 1

ORGANIZATIONS PARTICIPATING IN THE LAKE ERIE INTENSIVE STUDY

Agency or Organization	Anticipated Contributions
CANADA-FEDERAL	
1. Canada Centre for Inland Waters	Central Lake Erie oxygen study; water circulation study; atmospheric inputs
2. Department of Fisheries and Environment (Canada)	Wildlife contaminants study
CANADA-PROVINCIAL	
3. Ontario Ministry of the Environment	Tributary inputs; point source inputs; water intakes; beach surveys
4. Ontario Ministry of Natural Resources	Fish contamination surveys; fish stock assessment
UNITED STATES-FEDERAL	
5. National Aeronautical and Space Administration Lewis Research Center	Remote sensing images of suspended sediment and chlorophyll biomass; ice conditions; surface temperature
6. National Oceanic and Atmospheric Administration Great Lakes Environmental Laboratory	Water levels and flows; current meter survey/circulation patterns; nutrient models
7. U.S. Army, Corps of Engineers Buffalo District	Wastewater management study; loading calculations for tributaries and connecting channels
8. U.S. Environmental Protection Agency Great Lakes National Program	Main Lake Erie monitoring, Western, Central, and Eastern basins; TAT planning
9. U.S. Environmental Protection Agency Large Lakes Research Station	Oxygen and nutrient models; fish contaminants; Cladophora surveys
10. U.S. Environmental Protection Agency Region V, Eastern District Office	Logistical support; point source inputs; TAT planning
11. U.S. Fish and Wildlife Service	Fish contamination surveys; fish stock assessment
12. U.S. Geological Survey	Tributary stream gauging, flows and water quality
UNITED STATES-STATE AND COUNTY	
13. Erie County (PA) Department of Health	Tributary inputs; point source inputs; water intakes; beach surveys
14. Michigan Department of Natural Resources	Tributary inputs; point source inputs; water intakes; beach surveys; Detroit River discharge
15. New York State Department of Environmental Conservation	Tributary inputs; point source inputs; Niagara River discharge
16. New York State Department of Health	Beach surveys; water intakes
17. Ohio Department of Natural Resources	Fish stock assessment, fish kill investigations
18. Ohio Environmental Protection Agency	Tributary inputs; point source inputs; water intakes; beach surveys
UNITED STATES-MUNICIPAL	
19. City of Cleveland Water Quality Laboratory	Harbor monitoring for water quality
20. City of Toledo	Harbor monitoring for water quality
UNITED STATES-UNIVERSITY	
21. Heidelberg College	Central Lake Erie nearshore
22. Ohio State University	Western Lake Erie nearshore; Central basin oxygen depletion rates; Cladophora surveys; fish contamination survey at tributary mouths
23. State University College of New York at Buffalo	Eastern Lake Erie nearshore; Cladophora survey
24. University of Toledo	Limnological study of Maumee River and Bay
INTERNATIONAL	
25. International Joint Commission	Quality control/assurance for measurement; statistical procedures; logistical support for meetings and report preparation; final report printing and distribution

	Topic	Organization Responsible
A. MAIN LAKE		
1.	Main Lake Monitoring Report	USEPA/OSU/CLEAR
2.	Oxygen Studies	NWRI/CCIW
3.	Sedimentation/Carbon Flux	NWRI/CCIW
4.	Sediment Oxygen Demand	USEPA/LLRS
5.	Lake Response to Nutrient Loading	USEPA/LLRS
6.	Lake Circulation	NOAA/GLERL
7.	Lake Physics Studies: a. Interbasin transfer; b. Nearshore-offshore movement; c. Vertical drift	NWRI/CCIW
B. NEARSHORE		
1.	Canadian Nearshore	MOE
2.	Western Basin, U.S.	OSU/CLEAR
3.	Central Basin, U.S.	Heidelberg College
4.	Eastern Basin, U.S.	SUNY/GLL
5.	Cladophora	SUNY/GLL
6.	Cleveland Intakes	NOACA
7.	Toledo/Maumee Estuary	TPCA
C. INPUT AND PROBLEM AREAS		
1.	NY Beaches, Tributaries, Intakes and Pt. Sources	NYSDEC
2.	PA Beaches, Tributaries, Intakes and Pt. Sources	ECDH
3.	OH Beaches, Tributaries, Intakes and Pt. Sources	OEPA
4.	MI Beaches, Tributaries, Intakes, Point Sources, and Detroit River	MDNR
5.	ONT Beaches, Tributaries, Intakes, Point Sources, and Niagara River	MOE
6.	Tributary, Point Source, and Atmospheric Loading	IJC
7.	Meteorological/Hydrological Summary	NOAA/GLERL
D. CONTAMINANTS		
1.	Radioactivity	IJC
2.	Fish Contaminants	USEPA/USF&WS
3.	Wildlife Contaminants	Canada Wildlife
E. DATA QUALITY		
1.	Data Quality Report	IJC
2.	Data Management Report	IJC
3.	Field and Laboratory Procedures	IJC
F. SPECIAL CONTRIBUTIONS		
1.	Fish Stock Assessment	GLFC
2.	Remote Sensing Experiments	NASA
3.	Wastewater Management Study	USACOE
4.	Tributary and Storm Event Reports	USGS
5.	Phosphorus Management Study	IJC
6.	Primary Productivity Study	NWRI/CCIW OSU/CLEAR

Figure 1. Major Components of the Lake Erie Intensive Study.

The methods for data collection and sample analysis are outlined in the Lake Erie Surveillance Plan prepared by the Lake Erie Work Group (Winklhofer 1978). Specific methods employed for the Intensive Study are contained in the numerous reports submitted by the study participants (Herdendorf 1981). Of major importance were the methods used for the main lake and nearshore components, because six organizations cooperated in these components which covered the entire water mass of the lake and compatability of the data was essential. Table 2 lists the parameters and typical methods used for water, biological, and sediment measurements. To facilitate problem area assessment and the determination of long-term trends, emphasis was placed on those parameters subject to non-compliance with the Water Quality Agreement and/or jurisdictional criteria, standards, or guidelines.

For the purposes of the Intensive Study, the lake was divided into a series of main lake compartments and narshore reaches (Figure 2) with a combined station pattern totalling over 500 stations (Figure 3). Six organizations were responsible for the main lake and nearshore components; therefore data compatability was essential:

Main Lake

1. USEPA, Great Lakes National Program Office (USEPA)

2. Canada Centre for Inland Water (CCIW)

TABLE 2

PARAMETERS MEASURED FOR THE LAKE ERIE INTENSIVE STUDY

Water Parameters

1. Temperature
2. Wind speed and direction
3. Transparency, Secchi
4. Wave height
5. Extinction depth
6. Aesthetics
7. Turbidity
8. Suspended solids
9. Dissolved oxygen
10. pH
11. Specific conductance
12. Alkalinity
13. Total phosphorus
14. Total dissolved phosphorus
15. Soluble reactive phosphorus
16. Total kjeldahl nitrogen
17. Ammonia
18. Nitrate & Nitrite N
19. Dissolved reactive silicate
20. Chloride
21. Sulfate
22. Calcium
23. Magensium
24. Sodium
25. Potassium
26. Aluminum, total
27. Aluminum, dissolved
28. Cadmium, total
29. Cadmium, dissolved
30. Chromium, total
31. Chromium, dissolved
32. Copper, total
33. Copper, dissolved
34. Iron, total
35. Iron, dissolved
36. Lead, total
37. Lead, dissolved
38. Manganese, total
39. Manganese, dissolved
40. Nickel, total

Biological Parameters

1. Phytoplankton
2. Zooplankton
3. Chlorophyll a
4. Pheophytin
5. Aerobic heterotrophs
6. Fecal coliforms
7. Fecal streptococci
8. Benthos

Sediment Parameters

1. Solids, total
2. Solids, volatile
3. Chemical oxygen demand
4. Total organic carbon
5. Total phosphorus
6. Total kjeldahl nitrogen
7. Ammonia nitrogen
8. Arsenic
9. Selenium
10. Cadmium
11. Chromium
12. Copper
13. Iron
14. Lead
15. Nickel
16. Silver
17. Zinc
18. Mercury
19. Cyanide
20. PCB's, total
21. Hexachlorobenzene
22. beta-Benzenehexachloride
23. Lindane
24. Treflan
25. Aldrin
26. Isodrin
27. Heptachlor epoxide
28. Chlordane
29. DDT and isomers
30. Methoxychlor

TABLE 2 CONT.

Water Parameters	Sediment Parameters
41. Nickel, dissolved	31. Mirex 2
42. Vanadium, total	32. 4-D Isopropyl Ester
43. Vanadium, dissolved	33. Endosulfan I
44. Zinc, total	34. Endosulfan II
45. Zinc, dissolved	35. Dieldrin
46. Arsenic, total	36. Endrin
47. Mercury, total	37. Tetradifon
48. Selenium, total	38. Grain-size analysis
49. Silver, total	
50. Silver, dissolved	
51. Cyanide	
52. Phenol	
53. Total organic carbon	
54. Dissolved organic carbon	

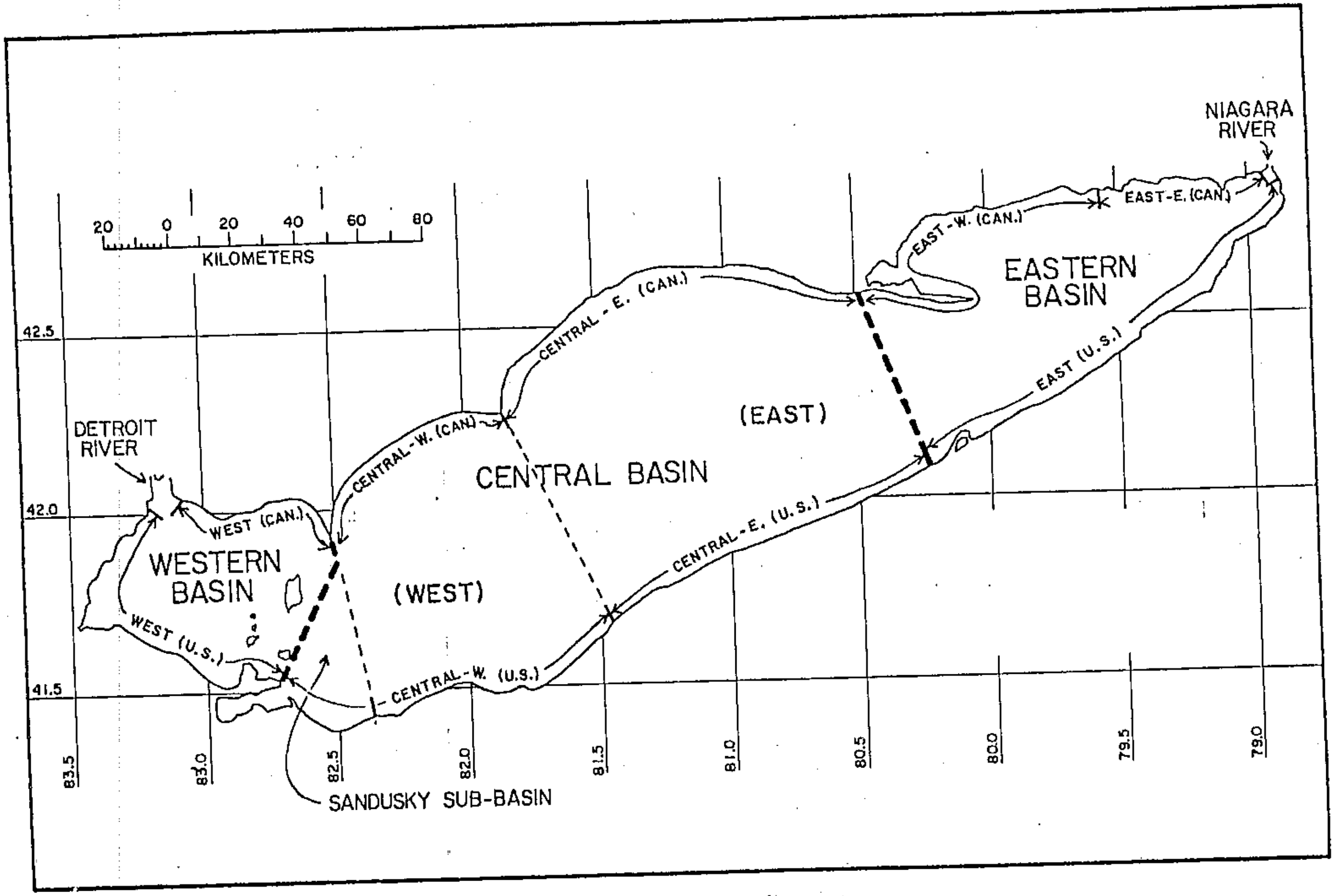


Figure 2. Lake Erie Major Nearshore Reaches and Main Lake Basins.

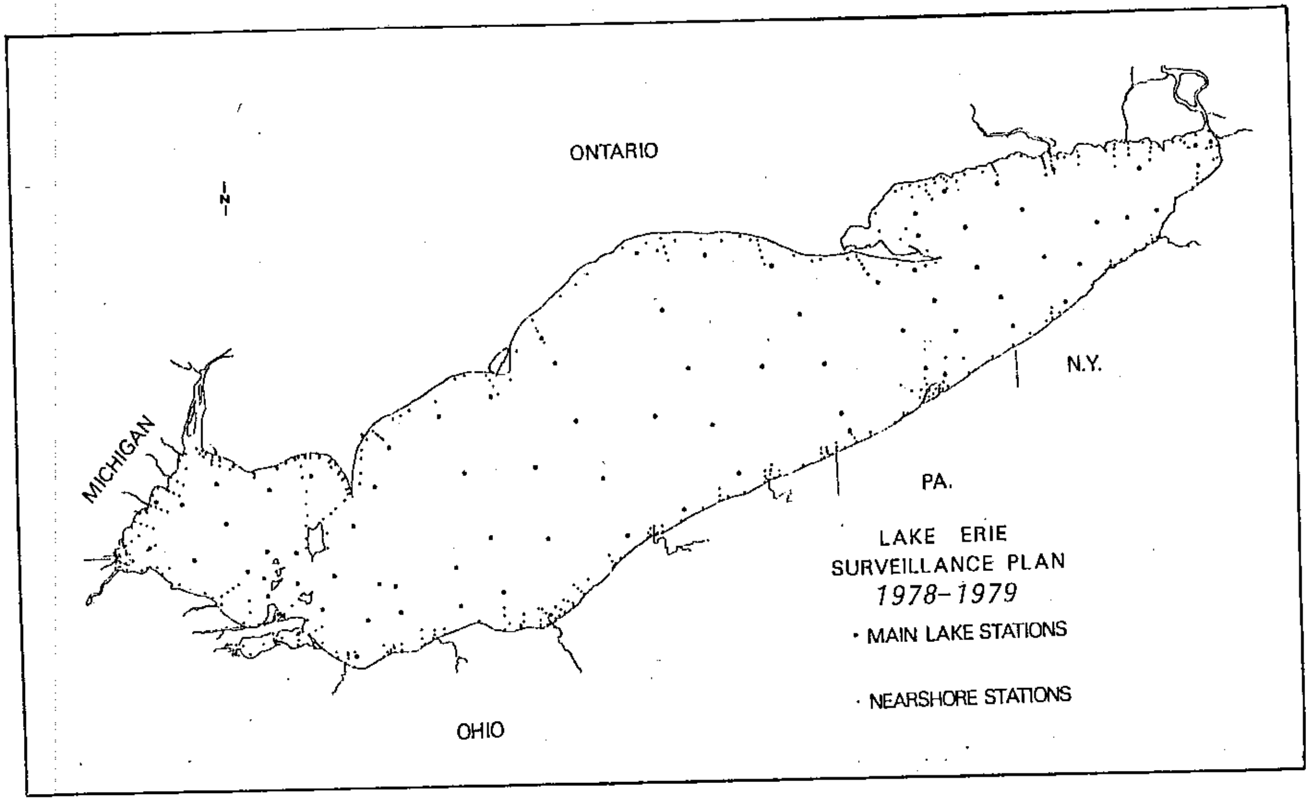


Figure 3. Lake Erie Intensive Study Station Plan.

Nearshore

1. Ohio State University, Center for Lake Erie Area Research (OSU) -western Lake Erie, Detroit River to Huron, Ohio

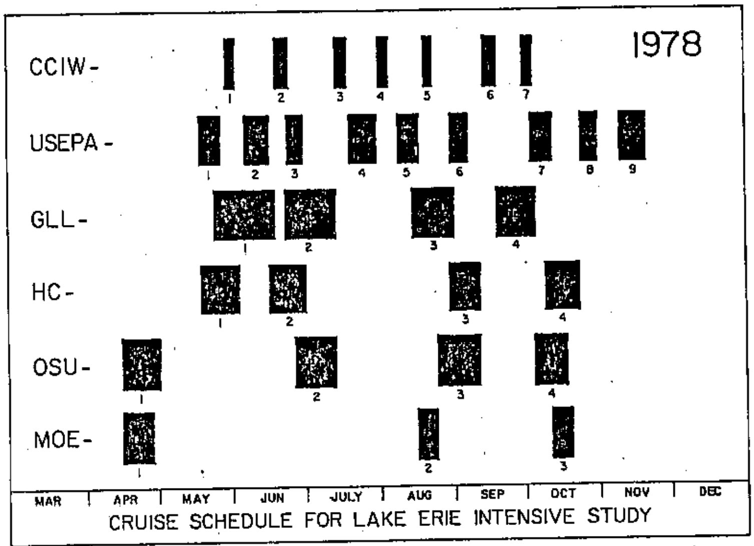
2. Heidelberg College (HC) - central Lake Erie, Vermilion, Ohio to Ashtabula, Ohio

3. State University of New York College at Buffalo, Great Lakes Laboratory (GLL) - eastern Lake Erie, Conneaut, Ohio to Buffalo, New York

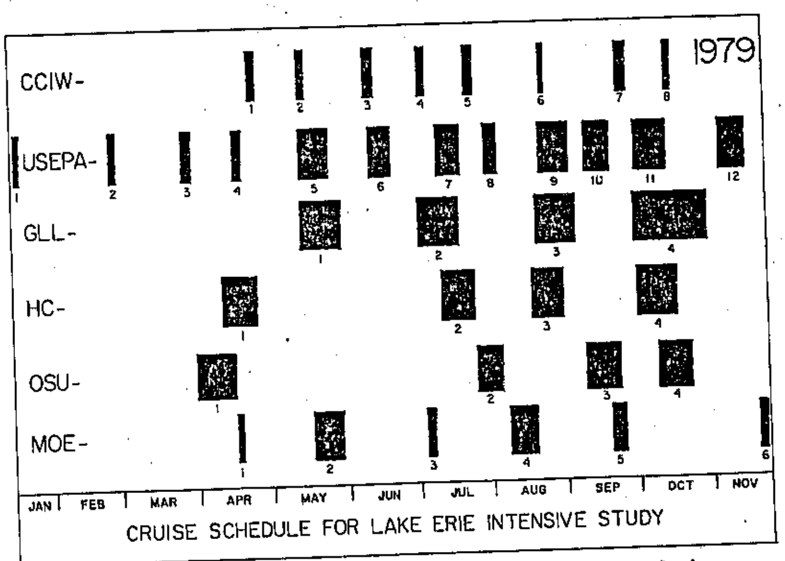
4. Ontario Ministry of Environment, Water Resources Branch (MOE) -western Lake Erie, Detroit River to Point Pelee, central Lake Erie, Point Pelee to Long Point, and eastern Lake Erie, Long Point to Niagara River

Cruises were scheduled to provide a reasonably synoptic view of the entire lake (Figure 4). Data from these cruises constitute the foundation for the whole lake assessment.

In order to assist the Lake Erie Work Group in meeting its responsibility to bring the general objective of the Intensive Study to fruition, the Center for Lake Erie Area Research (CLEAR) proposed the creation of a technical assessment team with scientific and technical knowledge of Lake Erie and report editing, research project administration, and data management skills. In March 1980, at the conclusion of the Intensive Study field investigations, such a team was established at Ohio State University by a grant from U.S. Environmental Protection Agency, Great Lakes National Program Office.



Lake Erie Intensive Study Cruise Schedule for 1978. Cruise numbers indicated below each cruise period.



Lake Erie Intensive Study Cruise Schedule for 1979. Cruise numbers indicated below each cruise period.

Figure 4. Lake Erie Intensive Study Cruise Schedules

The Lake Erie Technical Assessment Team (TAT) was thus formed to synthesize data from the diverse groups into a unified, whole lake assessment. TAT functioned to provide a scientific focus for coordination and cooperation, for promotion of information exchange and for creation of an atmosphere in which a consensus can be reached on technical matters. Specific objectives of TAT included:

1. To provide professional oversight and a pool of scientific and technical skills to supplement the international scientific staff involved in the intensive study.

2. To coordinate and guide, essentially on a daily basis, efforts of the various contributing scientists.

3. To exercise technical review and editorial responsibilities for the individual reports.

4. To perform an in-depth and integrated analysis of the data base for the purpose of a comprehensive assessment.

5. To assure that all pertinent baseline data resulting from Canadian and United States sources are entered in STORET for the purpose of this assessment and future analysis.

6. To exercise the aforementioned functions to bring together the individual Canadian and United States elements of intensive study to produce a timely unified whole lake report which will:

a. determine the status of the open water and nearshore areas of Lake Erie in terms of:

1. trophic level
2. toxic substances burden
3. pathogenic bacteria contamination
4. suspended materials load
5. oxygen demand

b. provide baseline data for the chemical, microbiological, and physical parameters of water quality against which future changes may be judged.

c. compare the plresent data with past data in order to determine how rapidly and in what manner the lake is changing.

d. determine how these changes are related to waste reduction, pollutant bans, nutrient control programs, and pollution abatement programs.

e. prepare recommendations concerning the scope of future remedial programs to enhance or maintain current lake water quality.

TAT Participants

The Lake Erie TAT consisted of a technical staff headquartered at Ohio State University and a select group of Canadian and United States scientists who contributed data, technical reports and guidance to the effort. The following individuals participated in the assessment undertaken by the Lake Erie TAT:

Technical Staff

1. Charles E. Herdendorf, Chairman
2. C. Lawrence Cooper, Coordinator
3. David E. Rathke, Editor
4. Laura A. Fay
5. John J. Mizera
6. Mark D. Barnes
7. R. Peter Richards

Contributors

1. Carl Baker - Ohio Department of Natural Resources
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4. Farrell Boyce - Canada Centre for Inland Waters
5. Noel Burns - Canada Centre for Inland Waters
6. Murray Charlton - Canada Centre for Inland Waters
7. James Clark, USEPA, Great Lakes National Program
8. John Clark - International Joint Commission
9. David DeVault - USEPA, Great Lakes National Program
10. Clay Edwards - International Joint Commission
11. Andrew Fraser - Canada Centre for Inland Waters
12. Raymond Fredricks - SUNY, Great Lakes Laboratory
13. Douglas Haffner - International Joint Commission
14. Douglas Hallett - Canada Wildlife Service
15. Yousry Hamdy - Ontario Ministry of the Environment
16. David Rockwell - USEPA, Great Lakes National Program

17. Fernando Rosa - Canada Centre for Inland Waters
18. Robert Sweeney - SUNY, Great Lakes Laboratory
19. Nelson Thomas - USEPA, Large Lakes Research Station
20. Richard Thomas - Canada Centre for Inland Waters
21. Joseph Vihtelic - Michigan Department of Natural Resources
22. Lester Walters - Bowling Green State University
23. Robert Wellington - Erie County Department of Health, Pennsylvania
24. Richard Winklhofer - USEPA, Region V, Eastern District
25. Stephen Yaksich - U.S. Army Corps of Engineers, Buffalo District

Appendix A lists the reports prepared by the Lake Erie Technical Assessment Team. Appendix B lists reports contributed to the Lake Erie Intensive Study by other investigators.

Study Limitations

Implementation of study plan. The study plan developed by the Lake Erie Work Group was implemented in most details and on schedule. Notable exceptions to complete implementation included:

1. Atmospheric loadings were not determined during the study period.

2. United States nearshore surveys were conducted for three consecutive days rather than five consecutive days specified in the plan.

3. Canadian nearshore surveys were not comprehensive for the entire shore, but localized at problem areas due to the availability of comprehensive data from earlier studies.

4. Soluble nutrients were not included in the eastern United States nearshore cruises.

5. EBT recordings for depth greater than 10 meters were not included in central United States nearshore cruises.

6. Samples for benthos and toxic organic compounds in main lake sediments were not obtained.

7. Radiological data was not collected, except in the vicinity of the Davis-Besse Nuclear Power Station near Port Clinton, Ohio.

Data gaps. In addition to the loss of data due to incomplete implementation of the plan, the following problems encountered during the field investiation and analysis phases of the study resulted in further loss of anticipated data:

1. Fish studies of the nearshore are only partially completed.

2. Metal analysis from both main lake and nearshore studies suffered from problems in analysis, as did analysis for toxic organics in nearshore water, sediment and fish samples.

3. Water intake data are incomplete for toxic organic compounds.

4. Zooplankton samples were only partially collected and analyzed.

5. Phosphorus data for 1978 from the main lake stations have a low bias.

6. Detection limits that exceed IJC objectives for some parameters resulted in excess violations to be reported.

7. In some cases, reports on individual studies (secondary components) were not prepared; however data are usually available.

Data compatability. Analysis of study results from the participating laboratories shows that the compatability of data is not seriously affected by differences in precision, except for dissolved and total metals which are present in the lake water at very low concentrations. However, differences resulting from individual laboratory biases are significant for several parameters, particularly phosphorus, when compared to the temporal and spatial variability observed in the lake. Therefore, it is not possible (in all cases) to assume complete compatibility of data gathered by different agencies, or by the same agency in different years. The question of data compatability is a relative one, and judgements about the compatibility of data must ultimately be made in the context of the specific questions to which the data is to be applied. Certainly the data gathered for the Intensive Study can be used to compare various portions of the lake, define the lake's overall status. However, the utility of combined data sets to establish long-term trends is less certain (specific problem parameters are identified in the Summary Report) and, for many parameters, specify violations of water quality objectives.

A test of data compatibility was performed in the western basin by pooling nearshore and offshore data gathered by CLEAR, MOE and USEPA. Using SYMAP plots of nine individual parameters, contoured distribution maps were constructed for seven cruises (see Figure 7 for example of SYMAP plot). These maps showed expected nearshore/offshore gradients and northshore/southshore differences with the absence of dicontinuities at agency interfaces. Experiments such as this add credibility to the lake-wide assessment attempted by this study.

CONCLUSIONS

The major issues considered by the Intensive Study can be categorized into four topics: (1) enrichment, (2) toxic substances, (3) public health, (4) land use activities and (5) lake response to remedial actions. In order to place the time period of the Intensive Study (1978-1979) into perspective, results are presented in reference to previous investigations and to those conducted since the end of the Intensive Study.

Enrichment

Prior to 1970, water quality investigations of Lake Erie were conducted at sporadic intervals with a wide variety of field procedures and analytical techniques. For these reasons it is difficult to document long-term trends to any degree of accuracy. Starting with Project Hypo (Burns and Ross 1972) in 1970 (a joint Canadian-United States project to investigate the eutrophication of Lake Erie), consistent shipboard and laboratory procedures have beeen utilized by the several research groups monitoring the status of the open waters of Lake Erie. For the past decade, cruises have been undertaken annually in the three basins of the lake by the following organizations: (1) Canada Centre for Inland Waters, (2) Center for Lake Erie Area Research, (3) Great Lakes Laboratory and (4) Great Lakes National Program Office (USEPA). The following discussion characterizes the conditions of the lake for several key (eutrophication-related) parameters during this period.

Lake levels. The mean Lake Erie water level for the period 1860 to 1970 was 570.37 feet above International Great Lakes Datum, 1955. For the period 1960 to 1970, the average level was 570.24 feet, only slightly below the mean. However, for the period 1970 to 1980, the average level rose to 571.74, a volumetric increase of approximately 3% between the two decades. Of significance to water quality, lake levels during the period 1970 to 1980 averaged about 0.5 m above levels for the preceeding decade. The lowest annual water level (569.01 feet for 1964) within the earlier decade was 1.1 m below the mean level for the highest year (572.72 for 1973) of the latter deade. This change amounts to about a 7 percent increase in lake volume.

Higher lake levels have primarily resulted from an increased flow of higher quality, upper Great Lakes water via the Detroit River. This dilution effect, in combination with more deeply submerged substrates in the nearshore regions and western basin shoals, may have had profound impacts on the lake biota. Greater attenuation of light reaching substrate suitable for the development of both planktonic and attached forms of algae has occurred. These factors are thought to partially account for the absence, in the mid-1970's, of the basin-wide algal blooms and massive growths of the filamentous algae, Cladophora glomerata, which were so prevalent in the mid-1960's.

Thermal structure. The western basin of Lake Erie is essentially isothermal throughout the year. This basin was determined to be unstratified during all 64 cruises undertaken during the period 1970-1980. However, periods of temporary stratification in isolated areas of the western basin have been reported by Britt (1955), Carr et al. (1965) and Zapotosky and Herdendorf (1980). Such stratification is usually transitory in nature but can result in severe oxygen depletion conditions due to high oxygen demand of the sediments.

The central basin of Lake Erie typically stratifies in early June and turns over in early September. The mean thicknesses of the epilimnion, mesolimnion and hypolimnion during the period 1973-1980 are presented below:

Central Lake Erie Thermal Strata

Strata	Thickness (m)
epilimnion	12.4 ± 2.3
mesolimnion	2.3 ± 1.4
hypolimnion	5.0 ± 1.6

In general, the hypolimnion decreases in thickness and increases in temperature throughout the stratified period. Table 3 compares monthly thicknesses and temperatures for the period 1973-1980. These data yield the following period means:

Hypolimnion Thicknesses and Temperatures

Period	Thickness (m)	Temperature (°C)
June	6.6 ± 0.8	8.9 ± 1.5
July	5.5 ± 1.1	11.4 ± 2.0
August	4.7 ± 1.4	12.3 ± 1.3
September	3.7 ± 1.3	13.8 ± 2.8

The thickness of the hypolimnion is related to the extent of anoxic conditions in the central basin. Herdendorf (1980) found that in 1975 the thickness of the

TABLE 3

COMPARISON OF 1970-1980 HYPOLIMNION CHARACTERISTICS IN CENTRAL LAKE ERIE

	1970 (Project Hypo)	1973	1974	1975	1976	1977	1978	1979	1980
MAY									
Thick. (m)	-	-	-	-	-	-	-	5.6	-
DO (mg/l)	-	-	-	-	-	-	-	12.0	-
Temp. (°C)	-	-	-	-	-	-	-	9.8	-
JUNE									
Thick. (m)	-	-	6.2	7.7	6.6	6.8	5.6	N.A.	-
DO (mg/l)	-	-	9.9	10.0	9.6	8.3	11.0	N.A.	-
Temp. (°C)	-	-	8.8	6.5	9.4	10.4	9.3	N.A.	-
JULY									
Thick. (m)	-	5.0	4.6	6.7	-	4.6	7.1	4.4	6.2
DO (mg/l)	-	4.9	5.2	7.8	-	5.1	7.5	7.2	7.8
Temp. (°C)	-	10.3	11.8	7.7	-	11.0	12.5	14.0	12.7
EARLY AUGUST									
Thick. (m)	-	4.4	4.3	6.8	3.0	3.0	5.5	N.A.	5.8
DO (mg/l)	-	1.6	2.1	3.3	0.7	2.1	5.4	N.A.	4.5
Temp. (°C)	-	11.9	13.5	10.2	13.7	11.9	11.5	N.A.	13.1
SEPTEMBER									
Thick. (m)	-	3.0	-	-	-	2.1	4.3	2.7	5.2
DO (mg/l)	-	1.1	-	-	-	0.5	3.0	6.3	3.0
Temp. (°C)	-	13.8	-	-	-	11.2	13.1	18.5	12.5
NET OXYGEN DEMAND (loss/day)									
Volume rate (mg/l)	0.11	0.12	0.13	0.10	0.13	0.13	0.09	0.09	0.11
Area rate (g/m^2)	0.38	0.53	0.60	0.67	0.75	0.58	0.51	0.41	0.63

Data sources: 1970--CCIW; 1973 to 1977, 1980--OSU/CLEAR; 1978 and 1979--USEPA/GLNPO.

hypolimnion was considerably thicker than earlier years of the decade and that the areal extent of anoxia was greatly reduced (Table 4). The average hypolimnion thicknesses and temperatures for the central basin, 1973-1980, are listed below:

Average Hypolimnion Characteristics

Year	Thickness (m)	Temperature (^{o}C)
1973	4.1 ± 1.0	12.0 ± 1.8
1974	5.0 ± 1.0	11.5 ± 2.5
1975	7.1 ± 0.6	8.1 ± 1.9
1976	4.8 ± 2.6	11.6 ± 3.0
1977	4.1 ± 2.1	11.1 ± 0.6
1978	5.6 ± 1.2	11.6 ± 1.7
1979	4.2 ± 1.5	14.1 ± 4.6
1980	5.7 ± 0.5	12.8 ± 0.3

The eastern basin of Lake Erie is normally stratified from June through October or early November. The mean thicknesses of the epilimnion, mesolimnion and hypolimnion during 1978 are presented below:

Eastern Lake Erie Thermal Strata

Strata	Thickness (m)
epilimnion	13.1 ± 6.0
mesolimnion	8.5 ± 4.0
hypolimnion	12.5 ± 1.0

Generally the hypolimnion in the eastern basin is of sufficient thickness that severe oxygen depletion problems do not develop.

TABLE 4

ESTIMATED AREA OF THE ANOXIC HYPOLIMNION OF THE CENTRAL BASIN OF LAKE ERIE 1930-1981

YEAR	ANOXIC AREA	PERCENT OF BASIN	
	(km^2)	Hypolimnion (%)	Total Basin (%)
1930	300	3.0	1.9
1959	3,600	33.0	22.3
1960	1,660	15.0	10.3
1961	3,640	33.0	22.5
1964	5,870	53.0	36.3
1970	6,600	60.0	40.4
1972	7,970	72.5	49.3
1973	11,270	93.7	69.8
1974	10,250	87.0	63.4
1975	400	4.1	2.5
1976	7,300	63.0	53.0
1977	2,870	24.8	20.8
1978	3,980	71.7	24.6
1979	N.A.	N.A.	N.A.
1980	4,330	35.9	26.8
1981	4,820	37.4	29.0

Data Sources:
1930--Fish (1960)
1959-1961--Thomas (1963)
1964--FWPCA (1968a)
1970--CCIW (Burns and Ross 1972)
1972-1977, 198, 1981--OSU/CLEAR
1978--ANL (Zapotosky and White 1980)

The thermal structure of Lake Erie is highly dependent on wind and other meteorological conditions. Calm weather in the western basin can be effective in forming transitory stratification during the summer months. In the central and eastern basins, calm weather during the late spring can result in a shallow thermocline and a correspondingly thick hypolimnion. This situation occurred in 1975 with a dramatic impact on the oxygen levels in the central basin hypolimnion and is well-documented by Herdendorf (1980).

Dissolved Oxygen

Low concentrations of dissolved oxygen, particularly in the central basin hypolimnion, is one of the most important environmental problems plaguing Lake Erie. Small areas of anoxic water in the central basin were observed as early as 1930 (Fish 1960). The size of the late summer anoxic portion of the lake continued to grow for the next several decades until 1973, when approximately 94 percent of the hypolimnion had oxygen concentrations below 0.5 mg/l (Herdendorf 1980). More recent surveys have shown wide fluctuations in the size of the anoxic area in the central basin, primarily due to the meteorological conditions discussed earlier, but the area and the percent of the hypolimnion experiencing anoxia have declined significantly in the period 1975 to 1980:

Central Lake Erie Anoxic Area Trends

Period	Anoxic Area (km^2)	Percent Hypolimnion	Total Basin
1970-1974	9,000 ± 2,100	78 ± 15	56 ± 13
1975-1980	3,800 ± 2,500	40 ± 28	26 ± 18

The estimated areas of anoxic hypolimnion of central Lake Erie for the period 1930 to 1981 are presented in Table 4. The depletion patterns for 1981 (Figure 5) are typical of conditions in the central basin for the past five years.

Another method for determining trends in the oxygen concentrations in hypolimnetic waters of the central and eastern basins involves determining the loss of oxygen in the interval between two cruises. Table 5 lists the net oxygen demand for 1930 to 1981 based on daily losses per unit area and per unit volume. Rates of oxygen loss for major blocks of years are compared below for these basins:

Net Oxygen Loss Per Day

	CENTRAL		EASTERN	
Period	Area Rate (g/m^2)	Volume Rate (mg/l)	Area Rate (g/m^2)	Volume Rate (mg/l)
1930-1970	0.2 ± .13	0.079 ± .022		
1970-1975	0.55 ± .12	0.115 ± .013	0.57 ± .24	0.034 ± .017
1976-1980	0.57 ± .13	0.111 ± .016	0.59 ± .01	0.048 ± .013

From these data it can be seen that the central basin hypolimnion has experienced a significant increase in the rate of oxygen loss for the period 1930-1970, but since 1970 the net oxygen demand has been relatively stable. The stability of the oxygen depletion rate from 1970 to 1980 in central Lake Erie, particularly during the month of August, is illustrated in Figure 6. Early data is not available for the eastern basin. A slight increase may be indicated from the first half to the second half of the past decade; however, the data shows an erratic pattern in the early 1970's (Table 5).

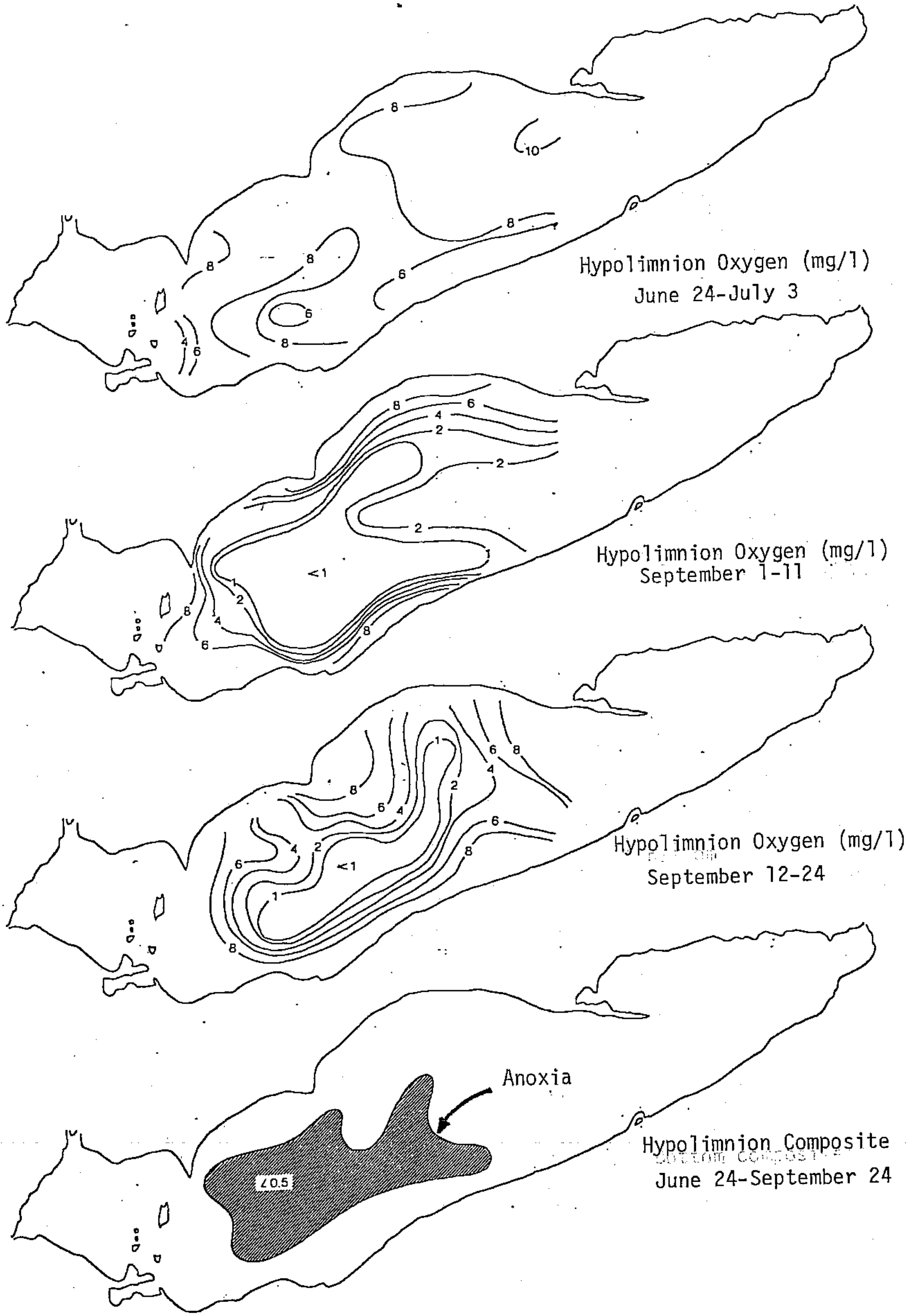


Figure 5. Dissolved Oxygen Concentrations in Central Lake Erie during the Summer of 1981.

TABLE 5

TRENDS IN NET OXYGEN DEMAND OF THE CENTRAL AND EASTERN BASIN HYPOLIMNIONS OF LAKE ERIE 1930-1981

DATA SOURCE*	YEAR	NET OXYGEN DEMAND PER DAY			
		Rate Per Unit Area (g/m^2)		Rate Per Unit Volume (mg/l)	
		Central Basin	Eastern Basin	Central Basin	Eastern Basin
1	1930	0.8	-	0.054	-
1	1940	0.15	-	0.067	-
1	1950	0.25	-	0.070	-
1	1960	0.37	-	0.093	-
2	1970	0.38	0.70	0.110	0.055
3,4	1973	0.53	0.23	0.120	0.016
3,4	1974	0.60	0.57	0.130	0.026
3,4	1975	0.67	0.76	0.100	0.040
3,4	1976	0.75	-	0.130	0.032
3	1977	0.58	0.68	0.130	0.060
2	1977	0.48	0.51	0.120	0.065
5	1978	0.51	0.58	0.092	0.048
2	1978	0.54	0.61	0.111	0.047
5	1979	0.41	0.58	0.090	0.049
3	1980	0.63	-	0.109	-
3	1981	0.47	-	0.085	-

*Data sources: (1) Dobson and Gilbertson (1971); (2) CCCIW--Noel Burns, personal communication; (3) OSU/CLEAR--Central Basin, 1973-1977; Eastern Basin, 1977; (4) SUNY/GLL--Eastern Basin, 1973-1976; (5) USEPA/GLNPO--rate calculation OSU/CLEAR.

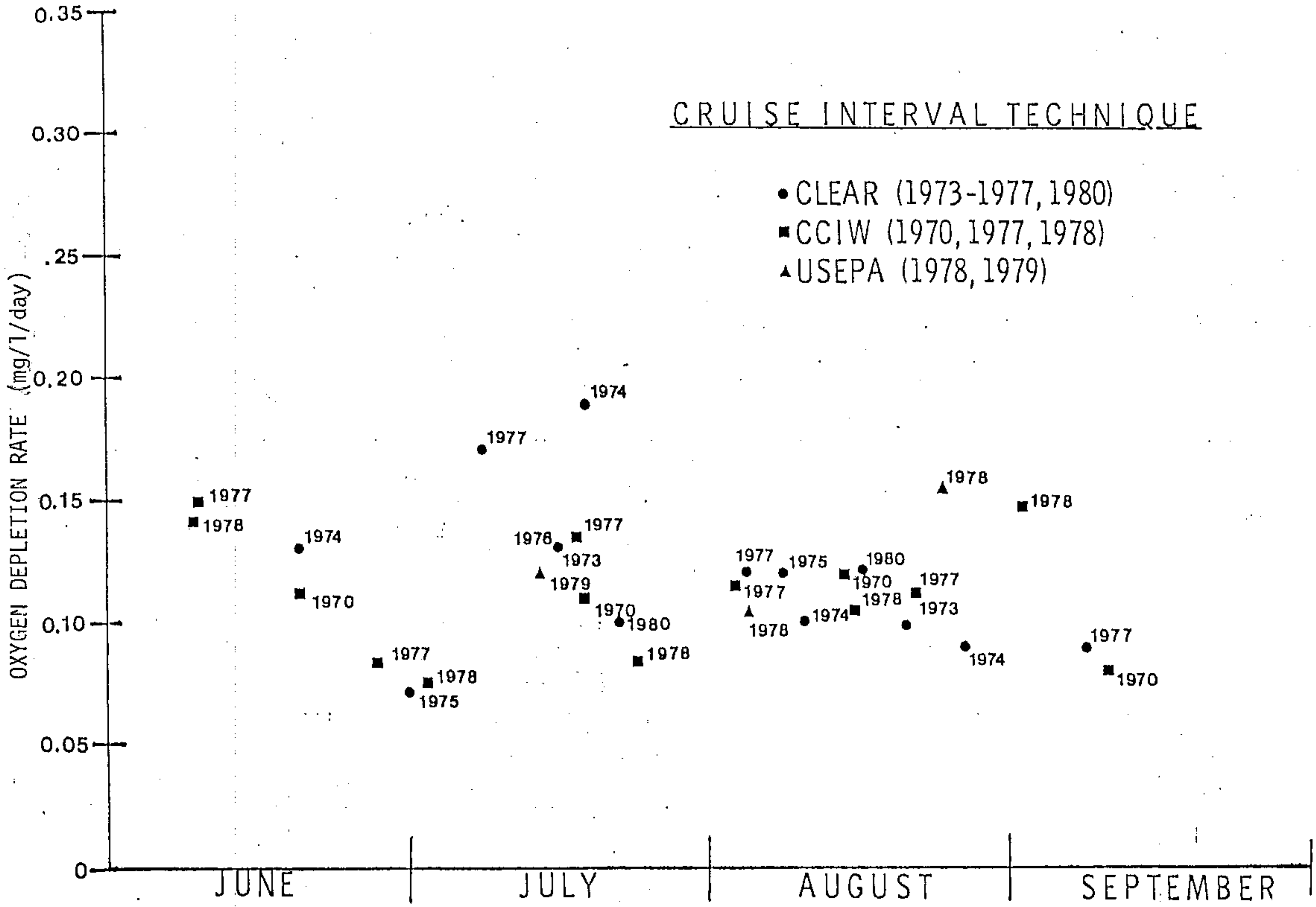


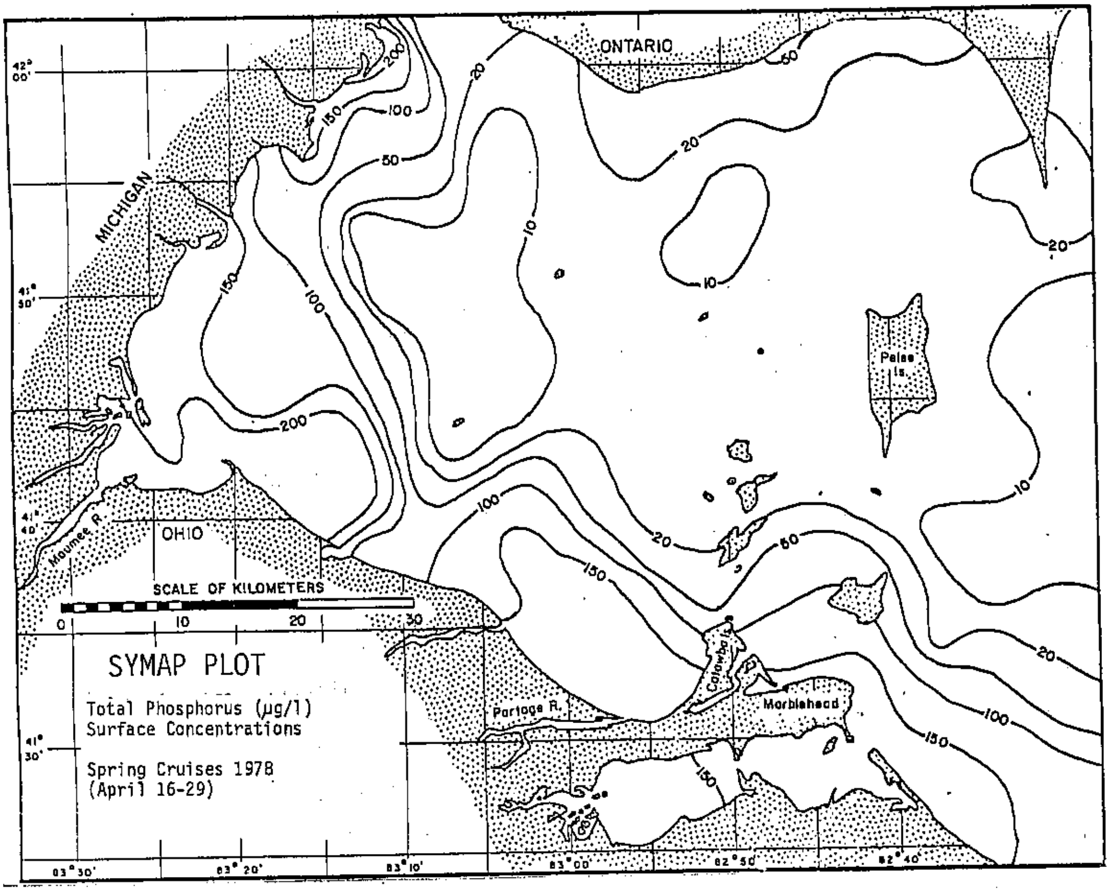
Figure 6. Hypolimnetic Oxygen Depletion Rates for Central Lake Erie 1970–1980.

Nutrients. The distribution of most nutrients throughout the lake shows similar patterns. Total phosphorus, for example is characterized by high concentrations near the mouth of the Maumee River in the western basin (Figure 7) and the Cuyahoga River in the central basin (Figure 8). There is a general west-to-east decrease with highest values located along the United States shore, particularly at the mouths of major tributaries. The Detroit River is an exception in that a large volume of upper Great Lakes water tends to dilute the nutrient load contributed by the urban and industrial complex adjacent to the river. Although low in concentration when compared to the Maumee River, the Detroit River in 1980 contributed about 27% of the total load of phosphorus to Lake Erie.

Phosphorus has been identified as a limiting nutrient for algal productivity in Lake Erie (Hartley and Potos 1971). Annual mean concentrations of total phosphorus for the period 1970-1980 in the three basins of Lake Erie are presented below:

Total Phosphorus Concentrations (ug/l)

Year	Western	Central	Eastern
1970 (CCIW)	44.6 ± 9.6	20.5 ± 7.8	17.5 ± 7.0
1973 (CLEAR/GLL)	34.7 ± 11.9	18.5 ± 6.2	31.1 ± 22.6
1974 (CLEAR/GLL)	35.1 ± 8.8	16.8 ± 2.7	20.8 ± 6.9
1975 (CLEAR/GLL)	42.3 ± 8.6	20.3 ± 6.8	27.6 ± 9.2
1976 (CLEAR)	44.9 ± 15.0	22.5 ± 5.2	
1977 (CLEAR)	40.7 ± 10.9	24.1 ± 8.1	18.3 ± 4.1
1978 (CCIW)		14.2 ± 1.2	13.0 ± 2.5
1979 (GLNPO)	33.9 ± 24.8	13.4 ± 2.7	10.8 ± 5.4
1980 (CLEAR)	28.8 ± 6.6	13.7 ± 6.9	
1970-1975	39.2 ± 5.0	19.0 ± 1.7	24.3 ± 6.2
1976-1980	37.1 ± 7.4	17.6 ± 5.3	14.0 ± 3.9
1978-1980	31.4 ± 3.6	13.8 ± 0.4	11.9 ± 1.6



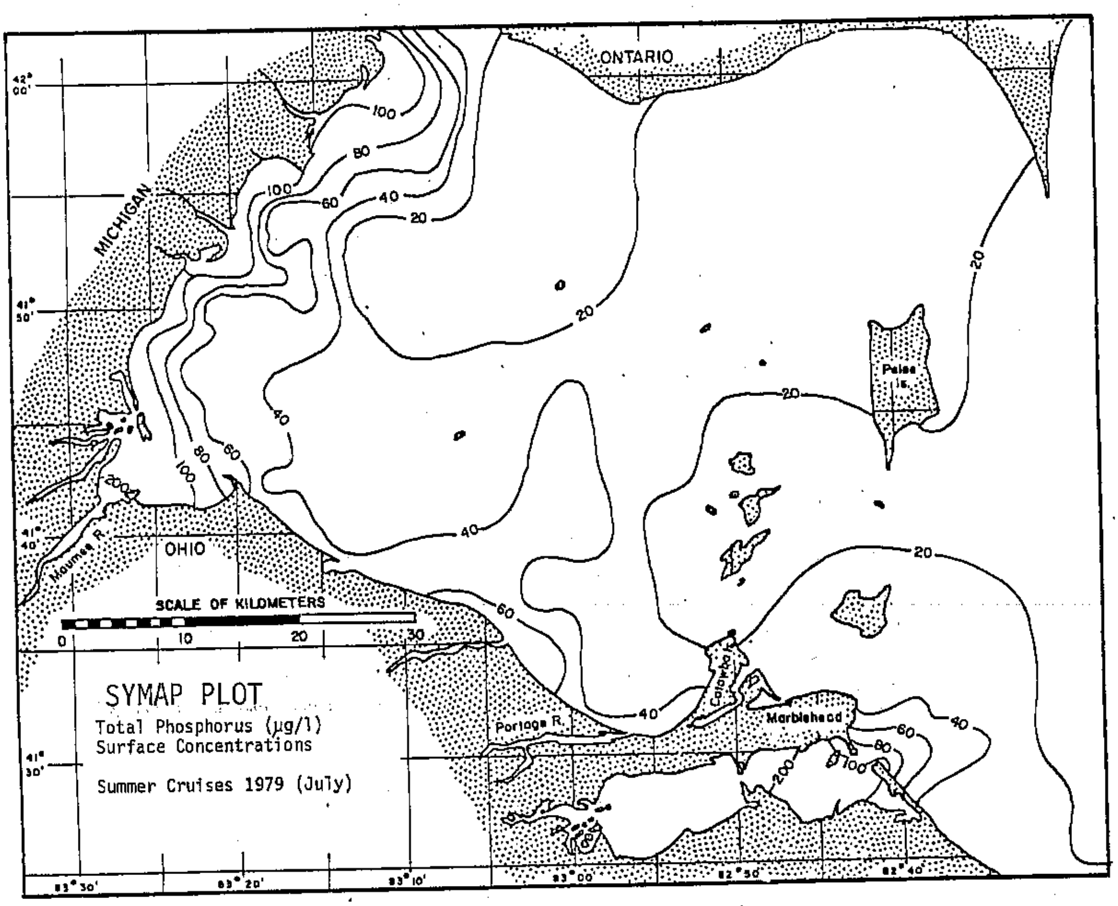


Figure 7. Distribution of Total Phosphorus in the Western Basin of Lake Erie.

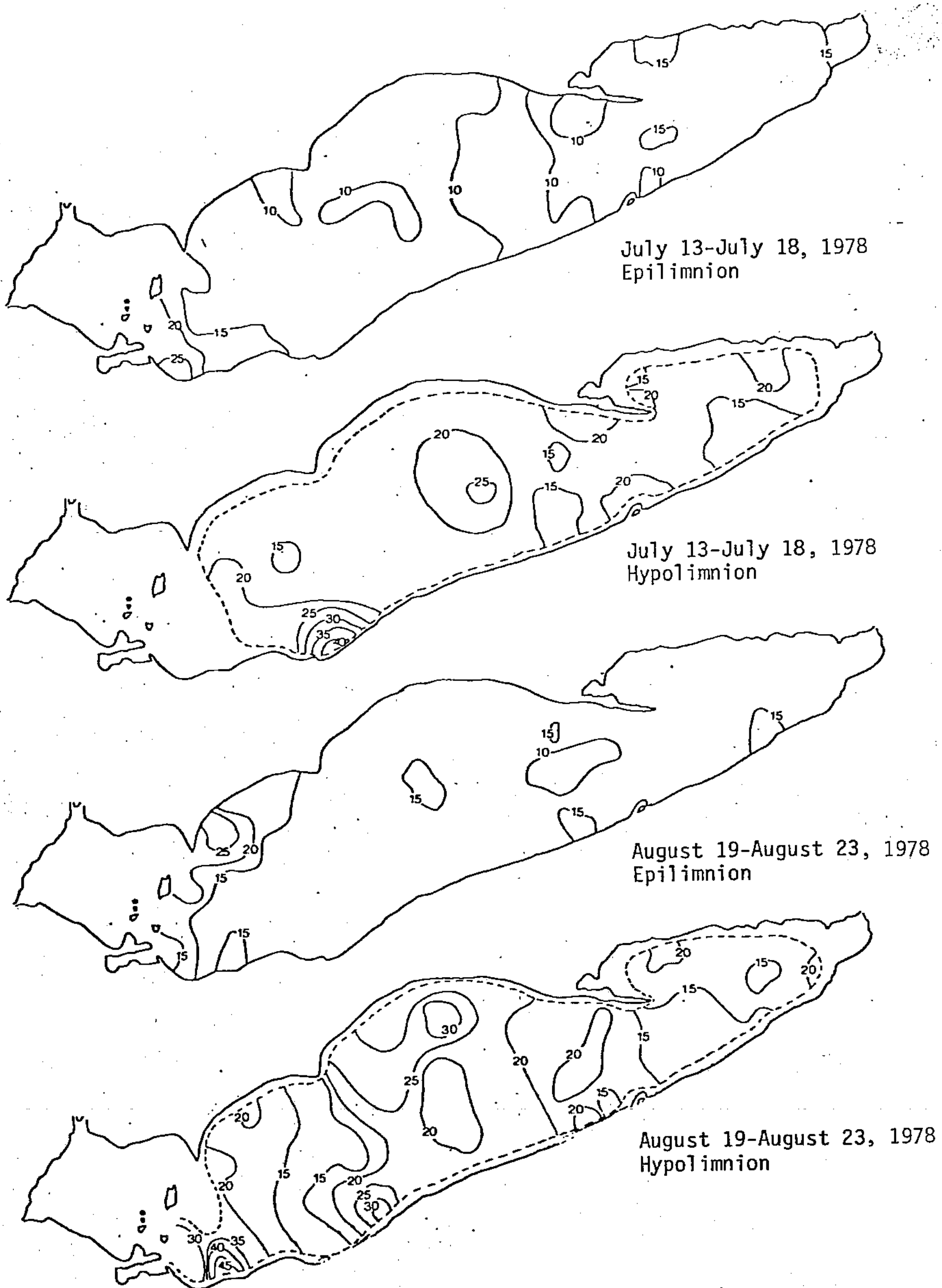


Figure 8. Distribution of Total Phosphorus in the Central and Eastern Basins of Lake Erie.

When concentrations for the first half of the decade are compared to those of the second half, very little difference can be seen for the western and central basins; however, data for 1978-1980 does show a significant decline. The eastern basin data shows a consistent reduction in total phosphorus from 1975 to 1979.

The loading of total phosphorus to the lake has declined at an average rate of nearly 800 mt/yr for the period 1970-1980 (Yaksich 1982). The 1970 loading to the entire lake from all sources, except shoreline erosion and atmospheric input, was about 22,300 metric tons; in 1980 the total loading is estimated at 11,600 metric tons (Figure 9). The quantity of total phosphorus in the central basin during the period 1970-1980 is illustrated in Figure 10. A progressive decline in the quantity of phosphorus in the lake, similar to that shown in the loading diagram (Figure 9) is not apparent. In fact, total phosphorus increased in minimum summer quantities for the period 1970 to 1976. This can be partially explained by phosphorus releases from sediment through wave resuspension and anoxic regeneration. Several investigations have demonstrated that approximately 80 percent of the phosphorus loading to Lake Erie becomes incorporated into the bottom sediments (Burns 1976 and Herdendorf 1980). Cruise data for 1978-1980, however, begins to show a response to decreasing phosphorus loading with lower summer minima and annual quantities.

Nitrate plus nitrite loading to Lake Erie has increased significantly during the period of record (1967 to 1979). Loading from the Detroit River alone averaged 160,000 kg/day in 1979, more than twice the amount reported for 1967. Lake concentrations have also increased significantly for nitrate plus nitrite nitrogen since the first comprehensive surveys in the mid-1960's. Open lake concentrations in the western basin for 1963-1965 averaged less than 0.2 mg/l while the central and eastern

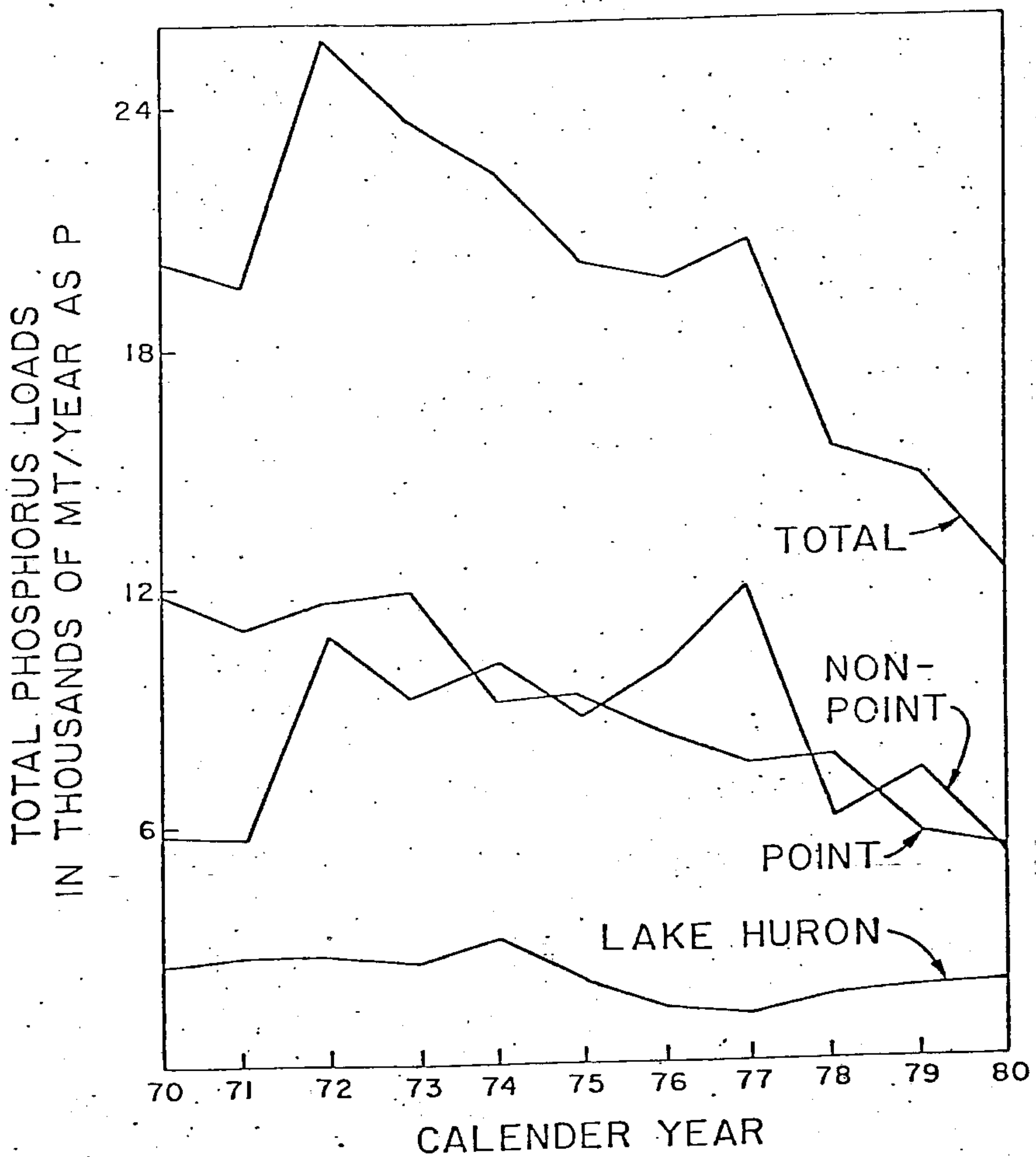


Figure 9. Total Phosphorus Loading to Lake Erie 1970–1980 (after Yaksich 1982).

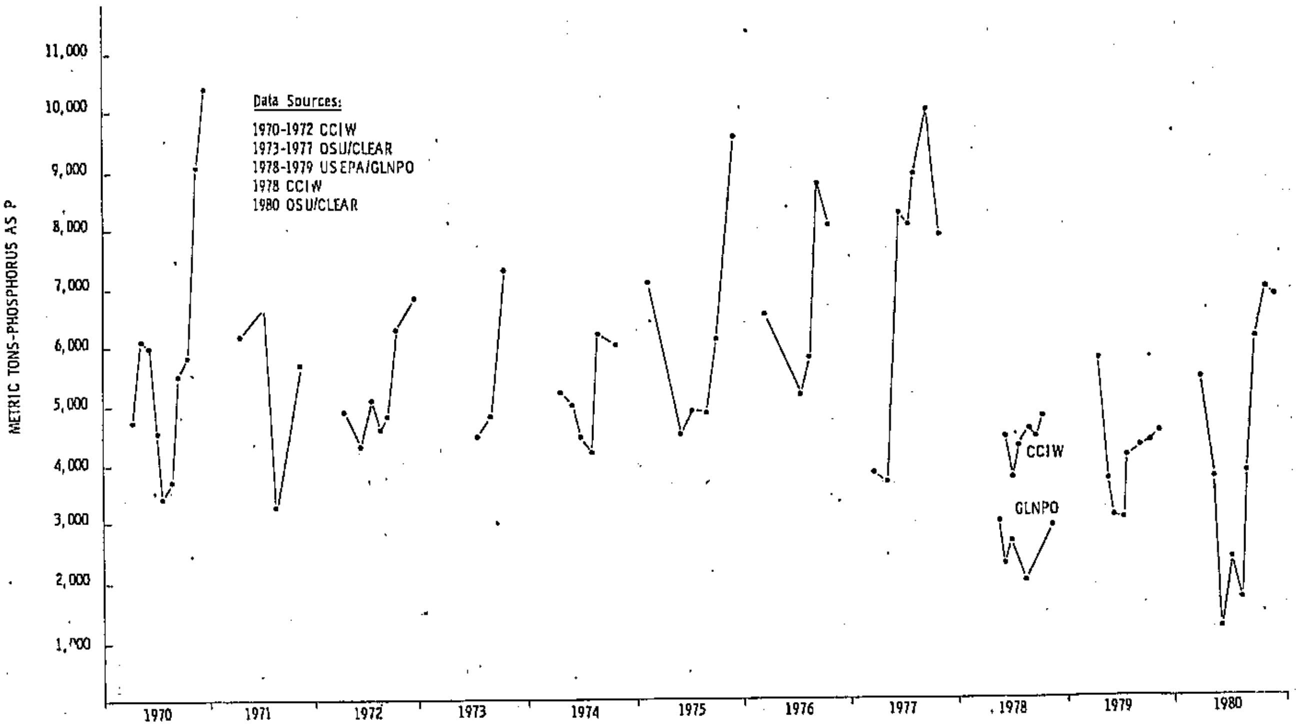


Figure 10. Total Phosphorus Quantities in the Central Basin of Lake Erie 1970–1980.

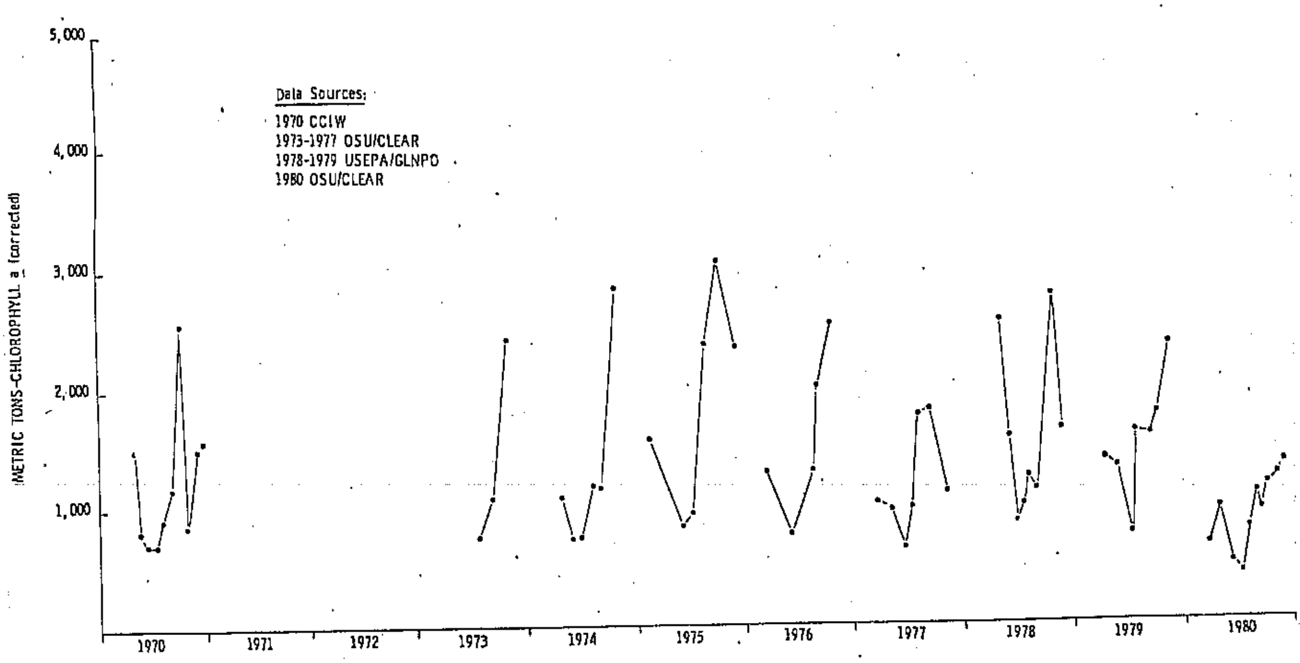


Figure 13. Chlorophyll a Quantities in the Central Basin of Lake Erie 1970–1980.

basins averaged less than 0.1 mg/l (FWPCA 1968a). Concentrations for the period 1978-1981 approached 0.5 mg/l for the western basin and 0.2 mg/l for the central and eastern basins:

Mean Nitrate + Nitrite Concentrations and Quantities

Years	Western		Central		Eastern	
	(mg/l)	(mt)	(mg/l)	(mt)	(mg/l)	(mt)
1963-1965	0.12	2,900	0.09	27,000	0.09	13,600
1973-1975	0.27	6,500	0.14	44,400	0.08	12,800
1978-1979	0.46	11,100	0.15	46,200	0.17	27,400

This is the only major dissolved constituent in the waters of Lake Erie which has shown a significant increase in the past two decades. Increased use of chemical fertilizers and gaseous emissions of nitrogen compounds within the drainage basin are thought to be the major causes.

Dissolved Substances. Trends in dissolved substances in Lake Erie water can be inferred from Lake Erie conductivity measurements and determination of major conservative ions, such as sulfate and chloride. STORET data files for the period 1966 to 1980 were used for a trend analysis, based on central basin cruise data supplied by Canada Centre for Inland Waters (CCIW), Ontario Ministry of Environment (MOE), USEPA, Great Lakes National Program Office (GLNPO) and Ohio State University, Center for Lake Erie Area Research (CLEAR). Ontario Ministry of Environment data was obtained from stations 1-7 km offshore, while data from the other three groups were from open lake stations, generally five or more km offshore. Annual mean values for conductivity, chloride and sulfate are listed below:

Dissolved Substances Trends in Central Lake Erie

Year	Conductivity (umhos/cm)	Chloride (mg/l)	Sulfate (mg/l)
1966	311	25.0	
1967	319 ± 0.6	24.4 ± 0.4	
1968	314 ± 3.4	24.4 ± 1.4	26.4 ± 1.1
1969	308 ± 8.6	23.7 ± 0.9	23.4
1970	312 ± 7.2	22.5 ± 1.0	23.1 ± 1.7
1971	318 ± 9.5	24.3 ± 1.2	24.0 ± 0.8
1972	303 ± 8.3	22.2 ± 1.5	
1973	289 ± 3.1	21.2 ± 2.6	22.4 ± 0.9
1974	282 ± 24.9	19.4 ± 2.8	21.7 ± 3.5
1975	282 ± 20.0	19.9 ± 1.6	22.5 ± 3.4
1976	283 ± 23.3	19.4 ± 4.2	
1977	272	19.5 ± 1.7	
1978	289 ± 8.4	19.6 ± 1.4	21.6 ± 5.2
1979	288 ± 2.9	18.4 ± 1.3	23.4 ± 1.1
1980	287 ± 10.7		
1966-1970	313 ± 4.1	24.0 ± 1.0	24.3 ± 1.8
1970-1975	298 ± 15.6	21.6 ± 1.8	22.7 ± 0.8
1975-1980	284 ± 6.3	19.4 ± 0.6	22.5 ± 0.9

Specific conductance data points on Figure 11 represent cruise mean values for periods of isothermal lake conditions (March-May and October-December). Conductivity thus indicates a rather slow decline for mean levels for the period of record. The mean value for 1975-1980 (284 umhos/cm) is approximately nine percent lower than the mean 1966-1970 value (313 umhos/cm). Trends in central basin chloride (Figure 12) shows a more noticeable decline from a mean concentration of 24.0 mg/l for 1966-1970 to 19.4 mg/l for 1975-1979. Sulfate concentrations showed no discernable trend.

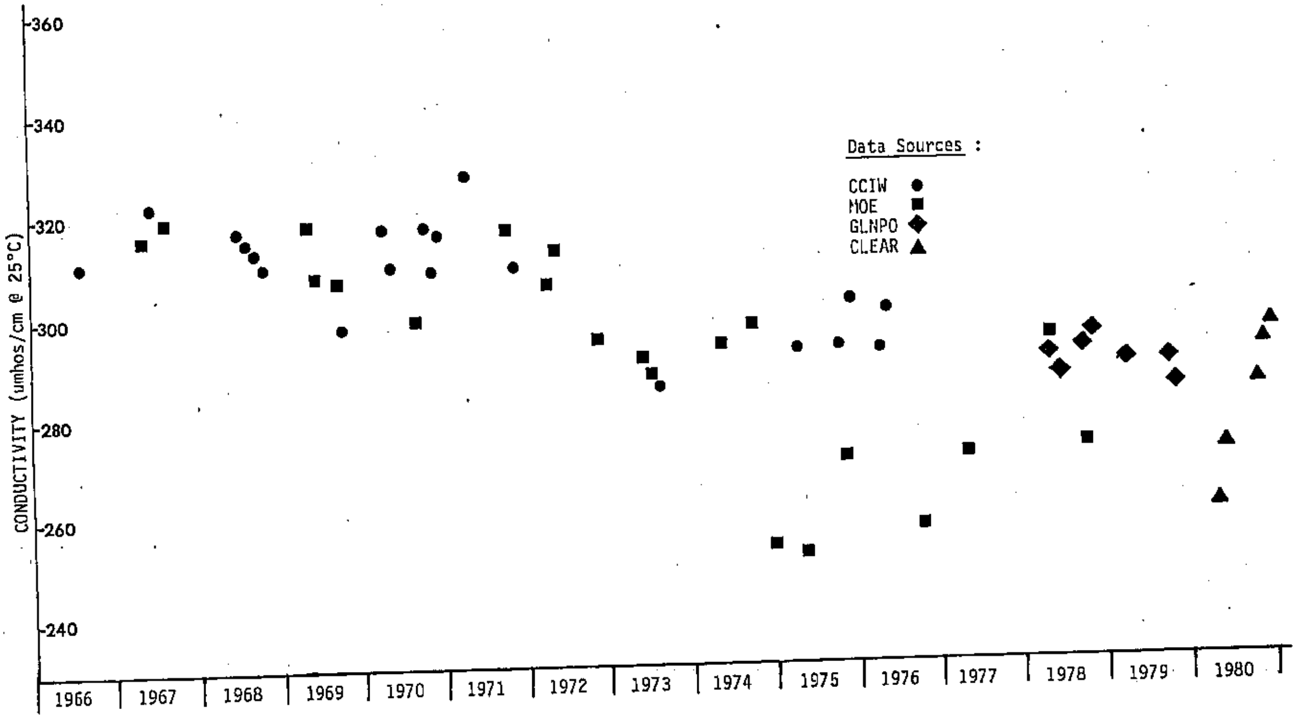


Figure 11. Specific Conductance of Central Lake Erie 1966–1980.

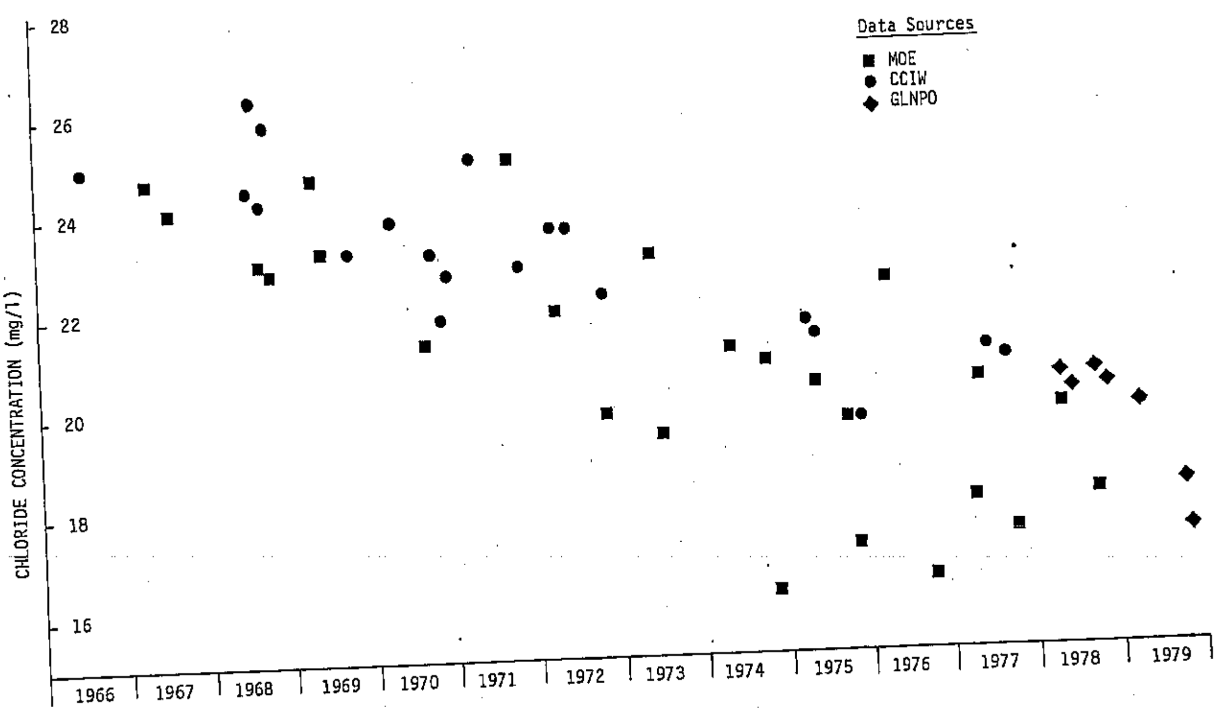


Figure 12. Chloride Concentrations in Central Lake Erie 1966–1979.

Clarity. An analysis of Lake Erie transparency was performed for the period 1973-1980 by area-weighting secchi disk results from 35 cruises in the western basin, 41 in the central basin and 5 in the eastern basin. No significant trends or improvements are demonstrated by the data. The mean summer values for each basin are presented below:

Secchi Disk Transparency

Year	Western	Central	Eastern
1973	1.94 ± 0.17 m	5.45 ± 1.01 m	
1974	1.72 ± 0.50 m	5.69 ± 0.81 m	
1975	1.21 ± 0.39 m	5.51 ± 2.24 m	
1976	1.82 ± 1.36 m	4.41 ± 0.02 m	
1977	1.09 ± 0.00 m	5.55 ± 0.94 m	5.60 ± 1.78 m
1978	2.14 ± 0.30 m	5.52 ± 1.45 m	5.74 ± 1.27 m
1979	2.19 ± 0.68 m	5.02 ± 1.33 m	5.27 ± 1.98 m
1980	1.58 ± 0.13 m	5.88 ± 1.18 m	

The year with the poorest water clarity in the western basin (1977) coincides with the year with the lowest lake level in that decade. This suggests that wave resuspension of bottom sediments may be more effective during low water periods. Transparency in the central basin was relatively constant throughout the period with the exception of 1976 when the mean decreased more than one meter from adjacent years. This may be the result of an early fall turnover (Table 3). From the limited data for the eastern basin, it appears that mean transparencies in the eastern and central basins are very similar. In general, the central basin transparency exceeds that of the western basin by a factor of 3.5.

Water clarity is an indicator of both phytoplankton biomass and inorganic particulate matter suspended in the water column. Turbidity patterns mirror those presented for total phosphorus. Central and eastern basin turbidity is primarily the result of the organic component, whereas, in the western basin spring meltwaters carry a large component of inorganic solids to the lake.

Chlorophyll. This pigment serves as a useful indicator of algal productivity in Lake Erie. Annual mean concentrations of corrected chlorophyll a for 1970-1980 in the three basins are listed below:

Chlorophyll a Concentrations (ug/l)

Year	Western	Central	Eastern
1970 (CCIW)	8.6 ± 4.6	4.5 ± 2.1	3.3 ± 1.4
1973 (CLEAR/GLL)	10.7 ± 2.1	4.6 ± 2.9	5.1 ± 1.8
1974 (CLEAR/GLL)	13.4 ± 3.4	4.2 ± 2.6	5.1 ± 1.6
1975 (CLEAR/GLL)	13.7 ± 5.9	5.9 ± 2.8	3.6 ± 1.3
1976 (CLEAR)	12.4 ± 4.6	5.2 ± 2.4	
1977 (CLEAR)	10.8 ± 6.1	4.0 ± 1.4	3.0 ± 1.1
1978 (GLNPO)	12.5 ± 4.3	5.2 ± 2.1	3.2 ± 1.3
1979 (GLNPO)	11.5 ± 4.5	5.1 ± 1.7	2.7 ± 0.9
1980 (CLEAR)	8.4 ± 3.1	3.1 ± 1.0	
1970-1975	11.6 2.4	4.8 0.8	4.3 ± 1.0
1976-1980	11.1 1.7	4.5 0.9	3.0 ± 0.3
1979-1980	10.0 2.2	4.1 1.4	2.7 ± 0.9

A comparison of the first half of the past decade to the last half shows very small differences and no discernable trends for the western and central basins. However, in likely response to reduced phosphorus concentrations, the 1980 chlorophyll levels indicate a possible decline in algal biomass. Figure 13 indicates a possible trend with a marked lowering in the quantity of central basin chlorophyll a in 1980, while Figure 14 demonstrates typical distribution patterns of chlorophyll a.

Algae. During each of the two years of the Intensive Study the western basin phytoplankton biomass was dominated by diatoms in the spring and co-dominated by diatoms and blue-greens through the summer and fall. This pattern is similar to that described for 1970 (Munawar and Munawar 1976). In the central and eastern basins diatoms and greens represented the major contributors to the phytoplankton commmunity throughout the season. Diatoms biomass was high in the early spring and in the fall following lake turnover. Green algae dominated in the summer but at a lower biomass than the diatom peaks. Biomass distribution indicates a west-to-east decrease in the standing crop of algae for the three basins:

Total Mean Biomass

Year	Western (g/m^3)	Central (g/m^3)	Eastern (g/m^3)
1978	4.0	1.8	1.2
1979	9.4	3.4	0.9

The highest concentrations of phytoplankton were observed along the United States shore of all three basins.

The basin-wide blooms of blue-greens in western Lake Erie which were so prevalent in the mid-1960's decreased in intensity and number in the 1970's. No basin-wide blooms were reported during the Intensive Study. Open lake phytoplankton

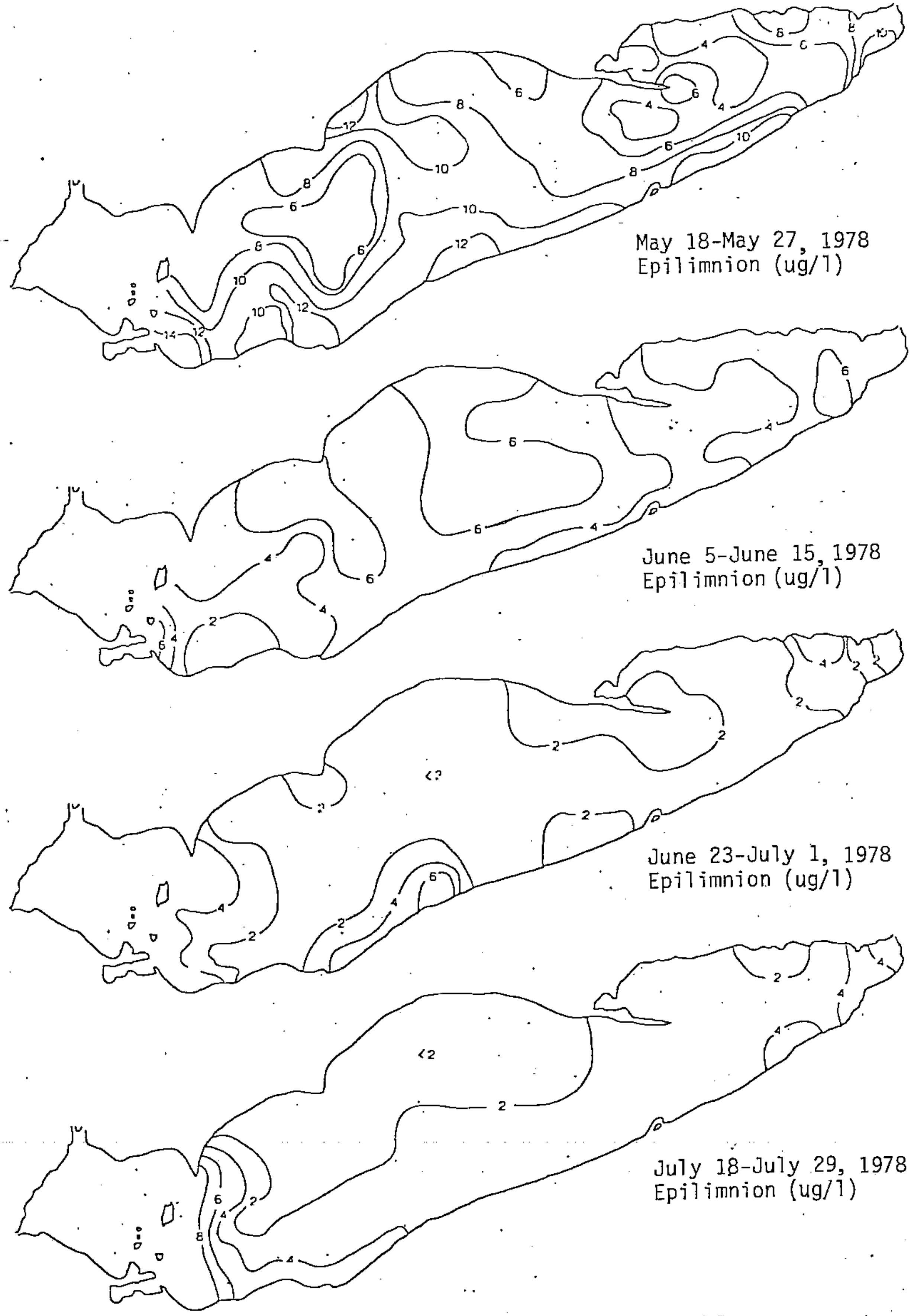


Figure 14. Distribution of Chlorophyll a in Lake Erie.

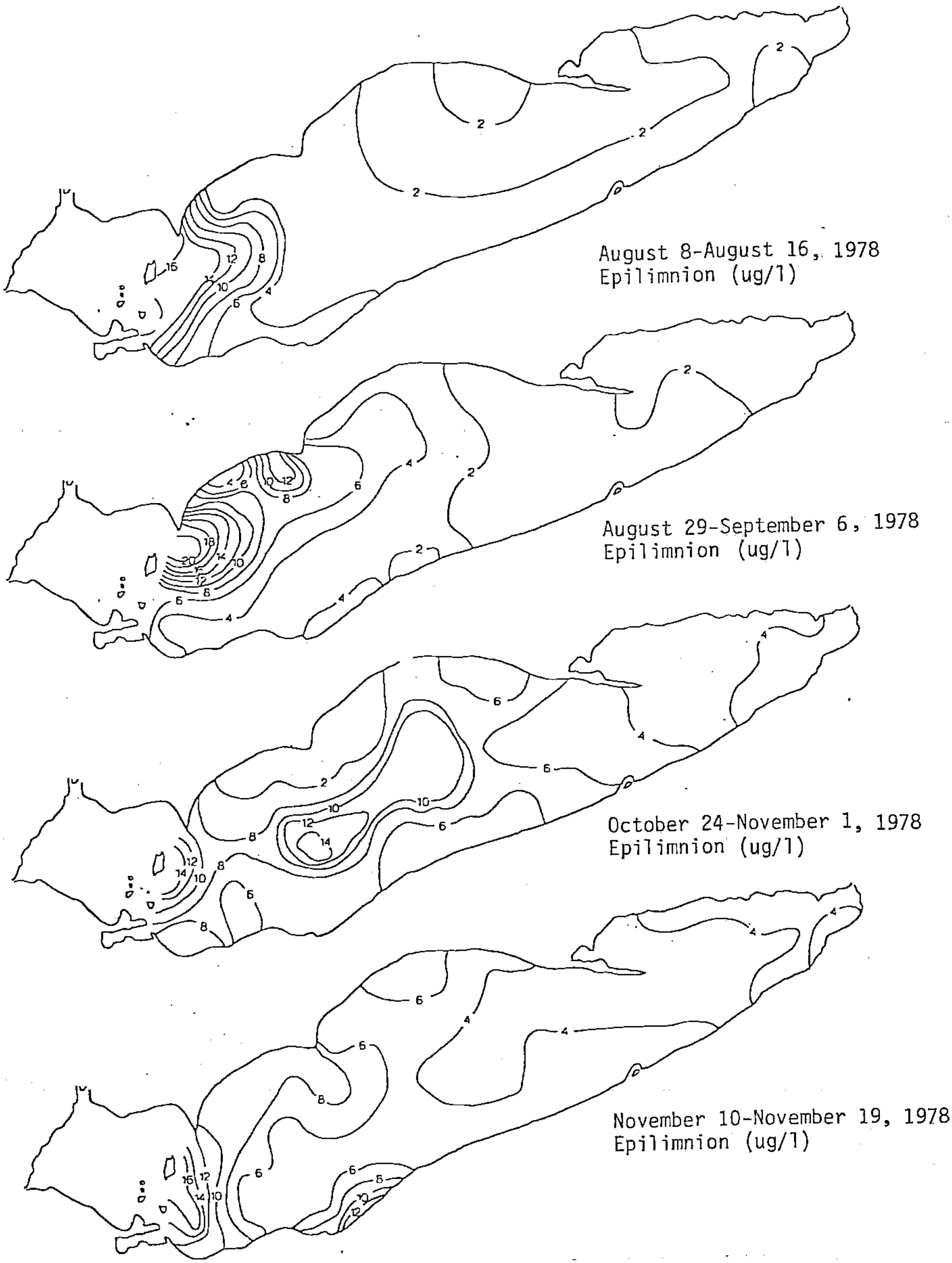


Figure 14. Distribution of Chlorophyll a Lake Erie (continued).

analysis, in all three basins, between 1970 and 1980 indicates a reduction in total phytoplankton biomass and a composition shift toward more oligotrophic species. Several eutrophic species were less abundant in 1979 than in 1970 and two oligotrophic species were first observed in 1979 (Munawar 1981). Analysis of samples from the Kingsville water intake along the northern shore of western Lake Erie indicates a marked decline in algal biomass in recent years. This apparent improvement along the Ontario shore has not been observed in the Michigan or Ohio nearshore water. This may be explained by the phosphorus decrease in the Detroit River outflow, which influences the Ontario shore (Figure 15), versus high concentrations of phosphorus in the Maumee River and other tributaries which influence the United States shore.

The filamentous, epilithic green alga Cladophora glomerata is well-adapted to rocky littoral reaches of Lake Erie, as evidenced by its profuse growth. This alga has been reported in Lake Erie since the late 1800's, but in the past few decades it has become increasingly abundant. Massive growths of Cladophora have created nuisance accumulations and obnoxious odors along recreational shores. It may also clog water intakes, foul fishing nets and submerged structures, and impede navigation due to growths on boat hulls. Thomas (1975) suggests that the Cladophora starts to become a nuisance at phosphorus concentrations of 15 ug/l, and it is only above this level that it interferes with certain water uses, especially recreation and as a source of drinking water. Because of the high concentrations of phosphorus in all three basins, the distribution and abundance of Cladophora in Lake Erie is largely limited by the lack of suitable substrate. Large populations of Cladophora were located at the eastern basin nearshore and island region of the western basin due to the large areas of exposed bedrock. The distribution of Cladophora was quantified in all three basins of the lake during the Intensive Study; however, with the lack of historical data, biomass trends cannot be established.

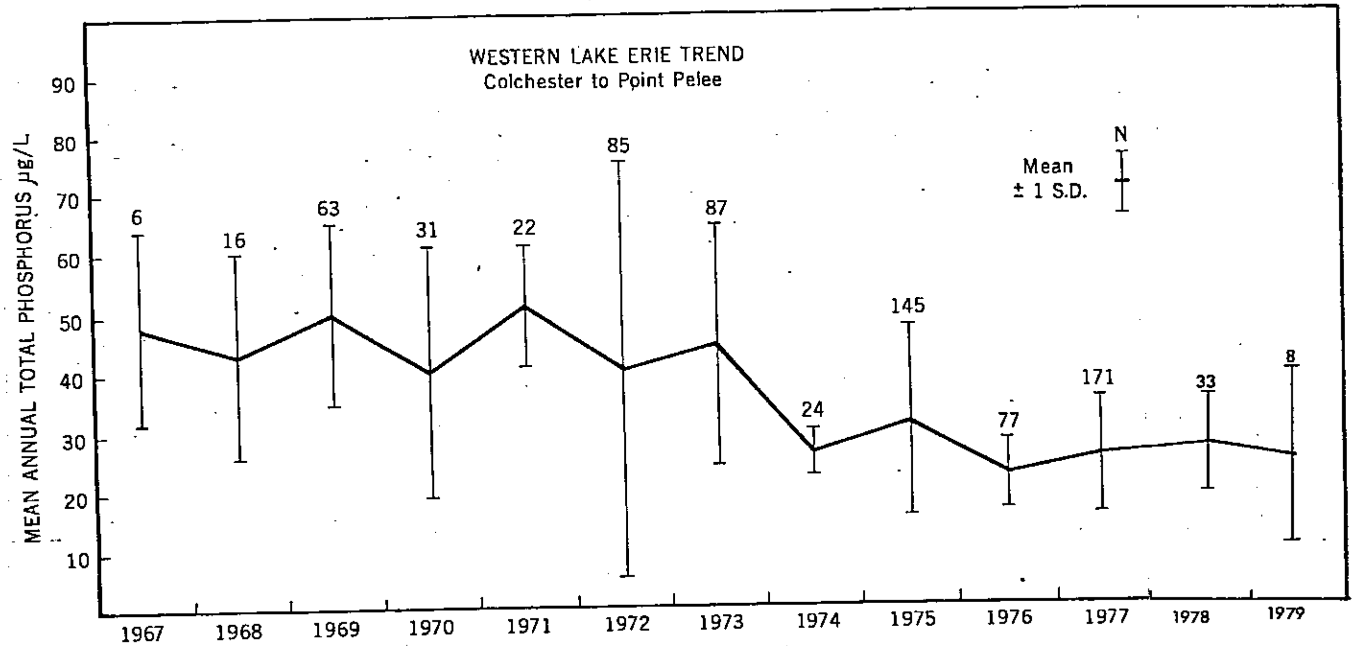


Figure 15. Total Phosphorus Trends in Western Lake Erie Nearshore Water (OME).

Maximum Standing Crop of <u>Cladophora</u> (g/m^2)

Year	Stony Pt., Michigan	So. Bass Is., Ohio	Walnut Creek, Pennsylvania	Hamburg, New York	Rathfon Pt., Ontario
1979	107 (0.5m)*	110 (2.0m)	24 (2.0m)	100 (3.0m)	983 (0.5m)
1980	186 (0.5m)	218 (0.5m)	59 (3.0m)	86 (3.0m)	------

*( ) depth of maximum biomass)

From the abundant growths observed along the Ontario shore of the eastern basin, it is suspected that light attenuation in the clear waters due to the turbid nature of the water in the western basin is a major limiting factor to <u>Cladophora</u> growth in the western end of the lake.

<u>Open lake trends</u>. An analysis of Lake Erie water quality data for the past decade, as an assessment of trends, indicates a general improvement in lake conditions. Water levels in Lake Erie have been above the long-term mean since 1970, which have provided some dilution of contaminants. Thermal structure of the lake is influenced by meteorological conditions which have resulted in thin hypolimnions and severe depletion of oxygen, as in 1973, and thick hypolimnions and relatively small areas of anoxia, as in 1975. In the past decade the oxygen demand rate in the central basin has been relatively constant after increasing dramatically from 1930 to 1970. The oxygen demand rate of the eastern basin may still be increasing slightly.

Concentrations of total phosphorus in the western and central basins were relatively constant during the period 1970 to 1977; however, for the next three years (1978-1980) significant declines in the concentrations and quantities in these basins have been observed. This improvement coincides with the approximately 800 mt/yr. reduction in total phosphorus loaded to the lake during the period 1970-1979. Eastern basin data also indicates a progressive decline in phosphorus since the mid-1970's. Transparency shows no discernable trends, but in 1980 the central basin had the highest average summer transparency during the period of record, 1973-1980. Chlorophyll a concentrations in 1980 were also the lowest average annual values on record (1970-1980) for the western and central basins. Dissolved substances, as measured by conductivity and chloride, also show a significant decline in the past 15 years.

Many of these trends are preliminary interpretations and must stand the test of further scientific scrutiny. However, the evidence is continuing to mount that Lake Erie is no longer degrading and that future improvements are imminent.

Nearshore trends. Nutrient distributions in the nearshore area correspond to major loading sources. Tributary mouths in the western basin and south shore of the central basin are characterized by high concentrations of nutrient throughout the year. Correlations of phosphorus and chlorophyll in the nearshore waters of Lake Erie are demonstrated in Figures 16 and 17. The following nearshore water quality trends have been observed for the past decade.

Analysis of the United States shore of the Detroit River indicates a decreasing trend in alkalinity, conductivity, turbidity, total dissolved solids, biochemical oxygen demand, ammonia, total Kjeldahl nitrogen, total organic carbon, total phosphorus, soluble phosphorus, phenols, iron and chlorides. No trends could be detected for silica, organic nitrogen, or total and fecal coliforms. With the exception of nitrate plus

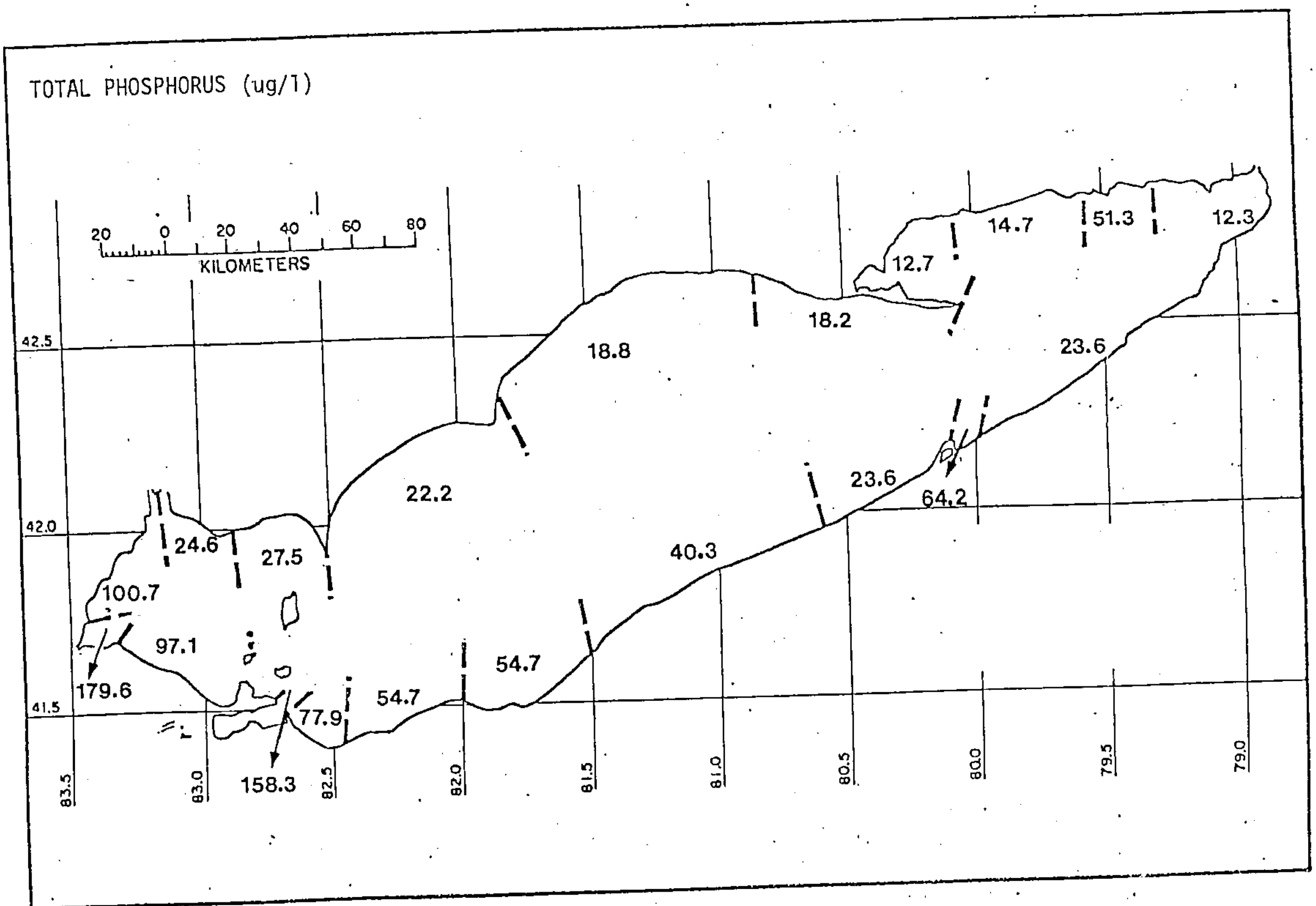


Figure 16. Mean Nearshore Concentrations of Total Phosphorus 1978–1979.

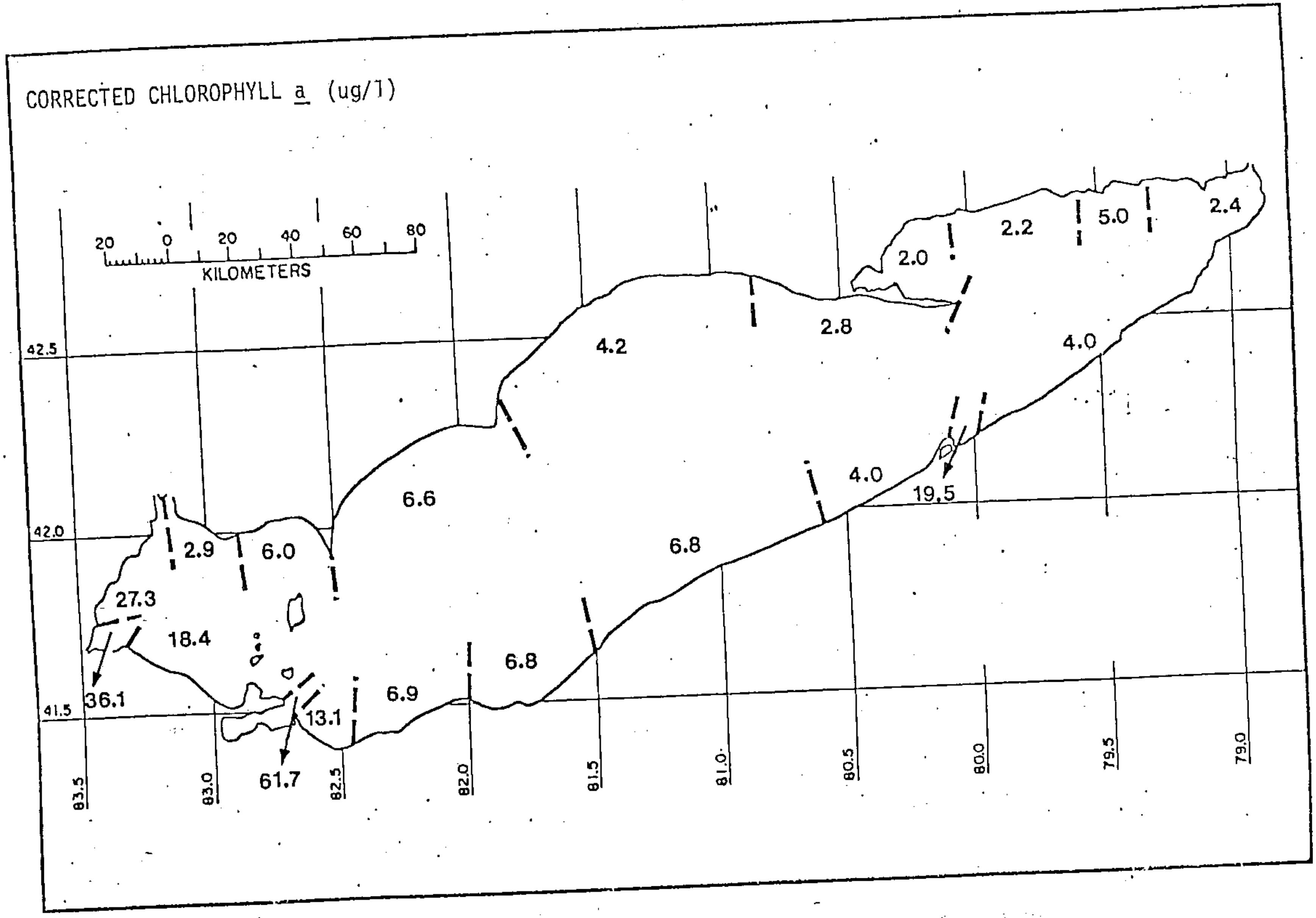


Figure 17. Mean Nearshore Concentrations of Chlorophyll a 1978–1979.

nitrite, no parameter at this reach is increasing significantly through time. Thus, a general improvement in the quality of water appears to be occurring along the western shore of the river.

The Livingstone Channel, which is considered representative of upper Great Lakes water, showed significant decreases in conductivity, ammonia, total Kjeldahl nitrogen, total organic carbon, total phosphorus, soluble phosphorus, phenols and chlorides. No significant trends were found for temperature, turbidity, residue, silica, BOD, organic nitrogen, nitrate plus nitrite or iron. Again, a general improvement in water quality is indicated for mid-river flow.

The Canadian shore of the Detroit River shows significant decreases in total organic carbon, total phosphorus, soluble phosphorus, total coliforms and phenols. No significant trends were observed for temperature, dissolved oxygen, turbidity, total dissolved solids, residue, silica, biochemical oxygen demand, organic nitrogen, ammonia, total Kjeldahl nitrogen, nitrate plus nitrite, iron or chlorides. Increases through time were observed for pH, conductivity, and fecal coliforms. Thus, while not as many parameter trends are significant at this site than at the other two segments in the Detroit River, a general improvement in water quality can be ascertained by decreases in major nutrient concentrations, total coliforms and phenols.

Monroe, Michigan water intake data shows only an increasing trend in phenols; all other parameters of interest were either not present in the data set or showed no significant change. Although the data set is limited, the analyses of existing nutrient and major ion parameters leads to an initial conclusion that water quality at this site in the lake may not have changed significantly within the period of record.

Rock Canal. Soluble phosphorus was the only parameter for which an increasing trend was discerned. No significant trend could be found for temperature, alkalinity, conductivity, turbidity, residue, biochemical oxygen demand, nitrates, ammonia, total coliforms, phenols or iron. The Niagara River at Lake Ontario showed no significant increase or decrease in pH, alkalinity, dissolved oxygen, turbidity, organic nitrogen, nitrate, ammonia, total coliforms or iron. The only significant trends which could be discerned were an increase in temperature and decreases in conductivity and chlorides. Thus, the Niagara River system does not appear to have changed significantly during the last decade.

Toxic Substances

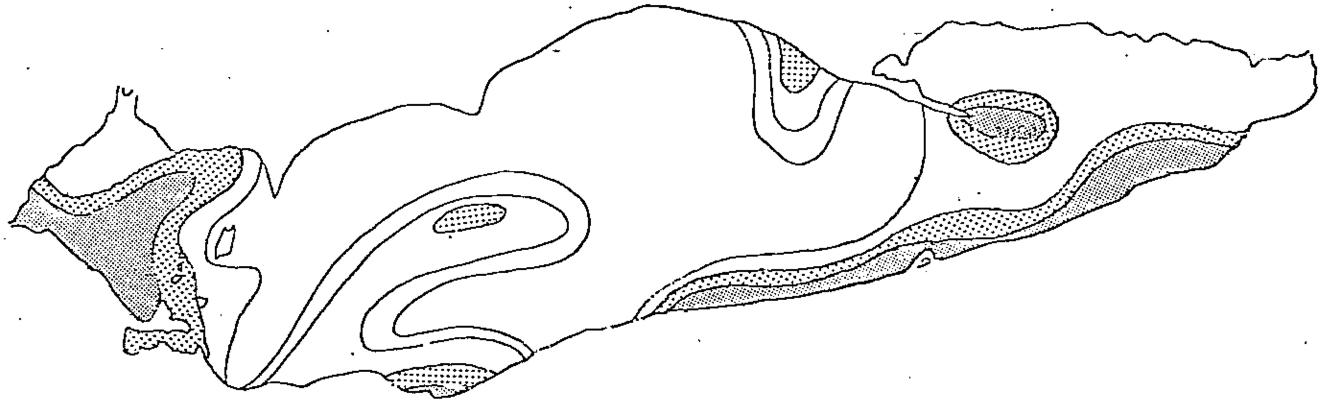
Toxic pollutants are introduced to Lake Erie through municipal and industrial point source wastewater discharges, atmospheric deposition, and urban and agricultural land runoff. In Lake Erie, interlake transfer via the connected channels (Detroit and Niagara rivers) can also be a significant source of contaminants. Preliminary data indicates that nine heavy meals (Cd, Cr, Cu, Pb, Mn, Hg, Ni, Ag and Zn) and six organic pollutants (benzene, chloroform, methylene chloride, bis [2 ethylexyl], phthatate, tetrachloroethylene, and touluene) were found in nearly all effluents from major municipal wastewater treatment plants in the Lake Erie basin. The International Joint Commission (1979) has conducted an inventory of the major municipal and industrial point source discharges to Lake Erie. The total annual load to Lake Erie from these sources for four trace metals is presented below:

Discharges of Trace Metals

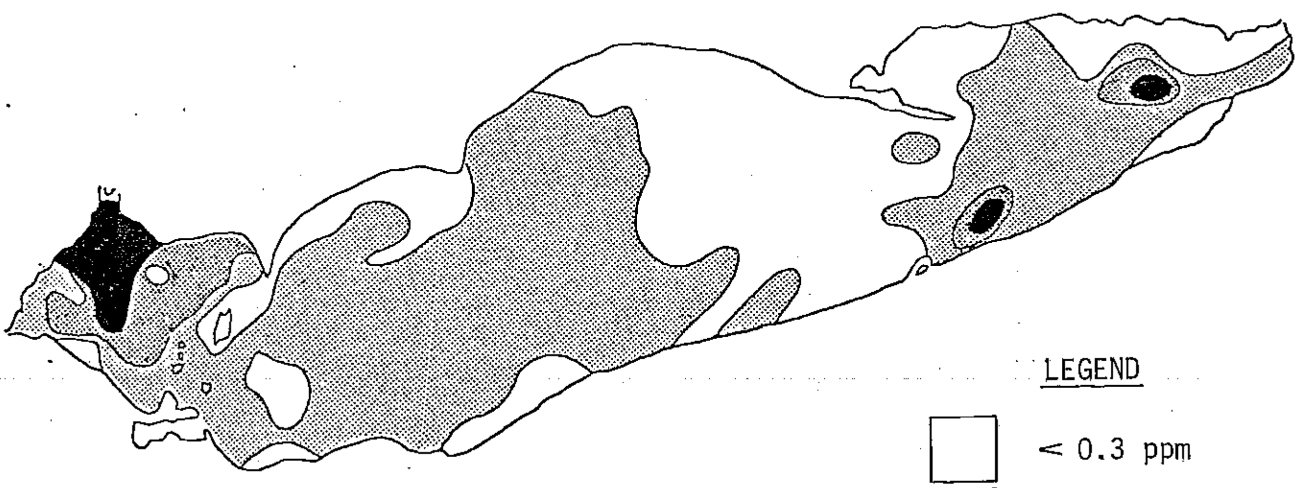
Metal	Municipal Sources (mt/yr)	Industrial Sources (mt/yr)
Zn	228.2	148.6
Pb	50.7	38.2
Cu	50.7	43.4
Cd	15.2	0.3

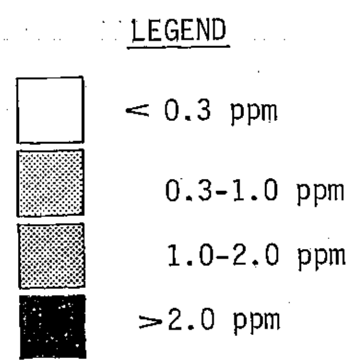
Data from the 1979 main lake surface sediment survey indicates that some metals are highly concentrated offshore from tributary mouths near major industrial areas. Lead, nickel, copper, silver, vanadium, mercury (Figure 18), zinc, cadmium and chromium show elevated levels offshore from the Detroit River. Mercury (Figure 18) is also high along the Pennsylvania/New York shoreline. Zinc and cadmium show high concentrations off Cleveland, Ohio and Erie, Pennsylvania. Chromium is also high near Buffalo, New York. The distribution of metal in the open lake sediments indicated highest mean concentrations corresponding to the major depositional zones particularly evident in the sink areas of the central and eastern basins. It is evident that the western basin sediments are eventually transported into the ajoining basins with the net movement from west to east.

Drynan (1982) points out that combined sewer overflows are an additional point source of toxic substances for which little or no information is currently available. It is very difficult to sample and obtain flow measurements for these highly variable discharges in order to make estimates of the total quantities of pollutants they introduce into the lakes. In some of the major metropolitan areas, such as Detroit and



Mercury in Surface Sediments 1979
(USEPA/GLNPO)





Mercury in Surface Sediment 1970
(Thomas and Jaquet 1976)

Figure 18. Mercury Distribution in Lake Erie Surface Sediments.

Cleveland, with combined sewers these discharges may be significant, particularly in terms of local water quality impacts. Their impact on total pollutant loadings and whole lake water quality, however, remain to be determined.

With further controls on point source discharges, it is becoming increasingly apparent that nonpoint sources, urban and agricultural land drainage and long range atmospheric transport and deposition must be given more consideration in water quality management plans. Although the estimate of atmospheric deposition of trace metals and organic substances in Lake Erie is hampered by a number of problems, Drynan (1982) concluded that it is possible to use approximations of wet and dry components to estimate total deposition:

Deposition of Airborne Trace Metals and Organics

Trace Metal	Deposition (mt/yr)	Organic Compound	Deposition (mt/yr)
Zn	*	Total PCB	3.1
Pb	754	Total DDT	0.19
Cu	151	α-BHC	1.1
Cd	75	γ-BHC	5.0
Ni	75	Dieldrin	0.17
Fe	3,270	HCB	0.53
Al	*	p,p' Methoxychlor	2.6
Mn	*	α-Endosulfan	2.5
Ag	*	β-Endosulfan	2.5
		Total PAH	51.0
		Anthracene	1.5
		Phenanthrene	1.5
		Pyrene	2.6
		Benz(a) athracene	1.3
		Perylene	1.5
		Benzo(a) pyrene	2.5
		DBP	5.0
		DEHP	5.0
		Total organic carbon	66,000

*Estimates not possible from available data

Shipboard collection of aerosol samples was undertaken as part of the Lake Erie Intensive Study to assess the contribution of atmospheric dry loading of aerosol trace elements and nutrients to the lake. Preliminary estimates of loading in metric tons per year (mt/yr) are presented below (Sievering 1982). The range in values shown are considered to be the 25% and 75% confidence limits of these estimates:

Atmospheric Dry Loading

Element	Load (mt/yr)	Element	Load (mt/yr)
Pb	4-9	Cr	5-12
Zn	75-175	Ni	4-8
Cd	4-9	SO_4	30,000-70,000
Cu	3-7		

Sediment cores taken at the mouth of the Detroit River and in western Lake Erie in 1971 yielded surface mercury concentrations up to 3.8 ppm and generally decreased exponentially with depth (Figure 18). High surface values were attributed to waste discharge from chlor-alkali plants on the Detroit and St. Clair rivers which operated during the period 1950 to 1970. Several years after these plants ceased operation the area was again cored with analyses showing that recent deposits covered the highly contaminated sediment with a thin layer of new material which had mercury concentrations approaching background levels (0.1 ppm). As a result of these discharges, mercury in fish of Lake St. Clair and western Lake Erie was a major contaminant problem in the early 1970's. Levels of total mercury in walleye (Stizostedion vitreum vitreum) collected from Lake St. Clair have declined from over 2 ug/g in 1970 to 0.5 ug/g in 1980. In western Lake Erie, 1968 levels of mercury were

0.84 ug/g as compared to only 0.31 ug/g in 1976. The rapid environmental response subsequent to the cessation of the point source discharges at Sarnia, Ontario and Wyandott, Michigan can be attributed to rapid flushing of the St. Clair-Detroit River system, the high load of suspended sediment delivered to western Lake Erie, and the high rate of productivity in the western basin (International Joint Commission 1981).

Fish contaminant surveys of Lake Erie and its tributaries indicate few problems, and these are usually associated with site specific areas. The highest concentration and the greatest number of organochlorine contaminants in fish samples were found in the River Raisin and the Maumee River. Excessive concentrations (i.e. 1.0 ppm for pesticides, 5.0 ppm for total PCBs) of the following contaminants were found: -BHC (Ashtabula River) and total PCBs (River Raisin, Maumee River, and Sandusky River). All other contaminants were found at low concentrations (1.0 ppm). Levels of PCB and DDT in spottail shiners (*Notropis hudsonius*) and in herring gull (*Larus argentatus*) eggs have declined in the past decade, illustrating a system-wide response to controls on production and use of these compounds. PCB levels in shiners at Point Pelee, Ontario, dropped from 844 ng/g in 1975 to 150 ng/g in 1980 while during the same period DDT fell from 92 to 21 ng/g. At Port Colborne, Ontario, gull eggs showed similar declines in PCB and DDT residues, but of a lesser magnitude (International Joint Commission 1981).

Public Health

Bacteria contained in wastewater inputs to the lake pose a direct health hazard near metropolitan centers such as Port Clinton, Lorain, Cleveland, Dunkirk, Buffalo, Port Stanley and Port Burwell. During the Intensive Study, approximately 16% of beaches along the Lake Erie shore were at least temporarily restricted from use, particularly for water contact recreational activities:

Recreational Beaches (1978-1981)

Jurisdiction	Beaches Monitored	Beaches Temporarily Closed or Restricted	Beaches Permanently Closed
Michigan	7	0	0
Ohio	52	8	4
Pennsylvania	40	1	0
New York	26	5	0
Ontario	4	2	0

In the past decade, significant progress has been made in removing bacterial contamination from the shoreline. In the late 1960's, 11 bathing beaches on the United States side of the lake were posted unsafe because of high bacterial contamination. Another 12 beaches were deemed as questionable because of moderate bacterial pollution and 27 were considered generally safe with only slight pollution. Only three beaches were found to be uncontaminated throughout the swimming season (FWPCA 1968b). By contrast, the above data shows that over 100 beaches are now safe. For example, in the late 1970's the beach at Sterling State Park, near Monroe, Michigan, was reopened after a 20-year closure when coliform bacteria counts dropped to levels that were in compliance for body contact recreation. The major bacterial problems that still persist are often associated with storm water overflows, such as at Cleveland, Ohio where heavy flows are delivered directly to the Cuyahoga River, contaminating the nearshore waters surrounding the metropolitan area.

Land Use Activities

The United States portion of the Lake Erie basin includes 12.5 million acres (5.1 million hectares), of which over half is cropland. In the western portion of the basin, nearly 70 percent of the land is devoted to cropland. The soils of this area are favorable for row crop production with corn and soybeans dominating cropland usage. The Lake Erie Wastewater Management Study (Yaksich 1982) showed that the effect of land use activities on water quality is a complex relationship, but several generalizations were confirmed and recommendations proposed:

1. The river basins which drain into the western and central basins of Lake Erie are contributing areas of diffuse phosphorus loads. The entire watersheds of these rivers are hydrologically active areas and contribute diffuse phosphorus loads to the lake.

2. Reducing sediment concentrations in tributaries lessened sediment yields and phosphorus loadings from large river basins. The mean ratio of total phosphorus to suspended solids in northwestern Ohio for 1974-1979 was 2.17 g/kg. Of this total, 25% was soluble phosphorus, which was readily available for plant growth, and 75% was particulate phosphorus. In general, higher concentrations of suspended solids resulted in lower phosphorus to suspended solids ratios.

3. Particulate and soluble phosphorus entering stream systems disappears rapidly from flowing water; however, it is resuspended and transported downstream as particulate phosphorus during later storm events. Therefore the process of transporting phosphorus from basin cropland to Lake Erie may require a considerable period of time.

4. Phosphorus from nonpoint sources is more bioavailable when reaching Lake Erie than phosphorus from point sources located on tributaries. Most of the soluble phosphorus which reaches the lake from tributaries is derived from nonpoint sources.

5. The western basin and southwestern portion of the central basin of Lake Erie have algal growth problems which will require phosphorus reductions in addition to those being provided or projected by point source removal. A program for control of phosphorus from diffuse sources is therefore needed, which is based on practices which have the lowest cost per unit quantity of phosphorus stopped from reaching the lake. Conservation tillage on suitable soils is the most cost-effective means of reducing sediment phosphorus loads to Lake Erie. The implementation of a conservation tillage program would ultimately achieve a 2,000 mt/yr reduction in total phosphorus loading to Lake Erie. The Great Lakes Water Quality Agreement of 1978 calls for an additional target phosphorus reduction for Lake Erie of 2,000 metric tons per year beyond the achievement of a 1.0 mg/l effluent concentration for all municipal wastewater treatment plants currently discharging more than 1 million gallons per day. The United States allocation of this reduction is 1,700 mt/yr. A conservation tillage program will more than reach this allocation at a benefit/cost ratio of 10:1.

6. A new base-year tributary phosphorus load to Lake Erie should be recognized; inclusion of tributary monitoring data from 1978-1980 in the computation gives a base-year total phosphorus load of 16,455 mt/yr. When the 1.0 mg/l effluent limitation has been achieved the total phosphorus load

to lake Erie will be 15,025 mt/yr. At that time an additional phosphorus reduction of 4,025 mt/yr (not 2,000 mt/yr as stated in Item No. 5) will be required to meet the 11,000 metric tons per year total loading objective of the Water Quality Agreement. The United States allocation of this reduction objective should be approximately 2,800 mt/yr. To reach this reduction objective an additional 770 mt/yr in reductions beyond the recommended program must be achieved through point source controls beyond the 1.0 mg/l effluent limitation, and at a cost of $5 million annually. The benefit/cost ratio of the recommended conservation tillage program is 17:1 compared to a program requiring the entire reduction to be achieved by point source control.

7. Relatively small amounts of agricultural pesticides reach water bodies via runoff (normally 1-2% of the application or as high as 6% after intense rainfall). Pesticides generally used in the Lake Erie basin are not inhibitory to invertebrates or fish at runoff concentrations; however, algae and aquatic macrophytes may be inhibited at observed stream concentrations. The increased usage of pesticides with conservation tillage is not expected to result in increased pesticide runoff since erosion and runoff would be decreased.

Lake Responses to Remedial Actions

The water from Lake Erie sustains the vast industrial complex which extends from Detroit to Buffalo. Water returned to the lake is highly enriched by municipal, agricultural, and industrial waste products. Studies conducted in the late 1920's revealed that the lake was already moderately rich in nutrients and was experiencing phytoplankton blooms in its western basin. Adjacent to the Detroit River mouth, sensitive mayflies were being replaced by tubificid worms. By the mid-1950's thermal stratification was resulting in oxygen depletion in the bottom water and mayfly nymphs suffered catastrophic mortality. The concentration of all the major ions, including the nutrients phosphorus and nitrogen, showed a marked increase during this period of time.

In the early 1960's Lake Erie gained the reputation as a "dead lake." Its western basin was the consistency of "pea soup" due to dense algal mats which left green wakes behind boats. Most municipal beaches were closed owing to high coliform bacteria counts or were redered unusable by reeking masses of decaying algae (largely Cladophora glomerata). one of its major tributaries, the Cuyahoga River, was so polluted by industrial wastes that it periodically caught fire. Anoxia in the central basin had caused the extirpation of virtually all cold-water fish species and detergent foam at the eastern end of the lake resulted in a disgusting spectacle in the plunge pool of Niagara Falls.

The concept of nutrient control for Lake Erie appears to have had its origin in 1965, when the U.S. Department of Health, Education and Welfare convened a conference on the pollution of Lake Erie and its tributaries under the authority granted in the Water Pollution Control Act of 1961. One of the recommendations forthcoming from the conference was that a "technical committee" be established to evaluate water quality problems related to nutrients in Lake Erie and to make recommendations to the conferees. In late 1965, the Lake Erie Enforcement Technical Committee was formally established to explore the problems related to nutrients and over-enrichment of Lake Erie. The committee received information and advice from leading authorities in water-oriented disciplines, and after a year of study a final report was issued. The report concluded that the major pollution problems in Lake Erie results directly or indirectly from excess algae and that these growths are stimulated by nutrients resulting from man's activities.

The technical committee recommended that water quality objectives be established that would prevent nuisance algae conditions, particularly by lowering the phosphate and nitrogen levels in the lake. The committee further recommended that new treatment processes be developed and employed to effect high phosphate removal. Based on these recommendations the Federal Water Pollution Control Administration (FWPCA), later the Federal Water Quality Administration (FWQA), and more recently the Environmental Protection Agency (EPA), as well as state and local agencies, have embarked on a program to control the flow of nutrients and toxic substances to Lake Erie. The necessity for this control was reinforced by findings of the International Joint Commission, resulting in the Canada-United States Water Quality Agreement of 1972 and 1978.

Nature of remedial actions. Today Lake Erie is beginning to respond to massive clean-up efforts started two decades ago. New sewage treatment plants have been constructed throughout the drainage basin and old plants have been modified to remove phosphates through tertiary treatment. Industries have been forced to reduce waste loads to the lake or in some instances cease operation, as in the case of chlor-alkali plants which discharged excessive amounts of waste mercury. Production and use of several toxic organic compounds have been banned. Agricultural practices are being modified to lessen soil loss to tributaries and to reduce fertilizer and pesticide requirements. The more significant actions include:

1. Detergent Modifications

During the late 1960's and early 1970's, the province of Ontario and all of the Great Lakes states, with the exception of Ohio and Pennsylvania, enacted legislation which limited the amount of phosphorus permitted in household detergents. A concentration of 0.5 ppm is permitted in the United States and 2.2 ppm in Canada. In Ohio, where no controls are in effect, phosphorus concentrations of 5.5 ppm are typical.

2. Point source controls

The most significant improvement in lowering phosphorus delivery to Lake Erie has been made in the loading from point sources. The point source loading has decreased from 11,900 mt/yr in 1970 to 4,500 mt/yr in 1980, as a result of the implementation of phosphorus effluent limitations to 1.0 mg/l at wastewater treatment plants (Yaksich 1982). In 1970, total phosphorus loading from the Detroit River accounted for 39% of the total load to the lake; by 1980, improvements in treatment had lowered this to only 27%.

3. Soil conservation

The practice of conservation tillage has expanded rapidly in the Lake Erie basin throughout the last decade. In the early 1970's little conservation tillage was seen, but by 1981, reduced tillage was being practiced on 22% of the basin's cropland, and no tillage was used on 4%. Besides changing tillage, several other agricultural practices (e.g. method of fertilizer application, pesticide usage and planting techniques, and establishing greenbelts along streams) have been altered, resulting in less soil loss and some reduction of phosphorus deliver to the lake.

4. Fishery management

Several fish species have been extirpated from Lake Erie as a result of environmental changes, over-exploitation, or a combination of these factors. Prudent management programs, such as the suspension of commercial fishing for walleye, have enhanced the population of sport fish. Commercial and recreational extractions, environmental changes and management programs will continue to affect the fish community as a whole. To a large extent, the structure of Lake Erie's fish community in the future will depend to a large degree on public perception of what structure would be most economically advantageous.

Positive responses. Annual monitoring programs initiated in the early 1970's, coupled with observations during the 1978-1979 Intensive Study, are beginning to provide some evidence of water quality improvement and possible lake recovery. The first signs of a positive response to remedial programs have not been dramatic, but then the pollution of the lake also took many decades. Some of the most promising indicators of improved lake conditions are presented below. Cause and effect relationships for all of these changes are not well understood nor can these changes be attributed to specific remedial actions:

1. Water Levels

Water levels in Lake Erie during the past decade have averaged 0.5 m above the 1960-1970 levels. The difference between the lowest year (1964) and the highest year (1973) was 1.1 m, an increase of approximately 7%. The dilution effect of more upper Great Lakes water flowing into Lake Erie, coupled with greater submergence of algal attachment sites, is thought to be partially responsible for the absence of basin-wide algal blooms and massive growths of the filamentous algae, Cladophora, that were so prevalent in the mid-1960's.

2. Water Clarity

The clarity of water in the western basin as measured by secchi disk, shows a slight improvement from the early 1970's to the end of the decade. The area-weighted transparency in July for 1973-1975 averaged 1.8 m with the maximum year (1974) at 2.2 m (Zapotosky 1980). For the same month in 1978-1980, transparency averaged 2.3 m with maximum year (1978) being 3.0 m. The central and eastern basins remained relatively stable throughout the decade with average July transparencies of 6.4 m and 7.0 m, respectively.

3. Dissolved Substances

Nearshore records for the period 1900 to 1960 in central Lake Erie show dramatic increases in conductivity, chloride, calcium, sulfate and sodium plus potassium (Beeton 1961 and 1965). From 1966 to 1980 conductivity (Figure 11) indicates a low decline in the total amount of dissolved substances in central Lake Erie, falling from an annual mean of 311 to 287 umhos/cm during this period. Chloride (Figure 12) shows a more dramatic improvement, dropping from 25.0 mg/l in 1966 to 18.4 mg/l in 1979. Most of this decline can be attributed to elimination of waste brine pollution from the Grand River near Painesville, Ohio in the early 1970's. In the eastern basin, Presque Ile Bay at Erie, Pennsylvania, has experienced a marked decrease in alkalinity (largely bicarbonate ions) from 1945 to 1978, falling from 96 to 87 ppm. Other conservative major ions (calcium, sodium and sulfate) have ceased to increase in the lake and have remained relatively stable over the past decade.

4. Phosphorus Loading and Lake Concentrations

Loading of total phosphorus to Lake Erie declined markedly during the period 1970 to 1979. The 1970 loading to the entire lake, from all sources except shore erosion, was estimated to be approximately 23,000 metric tons. By 1979, the total phosphorus load had decreased to an estimated 13,000 metric tons. The Detroit River, which supplies about 90% of the inflowing water to Lake Erie, has shown a remarkable improvement; phosphorus loadings have decreased 85% since 1968, primarily as a result of improvements to the Detroit wastewater treatment plant, particularly in the past three years.

In the early 1970's, the concentration of phosphorus in influent wastewater to municipal treatment plants averaged about 10 mg/l within the Lake Erie drainage basin and the mean effluent concentration was approximately 7 mg/l. By 1980, many plants had installed phosphorus removal systems which resulted in an average effluent concentration of only 1.6 mg/l for all Ohio plants (King et al. 1982) and concentrations as low as 0.6 mg/l for the Detroit sewage treatment plant in 1982 (Drynan 1982).

Concentrations of total phosphorus in western Lake Erie have declined from 44.6 ug/l in 1970 to 28.8 ug/l in 1980. Similarly, the central basin has dropped from 20.5 to 13.7 ug/l and the eastern basin from 17.5 to 10.8 ug/l during the past decade (Herdendorf and Fay 1981).

5. Hypolimnion Oxygen

In the central basin of Lake Erie, the rate of hypolimnetic oxygen consumption more than doubled between 1930 and the mid-1970's. In 1930, the volumetric rate has been estimated at 0.054 $g/m^2/day$ (Dobson and Gilbertson 1971), while in 1973 it was measured at 0.120 $g/m^2/day$. During the same period the area of the basin exposed to anoxic conditions rose from only 300 km^2 in 1930 (6) to 11,270 km^2 in 1973. Surveys conducted in 1981 show that the demand rate has dropped to 0.085 $g/m^2/day$ and the area of anoxia has been reduced to 4,820 km^2.

6. Toxic Metals and Organic Compounds

Sediment cores taken at the mouth of the Detroit River and in western Lake Erie in 1971 yield surface mercury concentrations up to 3.8 ppm (Walter et al. 1974) and generally decrease exponentially with depth to background concentrations of less than 0.1 ppm. High surface values were attributed to waste discharge from chlor-alkali plants (1950-1970) on the Detroit and St. Clair rivers. In 1977, several years after these plants ceased operation the area was again cored. Analyses showed that recent deposits were covering the highly contaminated sediment with a thin layer of new material which had mercury concentrations approaching background levels (Wilson and Walters 1978).

Mercury in fish of Lake St. Clair and western Lake Erie was a major contaminant problem in the early 1970's. Levels of total mercury in walleye (Stizostedion vitreum vitreum) collected from Lake St. Clair have declined from over 2 ug/g in 1970 to 0.5 ug/g in 1980. In western Lake Erie, 1968 levels of mercury were 0.84 ug/g as compared to only 0.31 ug/g in 1976 (International Joint Commission 1981). The rapid environmental response subsequent to the cessation of the point source discharges at Sarnia, Ontario and Wyandott, Michigan can be attributed to rapid flushing of the St. Clair-Detroit River system and the high load of suspended sediment delivered to western Lake Erie.

Levels of PCB and DDT in spottail shiners (Notropis hudsonius) and in herring gull (Larus argentatus) eggs have declined in the past decade, illustrating a system-wide response to controls on production and use of these compounds. PCB levels in shiners at Point Pelee dropped from 844 ng/g in 1975 to 150 ng/g in 1980 while during the same period DDT fell from 92 to 21 ng/g (International Joint Commission 1981). At Port Colborne, gull eggs showed similar declines in PCB and DDT residues, but of a lesser magnitude.

7. Algal Density and Composition

The basin-wide blooms of planktonic blue-green algae (Microcystis, Aphanizomenon and Anabaena) in western Lake Erie and massive growths of an attached, filamentous green algae (Cladophora glomerata) which were so prevalent in the mid-1960's, have decreased in intensity and number in the 1970's. No basin-wide blooms have been reported in recent years. Open lake phytoplankton analysis between 1970 and 1980 indicates a reduction in total phytoplankton biomass and a composition shift toward more oligotrophic species. Eutrophic species (Melosira granulata, Stephanodiscus tenius and S. niagara) were less abundant in 1979 than in 1970 and oligotrophic species (Dinobryon divergens and Ochromonas scintillans) were first observed in 1979 (International Joint Commission 1981; Munawar 1981).

8. Benthic Communities

The composition of the benthic macroinvertebrate communities of western Lake Erie has improved since 1967. Samples taken in 1979, when compared with 1967 data, showed that the bottom is still dominated by pollution tolerant tubificids (Limnodrilus hoffmeisteri, L. cervix and L. maumeensis); however, other less tolerant taxa of tubificids (Peloscolex spp.) were also common. The density of tubific worms has declined sharply at the mouth of the Detroit River between 1967 (13,000/m^2) and 1979 (2,400/m^2), while the number at the mouth of the Maumee River has remained stable. Midge (Chironomidae) larvae represented only 6% of the benthic population in 1967 but rose to 20% by 1979 (Ontario Ministry of the Environment 1981).

A modest reestablishment of the burrowing mayfly (Hexagenia limbata) has been observed at the mouth of the Detroit River and adjacent areas of western Lake Erie. This species was extirpated from the western basin in the mid-1950's following periods of anoxia in this normally unstratified portion of the lake. Prior to 1953, bottom sediments yielded about 400 nymphs per square meter in the Bass Islands region (Britt 1956 and 1973). Following the catastrophic kills of the 1950's, no Hexagenia nymphs were found in Lake Erie sediments for over 20 years. In 1979, 20 nymphs were collected near the mouth of the Detroit River and for the past several years a small emergence of adults has been observed on South Bass Island (Ontario Ministry of the Environment 1981).

9. Fishery

The annual sport angler harvest of fish in the Ohio waters of Lake Erie has increased from 9,094,000 lbs. (4,125,000 kg) in 1976 to 16,355,000 lbs.

(7,419,000 kg) in 1981, an increase of 80% (Ohio Division of Wildlife 1982). During this six-year period, yellow perch (Perca flavescens) harvests rose from 6,451,000 lbs. (2,926,000 kg) to 11,300,000 (5,126,000 kg) while walleye (Stizostedion vitreum vitreum) production jumped from 671,000 lbs. (304,000 kg) to 2,963,000 lbs. (1,344,000 kg). The increased walleye production has been attributed to good young-of-the-year recruitment and international management approaches to control sport and commercial harvests.

The abundance of walleye (Stizostedion vitreum vitreum) in western Lake Erie increased dramatically from 1970 to 1981. During the 1960's and early 1970's the "fishable" population of walleye, 14.5 inches (36.8 cm) in length and larger, was estimated at or below two million (Ohio Division of Wildlife 1982). The fishable population present in 1981 was nearly 20 million walleye.

Modest success in lake trout (Salvelinus namaycush) restoration efforts was reported for the eastern basin of Lake Erie in 1981 (Bur 1982). A few stocked fish have been recovered in good condition over a year after release, but reproductive success has yet to be determined.

The abundance of young-of-the-year gizzard shad (Dorosoma cepedianum), one of the principle forage species utilized by sport and commercial fisheries, shows a several-fold increase since 1976 and was rated as excellent in 1981.

10. Bathing Beaches

In 1967, 11 Lake Erie bathing beaches on the United States side of the lake were posted unsafe because of high bacterial contamination (FWPCA

1968b). Another 12 beaches were deemed as questionable because of moderate bacterial pollution and 27 were considered generally safe with only slight pollution. Only 3 beaches were found to be uncontaminated throughout the swimming season. By contrast, in 1981, only 4 beaches were closed throughout the year, 8 were open for restricted use and 76 were open as safe, uncontaminated beaches.

Continuing and emerging problems. The main water quality objective for which compliance has not been met is in the dissolved oxygen of the hypolimnion of the central basin. The Water Quality Agreement calls for year-round aerobic conditions. The attempt to control anoxia in Lake Erie has been through the implementation of secondary treatment at the United States municipal sewage plants, phosphorus removal to 1.0 mg/l at sewage treatment plants larger than 1 mgd in the Lake Erie basin, limitations on phosphorus in detergents, and control on diffuse source inputs. The target load for these phosphorus controls is 11,000 mt/yr as determined by the mathematical models of DiToro and Connolly (1980).

The 1978 Water Quality Agreement requires the development of new phosphorus target loads and the allocation of these loads between Canada and the United States. As part of this negotiation process, base phosphorus loadings ("base loads") were developed for the lower Great Lakes. The base load for Lake Erie, which is an estimate of the expected phosphorus load to the lake if the phosphorus concentrations in all municipal wastewater discharges were at 1.0 mg/l and if average conditions existed for land runoff, atmospheric, and upstream inputs, is established at 12,856 mt/yr (International Joint Commission 1981). The Lake Erie Wastewater Management Study (Yaksich 1968), however, recommends that a new base-year load of 16,455 mt/yr be accepted based on 1978-1980 tributary loading data (see Land Use Activities section).

In the nearshore regions of Lake Erie, several areas were found not to be in compliance with Water Quality Agreement objectives. (Table 6 provides a list of violations for specific areas of concern). The following general problem regions were observed:

1. Ohio and Michigan nearshore regions of western Lake Erie, particularly in the vicinity of major harbors, had persistent violations of dissolved oxygen, ammonia, fecal coliforms, total phosphorus and several trace metals.

2. Ohio and Pennsylvania nearshore regions of central Lake Erie, particularly at the major river mouths, have persistent violations of conductivity and three trace metals, cadmium, copper, and zinc.

3. Pennsylvania and New York nearshore regions of eastern Lake Erie were relatively free of violations except for Erie Harbor where fecal coliform numbers were high in late summer.

4. Ontario nearshore regions throughout the lake were generally in compliance with only minor violations at tributaries and ports.

Emerging problems are difficult to assess, particularly with lack of comprehensive data on the nature of toxic organic compounds in the water, sediment and biota of Lake Erie. Problems associated with toxic compounds are most likely to emerge in the nearshore waters, especially harbors such as Monroe, Toledo, Lorain, Cleveland and Ohio where preliminary indications have been observed.

TABLE 6

VIOLATIONS OF LAKE ERIE WATER QUALITY OBJECTIVES

LOCATION	PARAMETER	
	Infrequent Violations	Frequent Violations
Western Basin Nearshore		
1. Pointe Mouillee to Stony Point, Michigan	ammonia, cadmium copper, zinc, mercury	DO, pH, conductivity, fecal coliforms, iron, manganese, nickel
2. River Raisin Mouth/ Monroe, Michigan	DO, copper, zinc, mercury	pH, conductivity, iron, nickel
3. Maumee River Mouth/Maumee Bay, Michigan and Ohio	cadmium, copper, zinc, mercury	DO, pH, ammonia, conductivity, total phosphorus, fecal coliforms, iron, magnanese, nickel
4. Toussaint River Mouth/ Locust Point, Ohio	cadmium, copper, nickel, zinc	conductivity, iron
5. Portage River Mouth/ Port Clinton, Ohio	pH, conductivity, chromium, zinc	fecal coliforms, iron, nickel
6. Sandusky River Mouth/ Sandusky Bay, Ohio	DO, copper, mercury	pH, conductivity, fecal coliforms, iron, nickel
7. Bar Point to Lemington, Ohio	pH, total phosphorus	
Western Basin Main Lake		
1. Entire Basin, U.S. Canada	DO, pH, total phosphorus, zinc	iron
Central Basin Nearshore		
1. Huron River Mouth/ Huron, Ohio	pH, copper, zinc	DO, conductivity, fecal coliforms, iron, nickel
2. Black River Mouth/ Lorain, Ohio	DO, iron, nickel, zinc, phenols, ammonia	conductivity, cadmium, copper

TABLE 6 CONT.

LOCATION	PARAMETER	
	Infrequent Violations	Frequent Violations
3. Rocky River Mouth to Cuyahoga River Mouth/ Cleveland, Ohio	DO, conductivity, fecal coliforms, phenols, ammonia	cadmium, copper, iron, nickel, zinc
4. Grand River Mouth/ Fairport, Ohio	conductivity, iron, nickel	cadmium, copper, zinc
5. Ashtabula River Mouth/ Ashtabula, Ohio	DO, conductivity, iron	cadmium, copper, zinc
6. Conneaut Creek Mouth/ Conneaut, Ohio	DO, conductivity, cadmium copper, nickel, zinc	
7. Wheatly to Point Burwell, Ontario	DO, pH, total phosphorus, ammonia, phenols, fecal coliforms	
<u>Central Basin Main Lake</u>		
1. Entire Basin, U.S. and Canada	pH, total phosphorus, zinc	DO, iron
<u>Eastern Basin Nearshore</u>		
1. Presque Isle Bay/ Erie, Pennsylvania	DO, conductivity, fecal coliforms, cadmium, copper, nickel, zinc	
2. Barcelona to Buffalo, New York	DO, conductivity, cadmium, copper, nickel	
3. Long Point Bay to Fort Erie, Ontario	pH, conductivity, total phosphorus, cadmium, silver	iron, zinc
<u>Eastern Basin Main Lake</u>		
1. Entire Basin, U.S. and Canada	pH, total phosphorus, zinc	iron

Another problem of a totally different nature may also present itself by the end of the decade. Lake Erie sport fish production is at an all-time high. This production, primarily in the western basin and along the south shore of the central basin, is nurtured by high nutrient concentrations and associated primary/secondary productivity. As phosphorus controls become more and more effective in limiting algal production, which is needed to reduce the anoxic region of the central basin hypolimnion, the food for such important fish species as walleye (Stizostedion vitreum vitreum) and yellow perch (Perca flavescens) may be eroded. As the 1980's proceed, it will become increasingly important to consider the balance between western basin fish production and central basin hypolimnion oxygen content.

The fundamental conclusion of this assessment is that through 1977 no significant decrease in the loading of suspended solids, dissolved solids, or nutrients occurred. Therefore, during this period the concentration of solids, including nutrients, remained relatively stable. However, an encouraging sign of effective nutrient control was that although no reductions were observed, the continual increases of the previous several decades had been stopped. During this period, other indicators of eutrophication, such as hypolimnetic oxygen rates, chlorophyll concentrations, plankton and benthos populations and turbidity also remained relatively stable, but high.

During the late 1970's changes began to occur which are continuing in the early 1980's: nutrient loading declined, phosphorus concentrations in the lake dropped, sources of contamination by several toxic substances have been checked, levels of contaminants in lake sediments and biota are subsiding, "clean water" forms of plankton and benthos are showing modest signs of recovery and fish populations are rebounding. However, cause and effect relationships of all of these changes are not obvious, most of the improvements have been small, and for many parameters, conclusive trends have yet to be established. But evidence for improvement is beginning to mount and it is becoming obvious to scientists, fishermen and shoreline dwellers alike that Lake Erie is recovering. The extent of future improvements will depend on continuing efforts to control loading of nutrients and toxic substances to the lake, particularly those associated with industrial and agricultural practices. Surveillance of Lake Erie water, biota, and sediment conditions must continue if we are to establish clear relationships between remedial actions and lake quality.

RECOMMENDATIONS

The 1978-1979 Lake Erie Intensive Study has provided the most comprehensive set of data on the status of the lake ever assembled. However, many questions remain unanswered, particularly in reference to the loading of toxic substances to the lake and their ecological impact. Many cause and effect relationships in the lake are poorly understood as are effects of specific remedial actions. To improve our understanding of this complex system and to eventually improve the quality of Lake Erie the following surveillance activities, remedial actions, evaluations and special studies are recommended:

Surveillance

1. A comprehensive surveillance for Lake Erie should be conducted on an annual basis and should contain the following components: (1) main lake, (2) nearshore areas of concern, (3) water intakes, (4) tributaries and connecting channels, (5) point sources, (6) atmospheric deposition, (7) beaches and (8) biomonitoring.

2. Main lake surveillance should be conducted in spring, summer and fall to determine (1) the seasonal concentration and quantity of nutrients in each basin, (2) the oxygen depletion rate and area of anoxia in the central basin and (3) seasonal biomass.

3. Nearshore areas of concern should be stressed in an annual monitoring program due to the fact that these areas are the most highly impacted or

potentially impacted areas within the lake, particularly in terms of toxic substances.

4. Water intake monitoring should be integrated into the nearshore surveillance effort at areas of concern.

5. Because of the increasing importance of non-point source loading to Lake Erie, surveillance of major tributaries and connecting channels should be expanded to include both periodic and event sampling (e.g. Detroit, Raisin, Maumee, Sandusky, Black, Rocky, Cuyahoga, Grand (Ohio), Ashtabula, Buffalo, Niagara, Grand (Ontario) rivers).

6. Point sources, particularly wastewater treatment plants, should be monitored routinely to ascertain compliance with Water Quality Agreement objectives.

7. Atmospheric deposition (wet and dry) monitoring should be continued within the Lake Erie drainage basin.

8. Because of the obvious public health hazards, Lake Erie bathing beaches should be monitored for bacterial contamination throughout the summer season.

9. Bio-monitoring programs should be expanded to detect a wider array of toxic substances in Lake Erie biota (e.g. young-of-the-year spottail shiners).

10. Future intensive studies should not be necessary if a flexible annual surveillance plan is adopted which is reviewed and modified each year to address continuing and emerging problems.

Remedial Actions

1. Agricultural communities should be encouraged to adopt conservation tillage or no-tillage practices on all suitable soils within the Lake Erie drainage basin.

2. As specified in the Water Quality Agreement of 1978, actions should be taken to ensure that all municipal wastewater treatment plants within the Lake Erie drainage basin which discharge in excess of 1 mgd are operated so that total phosphorus concentrations in their effluents do not exceed a maximum concentration of 1.0 mg/l.

3. States not now limiting the amount of phosphorus in household detergents should enact legislation which permits no more than 0.5 mg/l.

4. Special efforts should be undertaken to identify and control sources of toxic substances.

5. Education programs should be developed for specific land use activities (e.g. agri-business, urban development, industry, recreation) to foster pollution control.

Evaluation

1. Future evaluations of water quality violations should be related to impaired use of the lake (e.g. beaches, water supply, fishery, etc.)

2. The Lake Erie surveillance plan should be reviewed and evaluated annually to ascertain if it is providing the necessary information for designing effective management actions.

3. Before new surveillance plans are developed, a careful evaluation of past data and statistical techniques should be undertaken to more clearly understand apparent trends, or lack thereof, in lake conditions and biota.

4. Once new surveillance programs are implemented they should be reviewed annually to determine their effectiveness in evaluating remedial programs.

Special Studies

1. Studies should be continued to determine the ecological impact to Lake Erie of herbicide and insecticide runoff from conservation tillage cropland.

2. Studies should be continued to determine the relative availability of the various forms of phosphorus for biological productivity.

In order for any of these recommendations to be effective, it is important an international body, preferably the International Joint Commission, assume a more dominant role in planning, organizing, and securing funds to implement those actions which are deemed necessary to enhance the quality of the Great Lakes. A greater degree of cooperation is required among federal and state agencies, research institutions and resource users to effect the recovery of Lake Erie. The International Joint Commission has a key role in fostering such cooperation.

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APPENDIX A

LAKE ERIE INTENSIVE STUDY REPORTS PREPARED BY THE LAKE ERIE TECHNICAL ASSESSMENT TEAM

TAT Cont. No.	CLEAR Tech. Rept. No.	Report Title	Principal Author(s)
1.	226	Introduction, Methods and Summary	C.E. Herdendorf
2.	227	Data Compatability Analysis	P. Richards
3.	228	Main Lake Water Quality	D. Rathke L. Fay
4.	229	Nearshore Water Quality	L. Fay D. Rathke
5.	230	Nearshore Nutrient Distribution - Detroit River to Huron, Ohio	J. Letterhos
6.	231	Trace Metals in Main Lake and Nearshore Waters	C.L. Cooper S. Hessler
7.	232	Microbiology in Main Lake and Nearshore Waters	C.L. Cooper C. Kimerline
8.	233	Main Lake and Nearshore Water Quality Problem Areas	C.L. Cooper A. Rush W. Snyder
9.	234	Water Quality Violations - Detroit River to Huron, Ohio	C.E. Herdendorf L. Fay
10.	235	Synoptic Mapping of Water Quality - Western Basin	Hamdy C.E. Herdendorf
11.	236	Water Quality Index Evaluation	J.J. Mizera C.E. Herdendorf
12.	237	Cluster Analysis of Nearshore Water Masses	C.E. Herdendorf J.J. Mizera

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13.	238	Nearshore Phytoplankton - Detroit River to Huron, Ohio	D.Z. Fisher D. Rathke
14.	239	Cladophora Surveillance Program - Western Basin	R. Lorenz C.E. Herdendorf
15.	240	Fisheries Status and Response to Water Quality	M.D. Barnes
16.	241	Toxic Organic Contaminants in Fish	B. Burby M.D. Barnes C.E. Herdendorf
17.	242	Nearshore Benthic Macroinvertebrates - Detroit River to Huron, Ohio	G. Keeler
18.	243	Macroinvertebrates in Main Lake and Nearshore Sediments	P.E. Steane C.L. Cooper
19.	244	Annotated Bibliography of Lake Erie Benthic Macroinvertebrates	G. Keeler
20.	245	Main Lake Sediment Chemistry	N. Carlson J.J. Mizera
21.	246	Sediment Oxygen Demand	W. Davis L. Fay C.E. Herdendorf
22.	247	Historical Water Quality Trends - Cleveland, Ohio	P. Richards
23.	248	Nearshore Water Quality Trends	A. Rush C.L. Cooper
24.	249	Main Lake Water Quality Trends	C.E. Herdendorf L. Fay
25.	250	Nutrient Loading to Lake Erie and Its Effect on Lake Biota	K-P Chen R. Sykes
26.	260	Final Report	D. Rathke et al.
27.	261	Management Report	C.E. Herdendorf

APPENDIX B

LAKE ERIE INTENSIVE STUDY REPORTS CONTRIBUTED TO THE LAKE ERIE TECHNICAL ASSESSMENT TEAM

I. Tributary Component

A.	Monthly monitoring data (computer print-out) for Clinton, Rouge, Ecorse, Huron, Raisin Rivers, 1978-1979	J. Vitelhic, MDNR	June 29, 1981
B.	Monthly monitoring data of Erie County, Pa. tributaries: Walnut, Elk, Sixteen-mile (tabular data)	R. Wellington, ECDH	Dec. 31, 1980
C.	Summary of phosphorus loading data for 1978 collected by IJC Regional Office (computer print-out)	Haffner, IJC-Windsor	June 3, 1980
D.	Toledo Area River and Stream Water Quality Data Report, 1968-1974 (March, 1976)	Russell, TPCA	July 11, 1980
E.	Water quality data collected by the Toledo Pollution Control Agency at the C&O docks at the mouth of the Maumee River, 1975-1981 (bench sheets)	Russell, TPCA	Feb. 23, 1981
F.	Estimation of tributary total phosphorus load into Lake Erie, evaluation of applicable models	Kuo-pin Chen, OSU-TAT	Dec. 17, 1980
G.	Periodic tributary monitoring data (computer print-out) of Lake Erie tributary surveillance conducted by the New York State Dept. of Environmental Conservation	Maylath, NYDEC	Dec. 18, 1980
H.	Summary of total phosphorus loadings for the water years 1970 to 1977 for Canadian streams draining into Lake Erie	R.D. Terry, OMOE	Feb. 2, 1981

I.	Total phosphorus loadings for the water years 1978 and 1979 for the Canadian streams draining into Lake Erie	R.D. Terry, OMOE	Jan. 1, 1981
J.	On Phosphorus and its availability in total loading into Lake Erie, 1970-1980	Kuo-pin Chen, OSU-TAT	May 15, 1981
II.	<u>Point Source Component</u>		
A.	Summary of the phosphorus loading data collected by the IJC Regional Office for 1978	Haffner, IJC-Windsor	June 3, 1980
III.	<u>Atmospheric Component</u>		
A.	Preliminary outline draft: final report for 1979-1980: An experimental study of Lake Loading by Air Pollution Transport and Dry Deposition	Sievering, et al. Governors State Univ.	Sept. 1982
B.	Summary of Great Lakes weather and ice conditions, winter 1978-1979. Tech. Mem. ERL GLERL-31	NOAA, GLERL	Aug. 1980
IV.	<u>Connecting Channels Component</u>		
A.	Water Year 1980-Detroit River (6 page rept.)	MDNR	June 29, 1981
B.	Water quality assessment of the Thames River mouth, Lake St. Clair, 1975.	Hamdy, Kinkead, Griffiths OMOE	June 10, 1980
C.	Great Lakes water quality data summary, Detroit River 1976	OMOE	June 10, 1980
D.	Great Lakes water quality data summary, St. Clair River 1976	OMOE	June 10, 1980

E.	St. Clair River organics study, waste dispersion	Hamdy and Kinkead, OMOE	June 10, 1980
F.	St. Clair River organics study. The detection of muagenic activity; screening of twenty-three compounds of industrial origin	Rokosh and Lovasz	June 10, 1980
G.	St. Clair River organics study. Biological surveys 1968 and 1977	OMOE	June 10, 1980

V. Nearshore Intensive Surveillance Component

A.	Investigation of water quality in the Leamington area of western lake Erie, 1973-1976	Hamdy and Kinkead OMOE	June 10, 1980
B.	Recent changes in the phyto-plankton of Lakes Erie and Ontario	K. Nicholls, OMOE	June 10, 1980
C.	Phytoplankton studies in the Nanticoke area of Lake Erie, 1969-1978	Hopkins and Lea, OMOE	June 10, 1980
D.	Water movements in the Nanticoke region of Lake Erie, 1976. Ibid., 1978	B. Kohli, OMOE	June 10, 1980
E.	Nanticoke Water Chemistry 1975, Ibid. 1976	J. Polak	June 10, 1980
F.	Nanticoke Aquatic Environment, 1967-1974	Palmer and Polak, OMOE	June 10, 1980
G.	Declines in the nearshore phyto-plankton of Lake Erie's western basin since 1971	K. Nicholls, et al. OMOE	June 10, 1980
H.	An assessment of water quality conditions Wheatley Harbour, Lake Erie 1979	Hamdy and Ross, OMOE	Sept. 1980
I.	An assessment of the bottom fauna and sediments of the western basin of Lake Erie, 1979	OMOE	May 1981

J.	Biological status in nearshore zone of the south shore of Lake Erie between Vermilion and Ashtabula, Ohio: Preliminary Report	Krieger et al. Heidelberg College	Feb. 1979
K.	Water quality and some aspects of chemical limnology in the near-shore zone of the south shore of Lake Erie between Vermilion and Ashtabula, Ohio: preliminary report	P. Richards, Heidelberg College	Feb. 1979
L.	Limnological surveillance of the nearshore zone of Lake Erie in central and eastern Ohio. Preliminary report. Part I: Chemical Limnology	P. Richards	Jan. 1980
M.	Chemical limnology in the near-shore zone of Lake Erie between Vermilion, Ohio and Ashtabula, Ohio, 1978-1979: Data Summary and Preliminary Interpretations and Appendices	P. Richards, Heidelberg College	Feb. 1981
N.	Historical trends in water chemistry in the U.S. Nearshore Zone, central basin, Lake Erie	P. Richards, Heidelberg College-TAT	Nov. 1981
O.	Data Compatability Analyses - Lake Erie International Surveillance Plan	P. Richards, Heidelberg College-TAT	Nov. 1981
P.	Environmental status of the southern nearshore zone of the central basin of Lake Erie in 1978 and 1979 as indicated by the benthic macroinvertebrates	K. Krieger, Heidelberg College	June 10, 1981
Q.	The crustacean zooplankton of the southern nearshore zone of the central basin of Lake Erie in 1978 and 1979: Indications of trophic status	K. Krieger, Heidelberg College	June 10, 1981
R.	Composition and abundance of phytoplankton of the central basin of Lake Erie during 1978-1979. Lake Erie Nearshore study	P. Kline, Heidelberg College	Oct. 23, 1981

S.	Bacterial water quality of the southern nearshore zone of Lake Erie in 1978 and 1979	Stanford, Heidelberg College	Sept. 1981
T.	A preliminary summary of the 1978 nearshore monitoring program for eastern Lake Erie	SUNY-Buffalo	March 1979
U.	Lake Erie nearshore monitoring program, Conneaut, Ohio to Buffalo, New York, Part 1, 1978	SUNY-Buffalo	April 1981
V.	Cruise means data for 1978 and 1979 nearshore monitoring program for eastern Lake Erie (computer print-out)	SUNY-Buffalo	Nov. 24, 1981
W.	Western Lake Erie nearshore intensive study 1978-1979: Microbiology	Diamond et al. OSU-CLEAR	Dec. 1980
X.	Western Lake Erie nearshore intensive study 1978-1979: Nearshore water quality problem areas	Herdendorf and Fay, OSU-CLEAR	Dec. 1980
VI.	Water Intake Component		
A.	Water intake monitoring data collected during 1978-1979 by the Erie County (Pa.) Dept. of Health (WQN Sta. 601)	Wellington, ECDH	Dec. 31, 1980
VII.	Beach Monitoring Component		
A.	Comprehensive summer beach surveillance data collected by the Erie County (Pa.) Dept. of Health	Wellington, ECDH	Dec. 31, 1980
VIII.	Cladophora Component		
A.	Cladopohora monitoring - central and eastern basins	Millner et al. SUNY-Buffalo	Dec. 31, 1979

IX. Main Lake Component

A.	Workshop on the analysis and reporting of Erie 79 and Erie 80 experiments (Stage I)	F. Boyce, CCIW	Nov. 17, 1980
B.	Report on summer phosphorus and oxygen for Lake Erie - 1970, 1977 and 1978	F. Rosa, CCIW	April 1979

X. Fish Contaminants Component

A.	Organic chemical residues in Region V watersheds (data rept.)	Veith and Kuehl, Duluth ERL	June 26, 1980
B.	Organochlorine contaminant concentrations and uptake rates in fishes in Lake Erie tributary mouths (abst. and data summary)	Herdendorf, Barnes, Burby, OSU-TAT	Dec. 9, 1980
C.	Laboratory report. Residues of polychlorinated dibenzo-p-dioxins and dibenzofuransin Great Lakes fish	Stallings, et al., USF & WS	July 25, 1981
D.	Trends in the mercury content of western Lake Erie fish and sediment, 1970-1977	Kinkead and Hamdy, OMOE	June 4, 1980

XI. Wildlife Contaminants Component

No reports to TAT

XII. Radioactivity Component

A.	1977-1979 environmental radiological monitoring for the Davis-Besse Nuclear Power Station at Locust Point and Lake Erie	Herdendorf/ Toledo Edison Co.	Aug. 29, 1980

APPENDIX C

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