United States
Environmental Protection
Agency

Great Lakes National
Program Office
536 South Clark Street
Chicago, Illinois 60605

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EPA

Lake Michigan Intensive Survey 1976-1977

LAKE MICHIGAN INTENSIVE SURVEY

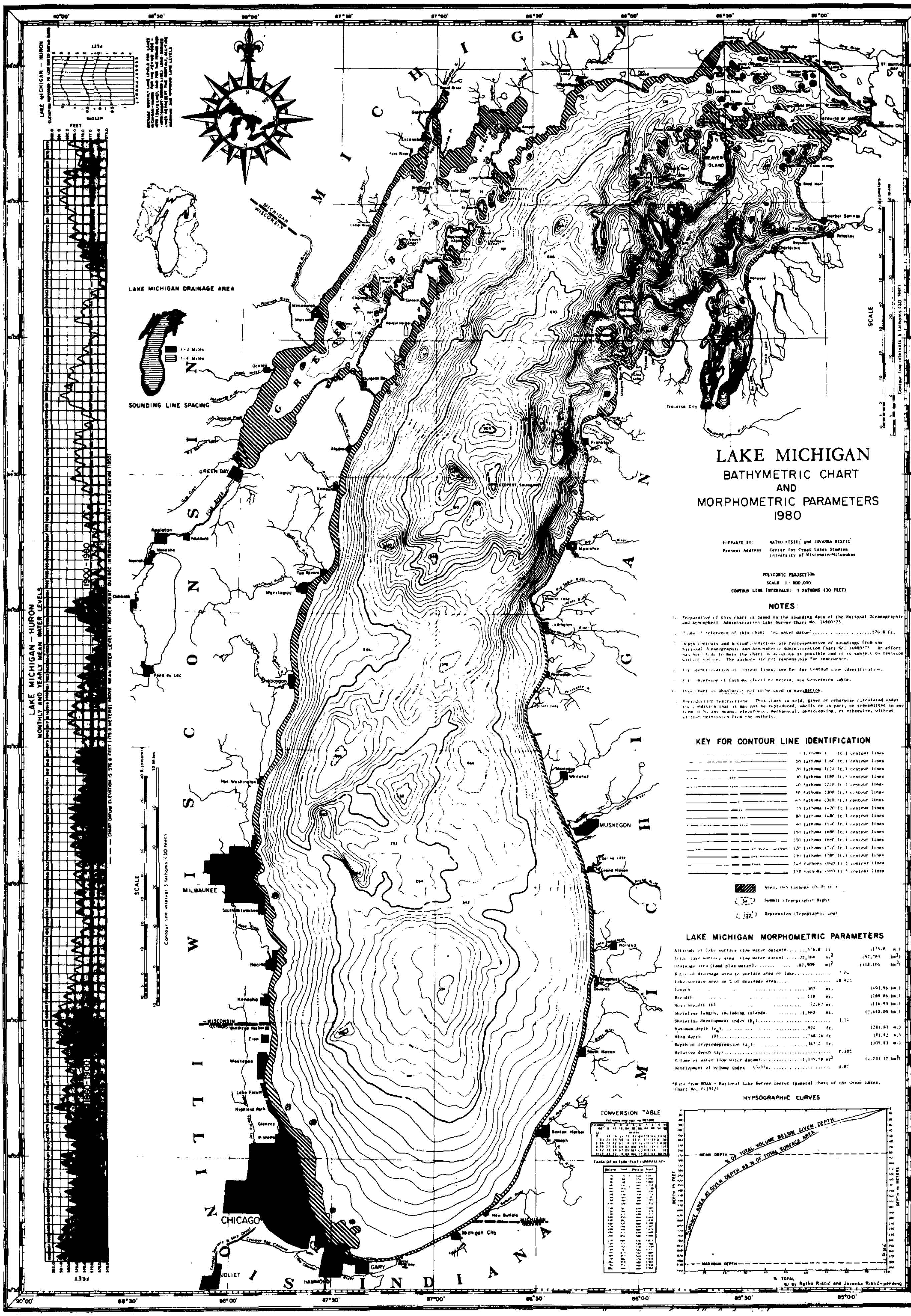
1976-1977

By

David C. Rockwell
David S. DeVault III
Marvin F. Palmer
Clyde V. Marion
Robert J. Bowden

For

Great Lakes National Program Office
United States Environmental Protection Agency
536 S. Clark Street Room 932
Chicago, Illinois 60605



LAKE MICHIGAN
BATHYMETRIC CHART
AND
MORPHOMETRIC PARAMETERS
1980
Present Address Center for Great Lakes Studies University of Wisconsin-Milwaukee
SCALE 1 : 800,000
CONTOUR LINE INTERVALS: 5 FATHOMS (30 FEET)
NOTES:
1. Preparation of this chart is based on the sounding data of the National Oceanographic and Atmospheric Administration Lake Survey Chart No. 14900/75.
KEY FOR CONTOUR LINE IDENTIFICATION
Summit (Topographic High)
LAKE MICHIGAN MORPHOMETRIC PARAMETERS
HYPSOGRAPHIC CURVES
TOTAL VOLUME BELOW GIVEN DEPTH
SURFACE AREA
CONVERSION TABLE
LAKE MICHIGAN DRAINAGE AREA
SOUNDING LINE SPACING
LAKE MICHIGAN – HURON
MONTHLY AND YEARLY MEAN WATER LEVELS
1900-1980
1860-1900
SCALE
FEET
MICHIGAN
WISCONSIN
ILLINOIS
INDIANA
GREEN BAY
BEAVER ISLAND
Traverse City
Frankfort
Manistee
Ludington
Muskegon
Grand Haven
Holland
South Haven
Benton Harbor
Michigan City
GARY
HAMMOND
CHICAGO
JOLIET
Kenosha
Racine
MILWAUKEE
Port Washington
Sheboygan
Manitowoc
Two Rivers
Algoma
Green Bay
Appleton
Oshkosh
Fond du Lac
DEEPEST SOUNDING

DISCLAIMER

FOREWORD

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

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

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INTRODUCTION

Monitoring and surveillance of the water quality of the lakes and of connecting waterways are vital if we are to determine the most practical means for protecting these irreplaceable freshwater supplies from physical, chemical, and bacteriological health hazards. The lakes are large and complex both individually and as a system. The Great Lakes water surface areas are approximately equal to the surface areas of some states: Maine (Lake Superior), West Virginia (Lake Huron or Lake Michigan), New Jersey (Lake Ontario), and New Hampshire (Lake Erie). The water they contain is estimated at 6000 trillion gallons.[1] If this water was spread evenly, all the conterminous states[2] would be under 10 feet of water.

The International Joint Commission's Great Lakes Water Quality Board has designed a long-term monitoring plan for the Great Lakes Basin providing for a 9-year repeating cycle of intensive studies on each lake. This plan is based, in part, on the assumption that the open waters of each lake are changing slowly in response to cultural and environmental impacts. The need for skilled personnel, large lake-going vessels, and demanding laboratory analytical precision and accuracy are constraining requirements in Great Lakes surveillance. Consequently, intensive studies are confined to one lake at a time. In cooperation with remedial programs, this program will ensure to the fullest extent possible that meaningful action can be taken for the prevention, reduction, and eventual control of pollution in the entire Great Lakes Basin.

During 1976 and 1977, the U.S EPA undertook, in cooperation with the University of Michigan, an intensive study of Lake Michigan. This two-year study is the basis for this report.

OBJECTIVES OF SURVEILLANCE PROGRAM

The Water Quality Board has established surveillance goals (International Joint Commission, GLWQB, 1976, p. VII) for the Great Lakes. One of these goals requires surveillance and monitoring of the Great Lakes:

> "To provide sufficient data to permit valid interpretation of water quality conditions in order to distinguish the impact of remedial programs from natural changes, both near to and remote from sources. This goal entails documentation of the loadings not under control of present remedial programs as well as monitoring ambient water quality or impacted biota in the system in order to distinguish the impact of controlled loadings from the impact from other causes."

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[1]U.S. Lake Survey estimates 5457 cubic miles of water in the Great Lakes.

[2]Continental U.S. contains 2,975,000 square miles- Rand McNally, Popular World Atlas, 1976.

The first general conclusion and recommendation (International Joint Commission, GLWQB 1976, p.3) is:

> "Monitoring and surveillance of the Great Lakes and connecting waterways are necessary to evaluate the degree to which the objectives, including non-degradation criteria, of the Canada-United States 1972 Great Lakes Water Quality Agreement are being achieved. As part of the above, monitoring and surveillance are needed to assess the effectiveness of pollution abatement measures. A surveillance program is required to ascertain the nature and degree of changes in Great Lakes water quality, particularly as a consequence of pollution from existing or new direct and indirect human activities. The program can also identify previously undetected contaminants before they have an adverse affect on the Great Lakes environment. Surveillance provides valuable inputs for establishing and revising limits and criteria for both loading and aquatic contaminants."

The surveillance program for Lake Michigan was designed with four objectives in mind:

1. To determine the status of the open and nearshore waters of Lake Michigan in 1976-77 and to compare with the standards, criteria, and objectives for the protection of aquatic life in Lake Michigan (Appendix A).

2. To provide data to characterize the chemical, physical, microbiological, and biological aspects of the environment against which future changes may be evaluated.

3. To compare present data with data collected in the past in order to determine if Lake Michigan is changing and how these changes may be occurring.

4. To determine how these changes are related to waste reduction and pollution abatement programs.

AUTHORITY FOR STUDY

The Federal Water Pollution Control Act as amended in 1972 by Public Law 92-500, Section 108 (a), authorized the EPA to enter into agreements and to carry out projects to control and eliminate pollution in the Great Lakes Basin. Section 104 (f) of the law provides the authority to conduct research, technical development, and studies with respect to the quality of the waters of the Great Lakes. Section 104 (h) grants authority to develop and to demonstrate new or improved methods for the prevention, removal, reduction, and elimination of pollution in the lakes. The Boundary Water Treaty between the United States of America and Canada in Annex 2, paragraph 10, of the Great Lakes Water Quality Agreement required both countries to monitor the extent of eutrophication in the Great Lakes system and to develop measures to control phosphorus and other nutrients. Article V (f) requires consideration of measures for the abatement and control of pollution from dredging activities. The agreement, signed in 1972, was reaffirmed in 1978.

PARTICIPANTS AND ROLES

The Great Lakes monitoring program is a cooperative effort involving several government agencies and universities, with the U.S. EPA's Great Lakes National Program Office (GLNPO), Chicago, providing overall coordination. Each organization whose data are reported on follows:

Great Lakes National Program Office (GLNPO)

The GLNPO conducted 12 open lake cruises during 1976 and 1977 on the southern basin of Lake Michigan. A special study was made to determine locations of heavy metal concentrations in the entire Lake during 1976 and 1977 by GLNPO. Nearshore studies were conducted in five areas; Chicago-Calumet, Indiana, Milwaukee, and Green Bay areas. Station locations are illustrated in Figure 1.

University of Michigan, Great Lakes Research Division (GLRD)

GLRD conducted five open lake cruises during 1976 in the northern half of Lake Michigan and provided phytoplankton and zooplankton analyses for nearshore studies uder grants fron the U.S. EPA. Station locations are illustrated (Figure 1) in the northern basin of Lake Michigan. Separate reports are in press for the northern basin and the zooplankton analysis of Green Bay and Indiana nearshore studies. Stoermer and Stevenson (1979) and Stoermer and Tuckman (1979) have completed reports on phytoplankton for Green Bay and the Indiana nearshore study respectively.

Michigan Department of Natural Resources (MDNR)

The MDNR conducted the first of the three nearshore surveys in Green Bay during 1977 under a grant from the U.S. EPA. Results can be found in Limnological Survey of Nearshore Waters of Lake Michigan 1976. EPA Grant R00514601. David Kenage, William Creal, and Robert Bash. In Press USEPA Grosse Ile, Michigan 48138.

METHODS

Methods Used by GLNPO

Vessel

In the Southern basin and nearshore cruises (Table 1) the R/V Simons was used. The R/V Roger Simons is an ex-Coast Guard vessel build in

Duluth, Minnesota by the Marine Iron and Shipbuilding Company as a lighthouse tender. The vessel was built in 1939. The vessel is of the WAGL-type, 122' overall length; beam-extreme 27'; draft maximum 7'; displacement, full load 342 tons; hull material, steel; twin screw, 460 SHP propulsion diesel.

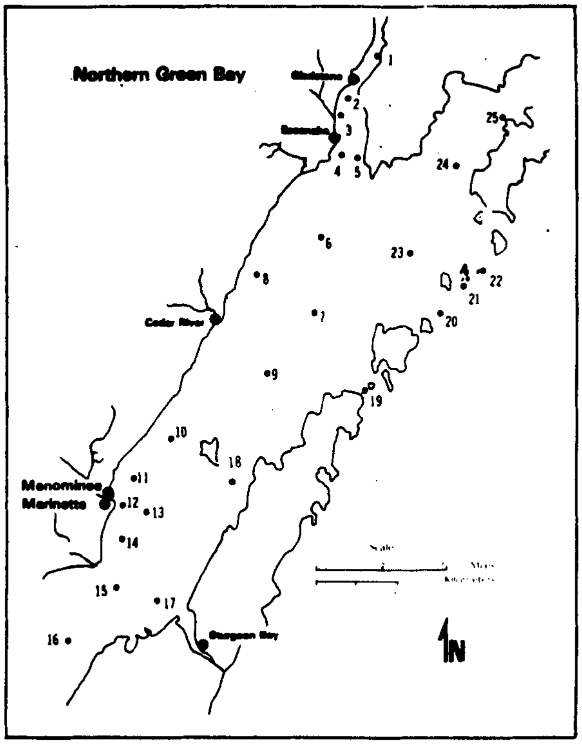
Station Selection. The locations of the stations in the southern basin (Table 2.) were the result of recommendations by the Monitoring Committee for the Conference on the Matter of Pollution of Lake Michigan and Tributary Basins (FWPCA 1968) and of the Great Lakes Water Quality Board (Internation Joint Commission, GLWQB 1976). All locations and data are available in the USEPA data management system called STORET (Appendix B). The locations of the open lake stations were influenced by the fact that they had previously been sampled by the Federal Water Pollution Control Administration in 1963 and 1970, the U.S. EPA in 1974 (STORET, 1975), or the U.S. Fish and Wildlife Service in 1954-55, (Beeton and Moffett, 1964). Stations were added to give greater coverage to the nearshore waters. Several special stations around the Manitowoc and South Haven water intakes were designated to evaluate water intake data in 1976.

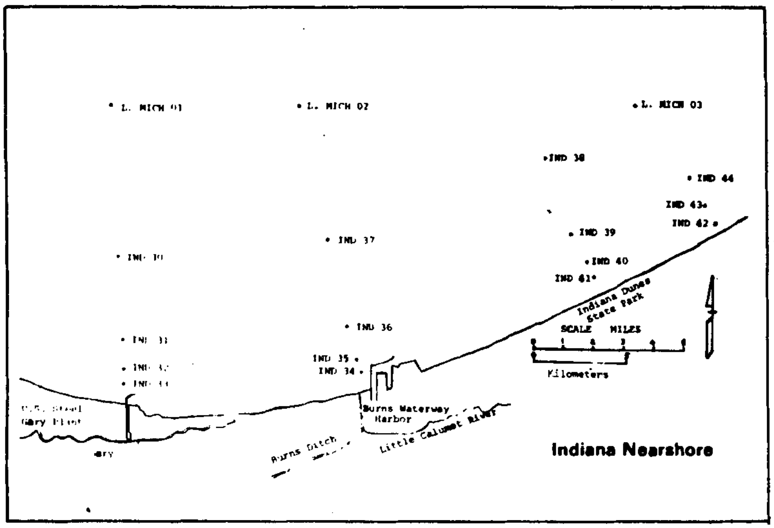
Depth Selection. During the first four cruises of 1976, each station was sampled, when possible, at 2,5,10,20,50,100 meters, and 1 meter above the bottom. Throughout the rest of 1976 and during 1977 additional samples were taken from thermally stratified stations at mid thermocline, 5M above and 5M below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

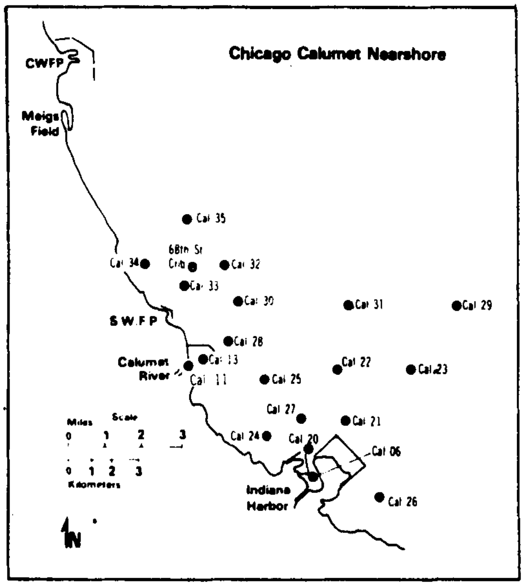
Sampling. Tables 3a and 3b give an overview of the parameters measured during each cruises in 1976-77. In the southern basin samples were collected by means of a hydrographic winch with 5/32 in. 5X7 stranded stainless steel aircraft cable, terminated with a 50 lb. steel weight. General Oceanics 8 liter and 5 liter rigid PVC Model 1010 Niskin water sampling bottles were closed at the designated depths by General Oceanics bronze messengers Model M1000MG. The bottles and messengers are designed so that a messenger released from the deck can simultaneously close the first bottle it encounters and cause this bottle to release a second messenger to close a subsequent bottle. This sequence continues until the lowest sampling bottle is encountered. A retractable overboard platform was used to hold the person loading the Niskin bottles onto and subsequently retrieving the bottles from the cable. Sterile pre-evacuated 250 ml. ZoBell bottles (APHA, 1975) were used for microbiology sample collection. A retractable boom, a metering wheel (Kahlsico 5/32 in. wire block) for determining sampling depths and the necessary cable blocks for configuring the cable completes the list of depth sampling equipment.

Water samples were processed as illustrated in the flow chart (Figure 2). Each Niskin sampling bottle was emptied into the sample bottles as soon as possible, normally within one minute and never later than 10 minutes, after collection. All chemistry sample bottles were rinsed once with sample before filling. New polyethylene containers (PEC), one gallon or two and one half gallon, were used to hold the samples for the onboard

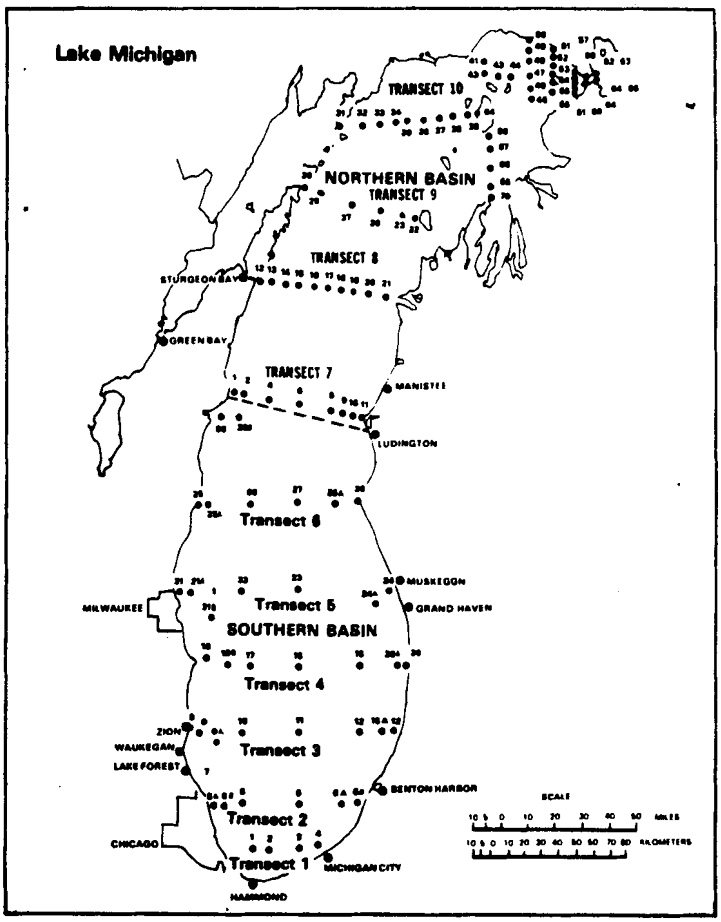
figure 1







Survey Cruise Stations



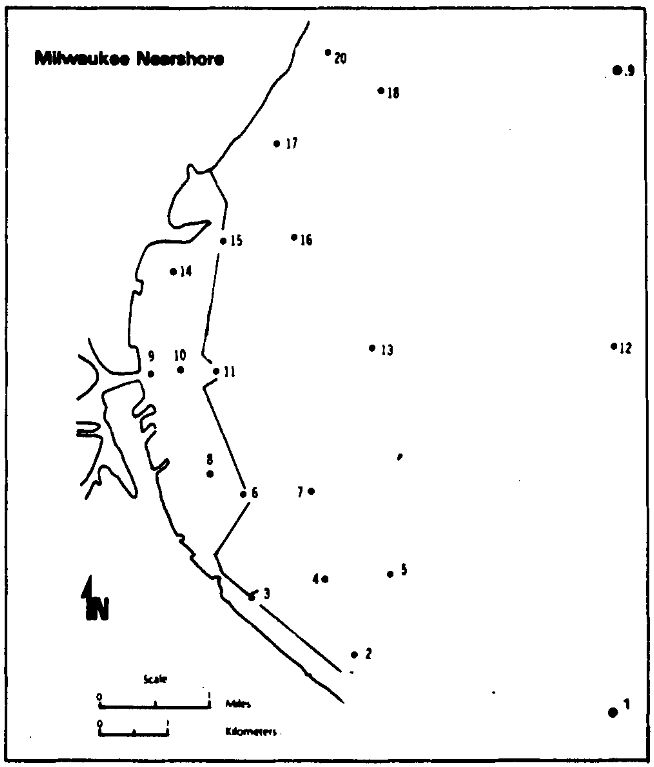


TABLE 1

EPA SPONSORED LAKE MICHIGAN SURVEYS

1976-1977

	Cruise Code
Northern Basin Open Lake Surveys (U. of Mich.) 1976	
#1 Apr 22/Apr 28	1
#2 Jun 02/Jun 08	2
#3 Jul 10/Jul 17	3
#4 Aug 10/Aug 19	4
#5 Oct 07/Oct 13	5
Southern Basin Open Lake Surveys 1976	
#1 May 01/May 03	1
#2 May 25/Jun 02	2
#3 Jun 15/Jun 21	3
#4 Jul 07/Jul 13	4
#5 Aug 03/Aug 10	5
#6 Aug 24/Sep 02	6
#7 Sep 14/Sep 20	7
#8 Oct 07/Oct 08	8
Whole Lake Two Day Surveys 1976	
Jul 16/Jul 18 South to North (West-side)	E
Jul 16/Jul 17 North to South (East-side) U. of Mich.	M
Southern Basin Open Lake Surveys 1977	
#1 Apr 19/Apr 24	1
#2 Jun 11/Jun 16	2
#3 Aug 20/Aug 25	3
#4 Sep 17/Sep 24	4
Trace Metal Surveys 1977	
Southern Basin Jul 06/Jul 10	S
Northern Basin Jul 26/Aug 01	N
Milwaukee Nearshore Surveys 1977	
#1 May 10/May 15	
#2 Jul 13/Jul 18	
Chicago-Calumet Nearshore Surveys 1977	
#1 May 23/May 28	
#2 Aug 30/Sep 03	

(contd.) TABLE 1

Indiana Nearshore Surveys 1977
- #1 Jun 11
- #2 Aug 20
- #3 Sep 24

Green Bay Surveys 1977
- #1 May 03/May 19 (Mich. DNR)
- #2 Aug 10/Aug 11
- #3 Oct 05/Oct 08

TABLE 2A

Stations Sampled By the U.S. EPA In the Southern Basin of Lake Michigan in 1976 and 1977

L. MICH STATION & DEPTH #	(m)	LATITUDE	LONGITUDE	PREVIOUS* SAMPLING F	P	74	OPEN LAKE CRUISES SAMPLED (See Table 1 for Cruise Codes) 1976 1	2	3	4	5	6	7	8	E	M	1977 1	2	3	4	S	N
01	15	41°46'00"	87°20'00"		X	X		X	X	X	X	X	X				X	X	X	X		
02	22	41 46 00	87 13 00		X	X		X	X	X	X	X	X				X	X	X	X		
03	18	41 46 00	87 00 00		X	X		X	X	X	X	X	X				X	X	X	X		
04	16	41 48 00	86 53 00		X	X		X	X	X	X	X	X				X	X	X	X		
05	35	42 00 00	87 25 00		X	X		X	X	X	X	X	X		X		X	X	X	X		
05a	6	42 00 00	87 37 00					X	X	X	X	X	X				X	X	X	X		
05b	13	42 00 00	87 33 20					X	X	X	X	X	X				X	X	X	X		
06	66	42 00 00	87 00 00		X	X		X	X	X	X	X	X			X	X	X	X	X		
06a	27	42 00 00	86 39 00					X	X	X	X	X	X				X	X	X	X		
06b	14	42 00 00	86 35 40					X	X	X	X	X	X				X	X	X	X		
07	4	42 12 00	87 43 00		X	X		X	X	X	X	X	X				X	X	X	X		
09	11	42 24 00	87 47 00		X	X		X	X	X	X	X	X				X	X	X	X		
09a	31	42 23 30	87 42 30					X	X	X	X	X	X				X	X	X	X		
10	97	42 23 00	87 25 00		X	X		X	X	X	X	X	X		X		X	X	X	X	X	
11	128	42 23 00	87 00 00		X	X		X	X	X	X	X	X			X	X	X	X	X		
12	62	42 23 00	86 35 00		X	X		X	X	X	X	X	X				X	X	X	X	X	
13	17	42 23 00	86 20 00		X	X		X	X	X	X	X	X				X	X	X	X		
13a	30	42 23 00	86 23 20					X	X	X	X	X	X				X	X	X	X		
15	37	42 37 00	86 18 00		X	X		X	X	X	X	X	X				X	X	X	X		
16	22	42 47 00	87 41 00		X	X		X	X	X	X	X	X				X	X	X	X		
16b	79	42 44 25	87 31 40	X				X	X	X	X	X	X				X	X	X	X	X	
17	100	42 44 00	87 25 00		X	X		X	X	X	X	X	X		X		X	X	X	X		
18	161	42 44 00	87 00 00		X	X		X	X	X	X	X	X			X	X	X	X	X		

(contd.) TABLE 2A

L. MICH STATION & DEPTH #	(m)	LATITUDE	LONGITUDE	PREVIOUS SAMPLING F	P	74	OPEN LAKE CRUISES Sampled (See Table 1 for Cruise Code) 1976 1	2	3	4	5	6	7	8	E	M	1977 1	2	3	4	S	N
19	92	42 44 00	86 35 00		X	X		X	X	X	X	X	X				X	X	X	X		
20	22	42 44 00	86 15 00		X	X		X	X	X	X	X	X				X	X	X	X		
20a	46	42 44 00	86 18 00					X	X	X	X	X	X				X	X	X	X		
21	10	43 08 00	87 53 00		X	X		X	X	X	X	X	X				X	X	X	X		
21a	44	43 08 00	87 47 45					X	X	X	X	X	X				X	X	X	X		X
21b	73	43 01 50	87 37 15	X				X	X	X	X	X	X				X	X	X	X		
22	78	43 08 00	87 25 00		X			X	X	X	X	X	X		X		X	X	X	X		
23	88	43 08 00	87 00 00		X			X	X	X	X	X	X			X	X	X	X	X		
24	16	43 08 00	86 19 00		X	X		X	X	X	X	X	X				X	X	X	X		
24a	80	43 06 00	86 28 00	X				X	X	X	X	X	X				X	X	X	X	X	
25	20	43 36 00	87 44 00		X	X	X	X	X	X	X	X	X	X			X	X	X	X		
25a	55	43 36 00	87 39 20				X	X	X	X	X	X	X	X			X	X	X	X		X
26	133	43 36 00	87 22 00		X		X	X	X	X	X	X	X	X	X		X	X	X	X		
27	112	43 36 00	86 55 00		X		X	X	X	X	X	X	X	X		X	X	X	X	X		
28	14	43 36 00	86 33 00		X	X	X	X	X	X	X	X	X	X			X	X	X	X		X
28a	77	43 36 00	86 47 00				X	X	X	X	X	X	X	X			X	X	X	X		
29	17	44 36 00	87 34 00		X	X	X	X	X	X	X	X	X	X			X	X	X	X		
29b	73	44 36 10	87 27 00	X			X	X	X	X	X	X	X	X			X	X	X	X		X
13c	18	42 24 35	86 19 20					X	X	X	X	X	X									
13d	6	42 24 00	86 17 30					X	X	X	X	X	X									
13e	6	42 22 55	86 17 50					X	X	X	X	X	X									
13w	2	42 24 00	86 17 00						X	X	X	X	X									
29c	6	44 08 20	87 33 30				X															
29d	9	44 07 00	87 33 35				X															
29e	11	44 06 05	87 35 10				X	X	X	X	X	X	X	X								
29f	6	44 07 07	87 36 25				X															
29g	10	44 04 55	87 37 05				X	X	X	X	X	X	X	X								
29h	6	44 05 25	87 38 25				X	X	X	X	X	X	X	X								
29j	6	44 03 35	87 30 30				X	X	X	X	X	X	X	X								
29w	2	44 06 00	87 40 00								X	X	X	X								

*Previous Sampling
F= U.S. Fish & Wildlife Service 1954/5, 1970/71
P= Federal Water Pollution Control Administration 1962/63
74= U.S. Environmental Protection Agency 1974

TABLE 2B

Stations Sampled by U. of Michigan and U.S. EPA in the Northern Basin of Lake Michigan in 1976 and 1977.

				OPEN LAKE CRUISES Sampled (See Table 1 For Cruise Codes)							
				1976							1977
STATION	DEPTH (m)	LATITUDE	LONGITUDE	1	2	3	4	5	E	M	N
NCM001	7	44°10'30"	87°30'24"	X	X	X	X	X			
NCM002	31	44 10 18	87 28 24	X	X	X	X	X			
NCM004	159	44 08 24	87 14 00	X	X	X	X	X	X		
NCM006	171	44 06 54	86 59 44	X	X	X	X	X			
NCM008	160	44 05 24	86 46 00	X	X	X	X	X		X	
NCM009	137	44 04 30	86 39 00					X			
NCM010	42	44 03 36	86 32 00	X	X	X	X				X
NCM011	7	44 03 33	86 31 18	X	X	X	X				
NCM012	7	44 47 30	87 17 48	X	X	X	X	X			
NCM013	28	44 47 00	87 12 42	X	X	X	X				X
NCM014	111	44 46 18	87 05 24			X					
NCM015	160	44 45 36	86 58 00	X	X	X	X	X	X		
NCM016	243	44 44 54	86 50 42			X					
NCM017	250	44 44 12	86 43 18	X	X	X	X	X			
NCM018	241	44 43 30	86 35 54			X					
NCM019	419	44 42 48	86 28 30	X	X	X	X	X		X	
NCM020	157	44 42 00	86 21 06	X	X	X	X	X			
NCM021	247	44 41 30	86 15 48	X	X	X	X	X			
NCM022	227	45 07 12	86 04 24	X	X	X	X	X			
NCM023	75	45 07 42	86 08 00	X	X	X	X	X			
NCM025	186	45 10 42	86 22 30	X	X	X	X	X		X	
NCM027	120	45 13 24	86 36 48	X	X	X	X	X	X		X
NCM029	28	45 16 12	86 51 24	X	X	X	X	X			
NCM030	32	45 17 36	86 57 42	X	X	X	X	X			
NCM031	7	45 36 24	86 35 48	X	X	X	X	X			
NCM032	34	45 36 42	86 32 42	X	X	X	X	X			
NCM033	66	45 37 06	86 25 30			X					
NCM034	82	45 37 30	86 18 00	X	X	X	X	X			X
NCM035	91	45 38 12	86 03 30	X	X	X	X	X			
NCM036	85	45 38 42	85 54 00			X					
NCM038	11	45 39 00	85 48 18	X	X	X	X	X			
NCM039	50	45 39 24	85 42 36	X	X	X	X	X			
NCM040	7	45 39 48	85 37 06	X	X	X	X	X			
NCM041	14	45 53 18	85 35 12	X	X		X	X			X
NCM042	25	45 57 00	85 35 12	X	X				X		
NCM043	28	45 52 42	85 28 30	X	X						
NCM044	31	45 51 24	85 22 00	X	X	X	X	X			
NCM045	26	45 48 36	85 15 00	X	X	X	X	X			
NCM046	75	45 51 12	85 15 00	X	X	X	X	X			
NCM047	137	45 53 42	85 15 00	X	X	X	X	X			
NCM048	101	45 56 00	85 15 00	X	X	X	X	X			
NCM049	75	45 58 54	85 15 00	X	X	X	X	X			

(contd.) TABLE 2B

STATION	DEPTH (m)	LATITUDE	LONGITUDE	OPEN LAKE CRUISES Sampled 1976: 1	2	3	4	5	E	M	1977: N
NCM050	26	46°01'24"	85°15'00"	X	X	X	X	X			
NCM051	7	45 59 24	85 00 00	X	X	X	X	X			
NCM052	18	45 57 30	85 00 00	X	X	X	X	X			
NCM053	22	45 55 00	85 00 00		X	X	X	X			
NCM054	23	45 52 30	85 00 00	X	X	X	X	X			
NCM055	40	45 50 00	85 00 00	X	X	X	X	X			
NCM056	7	45 47 06	85 00 00	X	X	X	X	X			
NCM057	7	45 51 24	84 49 24	X	X	X	X	X			
NCM058	22	45 50 06	84 49 24	X	X	X	X	X			
NCM059	34	45 48 48	84 49 24	X	X	X	X	X			
NCM060	23	45 47 24	84 49 24	X	X	X	X	X			
NCM061	7	45 46 12	84 49 24	X	X	X	X	X			
NCM062	7	45 49 48	84 45 00	X	X	X	X	X			
NCM063	21	45 49 06	84 45 00	X	X	X	X	X			
NCM064	21	45 48 30	84 45 00	X	X	X	X	X			
NCM065	7	45 47 42	84 45 00	X	X	X	X	X			
NCM066	7	45 34 48	85 33 30		X	X	X	X			
NCM067	119	45 29 00	85 33 24		X	X	X	X			
NCM068	77	45 21 48	85 33 12		X	X	X	X			
NCM069	34	45 15 00	85 33 06		X	X	X	X			
NCM070	7	45 13 00	85 33 00		X	X	X	X			X

TABLE 2C

LAKE MICHIGAN

Milwaukee Area Nearshore stations each sampled three times during each of the two 1977 surveys (See Table 1 for Cruise Codes)

STATION	DEPTH (m)	LATITUDE	LONGITUDE
MIL 01	24	42°59'00"	87°47'00"
MIL 02	10	42 59 12	87 51 22
MIL 03	6	42 59 38	87 52 28
MIL 04	11	42 59 46	87 51 55
MIL 05	15	42 59 48	87 51 10
MIL 06	12	43 00 29	87 52 36
MIL 07	15	43 00 31	87 51 52
MIL 08	12	43 00 31	87 53 01
MIL 09	10	43 01 32	87 53 38
MIL 10	10	43 01 33	87 53 20

(contd.) TABLE 2C

STATION	DEPTH (m)	LATITUDE	LONGITUDE
MIL 11	12	43 01 34	87 52 55
MIL 12	47	43 01 39	87 46 00
MIL 13	17	43 01 41	87 51 08
MIL 14	7	43 02 22	87 53 22
MIL 15	10	43 02 39	87 52 48
MIL 16	12	43 02 43	87 52 03
MIL 17	5	43 03 35	87 52 00
MIL 18	15	43 03 55	87 51 13
MIL 19	45	43 04 00	87 47 00
MIL 20	15	43 04 17	87 51 18

TABLE 2D

Indiana area Nearsore stations each sampled once during the 1977 open lake surveys #2, 3 and 4. (See Table 1 for Cruise Codes)

STATION	DEPTH (m)	LATITUDE	LONGITUDE
IND. 30	16	41°42'10"	87°19'55"
IND. 31	16	41 39 20	87 19 47
IND. 32	13	41 38 30	87 19 45
IND. 33	14	41 38 00	87 19 42
IND. 34	12	41 38 20	87 10 40
IND. 35	16	41 38 40	87 10 50
IND. 36	17	41 39 40	87 11 10
IND. 37	19	41 42 10	87 12 00
IND. 38	20	41 44 40	87 03 40
IND. 39	18	41 42 20	87 02 30
IND. 40	17	41 41 30	87 02 00
IND. 41	12	41 41 00	87 01 50
IND. 42	10	41 42 40	86 57 00
IND. 43	17	41 43 10	86 57 20
IND. 44	19	41 44 00	86 58 00

TABLE 2E

LAKE MICHIGAN

Chicago-Calumet area Nearshore stations each sampled three times during each of the two Chicago-Calumet nearshore surveys. (See Table 1 for Cruise Codes)

STATION	DEPTH (m)	LATITUDE	LONGITUDE
CAL 06	10	41°40'10"	87°26'20"
CAL 11	11	41 44 01	87 31 41
CAL 13	11	41 44 06	87 31 16
CAL 20	12	41 41 08	87 26 42
CAL 21	11	41 41 50	87 24 45
CAL 22	13	41 43 58	87 24 30
CAL 23	16	41 44 00	87 21 00
CAL 24	11	41 41 45	87 28 20
CAL 25	12	41 43 12	87 28 30
CAL 26	12	41 39 35	87 23 32
CAL 27	12	41 42 00	87 25 55
CAL 28	11	41 44 20	87 29 55
CAL 29	18	41 45 42	87 20 00
CAL 30	13	41 45 45	87 29 35
CAL 31	15	41 45 42	87 25 00
CAL 32	13	41 46 50	87 30 00
CAL 33	10	41 46 50	87 31 45
CAL 34	8	41 46 48	87 33 30
CAL 35	13	41 48 18	87 31 45

TABLE 2F

LAKE MICHIGAN

Green Bay stations sampled once during each Green Bay survey #2 and 3. Green Bay survey #1 conducted by Michigan's Dept. of Natural Resources. (See Table 1 For Cruise Codes)

STATION	DEPTH (m)	LATITUDE	LONGITUDE
GBAY 01	11	45°54'00"	86°57'00"
GBAY 02	15	45 49 00	87 03 00
GBAY 03	13	45 47 00	87 04 00
GBAY 04	16	45 43 00	87 04 00
GBAY 05	13	45 43 00	87 02 00
GBAY 06	17	45 33 00	87 07 00
GBAY 07	31	45 27 00	87 08 00
GBAY 08	11	45 30 00	87 17 00
GBAY 09	34	45 20 00	87 15 00
GBAY 10	26	45 12 00	87 28 00

(contd.) TABLE 2F

STATION	DEPTH (m)	LATITUDE	LONGITUDE
GBAY 11	15	45°08'00"	87°33'00"
GBAY 12	12	45 05 00	87 33 00
GBAY 13	20	45 04 00	87 31 00
GBAY 14	21	45 02 00	87 33 00
GBAY 15	26	44 57 00	87 33 00
GBAY 16	18	44 51 00	87 41 00
GBAY 17	9	44 53 00	87 25 00
GBAY 18	21	45 08 00	87 21 00
GBAY 19	35	45 18 00	86 58 00
GBAY 20	38	45 27 00	86 48 00
GBAY 21	22	45 29 00	86 44 00
GBAY 22	12	45 31 00	86 42 00
GBAY 23	24	45 32 00	86 53 00
GBAY 24	18	45 43 00	86 46 00
GBAY 25	9	45 47 00	86 39 00

TABLE 2G

GREEN BAY STATIONS SAMPLED DURING GREEN BAY SURVEY #1
(Michigan DNR Green Bay Stations - A= 21MICH)

STATION	DEPTH (m)	LATITUDE	LONGITUDE
550092	15	45°29'30"	87°15'16"
550093	34	45 19 57	87 16 41
550094	15	45 14 59	87 27 28
550095	15	45 06 50	87 33 22
550096	15	45 05 37	87 33 29
550097	26	45 05 14	87 30 00
210130	9	45 52 27	86 57 48
210131	9	45 48 27	87 01 25
210132	11	45 46 49	87 03 03
210133	17	45 42 19	87 02 59
210134	12	45 41 44	86 59 41
210135	30	45 34 49	87 01 53
210136	30	45 26 56	87 08 12
210138	30	45 30 26	86 44 12
210139	30	45 30 25	86 41 01
210140	30	45 32 22	86 51 38
210141	15	45 41 39	86 45 08
210142	12	45 47 07	86 38 18
860010	15	45 03 18	87 34 02
860011	16	44 57 16	87 34 32
860012	15	44 50 30	87 43 43
860013	15	44 53 56	87 24 47
860014	14	45 08 05	87 16 13
860015	30	45 17 50	86 58 30
860016	46	45 25 36	86 48 38

analyses and preparations. The temperature measurements were made on the sample in the Niskin bottle or the phytoplankton sample. The primary productivity samples were taken directly from the Niskin bottle.

Samples for Crustacean zooplankton were collected by vetical tow from 1 meter above the bottom to the surface. At stations over 26 meters in depth a second tow was made from 25 meters to the surface. A number 6 mesh net with a .5 meter mouth was used. Net efficiency was determined by mounting a flow meter in the net mouth. This reading was then compared to the reading obtained by raising the meter alone from the same depth as the tow.

Samples for rotifer analysis were collected by Niskin bottle at the same depths as chemical samples. The contents of each Niskin was filtered through a 53 micron mesh net and a single composite sample preserved for each station.

Dissolved nutrient samples were prepared by vacuum filtration of an aliquot from the PEC for onboard analyses within an hour of sample collection. Most samples were filtered within 30 minutes of collection. A 47mm diameter 0.45 um membrane filter (HAWP 04700) held in a polycarbonate filter holder (Millipore XX 11 04710) with a polypropylene filter flask was prewashed with 100 to 200 ml of demineralized water or sample water. New 125 ml polyethylene sample bottles with linerless closures were rinsed once with filtered sample prior to filling.

An aliquot was removed for the dissolved orthophosphate and the dissolved silica determinations after which the remainder was preserved with 1 ml/l concentrated sulfuric acid to be subsequently analyzed for total dissolved phosphorus.

Microbiological analyses described later were processed on-board the R/V Roger Simons. If analysis was not performed immediately, samples were frigerated at 4^{o}C until analysis could be performed.

Aesthetics. Reports of any unusual visual conditions that existed at any station were made. Conditions such as floating algae, detritus, dead fish, oil, unusual water color, or other abnormal conditions were recorded in the field observations.

Air Temperature was determined by use of a dial scale bimetallic helix thermometer such as Weston Model 4200. The thermometer was allowed to stabilize in the shade in an open area of the deck prior to recording the temperature to the nearest 0.5^{o}C.

Wind Speed and Direction Readings from a permanently mounted Danforth Marine type Wind Direction and Speed Indicator were taken and recorded while the vessel was stopped to the nearest 1^{o} (to the right of true north). Wind direction is accurate to $\pm$ 10^{o}. The reading of speed was estimated to the nearest nautical mile per hour and stored as

TABLE 3A

PARAMETERS MEASURED BY GLNPO

in 1976-1977

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

EBT= Electric bathythermograph/transmissometer
PEC= Polyethylene Cubitainer, one gallon or 2 1/2 gallon
PE = Polyethylene, preceding number indicates volume in mls.
(A)= 10 ml/l NaOH (1.0N) added as preservative
(S)= 1 ml/l concentrated sulfuric acid added as preservative
(N)= 5 ml/l concentrated nitric acid added as preservative
(L)= 5 ml/l Lugols

[1]Nutrients 610, 630, 665, 666, 671 & 955 not run on metal cruises

TABLE 3B

SELECTED CRUISE PARAMETERS MEASURED BY GLNPO

in 1976-1977

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

*Sampled on the 1977 metal cruises.

miles per hour. The reading of direction from which the wind was blowing (wind direction) was estimated to the nearest 10^{0} (to the right of true north).

Wave Height. Average Wave height (valley to crest distance) was estimated at each station by the senior crew member on the bridge. Wave heights were recorded to the nearest 0.5 ft. Wave direction was not recorded separately since it almost always coincided with wind direction.

Turbidity. Turbidity was measured with a Hach model 2100 Turbidimeter within two hours of sample collection. Calibration standards were obtained from the instrument manufacturer prior to the sampling season in 1976 and found identical within the readability of the instrument to a set that had likewise been obtained in early 1975. The turbidimeter was calibrated before analysis of each set of samples using a standard within the anticipated range of turbidity. Some turbidity samples were heated to 25°C to avoid condensation on the sample cuvet. Readings on the 0-1 range were recorded to the nearest 0.1 unit and readings from 1 to 40 range were recorded to the nearest unit.

Secchi Disc Depth was estimated at each station on all cruises by use of a standard 30 cm, all-white, Secchi disc. Secchi disc depths were recorded to the nearest 0.5 meters.

pH. pH analyses were made by electrometric measurement within 15 minutes of sample collection. pH meters were standardized against two buffers, pH 7.0 and 9.0(each prepared from commercial concentrates), to bracket the pH of lake water. In 1976, the readings were recorded to the nearest 0.1 pH unit from a Sargent Welch model PBX pH meter. Readings from a bimetallic dial thermometer were used to set the pH meter to compensate for temperature effects. In 1977, readings were recorded to the nearest 0.01 pH unit from an Orion model 701 pH meter equipped with an automatic temperature compensation probe. A combination glass membrane with a silver/silver chloride internal electrode elements was used both years.

Temperature was determined by use of a dial scale bimetallic helix thermometer such as Weston Model 4200. The thermometer shaft was immersed in the full Niskin bottle or in the 1000 ml plastic sample bottle for phytoplankton. Readings were estimated to the nearest 0.25°C within one minute of sampling. Prior to use each day the thermometer was checked at one temperature, and adjusted if necessary to comply with a mercury thermometer readable to 0.1°C (ASTM No. 90 C).

Temperature and Light Transmission Profiles. Vertical profiles were determined at each station from surface to bottom with a Martek Model EBT/XMS electronic bathythermograph/transmissometer with a 1 meter folded light path. The Martek constant speed electric winch with 1000 feet of cable had an extension and retraction rate of approximately 10 meters/minute. Profiles were recorded on a Hewlett Packard XYY' plotter model 7044A. The temperature-depth profile was recorded both on descent and ascent of the sensors. Because experience showed that the transmission depth profile was independent of speed or direction of travel of the

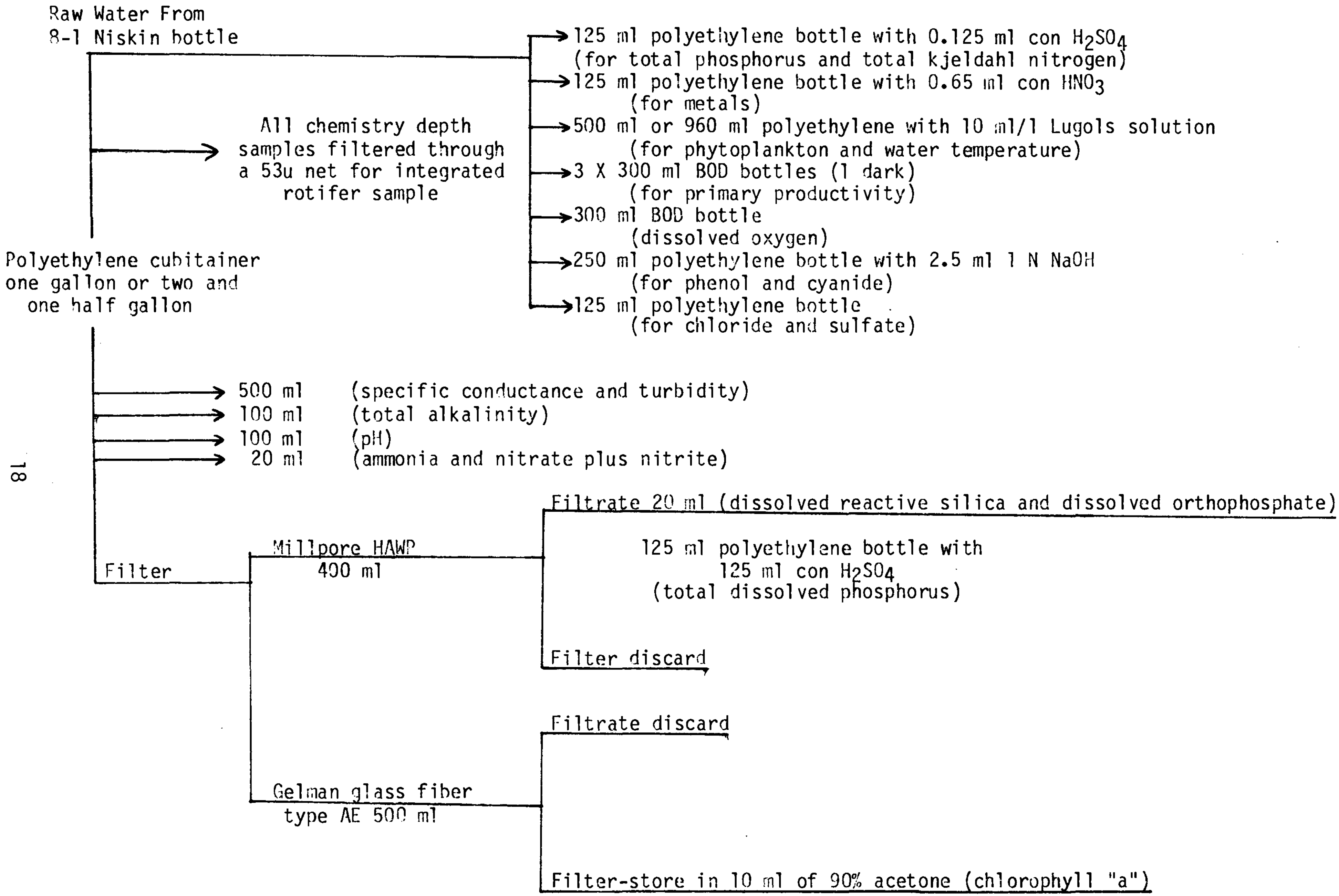


Figure 2
Flow chart illustrating sample processing on EPA monitoring vessel.

sensors (within the capability of the winch), this profile was sometimes made in only one direction. The relatively long time constant of the temperature sensor precluded the use of the temperature profile for accurate temperature records at depths at which the temperature gradient was large. Discrete readings of temperature, after sensor stabilization, were made at selected depths to better define the true temperature profile.

Dissolved Oxygen. Dissolved oxygen was measured on water samples from selected stations on some cruises. Analyses were made by the azide modification of the Winkler test(EPA, 1974), or by a YSI-5720 self-stirring BOD bottle probe which was calibrated daily against the modified Winkler test. The dissolved oxygen analyses were made as soon as possible after the samples were collected but in no case more than 30 minutes after collection. Dissolved oxygen analyses were performed immediately after sample collection when the probe was used. The dissolved oxygen sample aliquot was obtained by inserting an eight to ten inch length of flexible plastic tubing connected to the Niskin bottle outlet plug to the bottom of a 300 ml glass BOD bottle. Flow was regulated by the outlet plug so as to minimize turbulence and admixture of the sample with air. Thiosulfate titrant normality was 0.0375, with a sample volume of 300 ml, so that the ml of titrant was equal to the mg/l dissolved oxygen.

Dissolved Orthophosphate. Samples were analyzed for orthophosphate using a Technicon Autoanalyzer system II and Technicon's industrial method 155-71W(Murphy and Riley, 1962). This is the single reagent ascorbic acid reduction method in which a phosphomolybdenum blue complex is measured photometrically at 880 mu. The procedure was modified to eliminate the dilution water with a corresponding sample water increase. Levor IV, which was originally added to the dilution water, was added to the single reagent(2.5 ml/l). Analyses were performed on the filtered sample within two hours of sample collection.

Total Phosphorus and Total Dissolved Phosphorus. Samples were preserved with 1 ml/l concentrated sulfuric acid and stored in 125 ml plastic bottles for up to 90 days before analysis. Conversion of the various forms of phosphorus to orthophosphate was by an adaption of the acid persulfate digestion method (Gales et. al.,1966). Screw cap tubes containing sample and digestion solution were heated in a forced air oven for 1/2 hour at 150°C. After cooling, the resulting orthophosphate was determined by the Technicon Autoanalyzer system II and Technicons industrial method 155-71W (Murphy and Riley, 1962).

Dissolved (Reactive) Silica. A Technicon autoanalyzer system II was used with Technicon's industrial method No. 186-72W/Tentative (Technicon, 1973). This method is based on the chemical reduction of a silico-molybdate in acid solution to "molybdenum blue" by ascorbic acid. Oxalic acid is added to eliminate interference from phosphorus. Analyses were performed on the filtered sample within two hours of sampling using a working concentration range of 0-5 mg/l as SiO_2.

Specific Conductance. Specific conductance was determined within two hours of sampling using a Barnstead model PM70CB conductivity bridge and a conductivity cell (YSI 3401 or YSI 3403, K=1.0). An immersion heater(such as is used for heating a cup of water for instant coffee), connected to a proportional electronic temperature controller with thermister sensor was used to heat the sample in a 250 ml. polypropylene beaker to 25.0°C. The temperature was monitored with a mercury thermometer(ASTM 90C) with 0.1°C divisions. Rapid stirring was accomplished with an immersion glass paddle attached to a small electric motor. When the specific conductivity of a sample differed by more than (10% + 1 umho/cm) from the previous sample, a fresh aliquot was taken for the determination so as to minimize carry over from sample to sample. The apparatus was standardized daily against 0.15 gram per liter KCl solution according to the equation of Lind et al (1959).

Total Alkalinity as $CaCO_3$. Total alkalinity was determined within two hours of sampling by titration of a 100 ml aliquot to pH 4.5 with 0.02 N H_2SO_4. The pH controller/meter(Cole Parmer model 5997 with combination electrode) was standardized daily with pH buffers 4.0 and 7.0 (each prepared from Fisher Scientific concentrates). The acid was standardized against 20 ml(diluted to 100 ml) of 1.0600 gram/liter Na_2CO_3 (dried 3 hrs @ 180°C in a forced air oven).

Chloride. A Technicon autoanalyzer system II was used with Technicon's industrial method No. 99-70W(Zall et al, 1956; O'Brien, 1962) with diluent water and sample tubes changed to produce a working range of 0 to 20 mg/l. In this method chloride ion displaces mercury from mercuric thiocyanate forming un-ionized soluble mercuric chloride. The released thiocyanate reacts with ferric ion to form intensely colored ferric thiocyanate which is determined photometrically. Raw water samples, stored non-refrigerated in 125 ml or 250 ml polyethylene bottles with plastic closures were analyzed within 90 days of sample collection. Seven standards with no more than 4 mg/l spread between adjacent concentrations were run with each group of samples. A least squares regression technique was used to define the three constants of a quadratic equation used for reduction of chart readings to concentrations(Alder and Roessler, 1962).

Sulfate. Samples were analyzed for sulfate with a Technicon autoanalyzer using Technicon's industrial method 118-71W (Lazrus et al, 1965) with 1 ml/min sample and diluent pump tubes to give a 0-30 mg/l range. In this procedure the sample is first passed through a cation-exchange column to remove interfering cations. It is then mixed with an equimolar solution of $BaCl_2$ and methyl thymol blue (MTB). Sulfate reacts with a Ba reducing the amount of Ba available to react with MTB. The free MTB is then measured photometically. Raw water samples, stored non-refrigerated in 125 ml or 250 ml polyethylene bottles with plastic closures were anlayzed within 90 days of sample collection. Seven standards with 5 mg/l spread between adjacent concentrations were run with each group of samples. A least squares regression technique was used to define the four constants of a cubic equation used for reduction of chart readings to concentration (Alder and Roessler, 1962).

Total Nitrate & Nitrite Nitrogen. A Technicon autoanalyzer was used with Technicons industrial method No. 158-71W (Armstrong et al, 1967; Grasshoff, 1969; FWPCA, 1969). In this procedure nitrate is reduced to nitrite in a copper cadmium column, which is then reacted with sulfamilamide and N-1-napthylethylenediamine dihydrochloride to form a reddish purple azo dye. Nitrate & nitrite analyses were performed within 2 hours of collection.

Total Kjeldahl Nitrogen. Total Kjeldahl nitrogen samples were preserved for no longer than 90 days by the addition of 2 ml concentrated H_2SO_4 per liter and refrigeration at 4^oC. Preservative was added to samples within 30 minutes of sample collection. Analyses were made by an "ultra-micro semiautomated" method (Jirka et al, 1976), in which a 10 ml sample is digested with a solution of K_2SO_4, H_2SO_4, and HgO in a thermostated 370^oC block digestor. After cooling and dilution with water, the sample neutralization and ammonia determination (Berthelot Reaction) are accomplished on a Technicon Autoanalyzer system II.

Total Ammonia Nitrogen. Total Ammonia nitrogen analyses were performed with a Technicon Autoanalyzer system II using a modification of Technicon's industrial method 154-71W/Tentative (Van Slyke and Hillen, 1933). The pump tubes rates were as follows: sample 0.80 ml/min, complexing agent 0.42 ml/min, alkaline phenol 0.23 ml/min, hypochlorite 0.16 ml/min, nitroprusside 0.23 ml/min, and flow cell 1.00 ml/min. The ammonia determinations were performed onboard as soon as possible but always within eight hours of sample collection. Samples were maintained at 4^oC until analyzed.

Phytoplankton

Phytoplankton sample were collected at all depths at all stations in both years of the study. Unfortunately, due to lack of resources, many of the samples collected in 1976 were not analyzed and the majority of those that were, were not identified beyond major taxonomic categories (total blue greens, total greens, total flagellates, total pennate diatoms, total centric diatoms). In 1977 samples from all depths at all stations were analyzed to these same taxonomic categories. In addition, samples from the 5 meter depth were identified to genus and, where possible, species. Phytoplankton samples were collected with a Niskin-type sampler, 960 mls of sample were withdrawn and preserved with 5 mls of Lugols solution and stored in a cool dark place to await analysis.

The sample was vigorously shaken and 10 ml subsamples were removed and placed in settling chambers. This was allowed to settle for approximately 24 hours in a vibration free area prior to counting and identification with the inverted microscope. Twenty fields were counted and identified at 400X magnification.

Diatoms, flagellates, and unicellular greens and blue greens are reported as cells/ml. Colonial and filamentus greens and blue greens are reported as colonies/ml and filaments/ml.

All zooplankton samples were narcotized with club soda and preserved with 5 percent formalin. The samples were analysed by the Sedwick-Rafter Method (A.P.H.A. 1971).

The zooplankton data is not included in this report but is available from the Great Lakes National Program Office, 536 South Clark Street, Chicago, Illinois 60605.

Chlorophyll "a" and Pheophytin. Samples for chlorophyll (100 ml to 500 ml) were taken from the PEC and filtered at 7 psi vacuum along with 1 to 2 ml of $MgCO_3$ suspension (10 gm/l) usually within 30 minutes of sample collection. In some instances filtration was delayed for as long as 2 hours. The filters (Gelman type AE 47mm glass fiber) were retained in a capped glass tube containing 10 ml of 90% spectro-grade acetone at -10°C in the dark for up to 30 days prior to completion of the anlaysis. The tubes were placed in an ultrasonic bath for 20 minutes and then allowed to steep for 24 hours prior to fluorometric analysis using an Aminco dual monochromator spectrofluorometer (Strickland and Parsons 1972).

Primary Productivity (Carbon 14 Method). Primary productivity was measured at the 5-meter depth sample from all stations and from each sampled depth at selected stations. The samples were collected in an opaque Niskin bottle and transferred to one opaque and two transparent 300 ml BOD bottles. Each bottle was innoculated with 2 microcuries $NaH^{14}CO_3$. The samples were incubated in an on-board incubator. The incubator consisted of a container of circulating lake water to maintain the temperature at that of the lake's surface and was illuminated with fluorescent light. The light intensity in the incubator was approximately 120u $Ein/m^2/S$ which is roughly equivalent to the light intensity at 15m for an offshore station in Lake Michigan at noon on a clear June day as measured by a lambda quantum light meter by the GLRD of the University of Michigan. This light intensity is not high enough to saturate photosynthesis (Strickland and Parsons 1972). After four hours the productivity samples were immediately filtered through a 0.45 um membrane filter (Millipore AAWP 04700), using a vacuum of 6 to 8 inches mercury. The damp filters were immediately transferred to counting vials containing 20 ml of FilterSolv (Beckman). The vials were then refrigerated at 4°C in the dark for 24 hours prior to liquid scintillation counting. Radioactivity was counted on a Beckman model LS333 scintillation counter with quenching corrected by external standards and channels ratio techniques. The difference between the average of the transparent bottles and the dark bottle, along with the values obtained for pH, temperature, and total alkalinity, were used to calculate the primary productivity in $mgC/m^3/hr$.

Aerobic Heterotrophs. Aerobic heterotrophic bacterial densities were determined at several depths at all stations on all cruises by the membrane filtration technique, using Bacto Plate Count agar with aerobic incubation at 20°C for 48 hours (APHA, 1971). Counts were made with the aid of a 10-power stereomicroscope. Counts were made in accordance with Standard Methods, (APHA,1975) except that total plate count agar plates, presolidified in petri dishes, type 50 x 15 mm, were used in place of pour plates.

Fecal Coliforms. Fecal coliform densities were determined at selected stations using the membrane filtration method with M-fc broth base incubated at 44.5°C for 24 hours. Colony counts were made with the aid of a 10-power stereomicroscope and were recorded as organisms per 100 ml of water (APHA, 1975).

Metals Total (Aluminum, Barium, Beryllium, Boron, Cadmium, Calcium, Chromium, Cobalt, Copper, Iron, Lead, Magnesium, Manganese, Molybdenum, Nickel, Potassium, Silver, Sodium, Tin, Titanium, Vanadium, Zinc) were measured on samples from all depths at all stations on the first four cruises and the south-north cruise (Table 1) in 1976. During 1977, metal samples were collected from all parts of the lake using 21 nearshore transects and 20 selected open lake stations. Each nearshore transect was sampled at the 9m, 18m, 36m, and 54m bottom depth contours. Sampling depth was 5m at all locations. A teflon Niskin bottle was used, and no metallic implements were used in collecting the samples. These analyses were done by Inductively Coupled Argon Plasma Emission Spectroscopy (ICAP). The samples were preserved immediately upon collection with 5 ml/l nitric acid. Samples were analyzed within 90 days of collection.

In 1977, samples were concentrated 10 times by evaporation before analysis in order to increase the sensitivity of the analyses. This procedure resulted in increased concentration of alkaline earths which acted as an interference in the measurement of the heavy metals. This factor limited the improvement in level of detectability achievable by concentration. All analyses were made on unfiltered samples.

Total Arsenic was determined by flameless atomic absorption spectrophotometry using a Perkin Elmer Model 503 atomic absorption spectrophotometer equipped with an HGA 2100 Graphite Furnace (EPA, 1974).

Total Fluoride was determined by the specific ion electrode method. The procedure was automated using a Technicon ISE (ion selective electrode) module (temperature controlled) with automated addition of buffer, chelating agent and sodium chloride. One liter of aqueous reagent for one to one mixing with sample was prepared with 57 ml. of glacial acetic acid, 59 gm. of sodium chloride, 2 gm. of 1, 2 cyclohexylene dinitrilo tetraacetic acid and enough sodium hydroxide to make the pH of the reagent read between 5 and 5.5.

Cyanide. Cyanide was measured at selected stations on the first two nearshore cruises in 1977. Cyanide samples were preserved with 2 ml of 10N sodium hydroxide per liter within 10 minutes of sample collection, and stored at 4°C. Samples were analyzed within 48 hours of collection by the Technicon Industrial Method 315-74W.

Phenol. Phenol was measured at selected stations during the first nearshore cruises of 1977. Analyses were done by the 4-AAP method with distillation (EPA, 1974). Phenol samples were preserved with 1 g/l copper sulfate and acidification to a pH of less than 4.0 with phosphoric acid and refrigerated at 4°C. Phenol analysis was within 24 hours of sample collection.

Methods Used By GLRD

Vessel

Figure 3 shows the sample processing on board the Univeristy of Michigan's vessel Laurentian.

Station Selection

Stations for study in northern Lake Michigan were selected to address several questions related to physical, chemical, and biological conditions in the open lake, inshore-offshore differences, and influences of hydrologic exchange with Lake Huron through the Straits of Mackinac. Four east-west transects were selected so that distances between were approximately equal and so the transects could be run between natural physiographic features, either shoreline points or islands. A rather dense network of stations was established in the area west of the Straits of Mackinac to define the interaction of Lakes Michigan and Huron.

A line of stations running south from Beaver Island was included to represent that area of the Lake. One master station was selected on each of the east-west transects. The purpose of including master stations was to investigate the vertical structure in greater detail at a limited number of stations than could be accomodated within the time available for sampling at all stations. It would not have been possible to sample and analyze samples at every station, if samples had been collected at this frequency at every station.

Water samples were taken with 8-liter Niskin bottles at predetermined depths of 2 and 5 m or at 5, 10 and 20 m intervals to the bottom; deeper depths were adjusted so that 17 was the maximum number of Niskin bottles used per station. Specific depths are listed in Table 4 . Water transparency was measured with a 30-cm white Secchi disc. Temperature was measured with a mechanical bathythermograph, and in addition, surface water temperature was measured with a bucket and a 0.1^{o}C division mercury thermometer.

All methods used on the northern Lake Michgan cruises are described in a manual of field and laboratory procedures (Davis and Simmons, 1979). Samples for soluble chemical analyses were filtered through 47-mm HA Millipore filters that were previously soaked and rinsed at least 3 times with distilled-deionized water. These samples were stored at 4^{o}C until chemical analyses were completed in Nalge conventional polyethlene bottles that were rinsed at least once with excess sample before filling.

A Corning pH meter, Model 110 equipped with a digital expanded scale and an automatic temperature compensator, was used on shipboard to measure pH immediately after the samples were taken.

Specific conductance was measured on shipboard with a Leeds and Northrup Model 4866-60 conductivity bridge, corrected to 25^{o}C.

Subsurface light penetration was measured using a Licor model LI-192S underwater quantum sensor coupled with a Licor model LI-185 quantum meter. These measurements were not conducted at every station because of the time involved and the presumed predictability and constancy of the attenuation characteristics of Lake Michigan water.

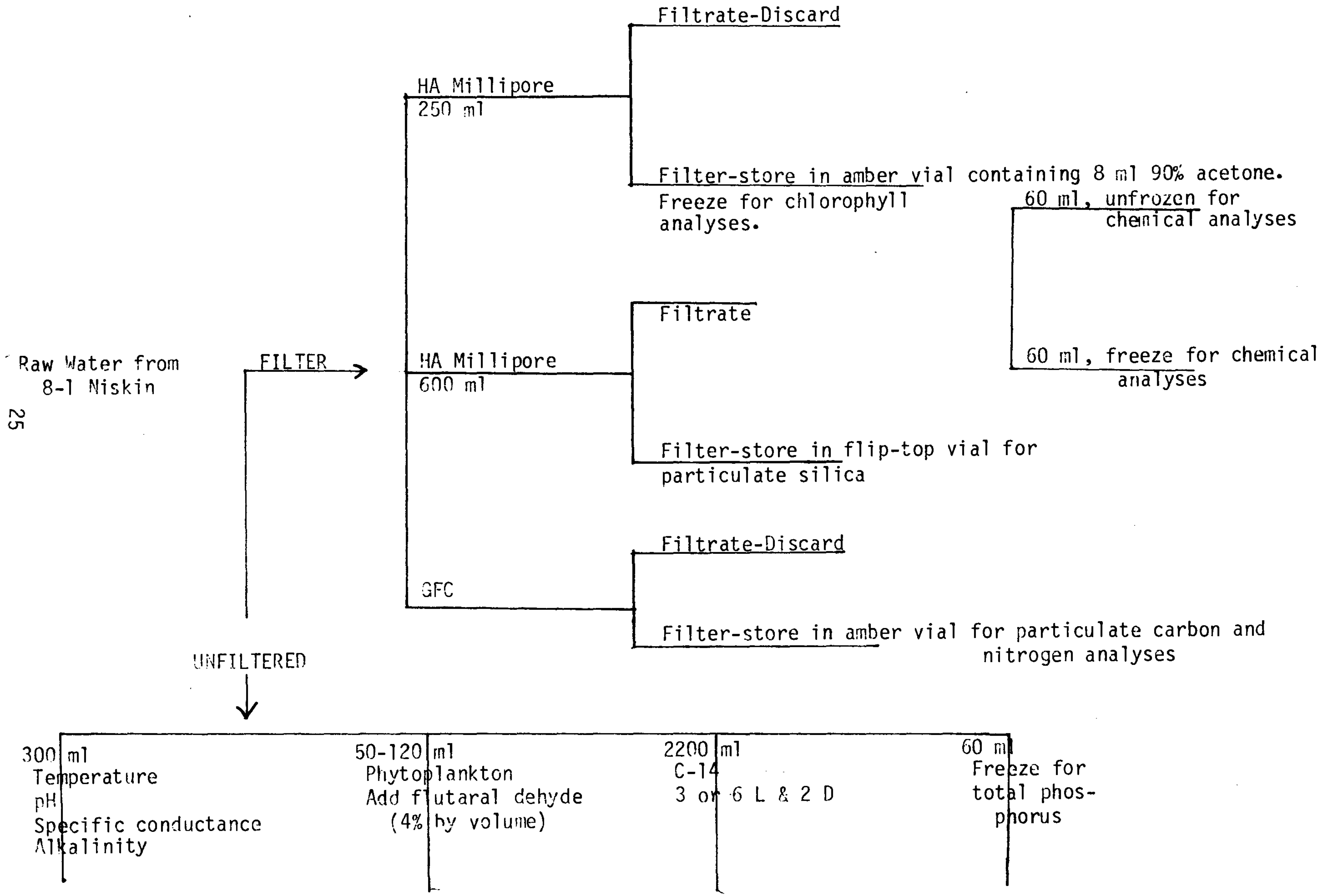


FIG. 3. Flow chart illustrating sample processing for study of northern Lake Michigan.

TABLE 4

NORTHERN LAKE MICHIGAN

Station #	Sampling Depths	No. of Samples
01	2, 5	2
02	5, 10, t, 1 m from bottom	4
04	5, 10, t, 50, 100, 1 m from bottom	6
06	5, 10, 20, 30, 40, 50, 70, 90, 110, 130, 150, 160 1 m from bottom	13
08	5, 10, t, 50, 100, 1 m from bottom (replicate station)	6
10	5, 10, t, 50, 1 m from bottom	5
11	2, 5	2
	Transect Total	38
12	2, 5	2
13	5, 10, t, 50, 1 m from bottom	5
15	5, 10, t, 50, 100, 1 m from bottom	6
17	5, 10, 20, 30, 40, 50, 70, 90, 110, 130, 150, 170, 190 210, 230, 240, 1 m from bottom	17
19	5, 10, t, 50, 100, 1 m from bottom (replicate station)	6
20	5, 10, t, 50, 100, 1 m from bottom	6
21	2, 5	2
	Transect Total	44
22	2,5	2
23	5, 10, t, 50, 1 m from bottom	5
25	5, 10, 20, 30, 40, 50, 70, 90, 110, 130, 150, 170, 180 1 m from bottom	14
27	5, 10, t, 50, 100, 1 m from bottom (replicate station)	6
29	5, 10, t, 50, 100, and/or 1 m from bottom	6
30	5, 10, t, 50, 100, 1 m from bottom	6
31	2, 5	2
	Transect Total	41
32	2, 5	2
34	5, 10, t, 50, 100, 1 m from bottom (replicate station)	6
36	5, 10, 20, 30, 40, 50, 70, 80, and 1 m from bottom	9
38	5, 10, t, 1 m from bottom	4
39	5, 10, t, 50, 100, 1 m from bottom	6
40	2, 5	2
	Transect Total	27

(con't) TABLE 4

NORTHERN LAKE MICHIGAN

Station #	Sampling Depths	No. of Samples
41	5, 10	2
42	5, 10, 20	3
43	5, 10, 15	3
44	5, 10, 20, 30	4
45	2, 5	2
46	5, 10, 20	3
47	5, 10, 20, 30	4
48	5, 10, 20	3
49	5, 10, 20	3
50	2, 5	2
51	2, 5	2
52	5, 10, 15	3
53	5, 10, 20	3
54	5, 10, 20	3
55	5, 10, 20, 30	4
56	2, 5	2
57	2, 5	2
58	5, 10, 20	3
59	5, 10, 20, 30	4
60	5, 10, 20	3
61	2, 5	2
62	2, 5	2
63	5, 10, 20	3
64	5, 10, 20	3
65	2, 5	2
	Straits Area Total	70

"t" denotes thermocline sample which was replaced with a 20 m sample during homothermous conditions.

Samples for primary production were obtained at 5m at all stations. Water samples (265 ml) were taken from the Niskin sampling bottles in glass-stoppered Pyrex bottles, injected with a known quantity of ^{14}C as sodium bicarbonate (ca 1.0 μ Ci) and incubated in a shipboard incubator. Surface lake water was pumped through the incubator to maintain temperature and fluorescent lights were used as the light source. The light in the incubator was approximately 120u Ein/m^2/S. Two lights and one dark bottle were incubated for 3 to 4 hours after which the entire contents were filtered onto 47-mm HA Millipore filters, rinsed with distilled water, and counted on a Nuclear Chicago liquid scintillation counter.

Alkalinity was determined from pH measurement on 20 ml samples which were added to 4 ml of 0.01N HCl. Measurements were made only on samples from 5m where ^{14}C productivity was measured.

Nutrient analysis was performed shortly after sample collecting using a Technicon AutoAnalyzer II equipped to measure five nutrients--nitrate plus nitrite nitrogen, ammonia nitrogen, soluble reactive silica, chloride, and soluble reactive phosphates. Samples for total phosphorus were frozen and returned to Ann Arbor for analyses. Methods used for these chemical analyses are described by Davis and Simmons (1979) and specific information is presented in the following paragraphs.

Nitrate was measured by reducing it to nitrite with a copper-cadmium reduction column. The nitrite produced and the nitrite initially present in the sample were then determined by a diazotization-coupling reaction using sulfanilamide and N-1-naphthyl-ethylene diamine. The resulting colored complex was measured at 550 nm. Nitrite was not analyzed separately, as quantitatively insignificant values would be expected in non-polluted oxygenated waters.

Ammonia and ammonium ions were measured by conversion of ammonium ions to ammonia in a basic medium. Ammonia reacts with hypochloride and phenol to produce an indolphenol blue color which was measured at 630 nm. The reaction was catalyzed by nitro-prusside and EDTA was added to prevent precipitation of alkali earth metals.

Silica was determined by reacting it with acidified molybdate to form a silicomolybdate complex that is reduced by ascorbic acid to an intense heteropoly blue which was measured at 660 nm. Oxalic acid was added to destroy any phosphomolybdate.

Soluble reactive phosphorus was measured by formation of antimony-phosphomolybdate complex in acid medium which was reduced by ascorbic acid and measured at 880 nm.

Chloride was determined from its reaction with mercuric thiocyanate that forms un-ionized but soluble mercuric chloride. The related thiocyanate in the presence of a ferric ion reacts to form a red complex, $Fe(SCN)_3$. The resulting color was measured at 480 nm.

Chemical analyses for total phosphorus and total soluble phosphorus were performed in the laboratory on thawed samples. Samples were concentrated by evaporation and then digested with acid potassium persulfate for one and a half hours in an oven at 110°C, as modified from Menzel and Corwin (1965). The samples were then analyzed for soluble reactive phosphorus on an AutoAnalyzer I. The blue color produced was measured at 630 nm.

Samples for total particulate silica were collected on 47-nm HA Millipore filters and placed in plastic flip-top vials. In the laboratory particulate silica was decomposed with HNO_3HF reagent. The excess hydrofluoric acid was complexed with boric acid. Silica concentrations in the decomposed samples were determined by atomic absorption spectrometry using a nitrous oxid-acetylene flame (David and Simmons 1979).

Samples for chlorophyll "a" (250 ml) were filtered onto 47-nm HA Millipore filters that were then extracted in 90 percent acetone buffered with magnesium carbonate. Samples were stored in amber vials in the dark at 0°C for a minimum of 12 hours. On the earlier cruises, some chlorophyll determinations were made on ship. Otherwise, they were done in our laboratory in Ann Arbor. Samples were centrifuged, and then 5 ml were transferred to sample cuvettes and read in a Turner Model 111 fluorometer. Samples were subsequently acidified with two drops of 50 percent V/V HCl and read in the flurometer for phaeopigment determination (Strickland and Parsons 1968). All results were corrected for phaeophytin. The phaeophytin fraction generally represented a small proportion of the chlorophyll "a", so possible errors resulting from the addition of excess amounts of hydrochloric acid (Riemann 1978) would probably be small.

Methods Used by MDNR

Details of methods can be found in Limnological Survey of Nearshore Waters of Lake Michigan 1976. EPA Grant R005146-01 David Kenage, William Creal, and Robert Bash In Press USEPA Grosse Ille, Michigan 48138.

Quality Assurance Used By GLNPO

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

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

Quality Assurance consisted of check standards, reagent blanks, duplicate samples, split samples and performance evaluation samples (unknowns).

Two check standards prepared from reagent materials were normally analyzed with every 10 to 20 samples (Table 5). These check standards were analytical checks as apposed to sampling checks, i.e. they were not carried through the sampling and preservation procedures.

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

Performance evaluation samples were provided as unknowns by EPA Region V Quality Assurance Office (Table 6).

Duplicate samples were obtained by lowering a second Niskin bottle to the same depth from which the original sample was taken. Each Niskin bottle (the original and the duplicate) was used to fill two sample bottles for each parameter. One duplicate/split sampling was performed with each 10 to 20 regular samples (Table 7).

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

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

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

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

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

TABLE 5

GLNPO Shipboard Check Standard & Reagent Blank* Summary

Parameter	Concentration	Number	Mean Found	Standard Deviation
1976				
Total Alkalinity mg/l	100	13	98.2	1.240
Total Alkalinity mg/l	80	14	80.14	1.724
Specific Conductivity umho/cm	293.3	26	291.73	2.017
Specific Conductivity umho/cm	245.0	22	244.77	0.712
Specific Conductivity umho/cm	196.5	4	196.50	0.577
Ammonia N mg/l	0.044	217	0.04430	0.00161
Ammonia N mg/l	0.02940	217	0.03003	0.00222
Ammonia N mg/l	0.01470	5	0.01580	0.00045
Ortho Phosphate P mg/l	0.0079	239	0.00792	0.00095
Ortho Phosphate P mg/l	0.0021	240	0.0021	0.00082
Silica SiO_2 mg/l	2.14	186	2.215	0.0276
Silica SiO_2 mg/l	1.07	186	1.120	0.0288
Nitrate + Nitrite N mg/l	0.72	166	73.0169	0.0313
Nitrate + Nitrite N mg/l	0.21	165	22.0715	0.0092

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

Parameter	Concentration	Number	Mean Found	Standard Deviation
1977				
Turbidity JTU	reagent blank	137	0.184	0.085
pH SU.	9.18	117	9.06	0.096
pH SU.	7.01	124	6.99	0.041
pH SU.	reagent blank	122	5.41	0.549

(contd.) TABLE 5

Shipboard Check Standard & Reagent Blank Summary

1977

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

TABLE 6

GLNPO
DIFFERENCES BETWEEN SPLIT SAMPLE ANALYSES
SOUTHERN LAKE MICHIGAN

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

(contd.) TABLE 6

	1977		
Turbidity (HTU)	222	0.019	0.17
Specific Conductance (umhos/cm)	224	0.094	0.76
pH (SU)	224	0.0067	0.044
Total Alkalinity	224	0.076	0.84
Suspended Solids	30	0.043	0.30
Total Ammonia-N	202	0.00012	0.0013
Total Kjeldahl-N	222	0.0038	0.055
Total Nitrate + Nitrite	214	0.0014	0.0078
Total Phosphorus	200	0.00040	0.0034
Total Chloride	206	0.035	0.26
Total Sulfate	34	0.044	0.67
Dissolved Reactive Silica	224	0.00094	0.028
Chlorophyll "a" (ug/l)	136	0.016	0.71
Pheophytin (ug/l)	134	0.12	0.14

*Unless Otherwise noted.

TABLE 7

Upper Lake Reference Group Performance
Standards Run During USEPA 1977 Cruises

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

This comuputation was developed to estimate average lake concentrations. Comparison of means and standard errors computed using TLVWA with computer volume weighted calculations (Yiu, 1978) for the southern basin gave similar statistic results for total phosporus and temperature. This comparison would suggest that in the southern basin TLVWA results can be used for other parameters which are more uniformly distributed and that the station network and sample depths were well chosen for characterization of lake water quality. In the northern basin, TLVWA results are affected by the dense station network in a relatively shallow basin of Lake Michigan near the Straits of Mackinac. This influence is most noticeable for epilimnetic values of chloride and conductance and can be seen by comparing figures 30 and 31; and 35 and 36 respectively.

The layering of the lake at 20 meters depth has been shown to representative of the average depth of the epilimnetic layer for both 1976 and 1977 (Barton and Schelske 1979, Rodgers, 1980).

Twenty-Four Hour Surveillance

Three 24 hour surveys on June 9-10, August 18-19, and September 6-7, 1977 were conducted at an open lake station L. Mich. 6 in the southern basin. The unique aspect of these monitoring efforts was regular two-hour sampling at one lake position for approximately 24 hours. Table 8 contains the results by depth for these visits. Except for the thermocline zone, the standard errors of the mean values are very low.

The importance of the uniformity of the results within the epilimnion and hypolimnion is the apparent insensitivity to actual time of sampling at a station during a given twenty-four hour period. The relatively larger standard errors of the mean concentrations in the thermocline region probably result from the internal wave structure and mixing between the layers in this region.

RESULTS

Temperature

Thermal stratification with a discernible epilimnion, thermocline, and hypolimnion occurred both years. The lake warmed first in the southern nearshore zones and exhibited a nearshore to offshore, south to north warming pattern. Epilimnetic water temperatures averaged 3° to 4°C warmer in 1976 than 1977 from June through September in the southern basin (Figure 4). In the southern basin, waters warmed from the first cruise in both years through August when the highest epilimnetic average temperatures of 19.7°C and 16.3°C were observed in 1976 and 1977 respectively. Northern basin waters followed the same warming pattern as described earlier. Some northern basin cruise average temperatures were 1-2°C cooler than southern basin even though the northern basin cruises usually followed corresponding southern basin cruises by one week. (Figure 4) The northern basin epilimnetic average temperature of 17.1°C occurred in the August 1976 cruise.

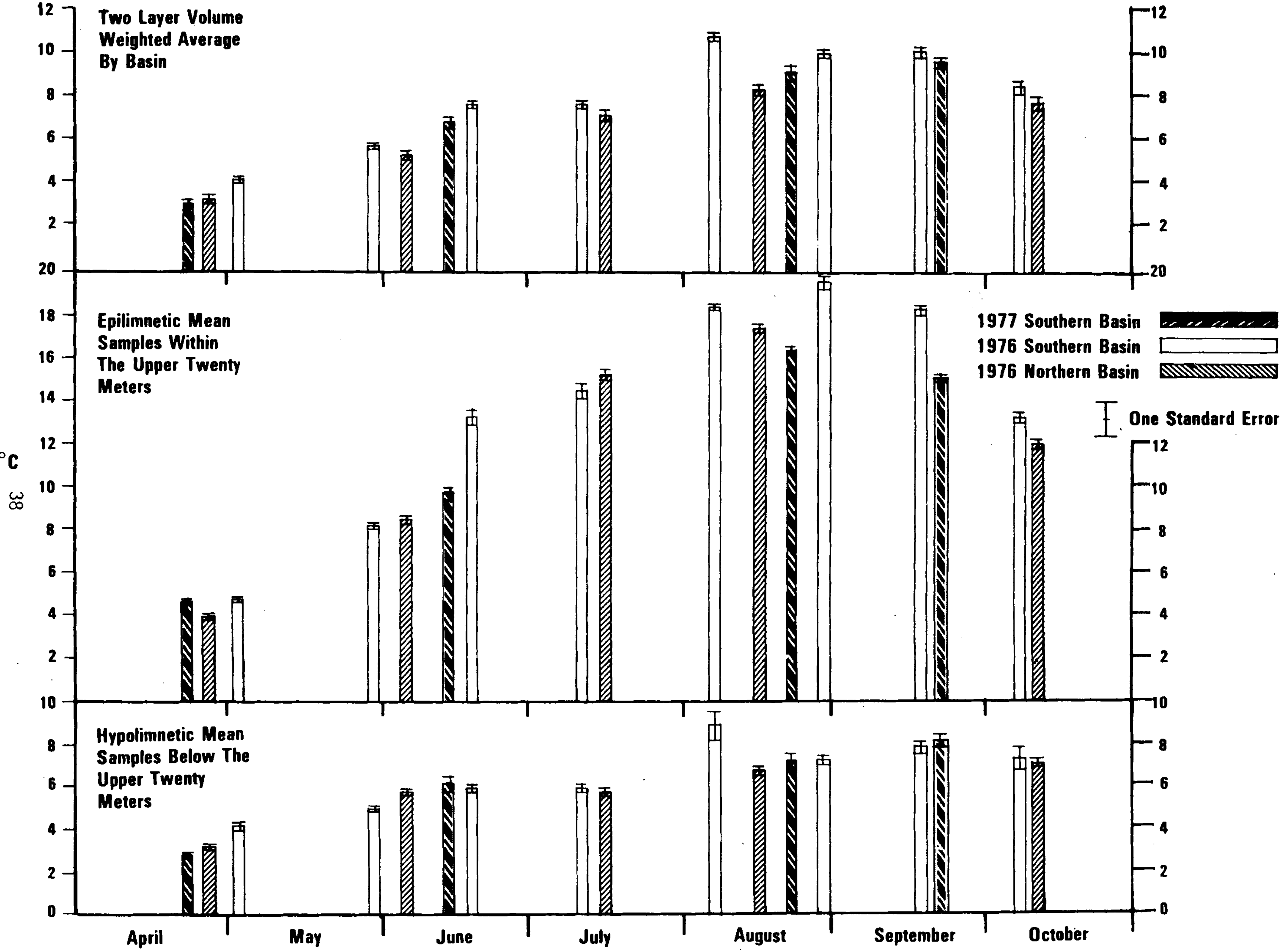
TABLE 8

Station L. MICH 06 24-Hour Surveys 1977

(number of samples) mean ± standard error of mean

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

figure 4 1976-1977 Lake Michigan Water Temperatures By Basin



A thermal bar was observed in the southern basin during April 19-24 in 1977. It was evident southward from 0-15 kilometers from shore along the eastern shoreline between transects 2 through 5, following transect 2 across the central portion of the southern basin and northward along the western shoreline between transects 2 and 3 up to 12 kilometers from shore (Figure 5).

In 1976, thermal stratification had begun along shore (to 2-6 kilometers offshore), in the southern portion (north to transect 2 and 3) during May 25-June 2, 1976. The entire southern basin had warmed 5° to $15^{\circ}C$ above hypolimnetic water temperatures by June 15-21, 1976. Stratification occurred later in 1977. During the June 11-16, 1977 cruise, thermal stratification had begun and extended to 9-15 kilometers offshore, in the southern basin south of transect 3, and along the eastern shorelines between transects 3 and 5. Complete stratification had occurred by the next survey on August 20-25, 1977 (Figure 5). The autumnal cooling period began after the August cruises in both basins in 1976 and the southern basin in 1977. The cooling period was similar to the spring warming with the lake cooling first in the nearshore.

Extreme upwelling events in the southern basin with water temperatures below $10^{\circ}C$ were not observed in 1976 or 1977. The somewhat offshore location (1 to 3 kilometer or greater distance from shore) of the nearest monitoring stations may have contributed to the absence of observed upwellings. However, there were indications of upwelling events in both years. These events were sometimes confined to a single transect during a cruise. Upwelling temperature patterns were observed at both eastern and western ends of a transect during the same day due to the 12 to 14 hour transit time to cross the lake.

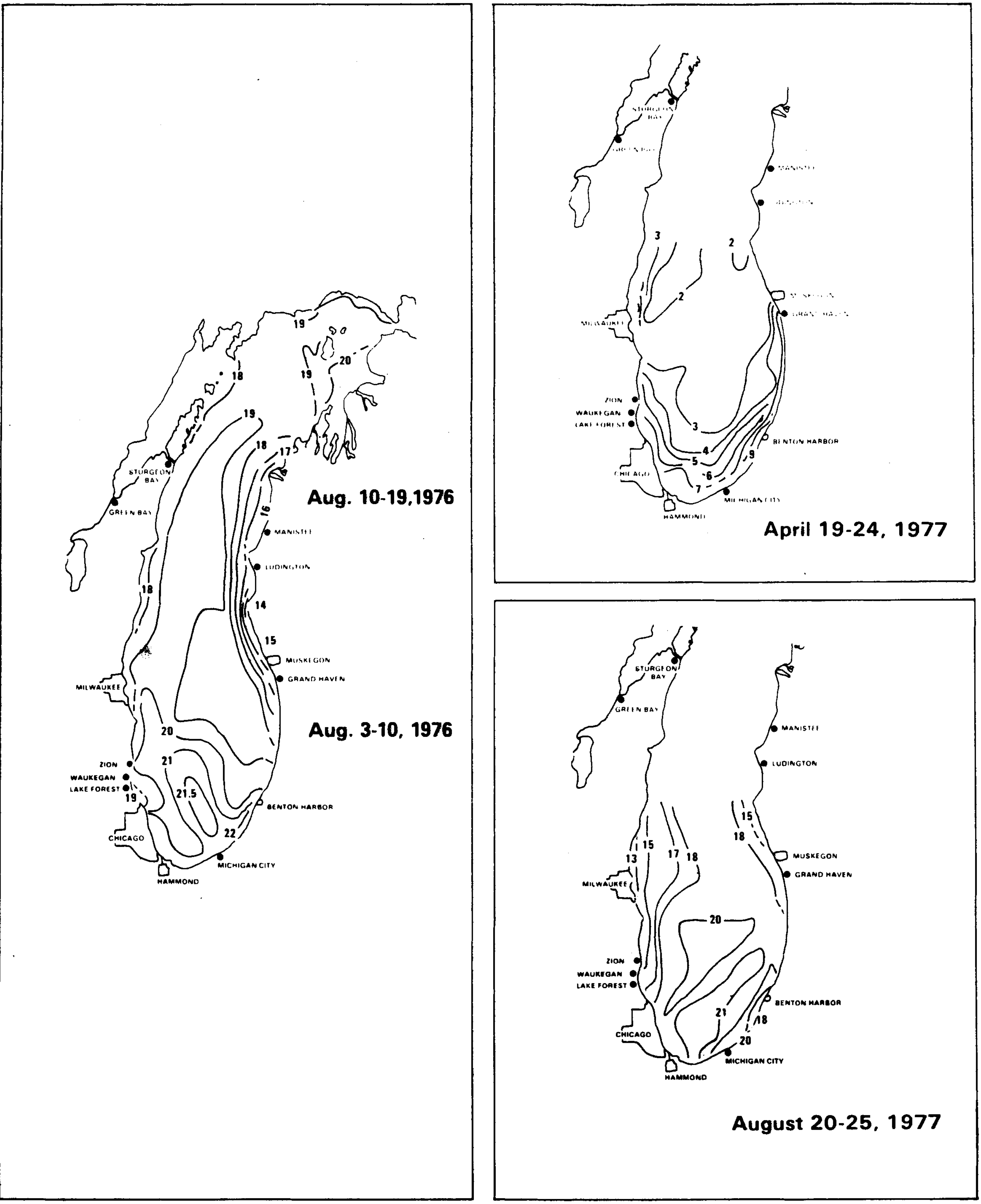
The most noticeable of upwelling events were observed during August 3-19, 1976 and during August 20-25, 1977. The August 1976 event appears to have been centered on transect 6 where an observed $5^{\circ}C$ change (19.0°-$14.0^{\circ}C$) in 5-meter depth temperatures occurred along the eastern coast. The August 1977 event occurred primarily near Milwaukee Wisconsin in the southern basin (Figure 5) with lowest observed nearshore temperature at transect 5. The greatest change in 5-meter temperatures in this event occurred on the western shore, transect 4, with a $5.8^{\circ}C$ change (14.2-$20.0^{\circ}C$) between stations 16 to 18, and on the eastern shore, transect 6, with a $4.7^{\circ}C$ change (18.0-$13.3^{\circ}C$) between stations 28a and 28 (Figure 5).

Appendix, Tables C1 thru C3 gives the vertical variation of some of the parameters sampled at the deepwater stations on 1976 and 1977 in both basins during the main lake cruises. The water column was remarkably uniform during isothermal conditions. After stratification was established the epilimnetic and hypolimnetic layers were also uniform. The metalimnetic layer exhibited the greatest varability.

Figure 6 contains reproductions of temperature stratification traces for the three twenty-four hour surveillance cruises. During the June 24-hour survey (Figure 6), the thermocline was most frequently at 25.5 meters and averaged 24.5 meters. The shallowest thermocline depth estimate was 20.5 meters and the deepest estimate was 26.5 meters. The thickness of the epilimnetic layer is estimated to be approximately 22 meters with minimum thickness of 18.5 and a maximum thickness of 23.5 meters.

figure 5

Temperature°C
5 Meter Depth



Maximum thickness occurred at 8 and 10 p.m. Temperature measured in the epilimnetic layer during this 24-hour period ranged from greater than 11° to 13.4°C. The metalimnetic layer, characterized by a 1°C/meter temperature gradient, is estimated at an average thickness of 8 meters with extreme values of 6 to 10 meters. Temperatures monitored in this layer during 24-hour period ranged from as low as 5.8°C to as high as 12.4°C. The temperature in the hypolimnetic layer averaged 5.4 $\pm$ 0.6°C during the ten sampling periods. Hypolimnetic waters began at a mean depth of 30 meters (range 26 to 33.5 meters). Hypolimnetic temperatures ranged from less than 7.9°C to a minimum of 4.4°C. Internal wave action on the metalimnetic interface is evident and reflected in the variations of thickness of each layer.

In the August survey (Figure 6) epilimnetic waters had warmed to a maximum of 22.2°C and were almost isothermal with a minimum temperature of 21.5°C. The thermocline's average depth occurred at 19.5 meters. The shallowest depth was at 25.5 meters. The thickness of the epilimnion averaged about 16.5 meters (ranging from 15.5-19.5 meters). The metalimnion averaged about 14 meters (ranging from 11 to 16.5 meters) thick. Metalimnion temperatures ranged from less than 22°C to greater than 5.6°C. The average temperature change in the metalimnetic layer on each sample run was 15.5 $\pm$ 0.4°C. Hypolimnetic waters began (on average) around 30.5 meters (ranging from 28.5 to 32 meters) deep. Hypolimnetic temperatures were less than 7.4°C to a minimum of 5.0°C.

The water column had begun to cool by September (Figure 6) and showed the deepest average thermocline location of the three 24-hour surveys at 25.5 meters. This depth, 25.5 meters, was also the most frequent depth estimate from the two-hour observations. The thermocline depth ranged in a narrow band from 23.5 to 25.5 meters.

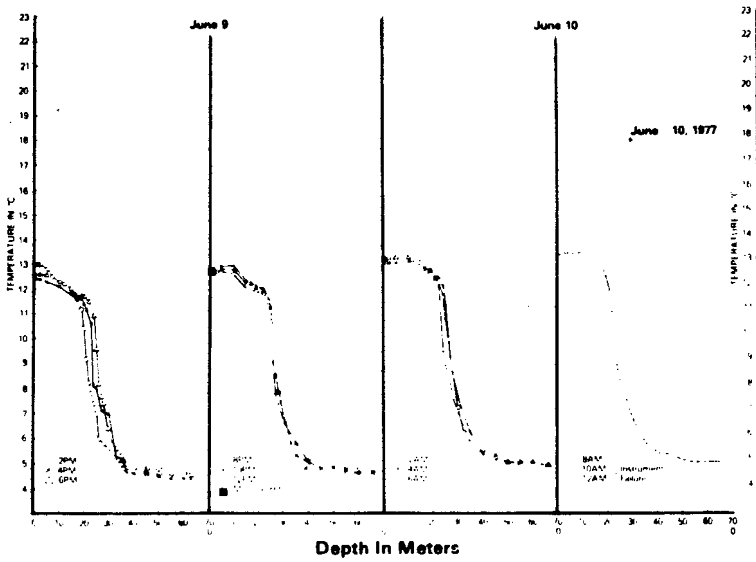
Secchi Disc and Turbidity

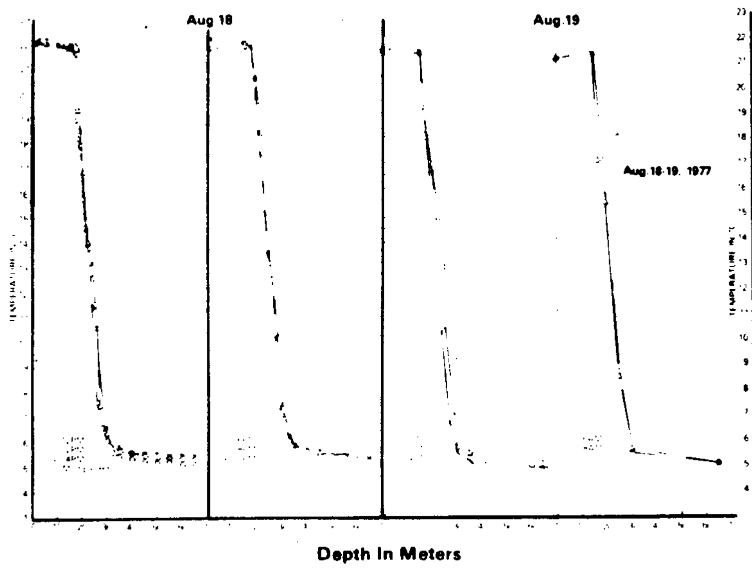
Secchi disc depth measurements were greater away from the nearshore zone. Figure 7 shows areal patterns from spring 1976 (the May 25-June 8 cruises) as well as the means for the 1976 and 1977 study periods. Water clarity was highest in the deep offshore waters of the northern basin and lowest near Milwaukee in 1976.

Secchi disc depth measurements declined in both basins throughout the summer until late August in both offshore and nearshore waters in 1976. A similar pattern was also observed in the southern basin in 1977. Secchi disc measurements in the northern basin averaged 1 to 3 meters greater than those in the southern basin at similar calendar periods throughout 1976. During July 1976 nearshore station measurements were 3 meters less than open lake stations in the southern basin. This difference was reduced to less than 0.5 meters during August and September 1976. A similar pattern occurred in the northern basin in 1976. Nearshore Secchi depth measurements varied less in both basins in 1976 than offshore station readings. Southern basin nearshore Secchi depths ranged from 2.9 to 4.9 meters and northern basin values ranged from 5.6 to 6.8 meters (Table 9).

figure 6

Station 6
24 Hour Survey EBT Traces





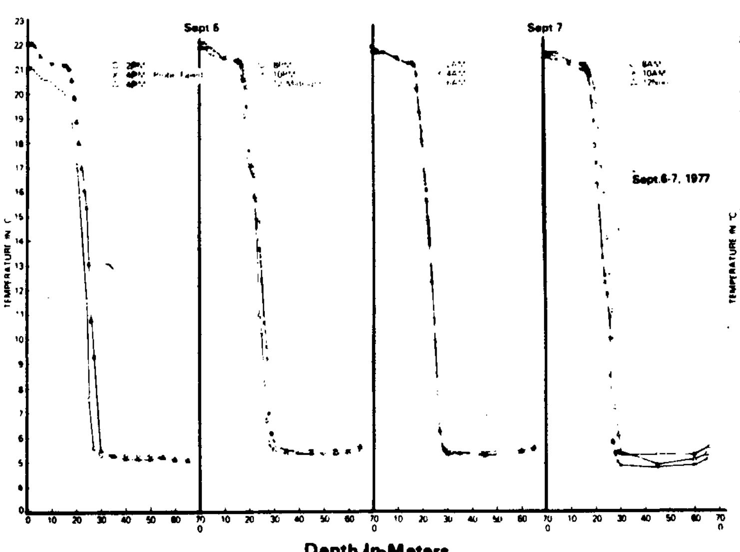


Figure 7

Distribution Of Transparency - Secchi Depth In Meters

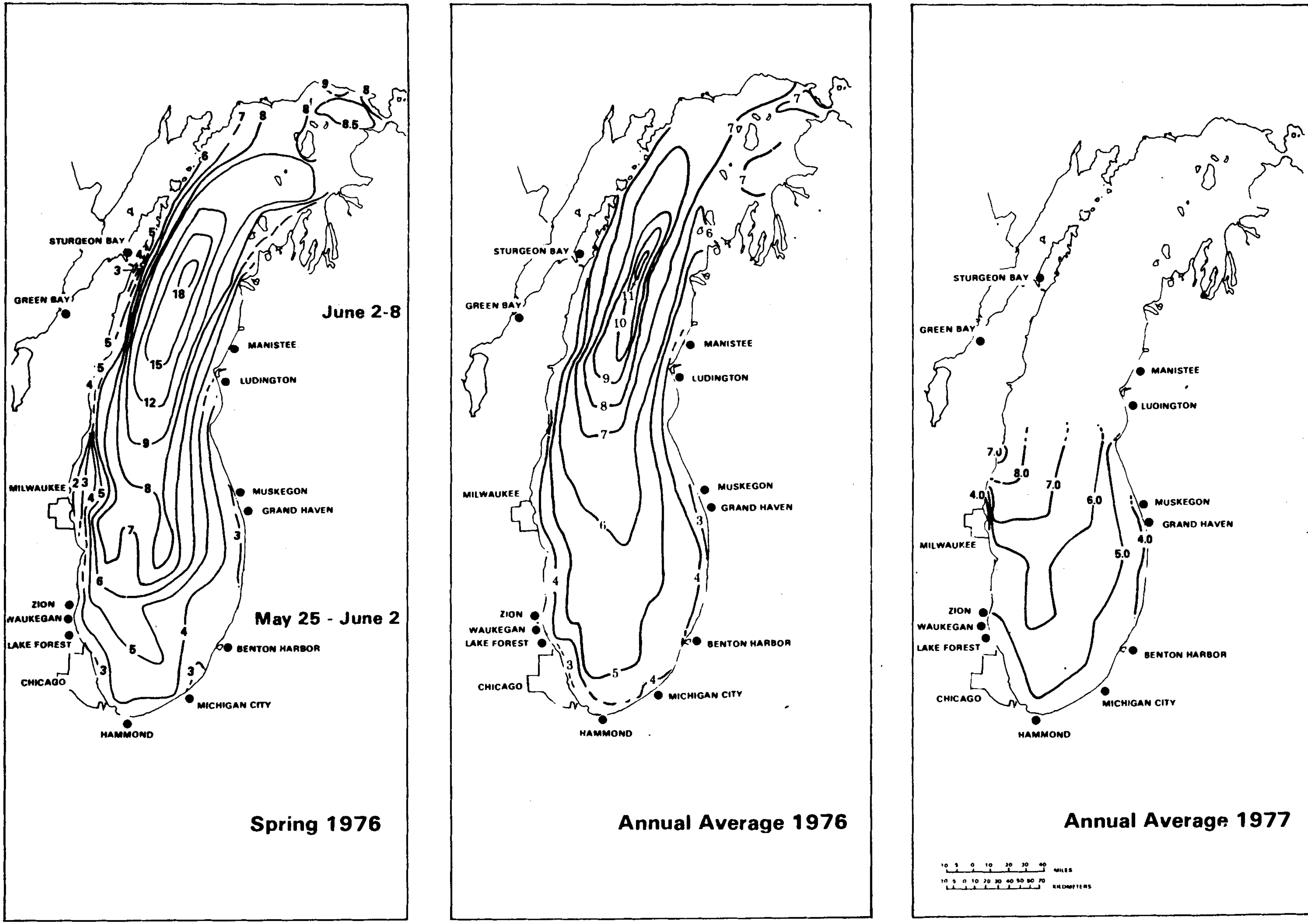


TABLE 9

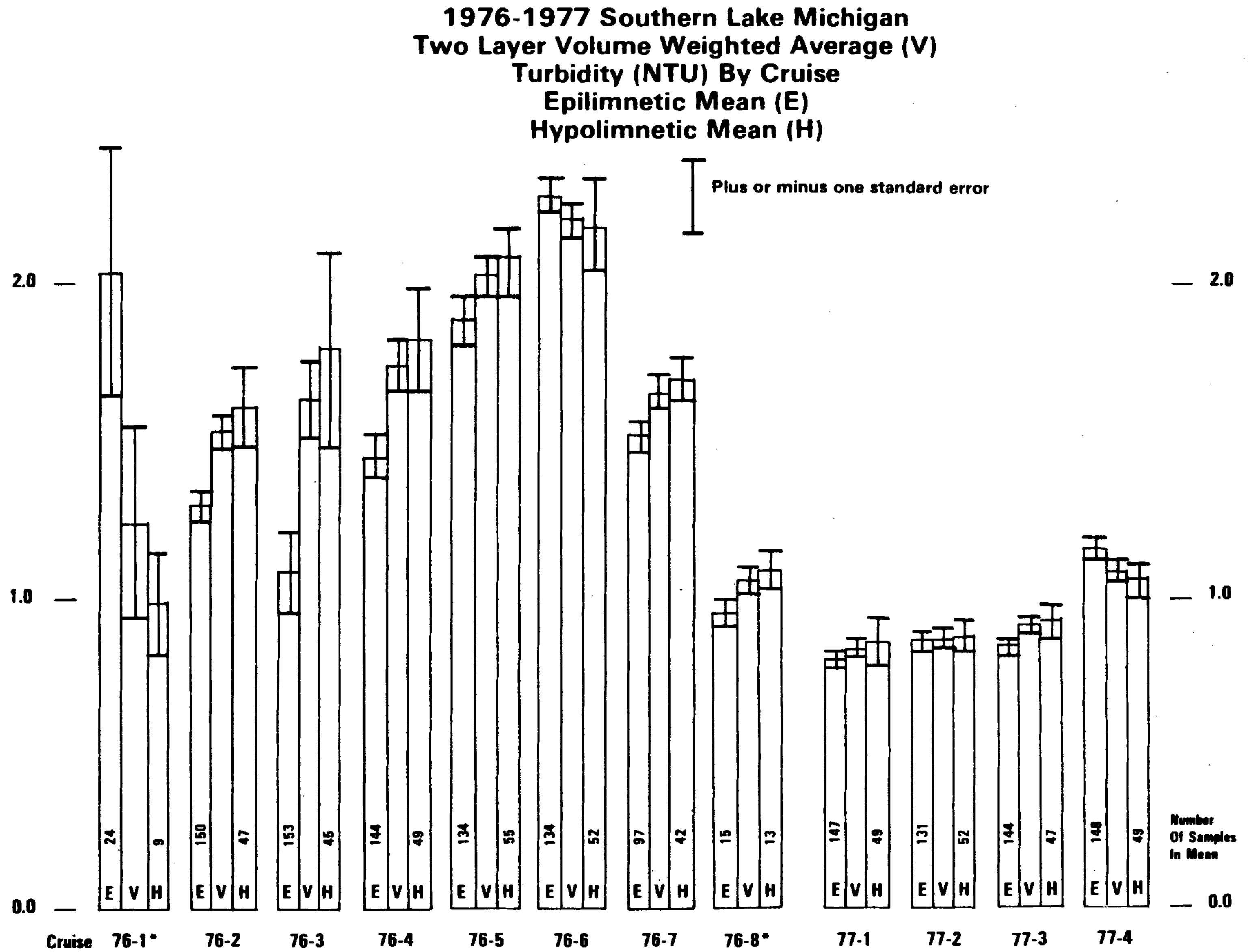
LAKE MICHIGAN

Transparency-Secchi Disc Depth (m)

Number of Samples Arithmatic Mean ± Standard Error

CRUISE DATES	No.	OPEN LAKE	No.	NEARSHORE	No.	Combined
		SOUTHERN BASIN 1976				
May 1-3	2	8.0 ± 2.0	1	1.5	3	5.8 ± 2.5
May 25-June 2	23	5.5 ± 0.4	16	3.4 ± 0.2	39	4.6 ± 0.3
June 15-21	23	7.3 ± 0.3	16	5.1 ± 0.4	39	6.4 ± 0.3
July 7-23	23	6.8 ± 0.5	16	3.7 ± 0.2	39	5.5 ± 0.4
Aug 3-10	23	4.4 ± 0.3	15	3.7 ± 0.2	38	4.1 ± 0.2
Aug 24-Sept 2	23	2.5 ± 0.1	16	2.9 ± 0.2	39	2.7 ± 0.1
Sept 14-20	23	3.8 ± 0.1	16	3.7 ± 0.2	39	3.7 ± 0.1
Oct 7-8	4	5.8 ± 0.8	2	5.0 ± 0.0	6	5.5 ± 0.5
		NORTHERN BASIN 1976				
April 21-29	42	10.8 ± 0.6	17	5.9 ± 0.4	59	9.4 ± 0.5
June 2-8	48	10.0 ± 0.5	16	6.8 ± 0.3	64	9.2 ± 0.4
July 10-19	47	7.5 ± 0.1	14	6.8 ± 0.3	61	7.3 ± 0.1
Aug 10-19	40	6.2 ± 0.3	16	6.1 ± 0.3	56	6.1 ± 0.2
Oct 5-15	30	6.5 ± 0.1	6	5.6 ± 0.5	36	6.4 ± 0.1
		SOUTHERN BASIN 1977				
April 19-24	23	6.7 ± 0.3	16	4.8 ± 0.3	39	5.9 ± 0.3
June 11-16	10	6.8 ± 0.6	9	5.5 ± 0.8	19	6.2 ± 0.5
Aug 19-25	23	6.1 ± 0.4	16	4.6 ± 0.2	39	5.5 ± 0.3
Sept. 17-24	23	4.4 ± 0.2	15	3.8 ± 0.3	38	4.2 ± 0.2

figure 8



* Transect 6 Only

Southern basin turbidity in 1976 and 1977 are plotted in Figure 8. Turbidity in 1976 ranged from 1 to 2.3 HTU in the epilimnetic waters. Exclusive of the first and last cruises where fewer samples were taken, turbidity increased until the cruise in late August 1976. In 1977, epilimnetic turbidity levels were observed around 0.8 HTU for most of the year with an increase to 1.2 HTU in the last cruise in September. The 1977 values were nearly constant and similar in both epilimnetic waters and hypolimnetic waters from the April cruise through the August cruise. There is little evidence that stratification had any affect on turbidity in the deep waters (Appendix Table C1 and C3).

Phosphorus

Between 1976 and 1977 large decreases were observed in total phosphorus in the southern basin. Reductions in the depth weighted mean total phosphorus concentrations occurred at ninty-two percent (36 of 39) of the southern basin stations. Using data from the six complete 1976 cruises and the four cruises in 1977 the reduction in total phosphorus in the southern basin was from 8.0 $\pm$ .8 ug/l in 1976 to 5.2 $\pm$ .2 ug/l in 1977. The five 1976 Northern basin cruises averaged 7.4 $\pm$ 1.0 ug/l. Epilimnetic and hypolimnetic concentrations decreased an average of 2.2 =g/l and 3.1 ug/l respectively. The distribution of total phosphorus in the epilimnion and hypolimnion was almost constant in 1977 while there was a greater variation in 1976 perhaps reflecting seasonal change in the total phosphorus concentrations (Figure 9). The total phosphorus concentrations in the epilimnion at the deep water stations tended to be lower but was not statistically different from the hypolimnion in both years and both basins. This can also be seen in the vertical distribution in Appendix Tables C1-C3.

The decrease in total phosphorus between 1976 and 1977 in the southern basin was also observed in the total dissolved fraction, which decreased from a median concentration of 3 ug/l in 1976 to below detectable levels (<3 ug/l) in 1977. The Mann Whitney Test (Zar, 1974) indicates that this difference is significant at the 95% confidence level. Median values of total dissolved phosphorus were at 3 ug/l or less than 3 ug/l in the epilimnion throughout 1976 in the southern basin. Median values of total dissolved phosphorus were at 4 ug/l or less in the hypolimnion throughout 1976 in the southern basin. In 1977 the median value was less than 3 ug/l throughout the entire basin. Lower detection limits for total dissolved phosphorus permitted real values to be reported for the northern basin in 1976 and appear to range between 2 to 5 ug/l through the summer.

Dissolved ortho-phosphate concentrations were frequently below the detection limits of the methodology (2 ug/l) in both 1976 and 1977 in the southern basin. In the northern basin Figure 10 contains three cruise results for detection limits at (1 ug/l).

figure 9

1976-1977 Lake Michigan
Two Layer Volume-Weighted Average (V)
Total Phosphorous P (ug/l) By Cruise
Epilimnetic Mean (E)
Hypolimnetic Mean (H)

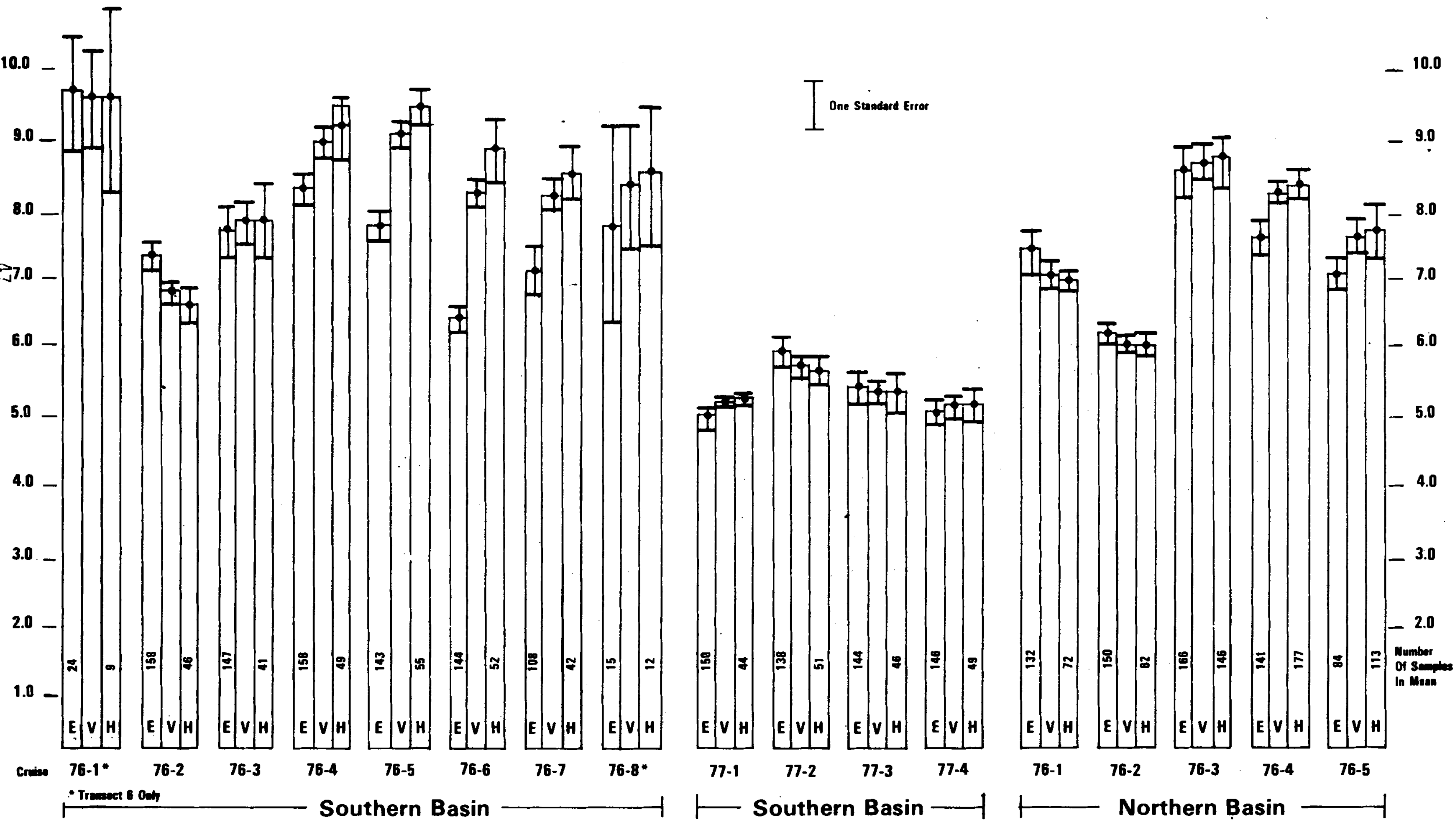
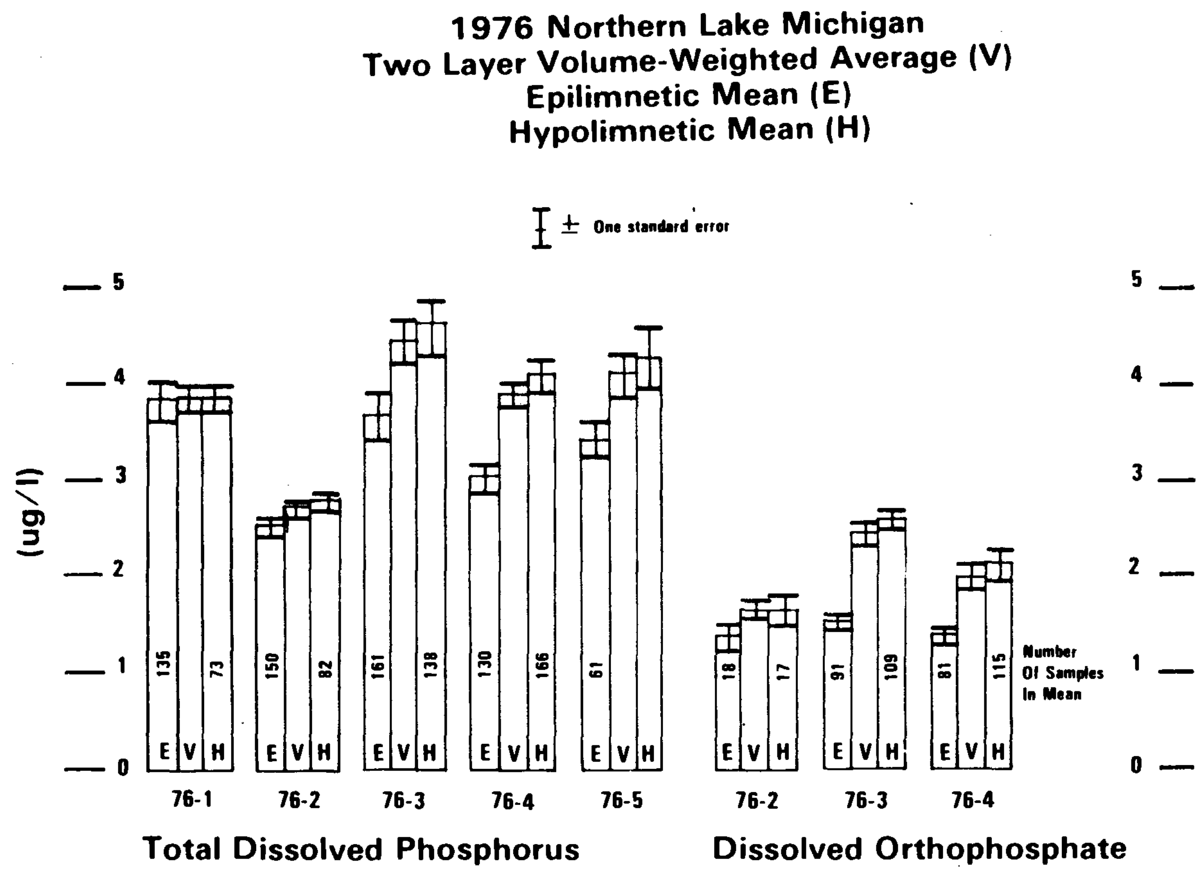


figure 10


1976 Northern Lake Michigan
Two Layer Volume-Weighted Average (V)
Epilimnetic Mean (E)
Hypolimnetic Mean (H)
± One standard error
(ug/l)
0
1
2
3
4
5
135
73
150
82
161
138
130
166
61
18
17
91
109
81
115
Number Of Samples In Mean
E V H
76-1
76-2
76-3
76-4
76-5
Total Dissolved Phosphorus
Dissolved Orthophosphate

Spacial variations in the upper twenty meter distribution of total phosphorus in 1976 and 1977 spring and summer cruises are displayed in Figure 11. Nearshore values are elevated due to nearshore processes and land run off. Elevated values occur near major urban centers and large tributaries. Water exchange from Green Bay increases the phosphorus load in northern Lake Michigan. Low total phosphorus values were found in the Straits of Mackinac. The reduction in total phosphorus between 1976 and 1977 in the southern basin in clearly evident when comparing the August cruises.

Silica

In both years in all areas of the lake, dissolved reactive silica (DRS) showed a progressive decrease in the surface water through the stratified period. Surface values away from shore declined from winter values ranging from 1.20 to 1.30 mg/l which were monitored at stations on the 40-50 meter contours near Sturgeon Bay in February 1977 to an observed average of 0.24 $\pm$ .01 mg/l in 1977 at the deep water stations during August (Appendix Tables C1 and C3). The average concentration in August 1976 at the deep water stations was 0.26 + 0.01 mg/l. These represent reductions of up to 80% of the silica concentrations found during isothermal conditions. Mean surface DRS concentrations were at an observed minima during August cruise both years when surface temperature were at an observed maxima. Hypolimnetic concentrations of DRS tended to increase during the summer. DRS concentrations appeared to decrease rapidly after water temperature had increased above 6°C.

Figure 12 shows the vertical distribution of DRS at station 18 (depth 60 meters) for the eight cruises starting May 29, 1976 and ending April 21, 1977 which covers a complete annual cycle. During May 1976 before stratification the vertical DRS distribution was approximately uniform. Surface concentration was 1.32 mg/l and 1.54 mg/l was measured near the bottom. As warming occurred, the surface concentration of DRS decreased until it reached 0.20 mg/l on August 7, 1976. Hypolimnetic DRS concentrations increased with the bottom sample reaching a maximum of 2.09 mg/l on August 7, 1976. DRS concentrations returned to a homogeneous distribution during the winter period. The homogeneous isothermal spring distribution was approximated by the first 1977 cruise in April when DRS values of 1.14 mg/l (surface) and 1.10 mg/l (bottom) were monitored. The pattern of epilimnetic DRS decrease during the stratified period also occurred in 1977. This seasonal cycle was typical of open lake stations where inputs of silica via upwelling, sediment resuspension and surface run off were not important (Appendix Tables C1-C3).

DRS minima in the metalimnion layer as seen most clearly in the June 18, 1976 and August 27, 1976 vertical profiles, was typical of open lake stations in both 1976 and 1977. The DRS depletion began first in the nearshore areas and southern latitudes and followed the warming patterns. By June 1976 and 1977 the concentrations of DRS at the surface of stations (depth 80 meters or greater) was reduced to levels found at the nearshore

Figure 11

Upper Twenty Meter Distribution Of Total Phosphorous In ug/l

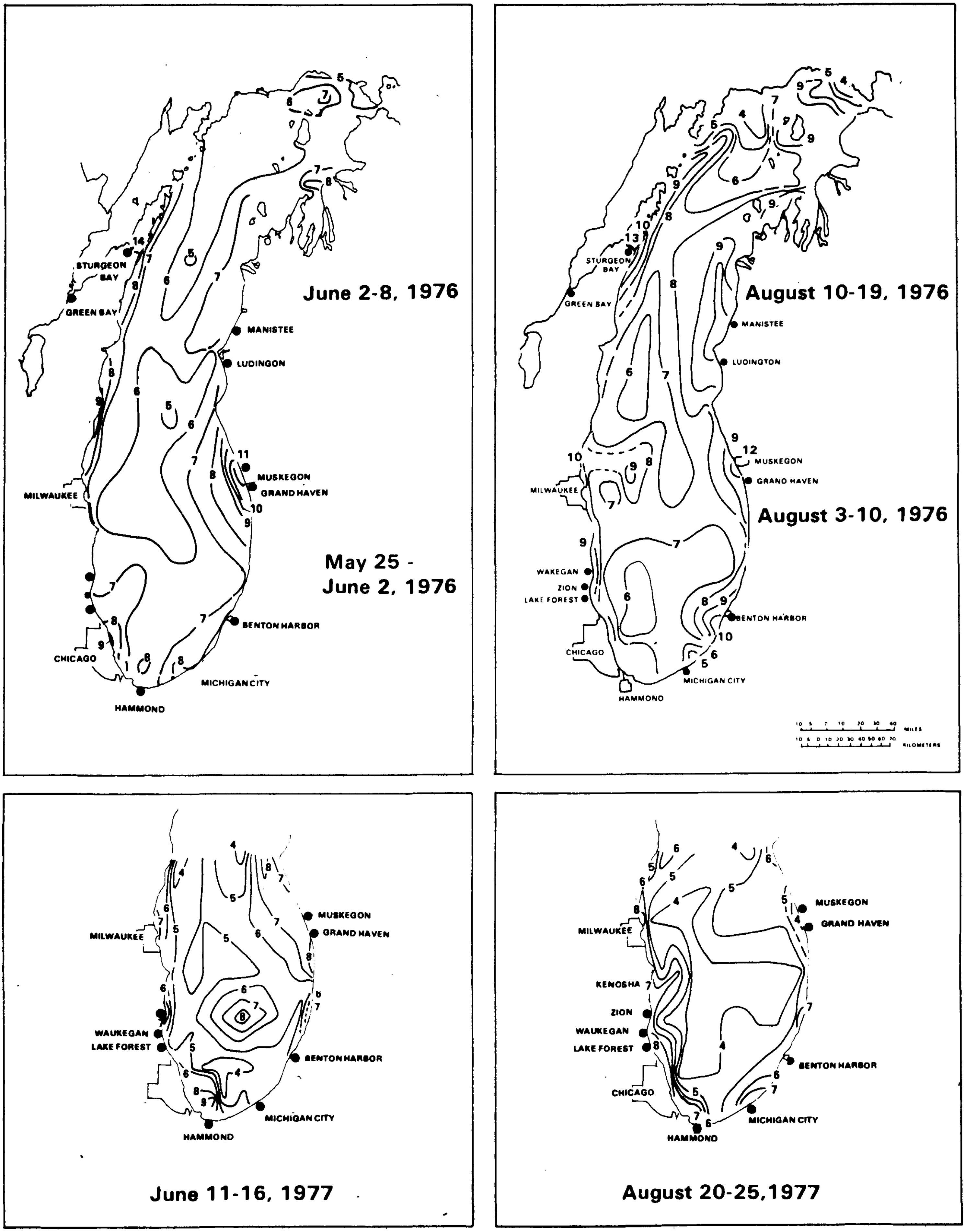
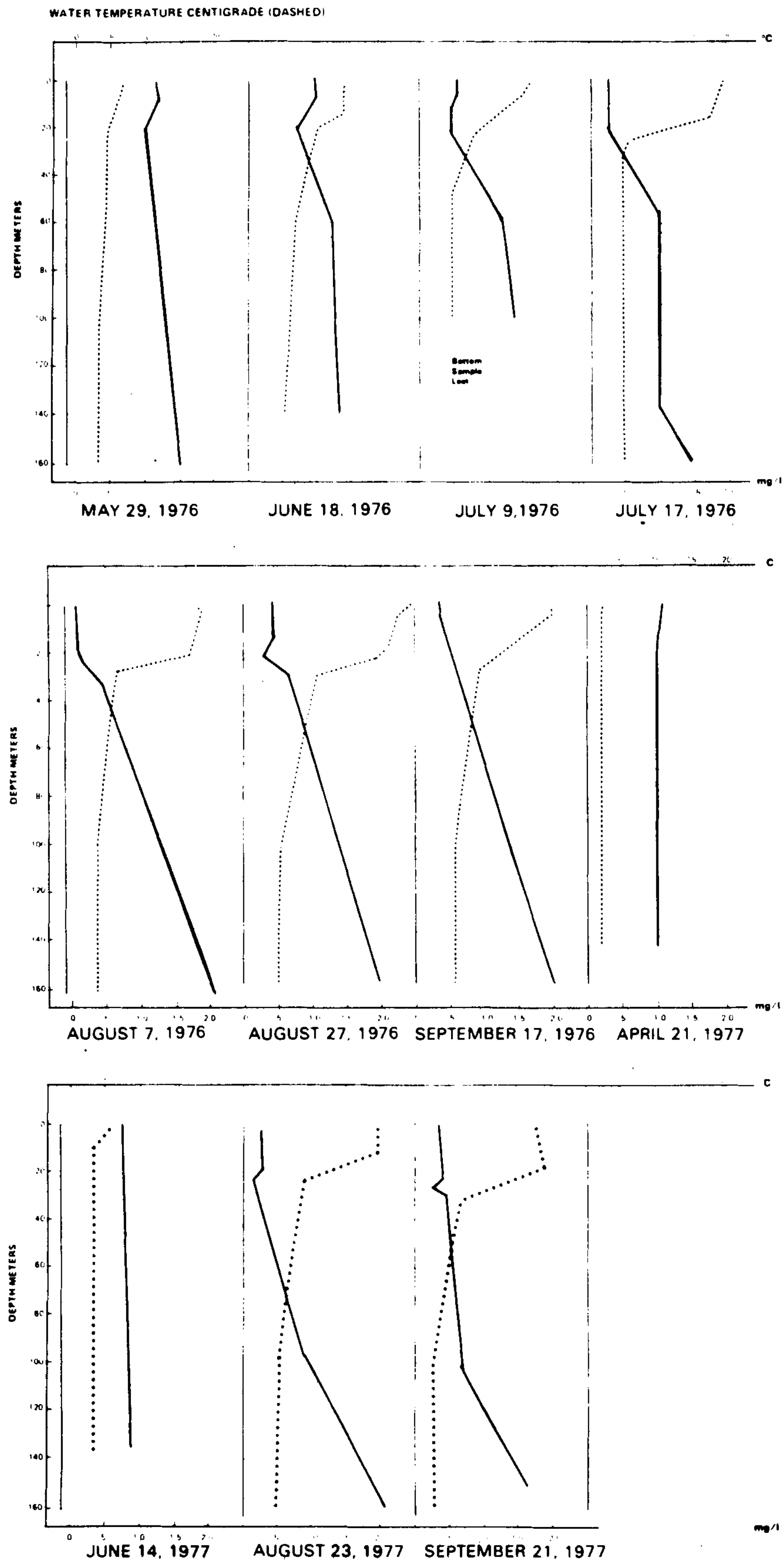


figure 12

Lake Michigan 18
Water Temperature Centigrade (Dashed) top scale
Dissolved Reactive Silica mg/l (Solid) bottom scale



stations in both basins (around .6 mg/l) (Appendix Tables C1-C3). Open lake epilimnetic water concentrations continued to decline to below .3 mg/l in August 1976 and 1977 while nearshore waters remained around .6 mg/l except for the Illinois and Indiana nearshore zone which declined below .3 mg/l in August 1976 (Figure 13).

Figure 14 compares the cruise results for both years, presenting the epilimnetic, hypolimnetic, and two layer volume weighted average in the southern basin. The southern basin epilimnetic DRS seasonal patterns in 1976 and 1977 are similar with epilimnetic cruise means of 0.50 $\pm$ .13 mg/l in 1976 and 0.63 $\pm$ .21 mg/l in 1977 with mean epilimnetic 1977 cruise values being higher than comparable calendar values in 1976. Total water column and hypolimnetic concentrations were lower during 1977 cruises than 1976 cruises in the southern basin. Open lake silica concentrations were at lower levels in 1977 than 1976. The nearshore waters in the western portion of basin, however were higher in 1977 leading to the higher epilimnetic mean (Figure 13).

Figure 15 compares cruise results for the northern basin in 1976 for DRS and suspended silica. The seasonal decrease in DRS concentrations was also apparent in the northern basin DRS. Suspended silica increased in the water column thru July and returned to April levels by October.

DRS depth weighted means were computed at each station in the southern basin of the lake between 1976 and 1977. The open water stations appear to have lower DRS concentrations in 1977 than in 1976. The zone (about 10 km wide, along the Illinois and Indiana shoreline showed an increase in DRS, (Rockwell et al 1980). This area had the lowest DRS concentration levels in the southern basin in 1976 (Figure 13).

In comparing spring and summer 1976 northern basin to southern basin DRS concentrations, the northern basin silica concentrations were generally lower (Figure 13). Northern basin cruise were one week later in the season than the southern basin cruises. While these differences may reflect, in part, differences due to ship laboratory analytical processess, surface water temperature differences, and the additional time available for silica uptake, a picture of lake wide seasonal depletions of DRS concentrations is documented.

Nitrate-Nitrite

Epilimnetic total nitrate + nitrite as nitrogen, (TNN), concentrations decreased through the stratified period in both years (Figure 16), while TNN remained essentially constant in the hypolimnetic waters throughout the season. Changes in the vertical distribution of TNN concentrations developed during the season. TNN showed lower concentrations in the epilimnion when compared with hypolimnion which were statistically significant ($p >.95$) in the latter half of the cruises in both 1976 and 1977. A similar seasonal effect is seen in dissolved nitrate and nitrite, (DNN), in the northern basin.

figure 13

Upper Twenty Meter
Distribution Of Dissolved Reactive Silica In mg/l

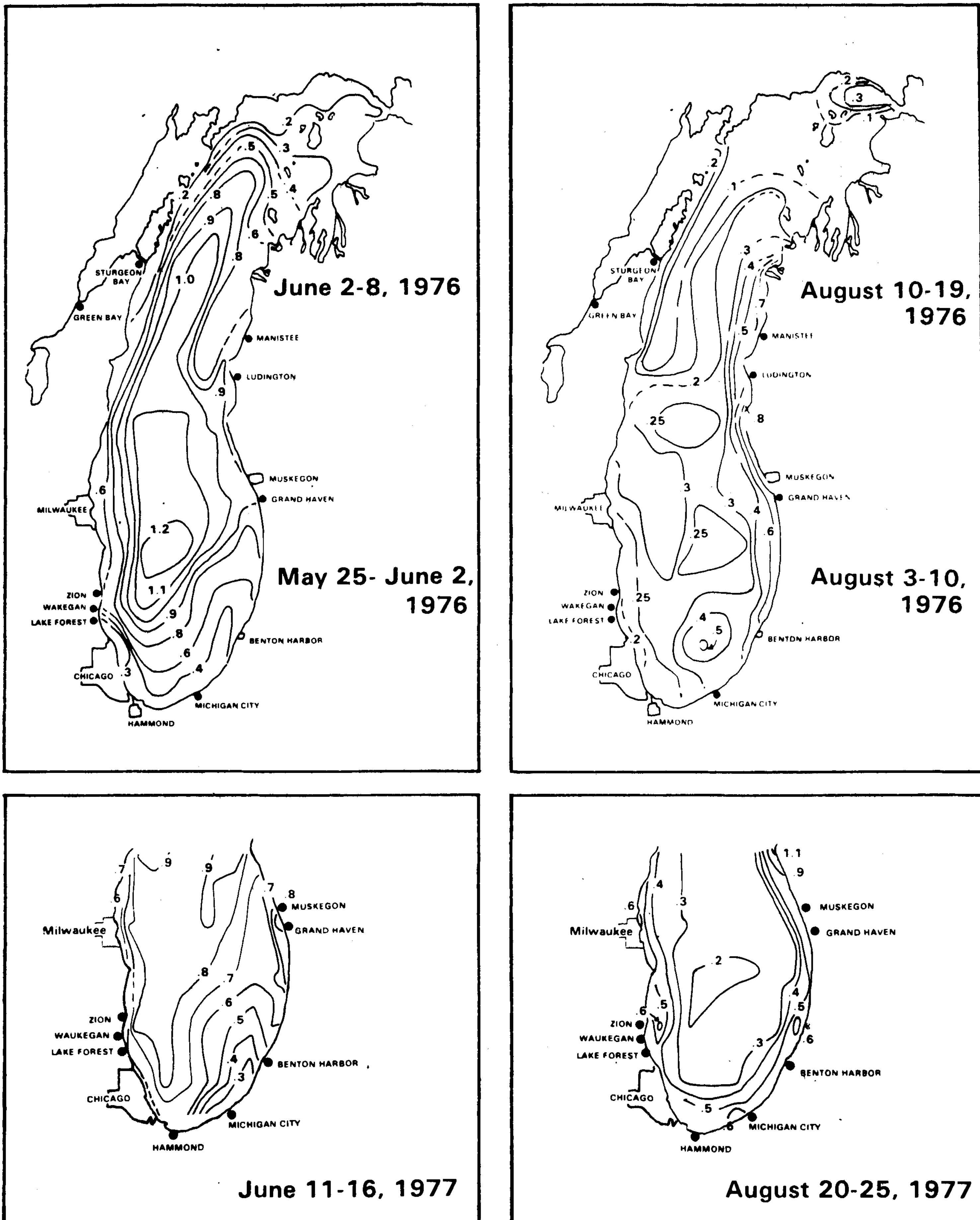
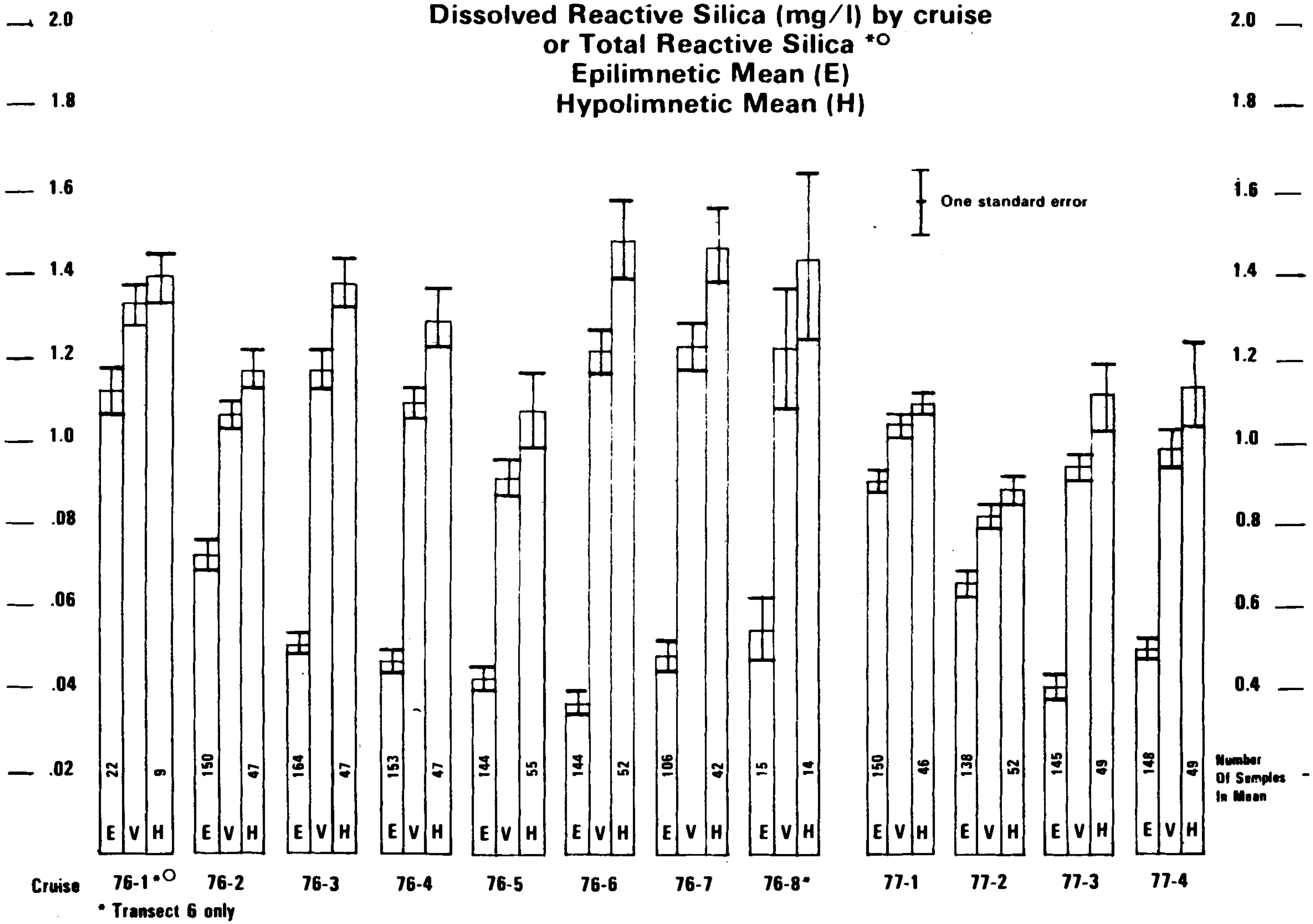


figure 14



1976-1977 Southern Lake Michigan
Two Layer Volume-Weighted Average
Dissolved Reactive Silica (mg/l) by cruise
or Total Reactive Silica *O
Epilimnetic Mean (E)
Hypolimnetic Mean (H)

figure 15

1976 Northern Lake Michigan
Two Layer Volume Weighted Average (V)
Silica (mg/l) By Cruise
Epilmnetic Mean (E)
Hypolimnetic mean (H)

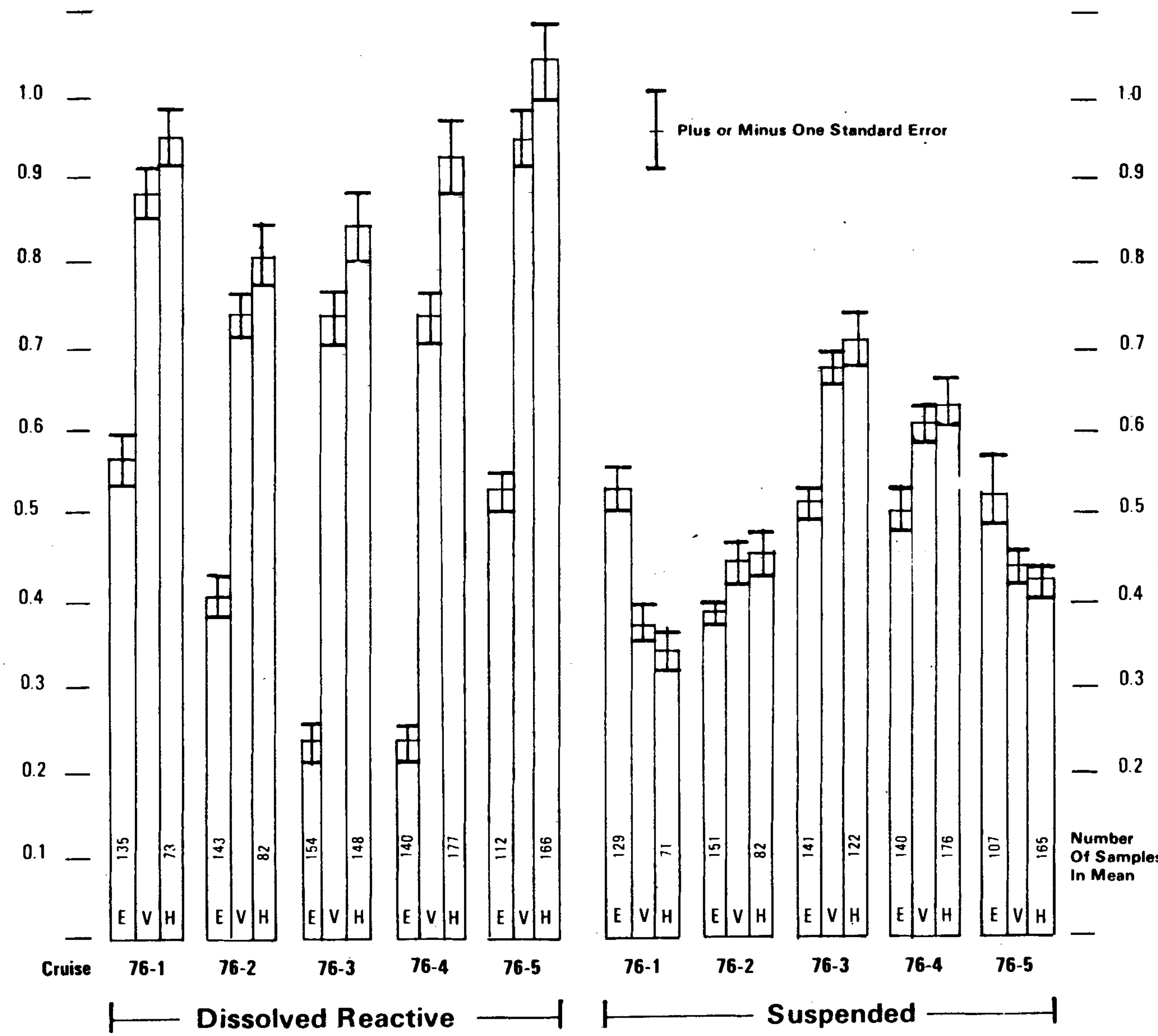


figure 16

1976-1977 Lake Michigan
Two Layer Volume-Weighted Average (V)
Nitrate + Nitrite N (mg/l) By Cruise
Epilimnetic Mean (E)
Hypolimnetic Mean (H)

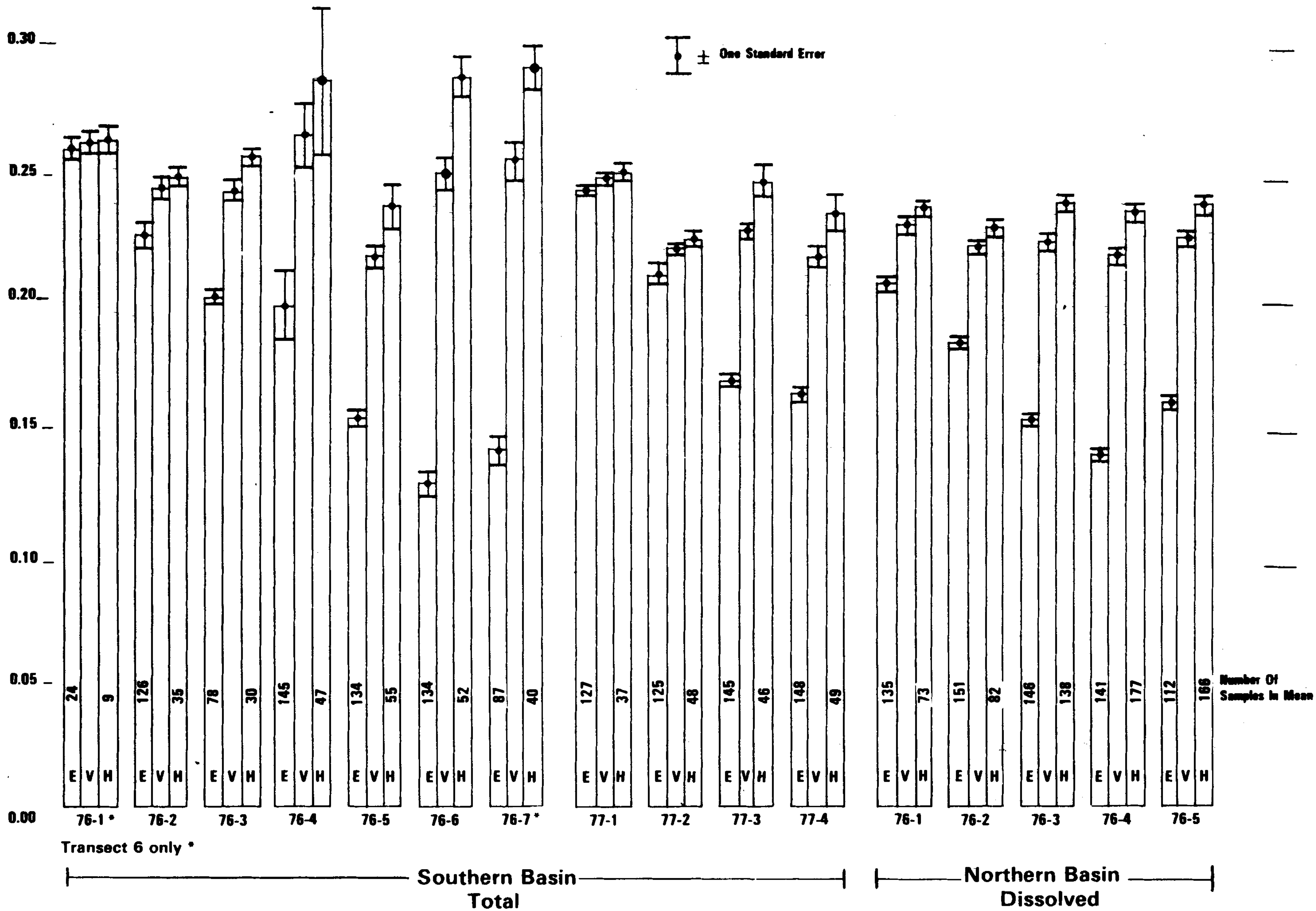


Figure 17 illustrates the seasonal variation in the vertical distribution of TNN, at Station 18, a typical deep water site. TNN's homogeneous distribution is evident during the isothermal regime in May 1976, and April and June 1977. Depletion of TNN in the epilimnion occurs during the other visits and is most severe in the August 1976 and September 1977 cruises.

In the northern basin (Figure 18), DNN did not appear to have statistically significant (p >.95) nearshore to offshore gradients over the season. In Figure 18 the northern basin data is DNN and the southern basin is TNN. The principal form of nitrate + nitrite is the soluble fraction since no significant differences were found in comparing TNN and DNN in the southern basin. Further comparison of TNN in the southern basin with DNN in the northern basin indicated no statistically significant differences (p >.95) in the epilimnion or hypolimnion.

Comparisons between the nearshore and open lake zones, showed relatively lower values for both TNN and DNN in the early cruises (June 1976-1977) in the nearshore epilimnetic waters, while the later cruises (August 1976-1977) showed relatively higher values in the nearshore epilimnetic waters (Figure 18). These patterns are illustrated with the depletion of DNN in the shallow nearshore zones in the northern basin near Green Bay and along the western shore into the southern basin in Figure 18. In the August cruises in areas where upwelling was noted, near Muskegan in 1976 and near Milwaukee in 1977, higher values of TNN are noted along shore when compared to deeper waters (Figure 18).

TNN was homogeneous (.256-.260 mg/l) throughout the water column during isothermal conditions in the deep water stations in both years (Appendix Tables C1 and C3). Depletion during the summer to levels around .088 ± .003 mg/l occurred in the open lake surface waters. This represented a 66% reduction in TNN concentrations in 1976. In 1977 observed depletion effects were not as severe with surface water TNN concentration lows at .134 ± .005 mg/l which represented a 50% reduction from isothermal condition concentrations. This depletion is widespread across the entire epilimnetic layer in the southern basin both in 1976 and 1977 (Appendix Table C1 and C3) in the deep waters of the lake. Depletion is also evident in the surface water DNN concentrations which declined from .230 ± .006 mg/l to .121 ± .003 mg/l in the northern basin in 1976 (Appendix Table C2).

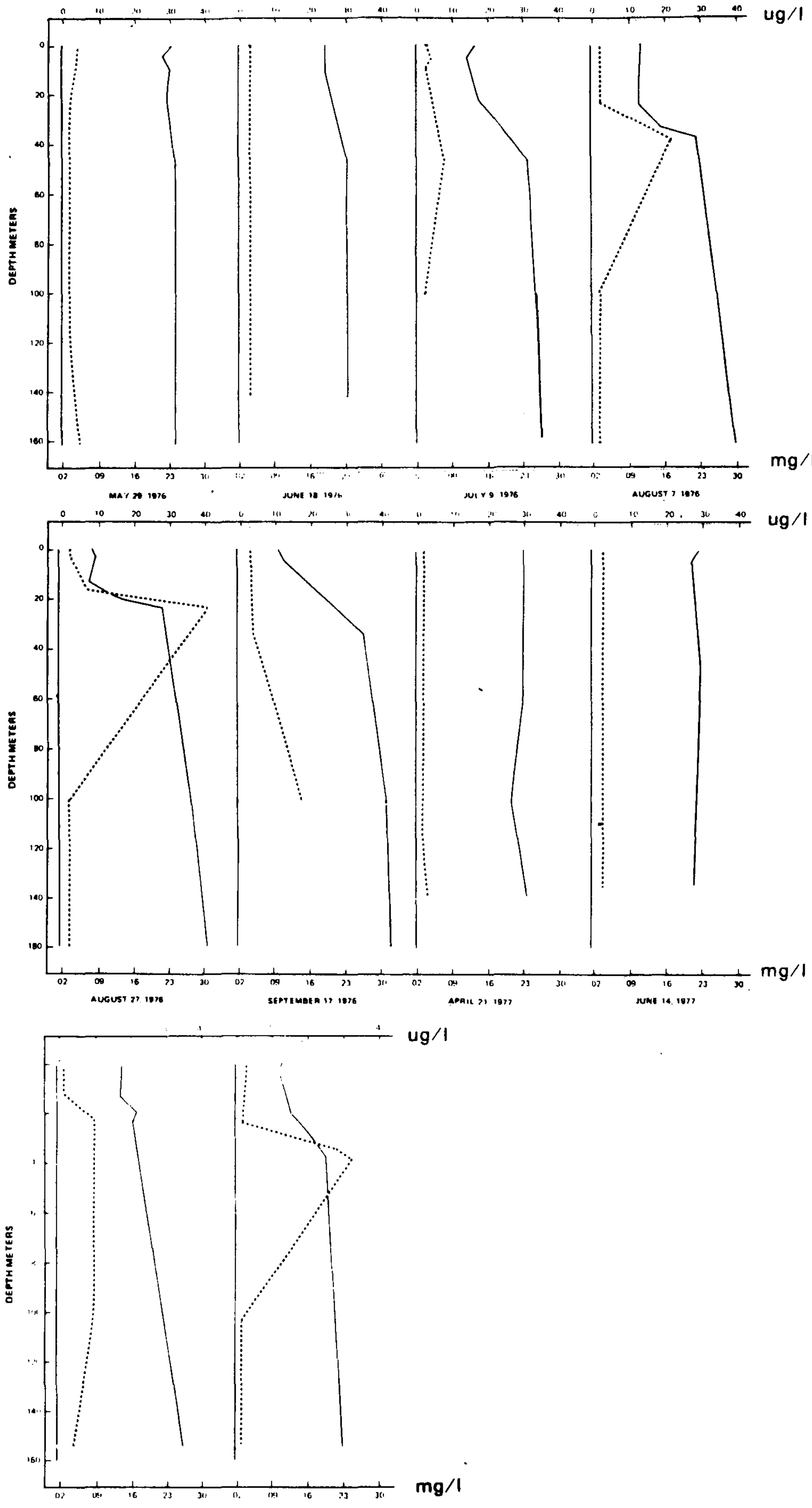
Ammonia

Ammonia levels encountered in Lake Michigan during 1976-1977 ranged from less than 1 ug/l to 30 ug/l with TLVWA of cruise data ranging from 2.7 ug/l to 8.6 ug/l. These levels are at least two orders of magnitude lower than those found in the harbor areas surveyed (Appendix B).

Figure 19 shows means for the epilimnion, hypolimnion, and volume weighted mean for 1976 and 1977 cruises. Total ammonia concentrations declined at 87% of the southern basin stations between 1976 and 1977.

figure 17

Lake Michigan 18 1976-1977 Cruise Results
Total Ammonia NH3-N ug/l (Dashed) Top Scale
Total NO2 + NO3 mg/l (Solid) Bottom Scale



TOTAL NO2 + NO3 MG/L (SOLID)

figure 18

Upper Twenty Meter Distribution Of Nitrate And Nitrite In mg/l

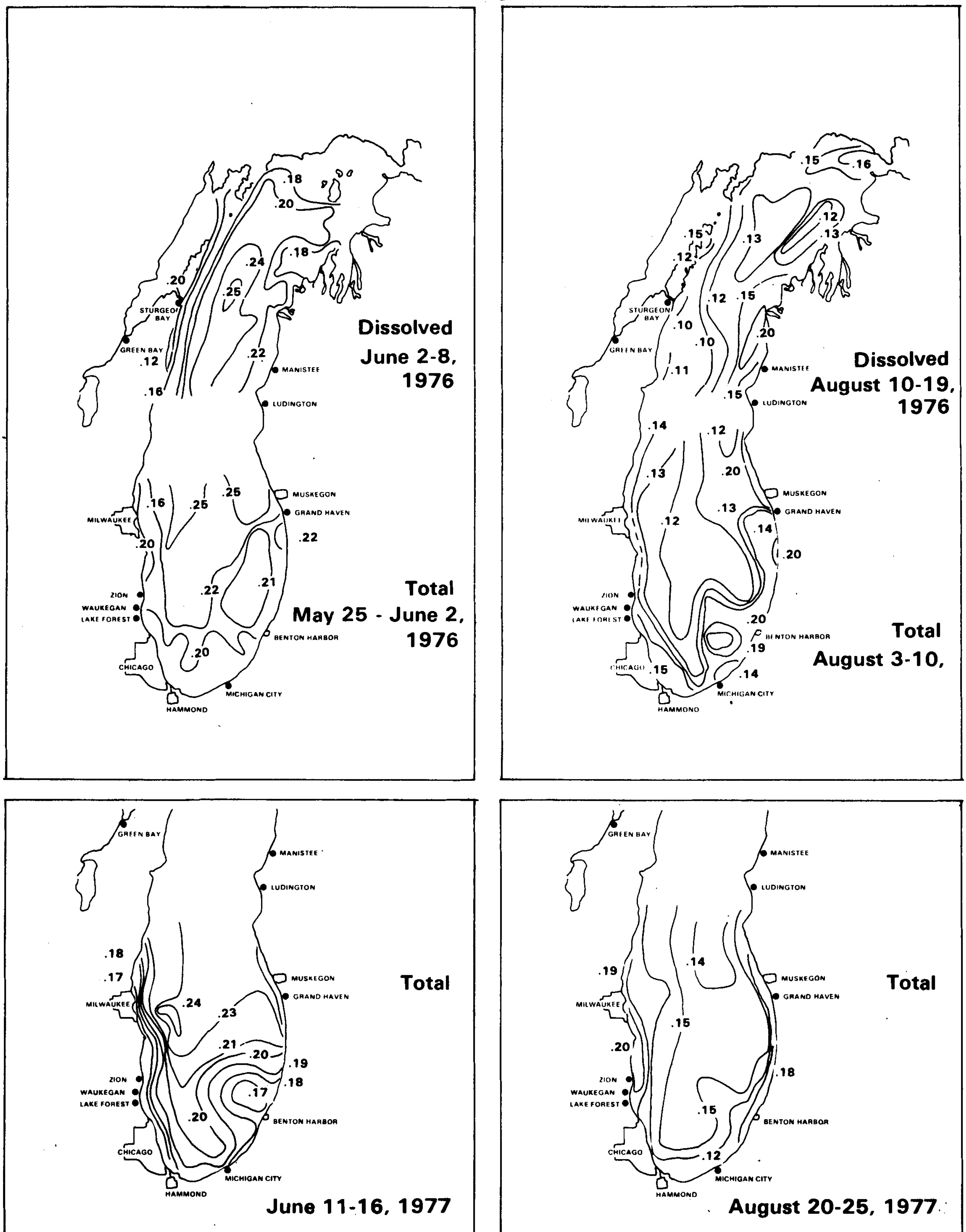
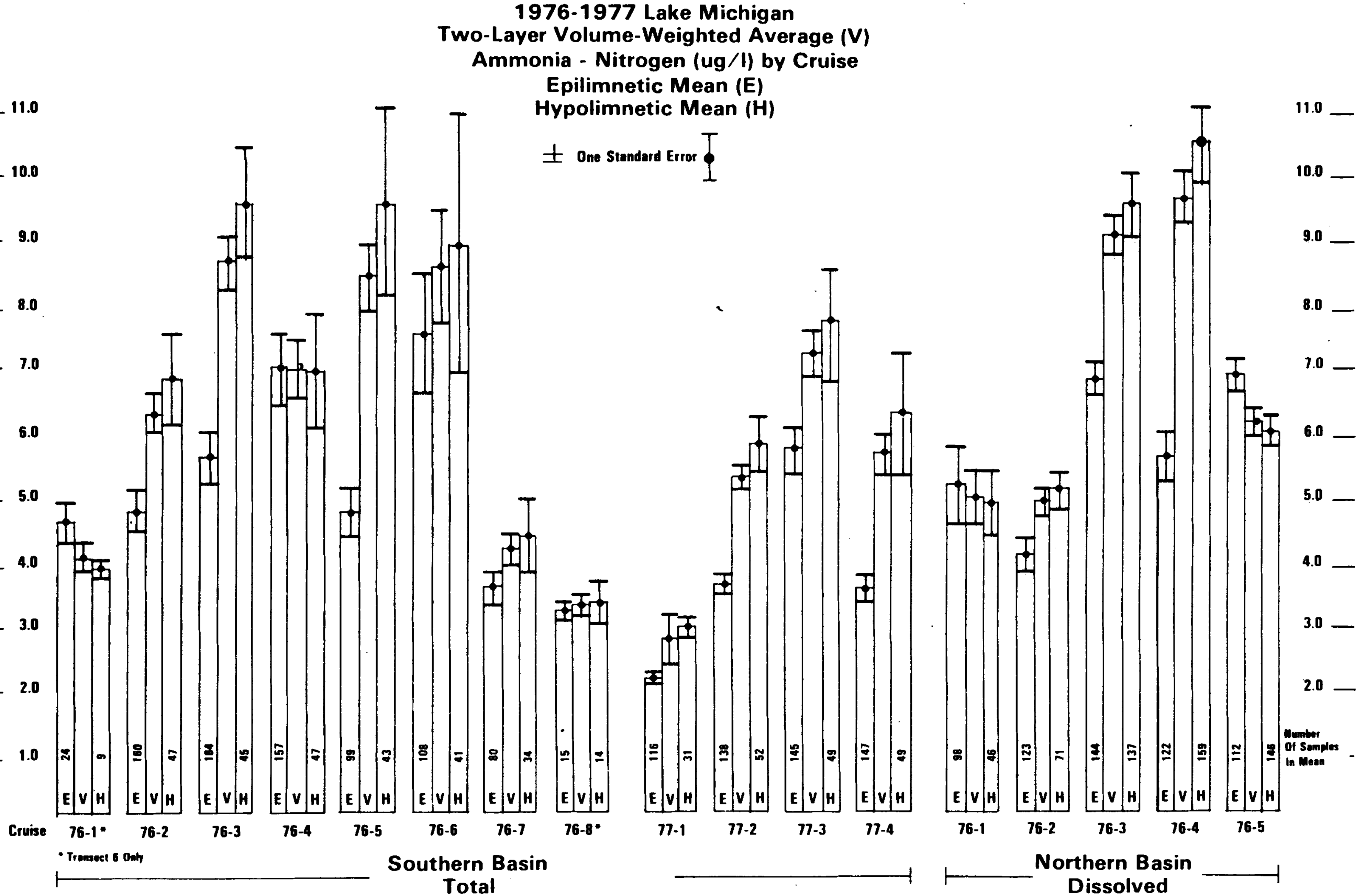


figure 19


1976-1977 Lake Michigan
Two-Layer Volume-Weighted Average (V)
Ammonia - Nitrogen (ug/l) by Cruise
Epilimnetic Mean (E)
Hypolimnetic Mean (H)
One Standard Error
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
Number Of Samples In Mean
24 9
160 47
184 45
157 47
99 43
108 41
80 34
15 14
116 31
138 52
145 49
147 49
98 46
123 71
144 137
122 159
112 146
E V H
Cruise
76-1*
76-2
76-3
76-4
76-5
76-6
76-7
76-8*
77-1
77-2
77-3
77-4
76-1
76-2
76-3
76-4
76-5
* Transect 6 Only
Southern Basin
Total
Northern Basin
Dissolved

This is reflected in southern basin total ammonia TLVWA of cruise data which ranged between 4.0 ± .2 to 8.6 ± .9 ug/l in 1976 as compared with 1977 values which ranged between 2.7 ± .1 to 6.2 ± .3 ug/l. Northern basin dissolved ammonia TLVWA of cruise data ranged between 5.2 ± .2 to 10.0 ± .4 ug/l in 1976.

Ammonia concentrations are highly variable in the lake and nearshore. During June 11-16, 1977 concentrations were below the cruise detection level (<3 ug/l) for most of the western portion of the southern basin. The following cruise during August 20-25, 1977 concentrations were above 18 ug/l in the same area (Figure 20).

Vertical variations in ammonia distribution were observed following stratification. The typical sequence observed was an increase in ammonia near and just below the thermocline of deep-water stations around the 20 to 30 meter depth. Figure 17 shows this development in both 1976 and 1977. This pattern was observed both years at deep water stations (Appendix Tables C1-C3) and suggests that this development is characteristic of the lake in both basins.

Total Kjeldahl Nitrogen (TKN)

In the first three cruises in 1976 and in all cruises in 1977 in the southern basin total kjeldahl nitrogen concentrations were consistently higher in the epilimnetic waters than in the hypolimnetic waters. TKN showed a tendency to increase in the metalimnion and developed a local maximum in the deep water stations (greater than 80 meters in depth) in the southern basin during the stratified period in 1976 (Appendix Table C1). The layer differences were statistically significant ($p > .95$) after the first cruise each year. Nearshore TKN values were greater than offshore values in the upper layer in 1976 during all three cruises. Figure 21 illustrate these spatial distribution of TKN during third and fourth cruise of 1977.

Chlorophyll "a"

The seasonal vertical chlorophyll "a" pattern is displayed in Figure 22 for cruises in 1976 and 1977 at station 18. The temperature distribution for these cruises can be found in Figure 12. The vertical distribution of chlorophyll "a" at this deep water station (Figure 22) was similar to that reported by Brooks and Torke (1971). The vertical distribution was homogeneous during the early isothermal cruises. With the onset of thermal stratification, higher concentrations occurred in the epilimnion with a maxima in the lower thermocline in June and July. This maxima disintegrated in September.

Figure 20

Upper Twenty Meter Distribution Of Total Ammonia In ug/l

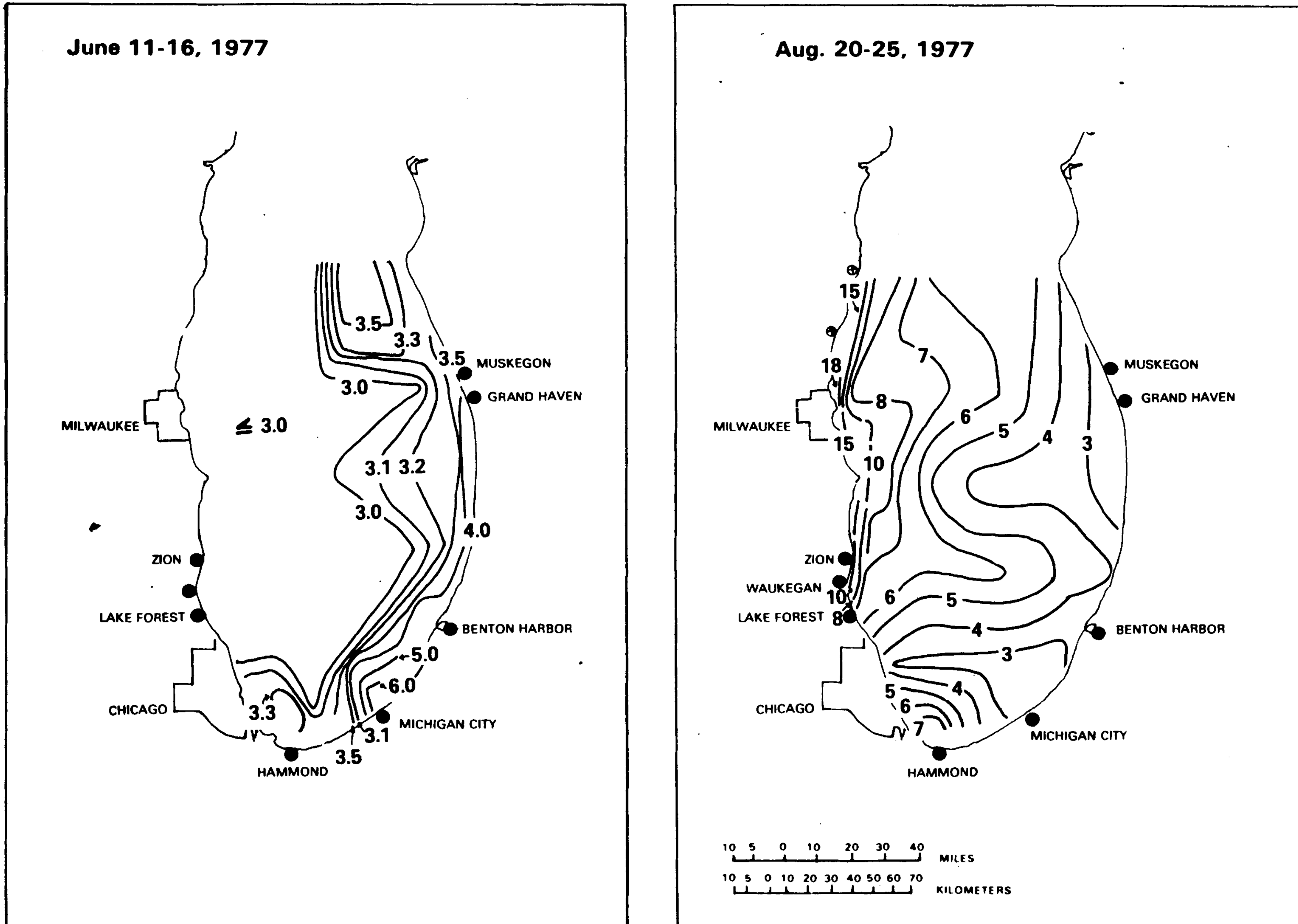
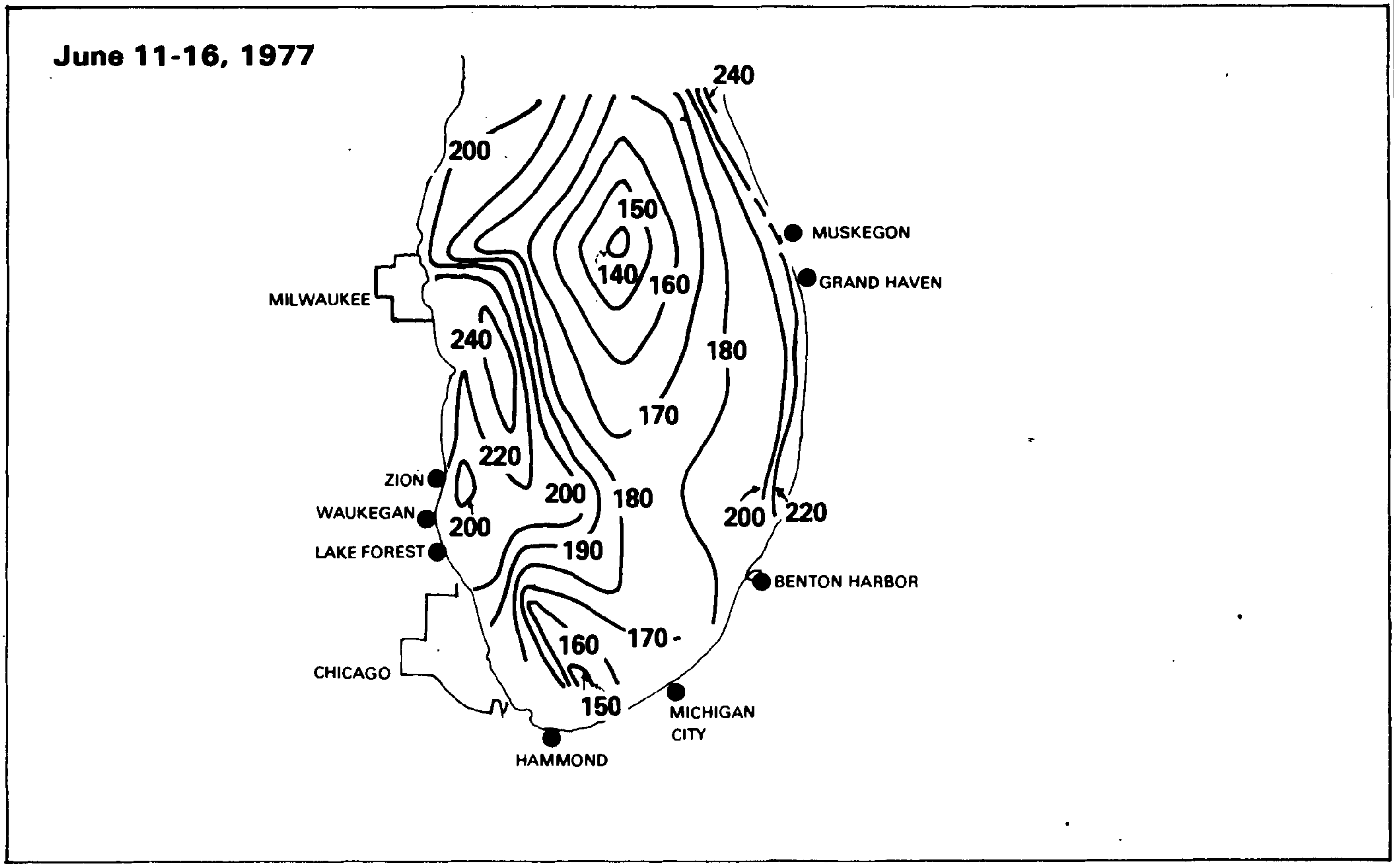
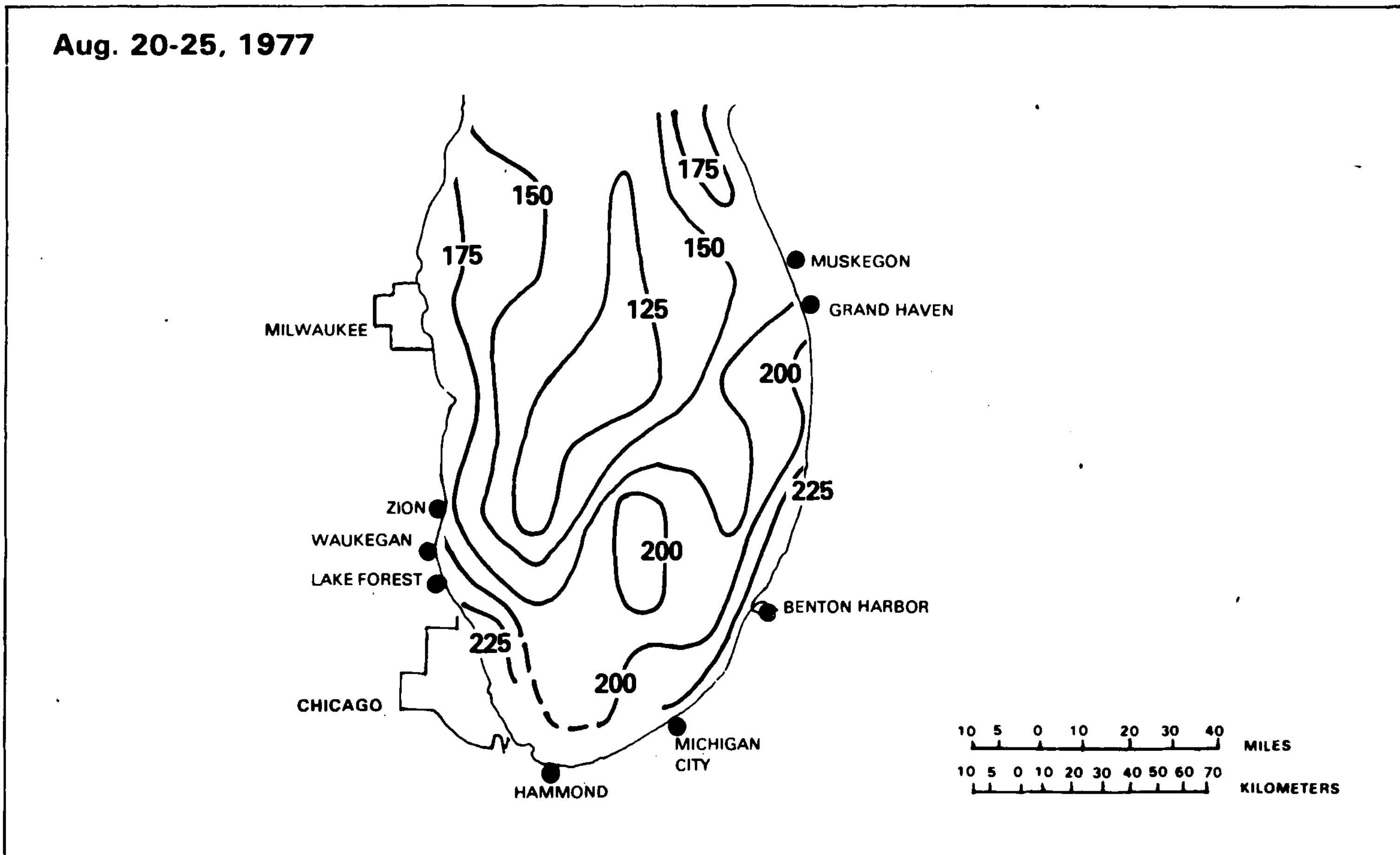


figure 21

Upper Twenty Meter Distribution Of Total Kjeldahl Nitrogen In ug/l





Lake Michigan 18 - 1976-1977 Cruise Results
Total Phosphorous ug/l (Dashed) Top Scale
Chlorophyll-a ug/l (Solid) Bottom Scale

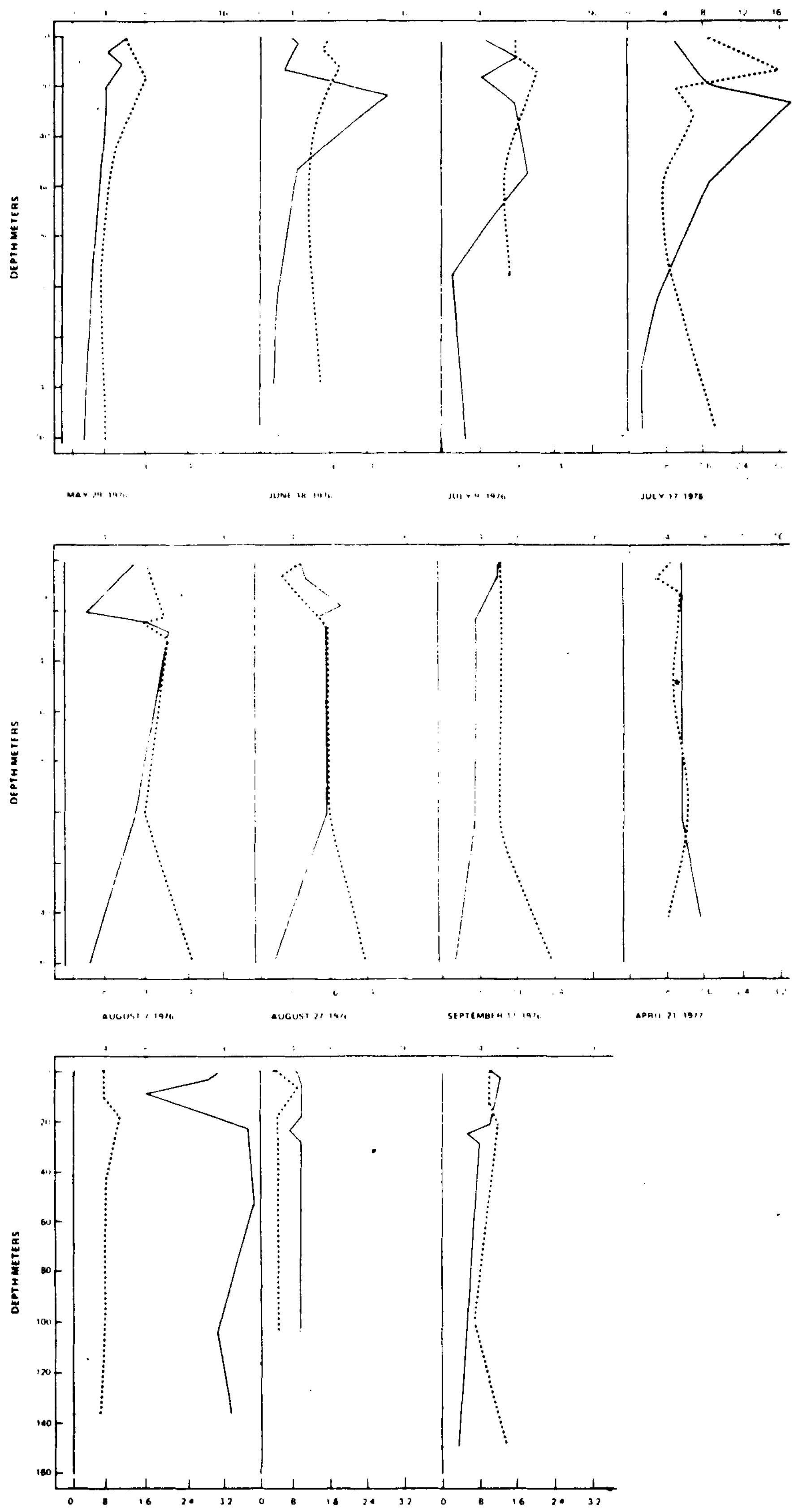


Figure 22

Higher average values were monitored in the epilimnetic layer when compared to the hypolimnetic layer in the southern basin (Figure 23). This pattern is also observed in the 1976 data in the northern basin. Epilimnetic values observed in the southern basin were lower throughout 1977 than those observed in 1976. In 1976 Northern basin chlorophyll "a" concentrations were similar to those in the southern basin.

Figure 24 illustrates the areal distribution of chlorophyll "a" during June and August 1976 and 1977. The pattern is fairly uniform in the open waters with concentrations ranging from 1 to 2 ug/l. Higher concentration occur in the nearshore zones and near tributaries and urban areas. In 1977 chlorophyll "a" values can be seen to be somewhat lower on the August cruise than in August 1976.

Primary Productivity

Mean incubated primary productivity for the eastern and western nearshore and openlake regions is illustrated in Table 10. Although productivity estimates can not be considered representative of in situ rates, the use of the on-deck incubator allows for comparison among all samples. The results of the ^{14}C uptake experiments indicate the amount of carbon the phytoplankton will fix given a uniform amount of light. Thus phytoplankton obtained from 5 meter stations where the water is clear and low in nutrients will yield low levels of ^{14}C uptake. On the other hand, phytoplankton collected where nutrients are plentiful but light is limiting are likely to respond with high levels of ^{14}C uptake. The high levels of uptake being a consequence of the higher light levels in the on-deck incubator compared to low in situ levels.

The results for 1976 (Appendix Table C1) showed a fairly high level of ^{14}C uptake from southern Lake Michigan. In the open lake uptake rates were highest in June and slightly lower in the midsummer and fall. These results imply sufficient nutrients for primary production, but with some reduction in photosynthesis by July and August. Both nearshore regions showed somewhat higher ^{14}C uptake than the open lake. These results, which were not unusual, indicate that higher nutrient levels induced higher levels of primary productivity. Most likely the nutrient levels nearshore were more than adequate for primary production and the phytoplankton were responding well to the high light intensities in the incubator.

The 1977 primary production results (Table 10) show a dramatic change from 1976. Levels of productivity were somewhat lower in 1977 especially in the eastern nearshore. Another difference between 1976 and 1977 was the relatively uniform level of ^{14}C uptake on a spatial basis in 1977. The difference between the eastern nearshore and openlake stations was markedly reduced in 1977.

figure 23

1976-77 Lake Michigan
Two Layer Volume - Weighted Average (V)
Chlorophyll a (ug/l) By Cruise
Epilimnetic Mean (E)
Hypolimnetic Mean (H)

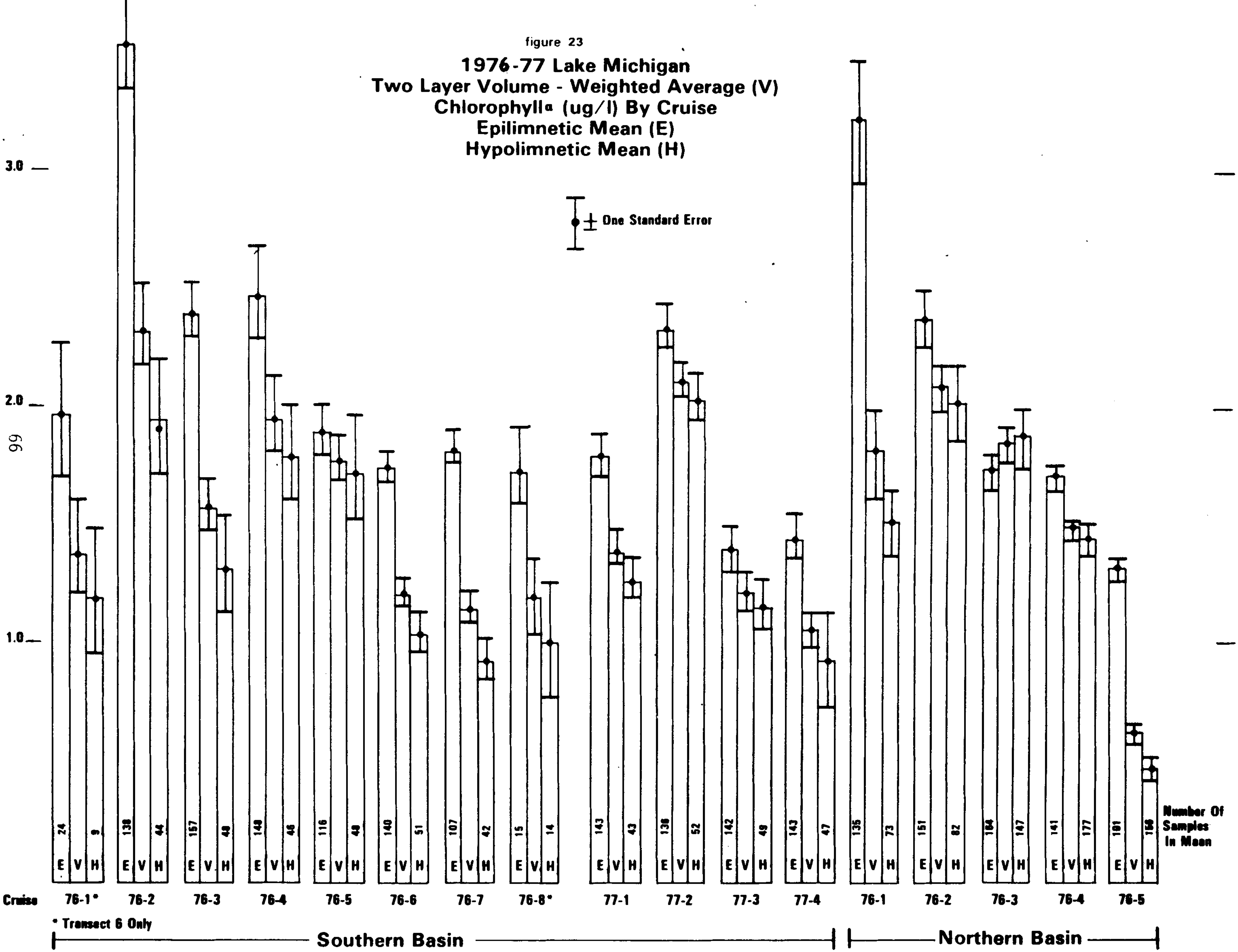


figure 24

Upper Twenty Meter Distribution Of Chlorophyll a In ug/l

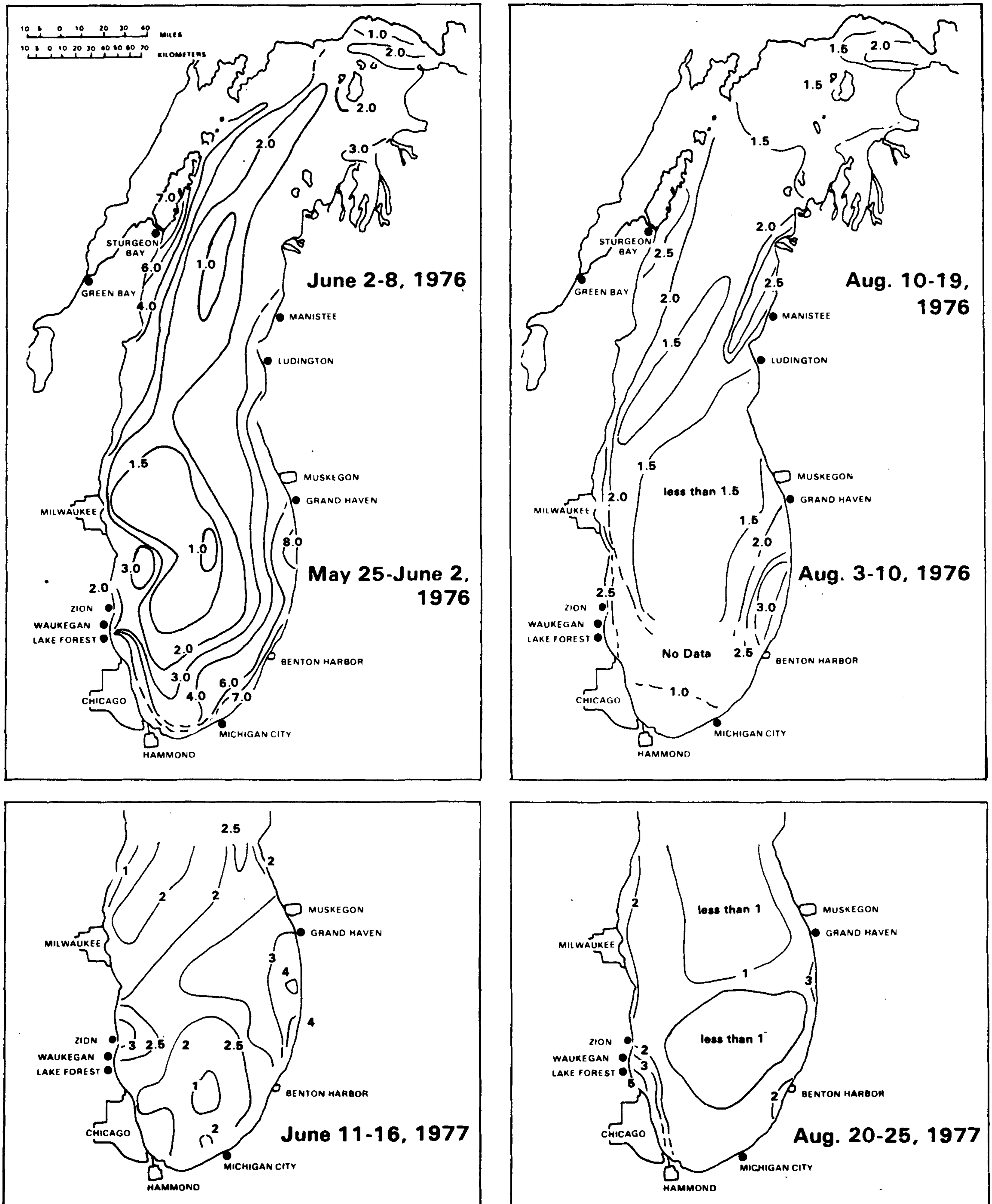


TABLE 10

Primary Productivity, Chlorophyll "a",

and Assimilation Coefficient

Crusies Date	Eastern Nearshore	Western Nearshore	Openlake
June 15-21, 1976			
Primary Production (mg c/m#/hr)	13.9 ± 9.0	5.3 ± 1.7	5.3 ± 2.0
Chlorophyll "a" (mg/m#)	3.0 ± 1.2	2.9 ± 1.5	1.7 ± 0.9
Assimilation coefficient	4.2 ± 1.7	2.0 ± 0.7	3.6 ± 1.8
July 7-13, 1976			
Primary Production (mg c/m#/hr)	15.9 ± 11.2	8.8 ± 5.7	4.6 ± 2.2
Chlorophyll "a" (mg/m#)	4.5 ± 3.6	2.5 ± 2.7	1.4 ± 0.6
Assimilation coefficient	3.8 ± 1.8	5.0 ± 2.5	3.8 ± 2.1
August 24-Septemebr 2, 1976			
Primary Production (mg c/m#/hr)	5.7 ± 2.1	8.8 ± 6.4	4.7 ± 3.1
Chlorophyll "a" (mg/m#)	1.5 ± 1.0	2.4 ± 1.1	1.6 ± 0.7
Assimilation coefficient	3.9 ± 1.4	3.7 ± 1.4	3.5 ± 3.2
September 14-20, 1976			
Primary Production (mg c/m#/hr)	6.2 ± 1.6	5.3 ± 2.1	4.9 ± 1.8
Chlorophyll "a" (mg/m^3)	1.9 ± 0.6	1.8 ± 1.0	1.6 ± 0.4
Assimilation coefficient	3.6 ± 1.6	3.7 ± 1.9	3.2 ± 1.3

(contd.) TABLE 10

Crusies Date	Eastern Nearshore	Western Nearshore	Openlake
April 19-24, 1977			
Primary Production (mg c/m^3/hr)	4.5 ± 0.8	5.6 ± 1.3	4.2 ± 1.1
Chlorophyll "a" (mg/m^3)	2.8 ± 0.7	3.5 ± 0.3	1.6 ± 0.7
Assimilation Coefficient	1.7 ± 0.6	1.6 ± 0.5 Only stations 5a and 9	2.8 ± 1.0
June 11-16, 1977			
Primary Production (mg c/m^3/hr)	6.2 ± 3.4	4.3 ± 2.2	3.1 ± 1.3
Chlorophyll "a" (mg/m^3)	2.9 ± 1.3	1.8 ± 0.8	2.2 ± 1.0
Assimilation Coefficeint	2.1 ± 0.8	2.5 ± 1.1	1.5 ± 0.6
August 20-25, 1977			
Primary Production (mg c/m^3/hr)	4.8 ± 1.3	7.3 ± 3.4	3.7 ± 1.4
Chlorophyll "a" (mg/m^3)	1.3 ± 0.6	2.5 ± 1.2	0.9 ± 0.3
Assimilation Coefficient	3.9 ± 1.1	3.0 ± 0.5	4.6 ± 1.5
September 17-24, 1977			
Primary Production (mg c/m^3/hr)	4.55 ± 0.7	5.3 ± .5	4.6 ± 1.0
Chlorophyll "a" (mg/m^3)	1.4 ± 0.4	2.0 ± .9	1.2 ± 0.5
Assimilation Coefficient	3.6 ± 1.4	3.5 ± 2.8	4.3 ± 1.5

Phytoplankton

Figures 25 and 26 illustrate the mean total phytoplankton (pannel A) and the precentage contribution (pannel B) of major groups in the nearshore, offshore, and open lake[1] in 1976 and 1977. In 1977 samples from both the 2 and 5 meter depth were analysed. These were averaged for Figure 26. In 1976 the majority of the samples were from the 5 meter depth in the early portion of the study (May 25-June 21). In the later portion of the 1976 study, many stations were represented by 2 meter samples only. Thus Figure 25 is based on the average of 2 and 5 meter samples or a single 2 or 5 meter sample from each station. This undoubtedly introduces some error as bluegreen algae were frequently more abundant in the 5 meter samples during stratified periods. We, however, feel a reasonable description of the size and gross composition of the phytoplankton population in the upper epilimnion is presented.

Phytoplankton populations were typically highest nearshore and decreased toward the open lake. Relative abundance of diatoms was usually more abundant on the early cruises and decreased through the stratified period. The greatest diatom populations were observed in the nearshore in May, 1976 and April, 1977. Diatom populations in the open lake increased through June. The Cyanophyta increased from a numerically minor component on the early cruises to the second most abundant group in midsummer (August or September) of each year. The period of greatest blue green abundance corresponds to the greatest epilimnetic water temperatures (Figure 5) and lowest epilimnetic silica concentrations (Figure 15).

The most (numerically) abundant component of the phytoplankton identified throughout both years of the study were the phytoflagellates which comprised between 45 and 67 percent of the total population. This composite group is comprised primarily of unidentified forms (called miscellaneous flagellates in this report), *Cryptomonas* spp. and *Dinobryon* spp. Also included, usually in small numbers, are *Ceratium*, *Chlamydomonas*, *Euglena*, *Phacus*, *Mallomonas*, *Periddinium*, *Trachelomonas*.

The results of this study may be affected by the low (400x) magnification used throughout the study. It is possible than smaller forms including small centric diatoms may be underestimated at magnifications below 1000x (Holland, 1979). The cruise interval was to long to detect seasonal flucuation. Holland (1979) recommends a minimum interval of 2 weeks between samples. The annual phytoplankton maxima were also possibly missed. Makarewicz and Baybutt (1980) report that this occurs as early as March in the Chicago nearshore.

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[1]Nearshore (0 to 3 km from shore)
Offshore (3 to 8 km from shore)
Open lake (greater than 8 km from shore)

Figure 25

Southern Lake Michigan
Total Phytoplankton And Relative Abundance Of Major Groups
1976

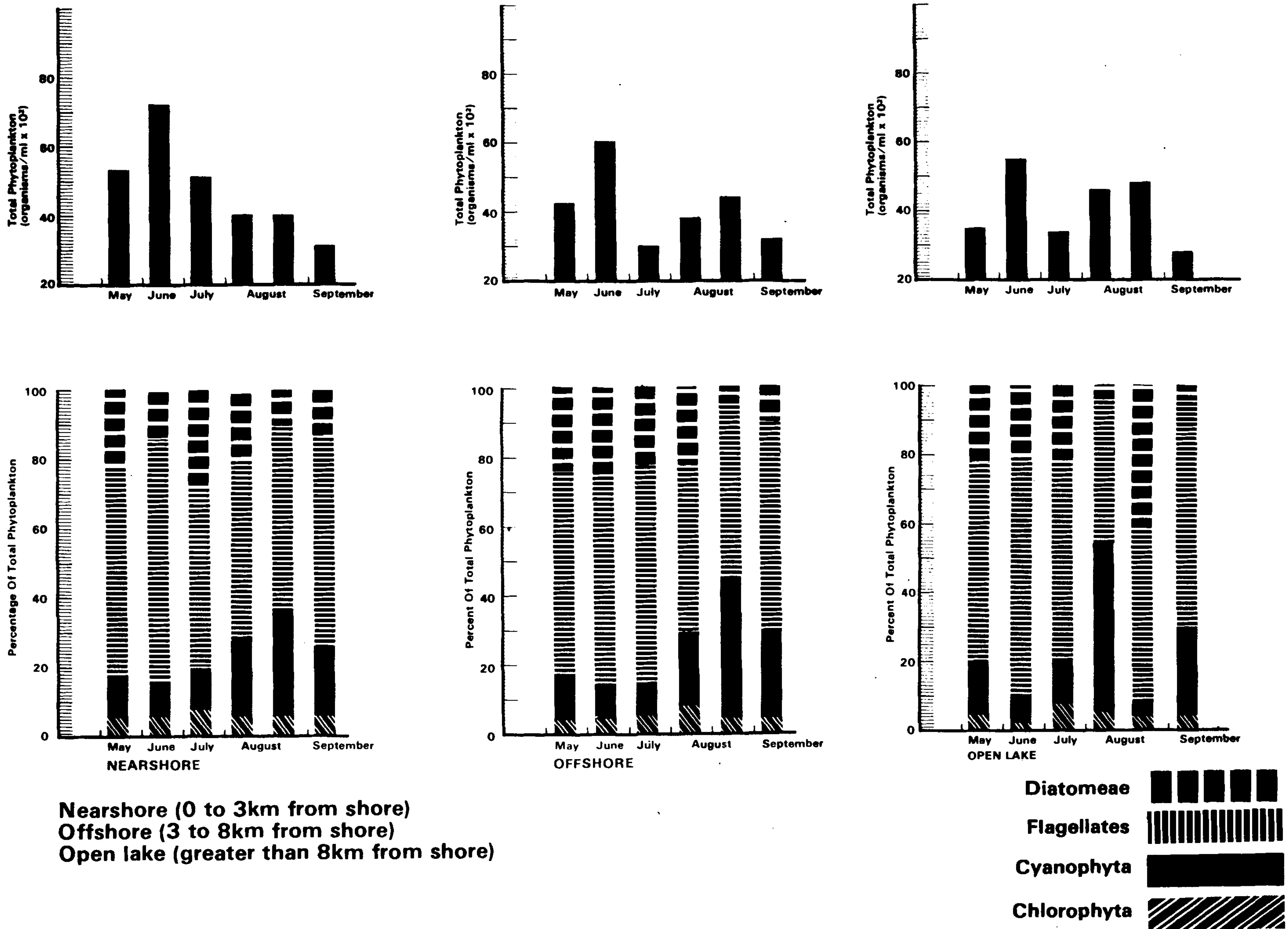
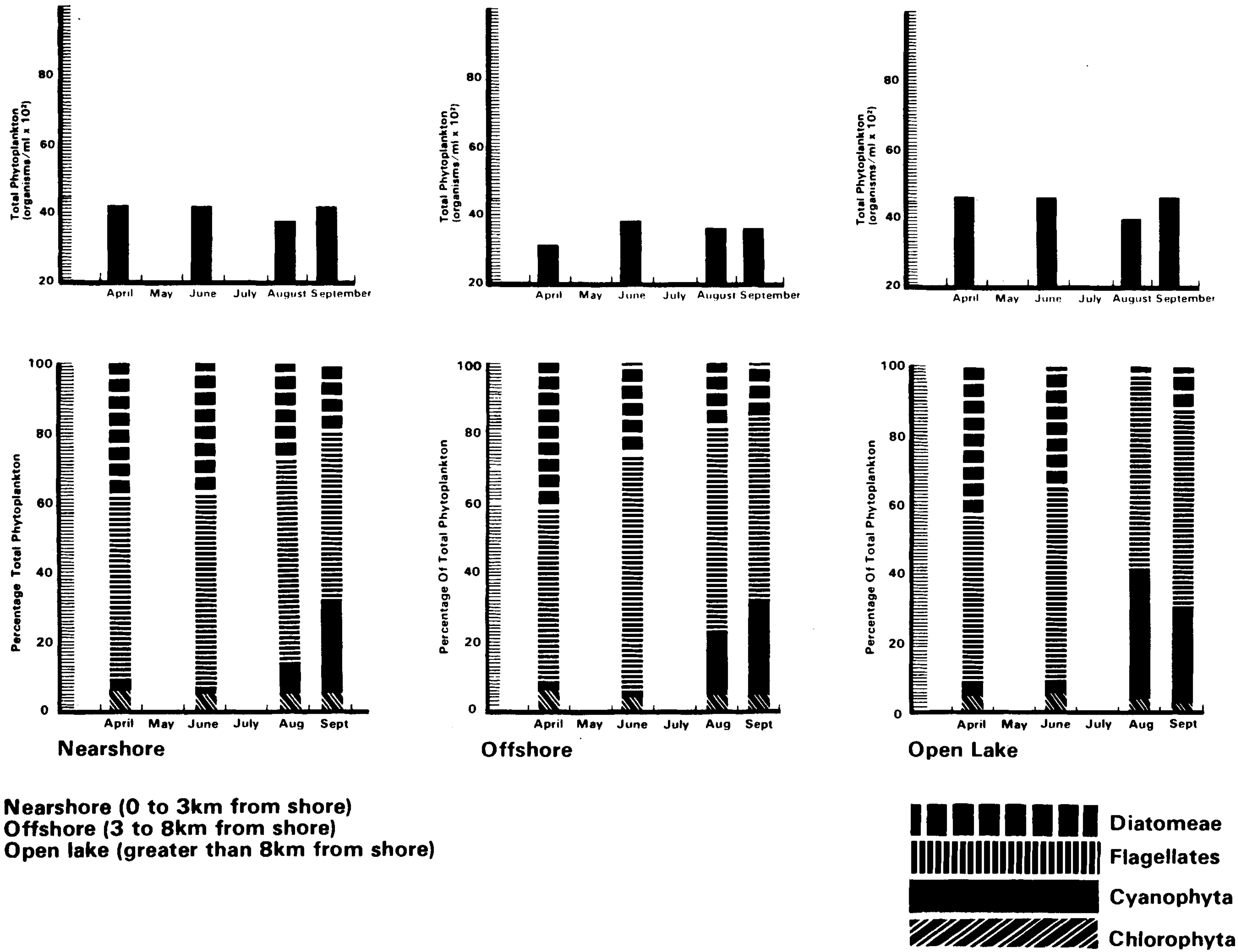


Figure 26

Southern Lake Michigan
Total Phytoplankton And Relative Abundance Of Major Groups
1977



Horizontal Distribution

Figure 27 illustrates the mean horizontal distribution of total phytoplankton at the 5 meter depth in the southern basin in 1977. As the thermal bar was located nearshore and appeared to be enhancing the inshore-offshore difference in populations in the south-western and central eastern portions of the basin in April, the annual mean represents the June, August and September cruises only. The individual cruises are also illustrated in Figure 27. The highest populations occurred nearshore throughout the study; however, some nearshore stations routinely exhibited relatively higher populations than others. These include station 5a off Chicago, stations 21 and 21a off Milwaukee, station 20 and 20a north of the Kalamazoo River and stations 16 and 16b south of Milwaukee.

During the April 1977 Cruise (Appendix Table D1) diatoms or flagellates dominated at all stations with green and blue green algae a very minor component. There was a striking difference in both size and composition at the generic and species level inshore and offshore. This was apparently related to the thermal bar (Figure 5) accentuating the difference between nearshore and open lake phytoplankton populations through warmer water temperatures and nutrient entrapment. The warmer (greater than approximately 6°C) water stations typically exhibited total phytoplankton populations 2 to 5 times those of the cold water stations. At most stations throughout the study, miscellaneous flagellates typically were dominant. When this dominance is ignored, a difference in composition of the plankton inshore and offshore of the thermal bar becomes evident. With the exclusion of miscellaneous flagellates, the warm (>6°C) water stations were dominated by large populations of Fragilaria crontonensis with Dinobryon spp and Cryptomonas spp., occasionally occurring as codominates. Subdominates included Dinobryon spp., Crytomonas spp. Cryptomonas ovata, Melosira spp., Synedra spp., and Ankistrodesmus falcatus. Other species (Appenidx Table D1) including Tabellaria fenestrata which were not among the dominates or subdominates were more abundant at the warm water stations than lakeward of the thermal bar. The colder stations beyond (lakeward of) the 6°C isotherm were dominated by Melosira spp., Cyclotella spp., and Cryptomonas spp. Subdominates at these stations included Melosira spp., Cyclotella spp., Oscillatoria limnetica, Ankistrodesmus falcatus, Asterionella formosa, and Crytomonas erosa. The eutrophic indicator Diatoma tenue var. elongatum (Stoermer and Yang, 1970) occurred at several nearshore, offshore and open lake stations. Greatest concentrations of this species were found at stations 5a, 6b, 20, 20a, 16b, with 60 cells/ml and station 24a with 140 cells/ml. The only blue green of any significance was Oscillatoria limnetica, which occurred at most stations in concentrations between 20 and 140 filaments/ml, and Schizothrix calcicola, found at several near and offshore stations (20 to 80 filaments/ml).

Cell counts of F. crotonensis and T. fenestrata were positively correlated with water temperature and negatively correlated with dissolved silica over ranges of 1.2 to 9.0°C and .35 to 1.24 mg/l respectively. These correlations were significant at the 99 percent confidence level and indicate that these species were probably responding to increased water temperature and were at least partially responsible for the decrease in silica observed above ~ 6°C (See Silica Results).

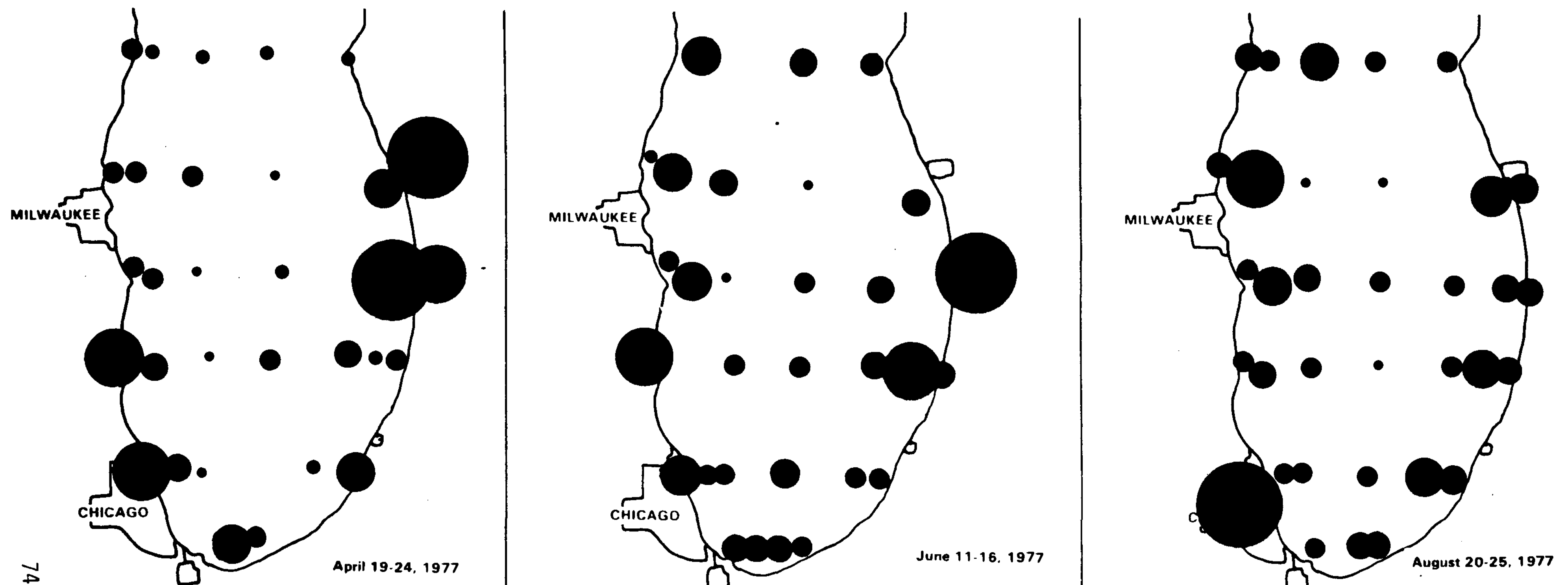
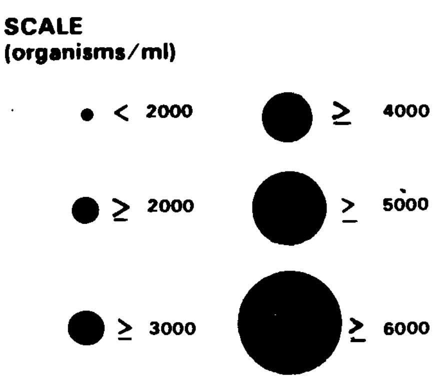
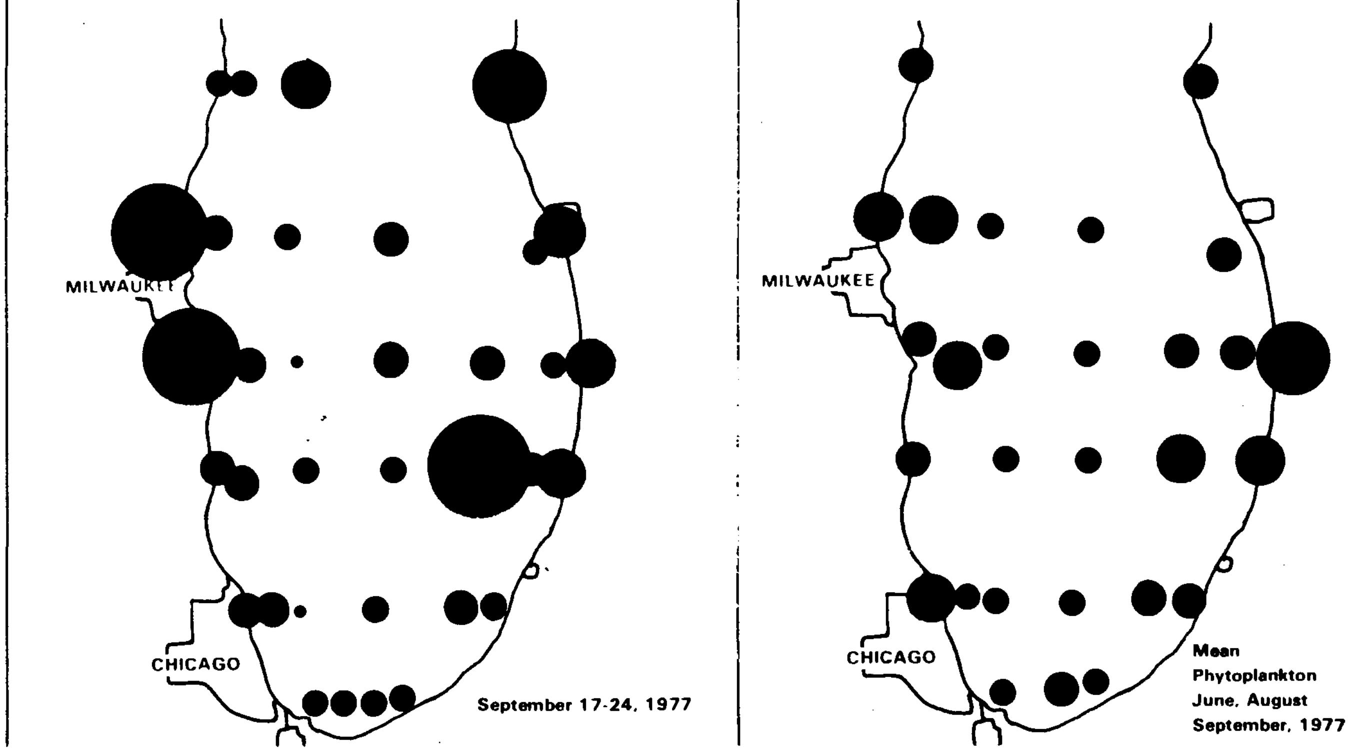


figure 27

**Total Phytoplankton
June, August, September
Mean And Individual Cruise
Results (April, June, August,
September)
5 Meter Samples 1977**





By the June 1977 cruise (Appendix Table D2) the population densities at those nearshore stations which had been within the thermal bar in April had decreased while those lakeward of the thermal bar had increased. Flagellates dominated at all stations with exception of 10, 17, and 18, comprising between 23 and 83 percent of the total population. Diatoms were the second most abundant group comprising between 10.7 and 49.8 percent of the populations at individual stations. The blue green algal component of the total population had increased to between 1.2 and 6.3 percent of the population.

All near and offshore stations with the exception of 21a and 25a were dominated by miscellanous flagellates in concentrations between 460 (21.9%) and 1820 (54.5%) cells/ml. Stations 21a and 25a were dominated by Dinobryon spp. (3240 cells/ml, 65.6%) and Cryptomonas spp. (1160 cells, 24.6%) respectively. Subdominates at the near and offshore stations included Cryptomonas spp, Fragilaria crotonensis, Rhizosolenia longiseta, Dinobryon spp, Melosira spp, Synedra ulna, Fragilaria intermedia, and Ankistrodesmus falcutus.

The open lake stations were dominated by either Dinobryon spp, Melosira spp. or miscellaneous flagellates. Subdominates were essentially those found in the near and offshore with the exception of the Cyanophyte Oscillatoria limnetica, which occurred among the subdominates at stations 5 (120 filaments/ml) and 12 (120 filaments/ml). Stations 10, 17, and 18 were dominated by Melosira spp. These stations also had lower 5 meter water temperatures ranging from 4.5 to 6.0°C as opposed to 6.0 to 15.5°C for the rest of the basin.

O. limnetica was common in the plankton, occurring in small (30 to 140 filaments/ml) concentrations at nearly all stations. Other relatively common bluegreens include Microcoleus lyngbyaccus which was found in nearshore samples in small (30 to 90 organisms/ml) numbers and Schizothrix calicola which was found in all areas of the basin in small numbers.

The eutrophic indicator Diatoma tenue var. elongatum (Stoermer and Yang, 1970) occurred at all of the nearshore stations with the greatest abundance (170 cells/ml) being observed at stations 5a and 13. D. tenue also occurred in lessor abundances at stations 5b (30 cells/ml), 5 (30 cells/ml), 25a (90 cells/ml), 16b (120 cells/ml), 18 (30 cells/ml), 24a (60 cells/ml) and 27 (30 cells/ml).

In August 1977 (Appendix Table D3) total phytoplankton densities had decreased from June levels at most stations. Blue green algae had increased dramatically and replaced the diatoms as the second most abundant group at most stations. Diatoms remained important at several nearshore stations where (Figure 13) silica concentrations higher than those in the open lake were observed.

Cell counts of A. formosa, T. fenestrata, and F. crotonensis were negatively correlated with water temperature and positively correlated with dissolved silica. These correlations were significant at the 95 percent confidence level for A. formosa and the 99 percent level for both T. fenestrata and F. crotonensis. In addition, T. fenestrata was positively correlated with nitrate-nitrite (p>.99). Temperature, silica, and nitrate-nitrite ranged from 11.0 to 21.5°C, .18 to 1.12 mg/l, and .13 to .23 mg/l respectively at the 5 meter depth in August. The lowest water temperature and highest nutrient concentrations were observed in the nearshore as a result of upwelling (See Figure 5, 13, and 18).

Miscellaneous flagellates were dominant at all near and offshore stations with the exception of station 13 where *Fragilaria crontonensis* dominated. Subdominants in the near and offshore areas included *Cryptomonas* spp., *Anacystis* spp., *Aphanothece* spp., *F. crontonensis*, *Melosira* spp. and *A. formosa*.

The open lake was dominated by miscellaneous flagellates, *Cryptomonas* spp., *Anacystis* spp. and at stations 23 and 27, *F. crontonensis*. *Aphanothece* spp. and *Gomphosphaeria lacustris* were common components of the offshore and open lake plankton. *O. limnetica*, while still common, had decreased from April and June levels particularly in the nearshore. Filamentous bluegreens were relatively unimportant with the exception of stations 16 and 19 where *Anabaena* spp. constituted 21.6% (580 filaments/ml) and 9.9% (230 filaments/ml) respectively.

Diatoma tenue var. *elongatum* occurred sporadically in small numbers (30-170 cells/ml) in all areas but was primarily confined to the southwestern portion of the basin. *D. tenue* reached its greatest abundance at station 5a off Chicago, 170 cells/ml.

Blue green algae and flagellates continued to dominate during the September 1977 cruise (Appendix Table D4). Total phytoplankton densities increased somewhat in the more northerly portions of the basin and decreased in the southerly portions (Figure 27) when compared to August. Diatoms were somewhat more abundant than during August along the lower 3 transects but had decreased in the more northerly portion of the southern basin. They also were more abundant in the nearshore.

Miscellaneous flagellates, *Crytomonas* spp., or *Anacystis* spp. were dominant at most stations. *A. formosa*, *F. crotonensis*, *R. eriensis*, and *O. limnetica* were negatively correlated (p>.95) with water temperature and positively (p>.95) correlated with nitrate-nitrite concentrations. These species appeared to be responding favorably to the decrease in temperature and possibly epilimnetic nutrient increases associated with autumnal cooling in the nearshore.

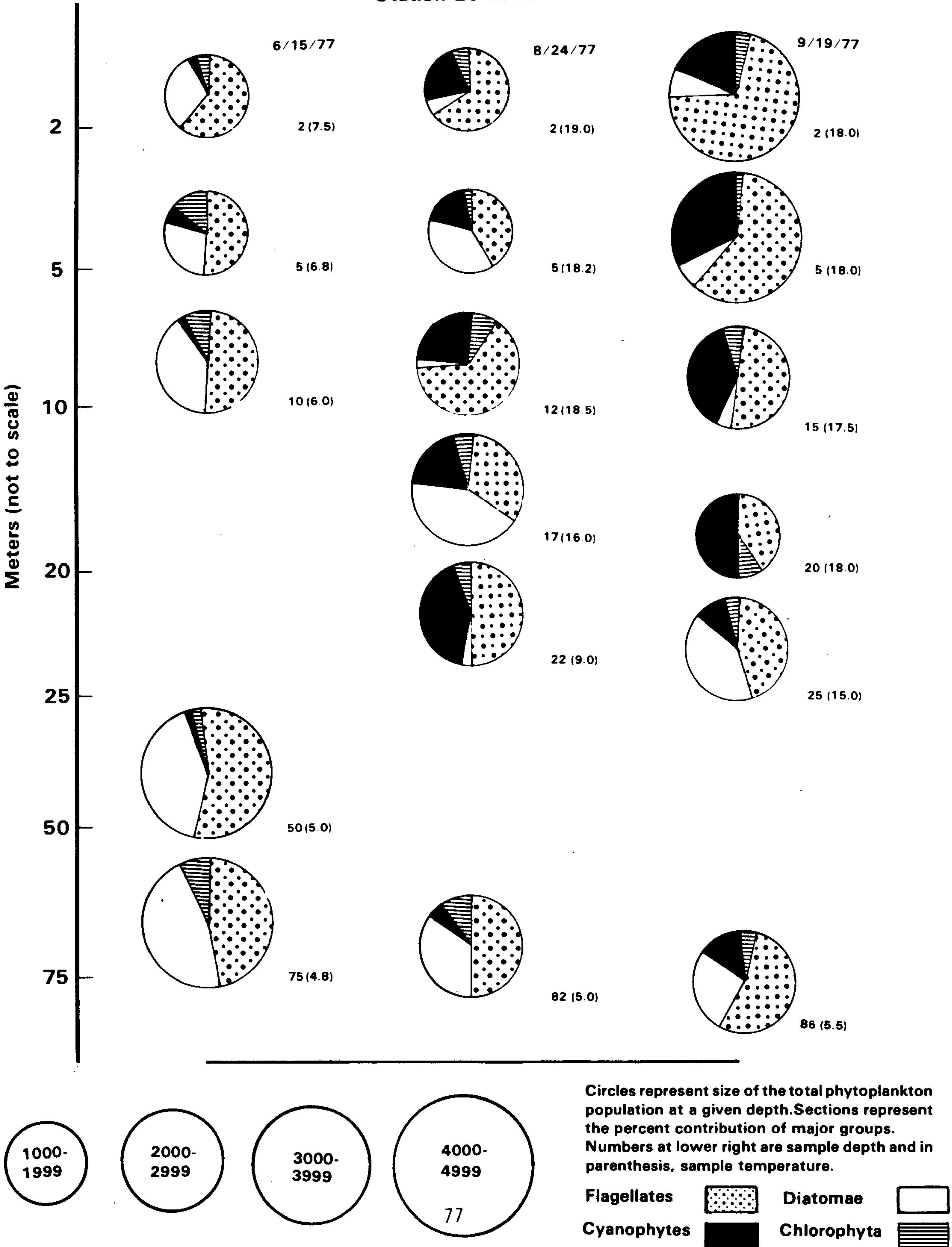
Vertical Distribution

Figure 28 illustrates the vertical distribution of total phytoplankton and the percentage contribution of the major phytoplankton groups at station 23 on the June, August, and September, 1977 cruises. This station was typical of the open lake stations in 1976 and 1977.

Throughout the season the number of total phytoplankton was remarkably uniform even in the deeper areas of the southern basin. The blue green algae were most abundant during August and September, with

figure 28

Total Phytoplankton And The Relative Contribution Of Major Groups At A Deep Water Station 23 In 1977



their greatest relative contribution frequently occurring in lower epilimnetic or metalimnetic samples. Diatoms were typically a major component at all depths in June. However, in August and September they were usually a minor component of epilimnetic assemblages. Diatoms were numerically important components in the metalimnetic and bottom samples throughout the 1976 and 1977 cruise periods. The phytoflagellates dominated the phytoplankton at all depths on all cruises in both years. The chlorophyll "a" maximum in the lower thermocline, previously discussed (See chlorophyll "a" results), corresponds to the diatom maximum.

Microbiology

In 1976 and 1977, heterotrophic bacterial densities in the open lake were found to be 9/ml (range 2-33) and 8/ml (range 2-35) respectively. In the nearshore zone in 1976 the geometric mean value for aerobic heterotrophs was 21/ml (range 5-87), and in 1977, was 30/ml (range 8-110) (Figure 29). Bacteria were generally more numerous near the shoreline where conditions exist such as immediate, more concentrated nutrient rich drainage water, and warmer temperatures which promote or maintain higher concentrations of bacteria, including transitory organisms than would be found farther out in the open lake (Taylor, 1940).

No fecal coliform bacteria were detected in samples taken from the open lake stations during the 1976 study. Nearshore counts were almost invariably 1/100 ml except for an occasional higher result not exceeding 12/100 ml. No fecal coliform determinations were performed on any open lake samples in 1977.

Chloride

Chloride concentrations are similar in values in vertical distribution (Appendix Table C1 and C3) and exhibit little if any seasonal trend (Figure 30). Epilimnetic chloride concentrations were higher than hypolimnetic values in both basins. Even though individual chloride measurements were almost the same between the epilimnion and hypolimnion there is a small but statistically significant ($p > .95$) increase in chloride concentrations in the upper layer (0-20 meter) when compared to the lower layer (20 to bottom). Chloride concentration in the southern basin in 1976 were 8.30 $\pm$ .06 mg/l and 8.02 $\pm$ .07 mg/l for the upper and lower layers respectively. In 1977 these concentrations were 8.32 $\pm$ .04 mg/l and 8.17 $\pm$ .03 mg/l. In 1976, northern basin concentrations were lower than those in the southern basin Figure 31. The average of TLVWA values for the five northern basin cruises was 7.7 $\pm$ 0.1 mg/l as compared to 8.0 $\pm$ 0.1 mg/l for the six complete cruises in the southern basin Figure 30. The dense stations network near the Straits of Mackinac biases the epilimnetic TLVWA values in the northern basin. With these stations removed, the five northern basin cruises epilimnetic chloride values ranged between 7.8 to 8.0 mg/l. The average of TLVWA values is estimated to be 0.1 mg/l low due to the dense station network near the Straits of Mackinac.

Figure 29

**Annual Geometric Mean Values
Distribution Of Aerobic Heterotrophs
In Organisms/ml.**

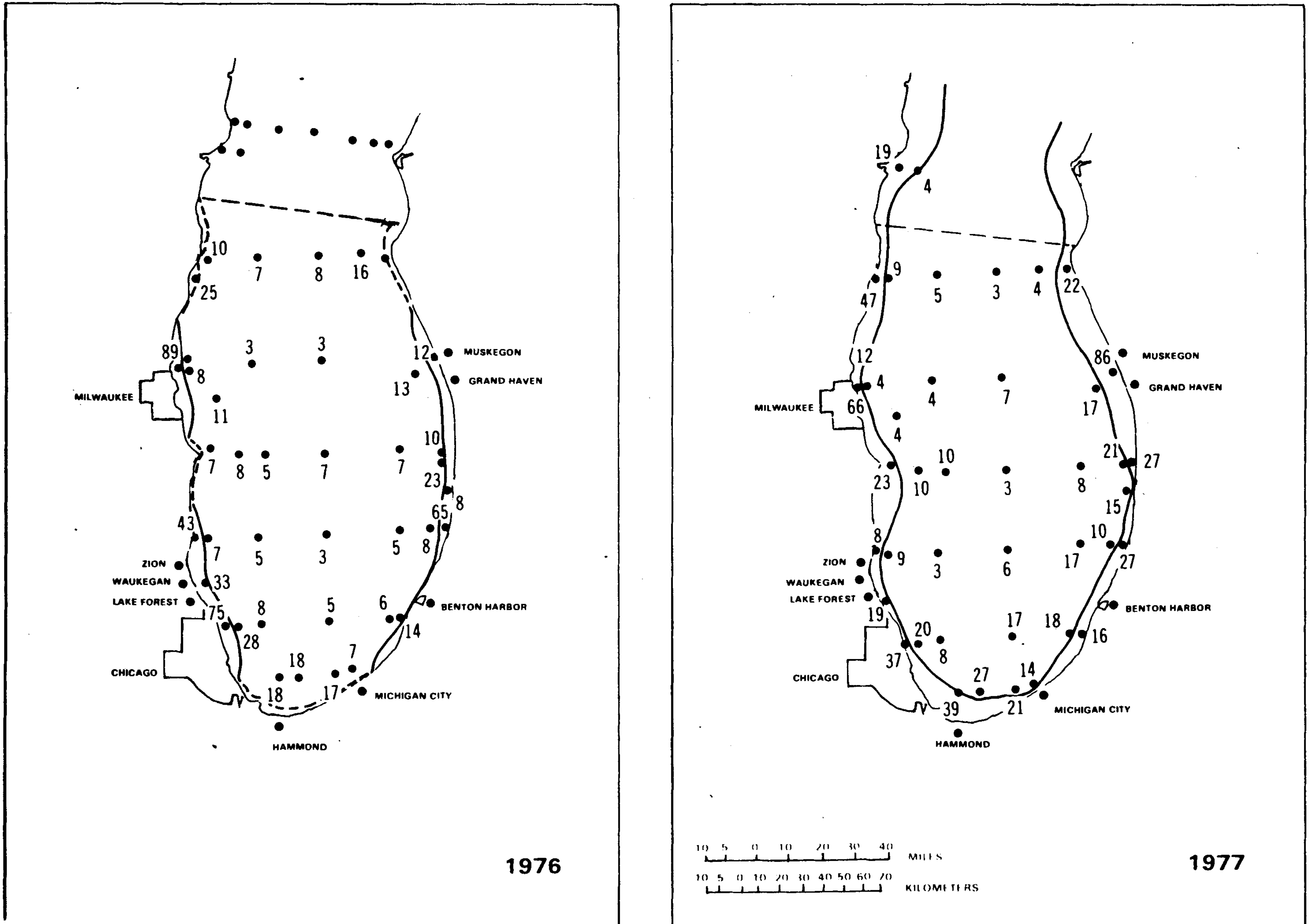
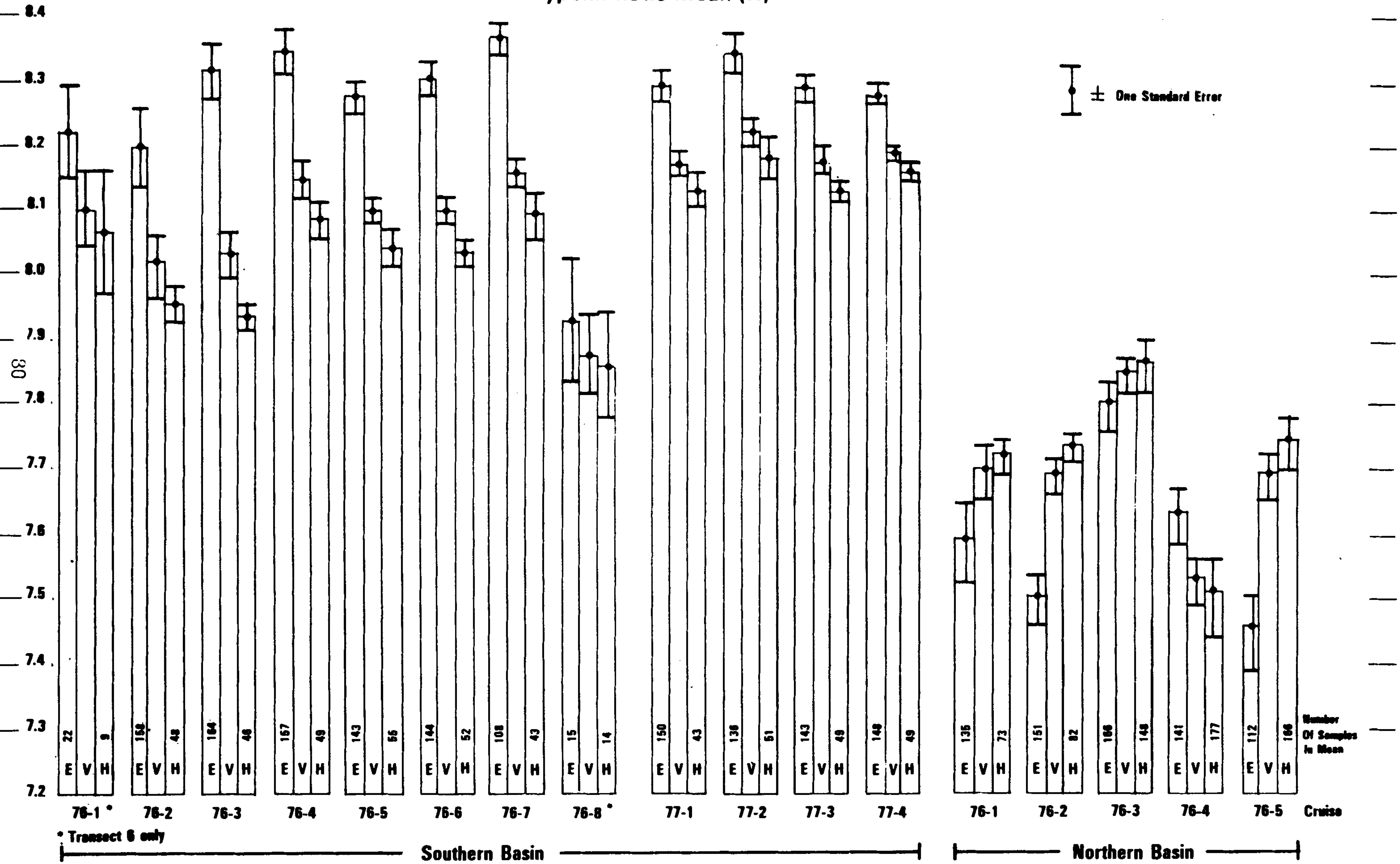


Figure 30

1976-77 Lake Michigan
Two Layer Volume-Weighted Average (V)
Chloride (mg/l) by cruise
Epilimnetic Mean (E)
Hypolimnetic Mean (H)



Whole water column mean concentrations averaged for each cruise period in 1976 and 1977 and are displayed in Figure 31. In the southern basin, chloride concentrations were greatest in the eastern and southeastern nearshore in both years. Lowest individual southern basin concentrations (7.8 mg/l) were found in the deep water stations. This pattern was also evident in 1977. The lowest concentrations 7.0 mg/l in the entire lake were found in the Straits of Mackinac. Greatest concentrations were observed at nearshore stations near Manistee and Ludington where an annual mean of 9.0 mg/l was observed in 1976.

Chloride concentrations exhibited a concentration gradient in the 1976 annual distribution (Figure 31) where values in the southern most portion of the southern basin were around 8.7 mg/l and decreased northward to the Straits of Mackinac (7.0 mg/l).

Sulfate

Sulfate levels found in the southern basin of Lake Michigan in 1976 varied in a narrow range seasonally, spacially and vertically. TLVWA cruise means averaged 21.1 ± .4 mg/l in 1976. The epilimnion had a slightly higher annual mean (21.3 ± .4 mg/l) than the hypolimnion (21.1 ± .4 mg/l) in 1976 (Figure 32). There may be a slight south to north gradient in the southern basin concentration of sulfate as seen in the 1976 annual distribution (Figure 33) and in spring (Cruise 2) and summer (Cruise 5) cruises. These contours represent entire water column average concentrations at each station. The annual distribution is an average over all cruises. Sulfate was not measured in 1977.

pH

In 1976, nearshore pH ranged from 7.5 to 8.6 in the southern basin and 8.0 to 9.0 in the northern basin. The open lake pH ranged from 7.6 to 8.8 in the southern basin and from 7.8 to 8.8 in the northern basin. In 1977 southern basin nearshore and open lake station pH ranged from 7.8 to 8.7 (Appendix B).

The open waters exhibited a seasonal change in pH in the epilimnetic waters. For stations with depths greater that 80 meters pH was uniform during isothermal conditions throughout the water column and had values from 7.9 to 8.0. (Appendix Table C1 and C3) By August each year epilimnetic pH values had increased to 8.4 tp 8.5 at these sites while hypolimnetic waters remained between 7.9 to 8.0. During the stratified period pH ranged 0.3 to 0.5 pH units greater in the epilimnetic waters of the offshore stations in the southern basin than in corresponding hypolimnetic water (Figure 34).

Spacial variations in pH in the southern basin in the epilimnetic waters of the open lake did not vary more that 0.1 units during an individual cruise. Lower pH values were occasionally found at the stations nearest shore.

figure 31

Chloride Concentration In mg/l
Annual Average

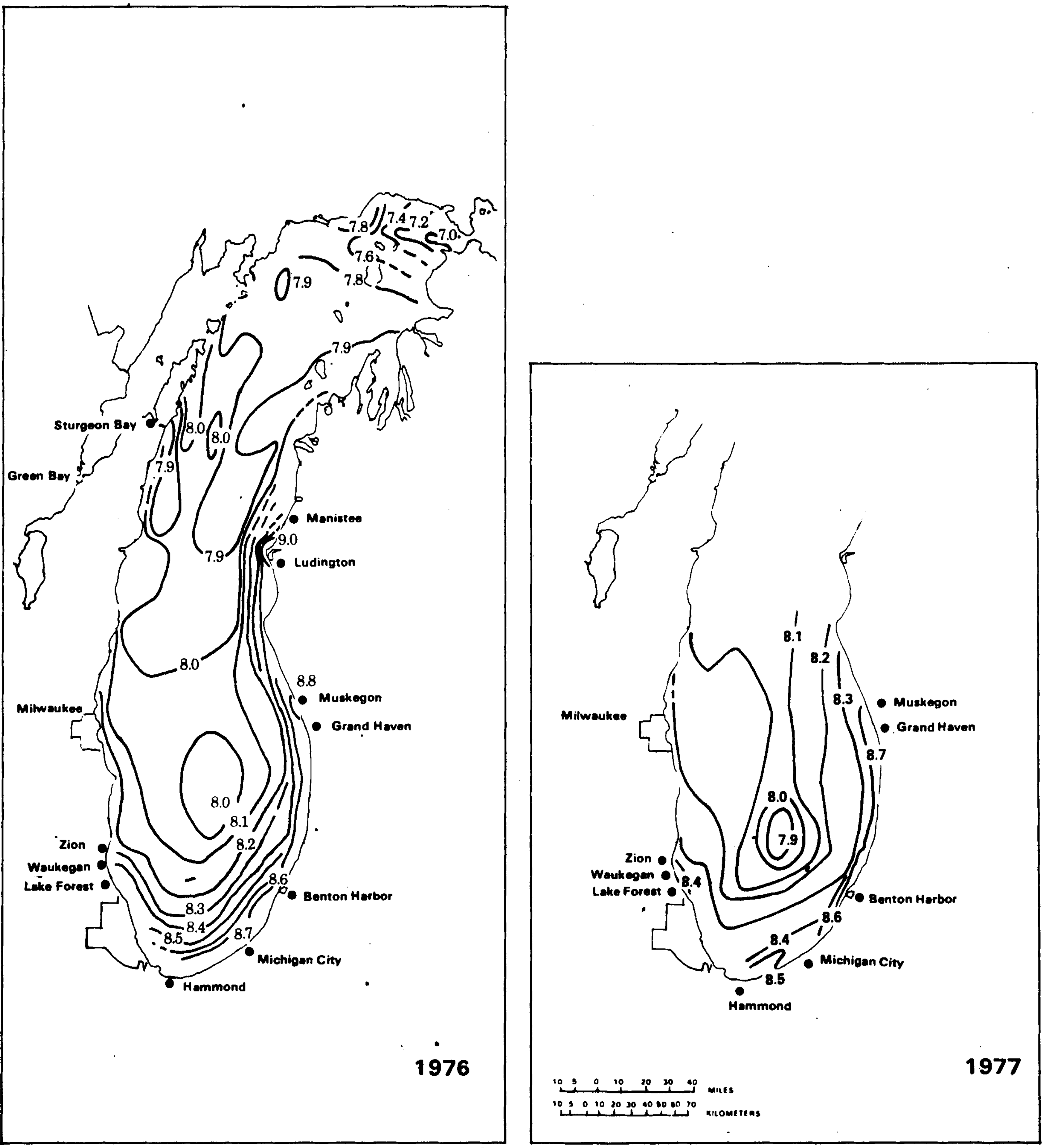


figure 32

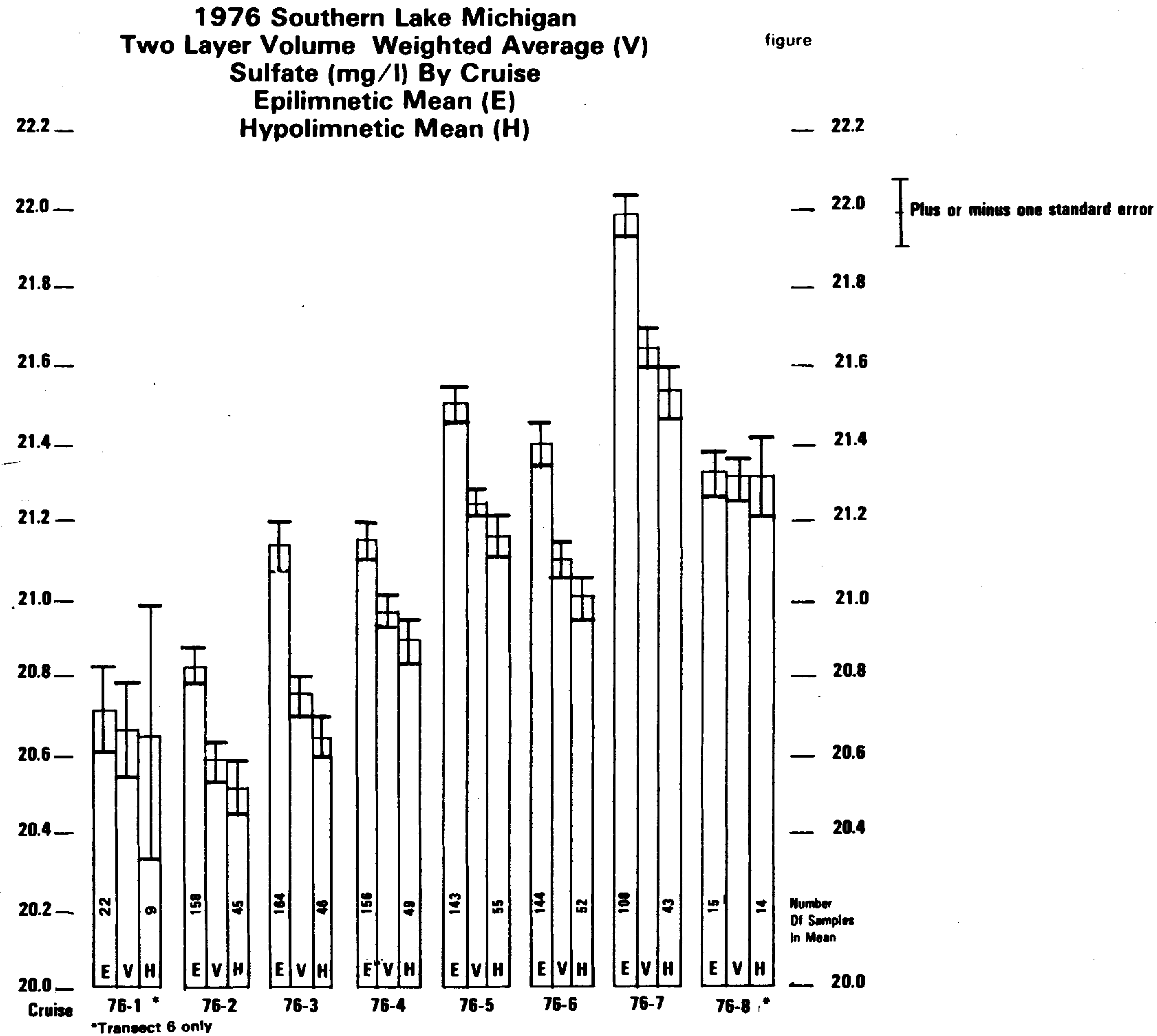

1976 Southern Lake Michigan
Two Layer Volume Weighted Average (V)
Sulfate (mg/l) By Cruise
Epilimnetic Mean (E)
Hypolimnetic Mean (H)
figure
22.2
22.0
21.8
21.6
21.4
21.2
21.0
20.8
20.6
20.4
20.2
20.0
Plus or minus one standard error
Number Of Samples In Mean
22
9
158
45
164
46
156
49
143
55
144
52
108
43
15
14
E V H
Cruise
76-1 *
76-2
76-3
76-4
76-5
76-6
76-7
76-8 *
*Transect 6 only

Figure 33

Distribution Of Sulfate In mg/l

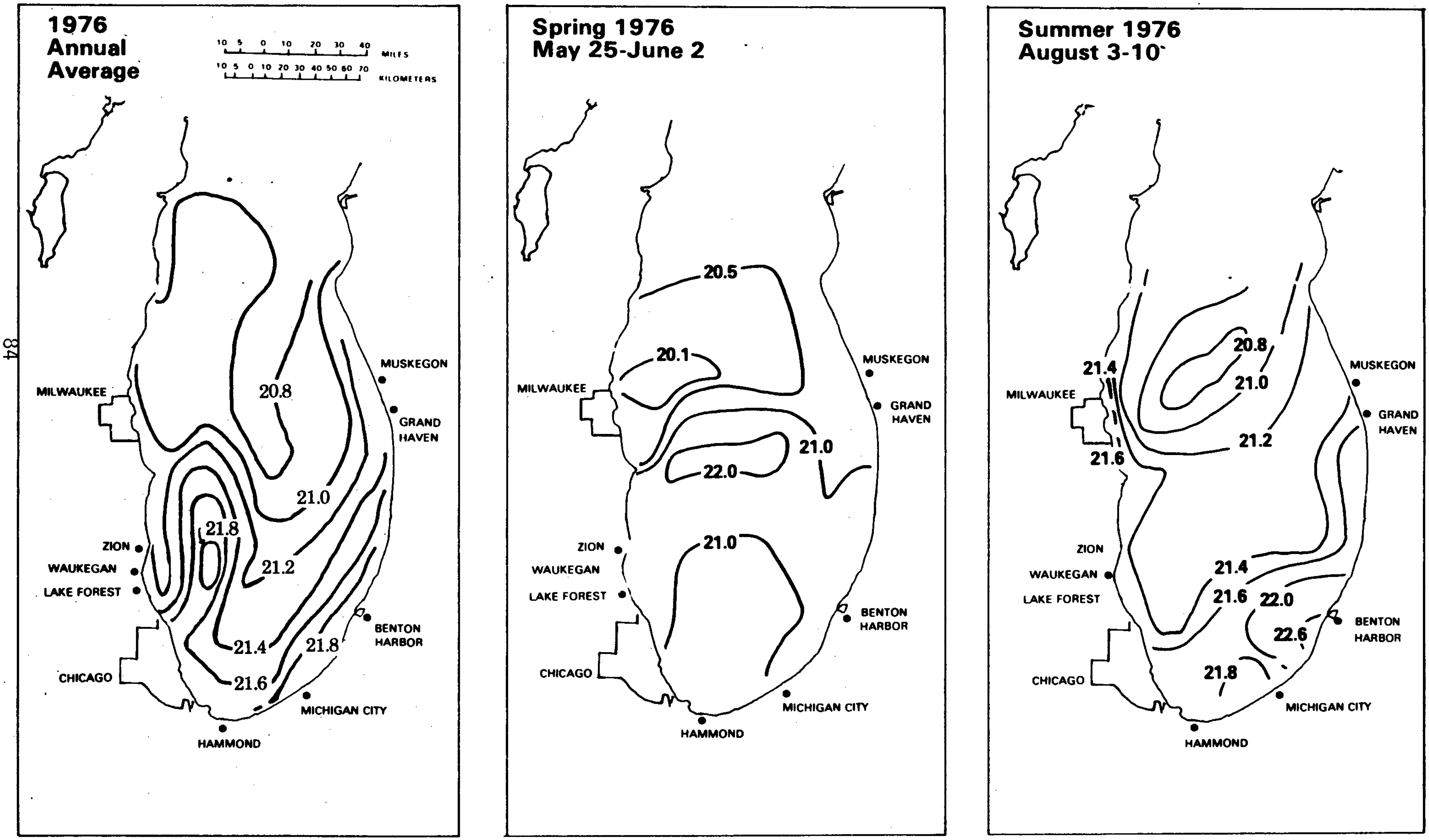
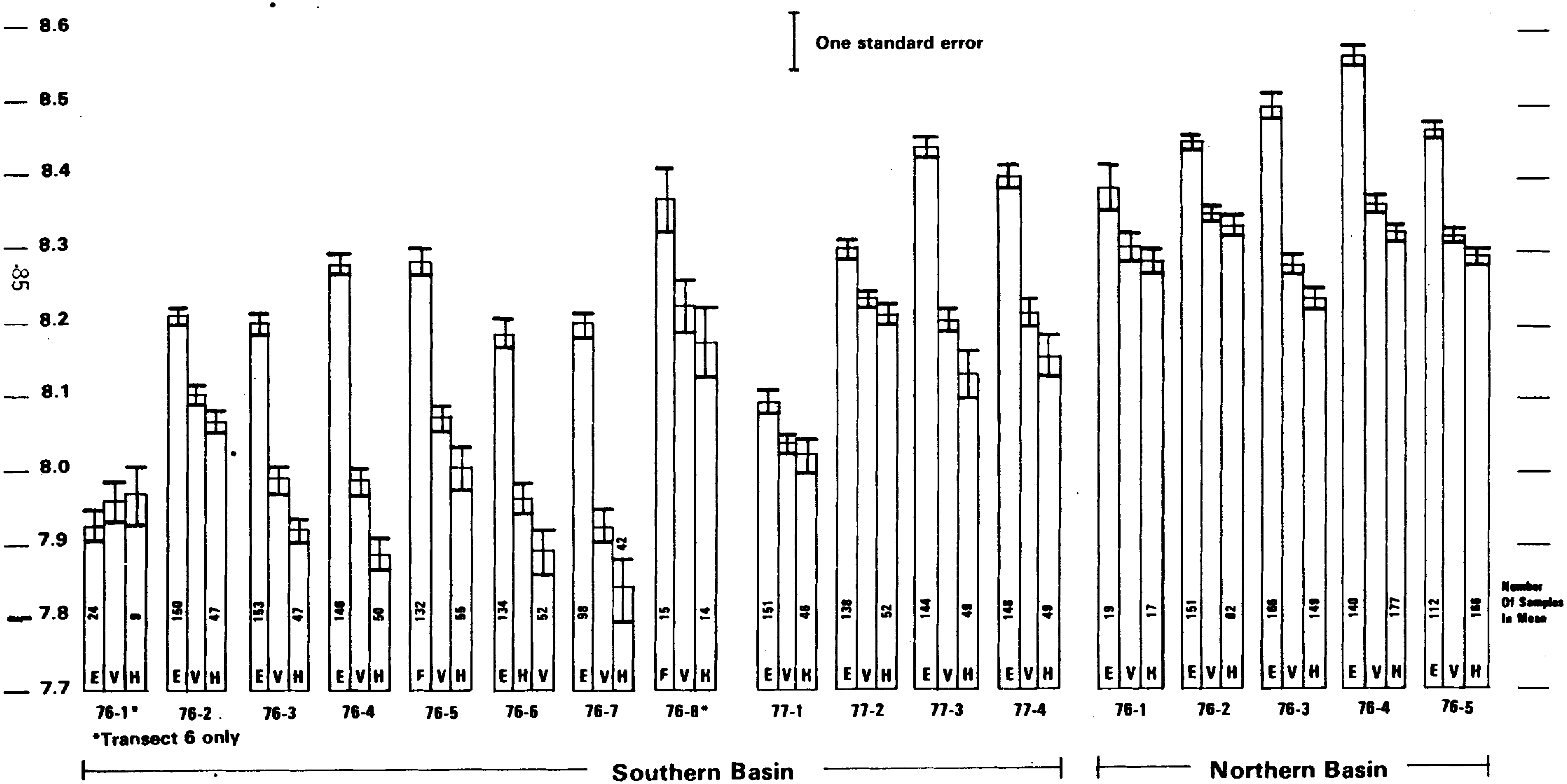


figure 34

1976-1977 Lake Michigan
Two Layer Volume Weighted Average (V)
pH (S.U.) By Cruise
Epilimnetic Mean (E)
Hypolimnetic Mean (H)



Specific Conductivity

The spacial distribution of specific conductivity in Figure 35 illustrates conductivity values plotted from the upper twenty meters at each station. Conductivity was higher nearshore and decreases lakeward. Uniform values for conductivity in transects 7-9 in the northern basin result in a random contour line. Lowest conductivity values (240-250 umhos/cm) are observed in the Straits of Mackinac. This spacial pattern appears to be representative of conductivity's distribution in the lake.

Conductivity in the epilimnetic waters exhibited a seasonal effect in the southern basin (Figure 36) with lower values occurring in August and September in both basins. Conductivity values during the early spring isothermal period appear to be uniform at the deep water stations (80 meters or greater) and had maximum levels between 274 and 276 umhos/cm throughout the water column in both basins (Figure 35 and Appendix Table C1-C3). For the northern basin the TLVWA epilimnetic values for conductivity are biased low (Figure 36) due to the dense station network in the shallow waters near the Straits of Mackinac. With these stations removed, epilimnetic values for conductivity ranged from 266 to 274 umhos/cm for the last four cruises.

TRACE METALS

Table 11 presents summary results for arsenic, barium, beryllium, cadmium, cobalt, copper, lead, manganese, molybdenium, nickel, silver, vanadium, zinc, calcium, magnesium, potassium, sodium and fluoride concentration in water samples. Some or all data for iron, chromium, tin, aluminum, boron, titanium, and zinc have not been presented because quality assurance tests indicate they were not reliable.

Results indicate that higher metal values in water samples were found more frequently in the transects north of Frankfort toward the mouth of Grand Traverse Bay. The source of these metals is unknown.

There have been several recent surveys of Lake Michigan water by other investigators for metals using atomic absorption spectroscopy (AAS), either by flameless graphite furnace (FGF), or by direct aspiration either without preconcentration (DA) or by solvent extraction of a metalo-organic complex (SE). Other methods used include neutron activation analysis of freeze dried samples (NAA), spark source mass spectroscopy of freeze dried samples (SSMS), and direct reading spectrography (DRS). This study used an Inductively Coupled Argon Plasma Emission Spectroscopy (ICAP) as a source for DRS. All of these surveys lacked thorough documented quality assurance procedures so that the role of contamination, positive and negative interferences and other sources of error is unknown.

A parameter by parameter discussion of our results and those available in other recent surveys follows.

Figure 35

Upper Twenty Meter Distribution Of Conductivity In umhos

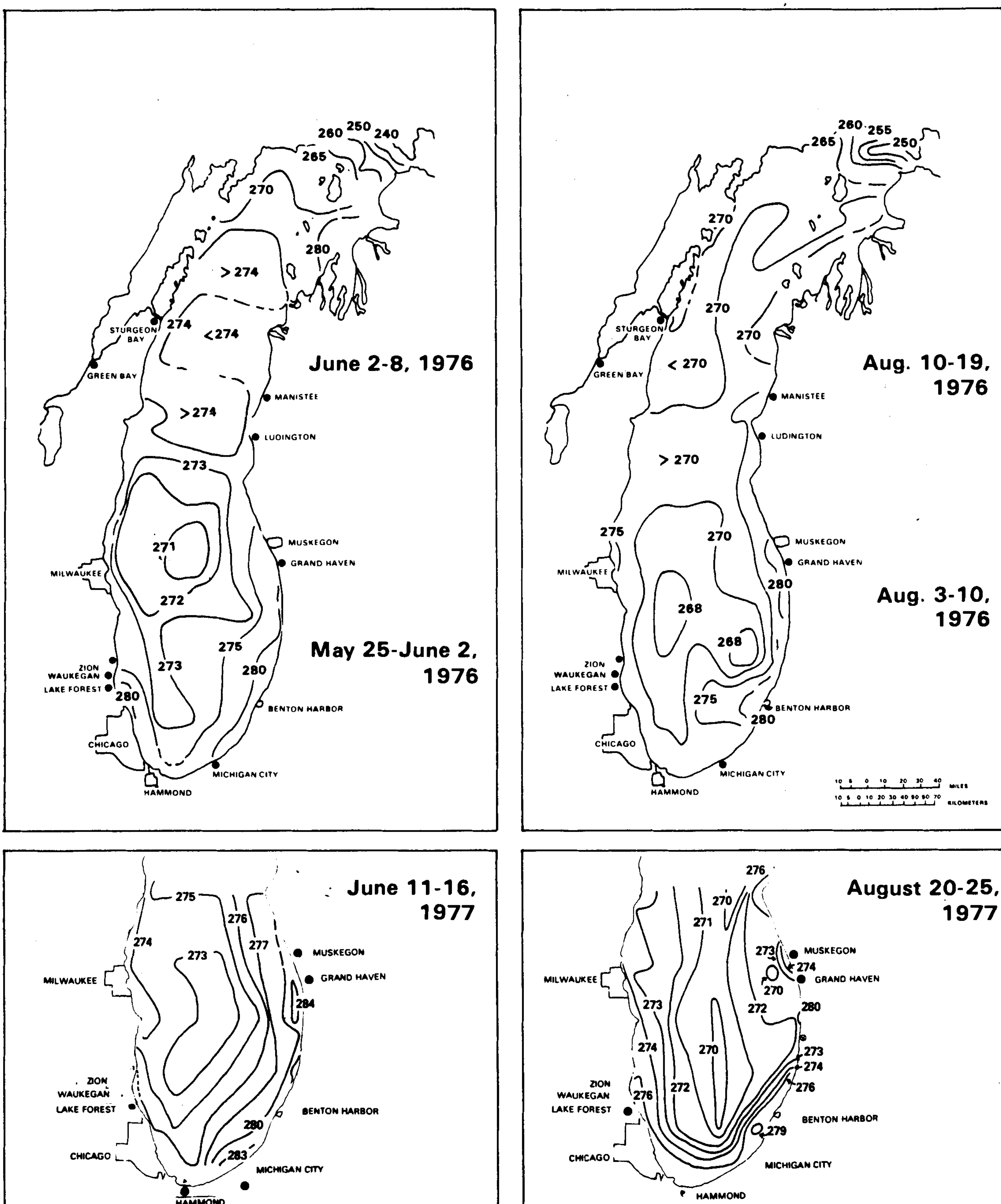


Figure 36

1976-77 Lake Michigan
Two Layer Volume-Weighted Average (V)
Specific Conductivity at 25°C (umhos/cm) by cruise
Epilimnetic Mean (E)
Hypolimnetic Mean (H)

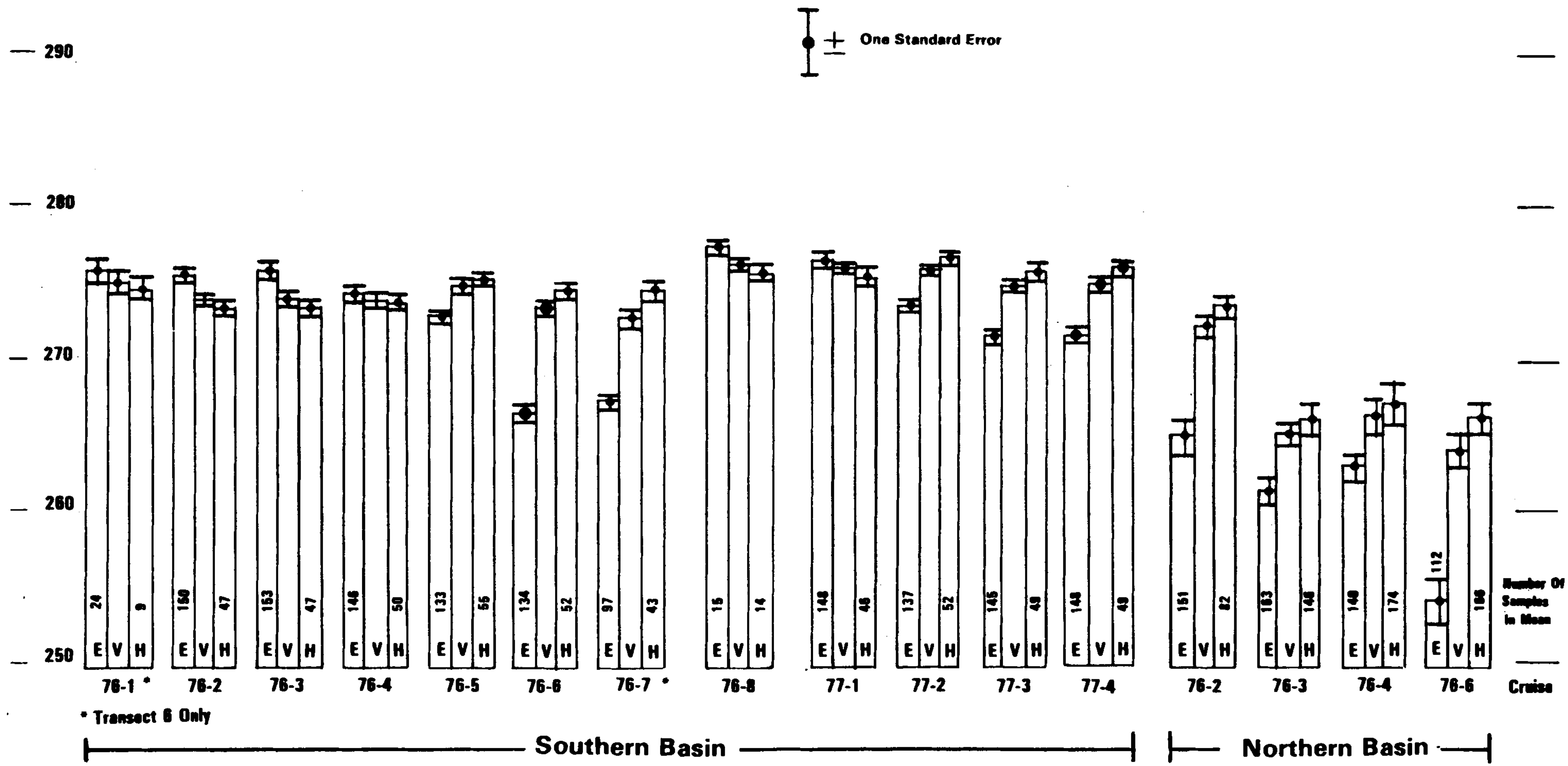


TABLE 11
LAKE MICHIGAN JULY - AUGUST 1977
SUMMARY OF METALS DATA FROM WATER SAMPLES
(all values in ug/l)

PARAMETER	TOTAL NUMBER OF SAMPLES	NO. SAMPLES LESS THAN INSTRUMENT RESPONSE LEVEL	INSTRUMENT LIMIT OF DETECTABILITY LESS THAN VALUES	MAX.	MEAN*	MIN	STAND. DEVIATION	DETECTION LIMIT**	IJC OBJECTIVE 1978
Arsenic	11	11	2	<2	<2	<2	---	2	50
Barium	102	0	1	40	12	8	4.2	1	---
Beryllium	102	102	2	<2	<2	<2	---	2	---
Cadmium	103	101	2	4	<2	<2	---	2	0.2
Cobalt	102	99	1	2	<1	<1	---	1	---
Copper	102	15	1	9	1.8	<1	1.3	7.5	5
Lead	102	50	6	19	6.6	<6	9.3	9	25
Manganese	103	81	1	8	<1	<1	---	1	---
Molybdenum	106	22	1	4	2.4	<1	1.2	2.2	---
Nickel	102	92	5	13	<5	<5	---	7.2	25
Silver	104	98	3	7	<3	<3	---	3	30
Vanadium	101	95	10	25	<10	<10	---	10	---
Zinc	38	1	3	20	11	<3	3.4	11	30
1976 & 1977 (all values in mg/l)									
Calcium	549	0	.1	46.5	34.9	20.7	2.2	0.5	---
Magnesium	550	0	.1	14.9	10.8	7.8	0.9	0.1	---
Potassium	794	0	.01	2.4	1.1	0.9	0.1	0.01	---
Sodium	550	0	.1	13.9	4.8	3.3	0.7	1.5	---
Fluoride	258	0	.1	0.114	0.102	0.07	0.004	0.1	1.20

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

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

Aluminum

There are no applicable water quality or drinking water standards for aluminium nor is there an objective stated by the Great Lakes Water Quality agreement of 1980 (Appendix A). According to data from Copeland and Ayers (1972) on dissolved aluminium and aluminium in sediment, it appears that any determination of total aluminium in the water would be highly dependent upon the amount of suspended sediment in the water. Table 12 shows mean values of total aluminium an order of magnitude higher than the values for dissolved aluminium in Lake Michigan water.

TABLE 12

Total Aluminium (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Lake County Illinois Water Plant Intake Weekly determination	Jan-Dec 1972 48 samples	200	<100-600	Industrial Biotest (1972b) AAS/DA
Monthly diurnal	Jan-Dec 1972 40 samples	300	<100-600	p. 172
Monthly replicate determination in Southwestern Lake Michigan Illinois-Wisconsin Stateline to Waukegan	Jun-Dec 1972 209 samples	100	<100-500	Industrial Biotest (1972a) Table A-22 p.277 AAS/DA
Monthly intake samples of Zion Nuclear generating Plant	July 73-Jun 77 178 samples	110	10-700	Nalco (1977) AAS/DA AAS/FGF
Monthly duplicates of two stations. 2.3 mi. North & 3.2 mi. South of Pt. Beach Nuclear Power Plant. 3 depths each	Sept 72-Nov 73 144 samples	500	100-6000	Wisconsin Electric (1972-76) Table 5.5-4 p.5.0-
	Nov 73-Oct 74 144 samples	300	100-1200	Table 2.3-60/82 p. 2.0-74/96
	Nov 74-Oct 75 138 samples	120	100-5000	Table 2.25/35 p. 2.0-49/59
	Nov 75-Oct 76 142 samples	250	100-800	Table 2-25/356 p. 2-57/68 AAS/DA

Dissolved Aluminium (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Three lakewide surveys surface samples	Aug 69-Jun 1970 54 samples	27	4.9-150	Copeland & Ayers (1972) NAA
Seventeen kilometer offshore near Grand	1971 1 sample	11		Wahlgren, Edgington, Rawlings (1972) SSMS

Arsenic

The 1977 lakewide survey for total arsenic consisted of 11 samples analyzed by AAS/FGF analysis. All values were below the 2 ug/l detection limit. The Great Lakes Water Quality agreement specifies that total arsenic in an unfiltered water sample from the boundary waters should not exceed 50 ug/l (Appendix A).

Data in Table 13 is near the detection limit in all cases. Although three different analytical methods are represented, the results are all in the same range. The dissolved arsenic appears to be in the same range as total arsenic though none of the total arsenic means represent lakewide surveys.

TABLE 13

Total Arsenic (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Replicate monthly determinations Southwestern Lake Michigan	Jan 1970-Apr 1971			Industrial Biotest (1972a)
Lake County Water Intake	44 samples	1.4	<.5-3.1	Table X
Kensoha Water Intake	44 samples	1.1	<.5-3.2	p II A-20
North Chicago Water Intake	44 samples	1.2	0.5-2.7	Arsine/Colorimetric
Monthly duplicates of two stations. 2.3 mi. North mi. South of Pt. Beach Nuclear Power	Sep 72-Nov 73 144 samples	1	<1-4	Wisconsin Electric (1972-77) Table 5.5-4 p 5.0-424
Plant. 3 depths each	Nov 73-Oct 74 144 samples	<1	<1-2	Table 2.3-60/82 p 2.0-74/96
	Nov 75-Oct 76 70 samples	<1	<1-2	Table 2-25/35b p 2-57/68
Sampled Dec, Apr, May Jul, Aug, Oct.	Dec 76-Oct 77 72 samples AAS/FGF	1	<1-8	Table 2-2 p 2-33/37

TABLE 13 (contd.)
Total Arsenic (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Monthly survey within three mile of Kewaunee Nuclear Power Plant 12 samples per survey	1973	1	<1-4	Nalco (1976) AAS/FGF
	1974	<1	<1-4	
	1975	1	<1-3	
	1976, 96 samples	1	<1-3	
Quarterly analyses of intakes at Pullian Power plant of Lower Green Bay	Jan-Dec 1973 8 samples	<50	<50-<50	Univ. of Wisc. (1974)
Monthly replicates near Hammond Indiana Bailly	May-Nov 1974 290 samples	<.8	<.8	Texas Instruments (1975)
Metals survey Figure 37	July-August 1977 11 samples	<2	<2	This study ICAP
		Dissolved Arsenic (ug/l)		
Three lakewide surveys surface samples	Aug 1969-Jun 1970 54 samples	1	0.16-2.6	Copeland & Ayers (1972) NAA

Barium

The 1977 survey data showed a mean of 12 ug/l, and a range of 8 to 40 ug/l with 102 samples. With the exception of three values 25, 30 and 40 ug/l, all values were between 3 and 21 ug/l. The 25, 30, and 40 ug/l values were associated respectively with the samples from the fifty-four meter contour of transect XIV off Pt. Detour, the nine meter contour of transect XVII north of Charlevoix MI, and station 29 off Manitowoc, WI.

This survey could be biased as much as 8 ug/l low because of an over-compensation for an interference. Even so, the mean value would be only about half the mean value found by Copeland and Ayers (1972).

Worst case examples of duplicates from the same Niskin bottle for this survey were 10, 15, and 14, 18 even though the resolution of the procedure is a small fraction of a microgram per liter.

Applicable water quality and drinking water standards for total barium in Lake Michigan are all 1 mg/l (Appendix A). The Great Lakes Water Quality agreement contains no objective for barium.

Table 14 reveals a rather broad range of values by each author both temporally and spacially. The means and ranges of Copeland and Ayers (1972) and Rossman (1980) are very similar, though the former reports a lakewide survey using neutron activation analysis of freeze dried water while the later surveyed a small area near Cook Power plant by atomic absorption spectroscopy. The values given by Kopp and Kroner (1968) are three month composites of weekly samples from a single point. Though one might expect minimal variation in such a survey, their samples showed nearly a three fold variation in magnitude. The limited solubility of barium sulfate could create problems in a pre-concentration procedure such as used by Kopp and Kroner (1968), Copeland and Ayers (1972), and the present survey, though Rossman (1980) indicated no such pre-concentration step.

TABLE 14

Total Barium (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Metals Survey Figure 37	July-Aug 77 102 samples	12	8-40	This Study ICAP

Dissolved Barium (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Three month composites of weekly samples from public water intakes at	1962/ 1967			Kopp & Kroner (1968) DRS
Milwaukee, Wisconsin and	10 samples	18	10-26	P H-6
Gary, Indiana	9 samples	21	14-41	P H-7
Three lakewide surveys, surface samples	Aug. 1969/ June 1970 54 samples	37	6.1-110	Copeland & Ayers (1972) NAA
Seventeen kilometer offshore near Grand River	1971 1 sample	24		Wahlgren, Edgington, Rawling. (1972) SSMS
Nearshore samples near Cook Nuclear Power Plant	1974/1975 88 samples	44	14-69	Rossman (1980) AAS

Beryllium

All 136 samples from the 1977 Lake Michigan survey were below the 2 ug/l detection limit. Water Quality criteria and drinking water standards are not available for beryllium (Appendix A) though the metal is toxic enough to man that special precautions are necessary when working with the metal or its salts. (Handbook of Chemistry and Physics 1970-1971) Kopp and Kroner (1968) reported no dissolved beryllium in composites from Gary Indiana and Milwaukee Wisconsin water plant intakes 1962/67 at a detection limit of 0.1 ug/l.

Boron

The results for boron on the 1977 survey were unuseable because of negative quality assurance data. Applicable drinking water and water quality standards for boron are 1.0 mg/l. The Great Lakes Water Quality agreement does not specify an objective for boron. (Appendix A)

Table 15 shows a median value of means for total boron to be 50 ug/l in Lake Michigan proper while the one sample for dissolved boron is 33 ug/l.

TABLE 15

Total Boron (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Replicate monthly determinations Southwestern Lake Michigan	Jan 1970/Apr 1971			Industrial Biotest (1972a) Table X
Lake County Water Intake	44 samples	100	50-160	p II A-21
Kenosha Water Intake	44 samples	100	50-200	Colorimetric
North Chicago Water Intake	44 samples	100	50-140	
Lake County Illinois Water Plant Intake Weekly determination	Jan-Dec 1972 52 samples	50	20-220	Industrial Biotest (1972b) p. 172
Monthly diurnal	Jan-Dec 1972 40 samples	60	20-220	Industrial Biotest (1972b) p. 172
Monthly replicate determinations in Southwestern Lake Michigan Illinois-Wisconsin Stateline to Waukegan	Jun-Dec 1972 207 samples	68	<10-160	Industrial Biotest (1972b) Table A-23 p. 278 Colorimetric
Monthly intake samples of Zion Nuclear generating plant	July 73-Jun 77 178 samples	30	10-110	Nalco (1977) Colorimetric
Monthly duplicates of two station. 2.3 mi. North & 3.2 mi. South of Pt. Beach Nuclear Power Plant. 3 depths each	Sep 72-Nov 73 144 samples	<100	<100-<100	Wisc. Electric (1972-76) Table 5.5-4 p 5.0-424/6
	Nov 73-Oct 74 144 samples	<200	<200-<200	Table 2.3-60/82 p 2.0-74/96

TABLE 15 (contd.)
Total Boron (ug/l)

Sample Description	Date/Number	Mean	Range	Source
	Nov 74-Oct 75 138 samples	<200	<200-<200	Table 2.0-25/35 p 2.0-49/59
	Nov 75-Oct 76 142 samples	<200	<200-<200	Table 2-25/35b p 2-57/68
Monthly survey within three miles of Kewaunee Nuclear Power Plant 12 samples per survey	1973 1974 1975 1976, 96 samples	30 30 30 30	10-120 <10-150 <10-170 <10-80	Nalco (1976) Colorimetric
Quarterly analyses of intakes at Pullian Power Plant Lower Green Bay	Jan-Dec 1973 8 samples	6.5	4.6-8.5	Univ. of Wisc. (1974)
Dissolved Boron (ug/l)				
Seventeen kilometer offshore near Grand River	1971 1 sample	33		Wahlgren, Edgington, Rawling (1972) SSMS

Cadmium

In the 1977 lakewide survey, 101 of 103 samples were below the 2 ug/l detection limit of the ICAP procedure. Maximum value detected was 4 ug/l. Applicable water quality and drinking water standards specify a maximum of 10 ug/l. (Appendix A) The Great Lakes Water Quality agreement of 1978 specifies an objective of 0.2 ug/l on an unfiltered water sample. Most of the data in the Table 16 tend to indicate that the actual values are in the low tenths of a ug/l. Nalco 1977 (Zion intake), Texas Instruments (1975) (lake samples in the vicinity of the Bailly plant) and the University of Wisconsin (1974) (Lower Green Bay) indicate mean values over 1 ug/l.

TABLE 16

Total Cadmium (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Replicate monthly determinations Southwestern Lake Michigan	Jan 1970/Apr 1971			Industrial Biotest (1972a) Table X

TABLE 16 (contd.)
Total Cadmium (ug/1)

Sample Description	Date/Number	Mean	Range	Source
Lake County Water Intake	44 samples	<1	<1-<1	p II A-20
Kenosha Water Intake	44 samples	<1	<1-<1	AAS/SE
Six hour composites at the Waukegan Generating Station during a 24 hr. period (Replicates implied)	30/31May 1972 4 samples	<.1	<.1-<.1	Industrial Biotest (1972b) Table 26 p 127
	29/30Jun 1972 8 samples	0.2	0.1-0.6	Table 27 p 132
	20 Sep 1972 8 samples	0.5	0.4-0.6	Table 28 p 139
	6 samples 8 samples	0.4	0.2-0.8	Table 29 p 142 AAS/SE
Lake County Illinois Water Plant Intake				Industrial Biotest (1972b)
Monthly diurnal 60 samples	Jan-Dec 1972	0.2	<.1-1.1	Table 5 p 172
Monthly replicate determinations in Southwestern Lake Michigan Illinois-Wisconsin Stateline to Waukegan	Jun-Dec 1972 209 samples	0.2	<.1-3.0	Industrial Biotest (1972b) Table A-24 p 279
Monthly intake samples of Zion Nuclear Generating plant	Jan 74-Jun 77 82 samples	1.1	0.01-16	Nalco (1977) AAS
Monthly duplicates of two stations. 2.3 mi. North 3.2 mi. South of Pt. Beach Nuclear Power Plant. 3 depths each	Sep 72-Nov 73 144 samples	0.6	<0.1-1.2	Wisconsin Electric (1972-76) Table 5.5-4 p 50-42416
	Nov 73-Oct 74 144 samples	0.1	0.1-1.2	Table 2.3-60/82 p 2.0-74196
	Nov 74-Oct 75 138 samples	<0.1	<0.1-1.2	Table 2.0-25/35 p 2.049/59
	Nov 75-Oct 76 142 samples	0.2	<0.1-9	Table 2-25/35b p 2-57/68
Quarterly analyses of intakes at Pullian Power plant on Lower Green Bay	Jan-Dec 1973 8 samples	1.2	1.0-1.3	Univ. of Wisc. (1974)

TABLE 16 (contd.)
Total Cadmium (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Monthly replicates snear Hammond Indiana Bially nuclear plant	May-Nov 1974 290 samples	2.0	<1-63*	Texas Instrument (1975) AAS
Metals Survey Figure 37	July-August 77 103 samples	<2	<2-4	This Study ICAP
		Dissolved Cadmium (ug/l)		
Seventeen kilometer offshore near Grand River	1971 1 sample	0.1		Wahlgren, Edgington Rawling (1972) SSMS

*Replicate was 2, next highest value 11.

Chromium

Applicable drinking water and water quality standards and the Great Lakes Water Quality Agreement of 1978 specify 50 ug/l Chromium as a maximum value (Appendix A).

Table 17 shows a median mean of 2 ug/l with 75% of the means within the range 1 to 3 ug/l. The values obtained on the 1977 survey were between 3 and 13 ug/l with a median value of 7. It is not obvious how an interference could produce such a range of data, however it seems likely in view of the data from Table 15 that these values are biased high.

TABLE 17

Total Chromium (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Replicate monthly determinations Southwestern Lake Michigan	Jan 1970/Apr71			Industrial Biotest (1972a) Table X

TABLE 17(contd.)
Total Chromium (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Lake County Water Intake	44 samples	2	<1-9	p II A-22
Kenosha Water Intake	44 samples	2	<1-7	AAS/SE
North Chicago Water Intake	44 samples	2	<1-4	
Six hour composites at the Waukegan Generating Station during a 24 hr. period (Replicates implied)	20 Sep 1972 8 samples	5	3-7	Industrial Biotest (1972b) Table 28 p 138
	6 Dec 1972 8 samples	9	6-10	Table 29 p 142
Lake County Illinois Water Plant Intake				Industrial Biotest (1972b)
Weekly determination	Jan-Dec 1972 48 samples	2	<1-6	Table 5 p 172
Monthly diurnal	Jan-Dec 1972 40 samples	3	1-8	Table 5 p 172
Monthly replicate determinations in Southwestern Lake Michigan Illinois-Wisconsin Stateline to Waukegan	Jun-Dec 1972 209 samples	2	<1-28	Industrial Biotest (1972b) Table A-28 p 283 AAS/SE
Monthly intake samples of Zion Nuclear generating plant	Jul 73-Jun 77 82 samples	12	<1-120	Nalco (1977) AAS/SE AAS/FGF
Monthly duplicates of two stations. 2.3mi. North & 3.2mi. South of Pt.Beach Nuclear Power Plant 3 depths each	Sep 72-Nov 73 144 samples	3	<5-<20	Wisconsin Electric (1972-76) Table 5.5-4 p 5.0-424/6
	Nov 73-Oct 74 144 samples	<5	<5-<5	Table 2.3-60/82 p. 2.0-74/96
	Nov 74-Oct 75 138 samples	1.6	<1-9	Table 2.0-25/35 p. 2.0-49/59
	Nov 75-Oct 76 142 samples	2.4	<1-16	Table 2-25/35b p. 2-27/68
Monthly survey within three mile of Kewaunee Nuclear Power Plant 12 samples per survey	1973	2	1-7	Nalco (1976)
	1974	1	0.1-5.8	AAS/SE
	1975	0.8	0.1-3.7	AAS/FGF
	1976, 96 samples	1.0	0.1-4.1	
Quarterly analyses of intakes at Pullian Power Plant on Lower Green Bay	Jan-Dec 1973 8 samples	<10	<1-<10	Univ. of Wisc. (1974)

TABLE 17 (contd.)
Total Chromium (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Monthly replicates near Hammond Indiana Bially Nuclear Plant	May-Nov 1974 40 samples	3	<1-12	Texas Instruments (1975) AAS
Dissolved Chromium (ug/l)				
Three lakewide surveys surface samples	Aug 69-Jun 1970	1.7	0.5-4.0	Copeland & Ayers (1972) NAA
Nearshore samples near Cook Nuclear power plant	Apr, May, Jul 1974 & Apr &Jul 1975 88 samples	1.6	0.7-4.1	Rossman (1980) AAS/FGF
Seventeen kilometer off-shore near Grand River	1971 1 sample	7.2		Wahlgren, Edgington, Rawling (1972) SSMS

Cobalt

Cobalt levels found in 1977 were below the level of detection (1 ug/l) in 131 samples out of 136 analyzed. Of the remaining five samples, a value of 3 ug/l was found at the 54 meter contour of transect XIV and the other 4 samples, one at 2 ug/l, and three at 1 ug/l were measured in an area north of Frankfort to Grand Traverse Bay. Bowen (1966) gives 0.9 ug/l Co as a typical level in fresh water. Copeland and Ayers found values ranging from 0.033 to 0.57 ug/l soluble cobalt. Rossman (1978) reported 0.1-3.0 ug/l soluble cobalt in the epilimnetic and hypolimnetic waters of nearshore Lake Michigan between St. Joseph Michigan and Michigan City, Indiana.

Copper

The Great Lakes Water Quality agreement specifies a maximum of 5 ug/l copper for the protection of aquatic life (Appendix A). The drinking water standards are 1 mg/l for USPHS, and 1 mg/l for EPA and Illinois has a water quality standard of 20 ug/l (Appendix A).

Table 18 shows an overall range of 0.1 to 143 ug/l with a median mean of 3 ug/l. Total and dissolved copper appear to be of the same order of magnitude. Rossman (1980) presented a figure of 0.64 ug/l contamination from sample handling.

The ICAP detection limit for the 1976 samples was 4 ug/l. Of 581 samples, 16 exceeded that limit (3%), however 3 out of 16 (18%) of the quality control blanks exceeded that same limit. For the 1977 survey, using a ten-fold concentrate on the ICAP, the detection limit was 1 ug/l Of 130 samples, 24 were less than 1 ug/l, while 6 out of 21 quality control blanks were less than 1 ug/l. Nine samples were 4 ug/l or more (7% compared to 3% in 1976), while one quality control blank was 4 ug/l (5%). Mean sample concentration was 1.75 ug/l, calculated by arbitrarily assigning a value of 0.5 ug/l to those samples below the 1 ug/l detection limt. Mean collection contamination was 1.05 ug/l compared to Rossman's 0.64 ug/l. This does not include any contamination that may have occurred in or before the Niskin bottle in either the Rossman or the EPA survey.

TABLE 18

Total Copper (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Replicate monthly determinations Southwestern Lake Michigan	Jan 1970/Apr 1971			Industrial Biotest (1972a) Table X
Lake County Water Intake	44 samples	3	1-7	p II A-
Kenosha Water Intake	44 samples	77	44-120	AAS/SE
North Chicago Water Intake	44 samples	2	<1-2	
Six hour composites at the Waukegan Generating Station during a 24 hr. period (Replicated implied)	30-31 May 1972 4 samples	18	8.4-24	Industrial Biotest (1972b) Table 26, p 128
	29-30Jun 1972 8 samples	23	2.6-83	Table 27, p 122
	20 Sep 1972 8 samples	8	5.7-11	Table 28, p 139
	6 Dec 1972 8 samples	30	19-72	Table 29, p 142 AAS/SE
Lake County Illinois Water Plant Intake Monthly diurnal	Jan-Dec 1972 60 samples		0.9-12	Table 5 p 172
Monthly replicate determinations in Southwestern Lake Michigan Illinois-Wisconsin Stateline to Waukegan	Jun-Dec 1972	4	0.7-35	Industrial Biotest (1972b) Table A-3 p 28/6
Monthly intake samples of Zion Nuclear generating plant	Jul, 73-Jun77 82 samples	5.4	0.0-32	Nalco (1977) AAS/SE AAS/FGF

TABLE 18 (contd.)
Total Copper (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Monthly duplicates of two stations. 2.3 mi. North & 3.2 mi. South of Pt. Beach Nuclear Power Plant. 3 depths each				Wisc. Electric (1972-77)
	Sep 72-Nov 73 144 samples	3	<5-10	Table 5.5-4 p 5.0-424/6
	Nov 73-Oct 74 144 samples	3	1.7-5	Table 2.3-60/82 p 2.0-74/96
	Nov 74-Oct 75 138 samples	2	<1-17	Table 2.0-25/35 p 2.0-49/59
	Nov 75-Oct 76 142 samples	1	<1-4	Table 2-25/35b p 2-57/68
Sampled Dec, Apr,May, Jul, Aug, Oct.	Dec 76-Oct 77 72 samples	1	<1-8	Table 2-2 p 2-33/37 AAS/SE AAS/FGF
Monthly survey within three mile of Kewaunee Nuclear Power Plant 12 samples	1973	1.4	0.1-4.9	Nalco (1976)
	1974	1.9	0.8-9.2	AAS/SF
	1975	0.9	<0.1-5.8	AAS/FGF
	1976, 96 samples	1.7	0.5-12	
Quarterly analyses of intakes at PullianPower plant on LowerGreenBay	Jan-Dec 1973 8 samples	6.9	6.0-8.1	Univ. of Wisc. (1974)
Monthly replicates near Hammond Indiana Bially Nuclear plant	May-Nov 1974 40 samples	3	<1-10	Texas Instruments (1975)
Metals Survey figure 37	July-Aug 77	1.8	<1-9	This Study ICAP

Dissolved Copper (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Three lakewide surveys surface samples *next highest value 17	Aug 69-Jun 1970 54 samples	5	<7-14.2*	Copeland & Ayers
Nearshore samples near Cook Nuclear Power Plant 88 samples	Apr, May, Jul 1974 & Apr & Jul 1975	2.5	0.8-8.0	Rossman (1980) AAS/FGF
Seventeen kilometer off-shore near Grand River	1971 1 sample	9.3		Wahlgren, Edgington, Rawlings (1972) SSMS

Iron

Applicable water quality and drinking water standards and the Great Lakes Water Quality Agreement specify a maximum iron concentration of 300 ug/l (Appendix A). Table 19 provides a range of means for total iron from nearshore areas of 38 to 1200 ug/l. The range of means for dissolved iron is 7 to 39 ug/l.

Values from the 1976 survey averaged 34 ug/l with a standard deviation of 57 ug/l and a detection limit of 20 ug/l. Two of the ten quality control blanks exceeded the 20 ug/l detection limit (i.e. 21 and 40 ug/l). For the 1977 survey the concentration technique provided a detection limit of 2 ug/l. The 1977 mean of 23 ug/l with a standard deviation of 22 ug/l for 134 samples was accompanied by 21 quality control blanks with a mean of 19 ug/l and standard deviation of 13 ug/l. It would appear from this that the actual mean value for the entire lake may be less than 10 ug/l.

TABLE 19

Total Iron (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Replicate monthly determinations Southwestern Lake Michigan	Jan 1970/Apr 1971			Industrial Biotest (1972a) Table X
Lake County Water Intake	44 samples	240	9-450	p II A-21
Kenosha Water Intake	44 samples	210	9-460	AAS/SE
North Chicago Water Intake	44 samples	170	7-490	
Six hour composites at the Waukegan Generating Station during a 25 hr. period (Replicated implied)	30-31 May 1972 4 samples	840	730-940	Industrial Biotest (1972b) Table 26, p 128
	29-30 Jun 1972 8 samples	260	200-350	Table 27, p 132
	20 Sep 1972 8 samples	470	330-800	Table 28, p 139
	6 Dec 1972 8 samples	1100	940-1200	Table 29, p 142 AAS/SE
Lake County Illinois Water Plant Intake				
Monthly diurnal 60 samples	Jan-Dec 1972	350	10-1100	p 173, 186 AAS/SE

TABLE 19 (contd.)
Total Iron (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Monthly replicate determinations in Southwestern Lake Michigan Illinois-Wisconsin State-line to Waukegan	Jun-Dec 1972 209 samples	138	14-630	Industrial Biotest (1972b) Table A-Z4 p 289 AAS/SE
Monthly intake samples of Zion Nuclear generating plant	Jul 73-Jun 77	1200	13-940	Nalco (1977) AAS/SE AAS/FGF
Monthly duplicates of two stations. 2.3 mi. North & 3.2 mi. South of Pt. Beach Nuclear Power Plant. 3 depths each	Sep 72-Nov73 144 samples	260	50-1400	Wisconsin Electric (1974) Table 5.5-4 p 5.0
	Nov 73-Oct 74 144 samples	200	<100-600	Table 2.3-60/82 p 2.0-74/96
	Nov 74-Oct 75 138 samples	110	<100-500	Table 2.0-25/35 p 2.0-49/59
	Nov 75-Oct 76 142 samples	220	<100-500	Table 2-25/35b p 2-57/68
Sampled Dec, Apr, May Jul, Aug, Oct.	Dec 76-Oct 77 72 samples	<100	100-350	Table 2-2 p 2-33/37 AAS
Monthly survey within three mile of Kewaunee Nuclear Power Plant 12 samples per survey	1973	93	2-950	Nalco (1976)
	1974	140	5-1600	AAS/SE
	1975	38	2-300	AAS/FGF
	1976, 96 samples	79	2-710	
Quarterly analyses of intakes at Pullian Power plant on Lower Green Bay	Jan-Dec 1973 20 samples	700	300-1900	Univ. of Wisc. (1974)
Monthly replicates near Hammond Indiana Bially nuclear plant	May-Nov 1974 290 samples	44	1-200	Texas Instruments (1975) AAS

Dissolved Iron (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Three lakewide surveys surface samples	Aug 69-Jun 1970 54 samples	19	5-56	Copeland & Ayers (1972) NAA

TABLE 19 (contd.)
Total Iron (ug/l)

Samples Description	Date/Number	Mean	Range	Source
Nearshore samples near Cook Nuclear Power Plant	Apr, May, Jul 1974 & Apr & Jul 1975 88 samples	7	1.4-18	Rossman (1980) AAS/FGF
Monthly replicates near Hammond Indiana Bially nuclear plant	May-Nov 1974 290 samples	39	2-186	Texas Instruments (1975) AAS

Lead

Public water supply sources are limited to 50 ug/l lead. The recommended IJC objective for lead is 25 ug/l (Appendix A). This objective was not violated in any of the samples from our 1977 survey.

The maximum value found was 19 ug/l at one station near the mouth of Indiana Harbor while fifty of the 102 samples were below the 6 ug/l detection limit. An overall mean concentration of 6.6 ug/l was calculated by arbitrarily assigning a value of 3 ug/l lead to all <6 results.

In Table 20 the median of the means is 3 ug/l and the maximum value found was 170 ug/l.

TABLE 20

Total Lead (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Replicate monthly determinations Southwestern Lake Michigan	Jan 1970/Apr 1971			Industrial Biotest (1972a)
Lake County Water Intake	44 samples	3	2-6	Table X
Kenosha Water Intake	44 samples	2	1-5	p II A-23
North Chicago Water Intake	44 samples	2	1-5	AAS/SE
Six hour composites at the Waukegan Generating Station during a 24 hr.	30-31 May 1972 4 samples	4	3-5	Industrial Biotest (1972b) Table 26p 128
period. (Replicates implied by eight samples	29-30 Jun 1972 8 samples	3	2-4	Table 27 p 133

TABLE 20 (contd.)
Total Lead (ug/l)

Sample Description	Date/Number	Mean	Range	Source
	20 Sep 1972 8 samples	10	5-19	Table 28 p 140
	6 Dec 1972 8 samples	8	5-18	Table 29 p 143 AAS/SE
Lake County Illinois Water Plant Intake Monthly diurnal	Jan-Dec 1972 46 samples	2	<1-8	Industrial Biotest (1972b) Table 5 p 173
Monthly replicate determinations in Southwestern	Jun-Dec 1972 209 samples	3	<1-15	Industrial Biotest (1972b) Table A-35 p 290 AAS/SE
Monthly intake samples of Zion Nuclear Generating Plant	Jul 73-Jun 77 82 samples	5.5	<1-30	Nalco (1977) AAS/SE AAS/FGF
Monthly duplicates of two stations. 2.3 mi. North & 3.2 mi. South of Pt. Beach Nuclear Power Plant. 3 depths each	Sep 72-Nov 73 144 samples	2	<1-<10	Wisconsin Electric (1972-77) Table 5.5-4 p 5.0-424/6
	Nov 73-Oct 74 144 samples	1	<1-6	Table 2.3-60/82 p 2.0-74/96
	Nov 74-Oct 75 138 samples	1	<1-2	Table 2.0-25/35 p 2.0-49/59
	Nov 75-Oct 76 138 samples	14	<1-170	Table 2-25/35b p 2-57/68
Sampled Dec, Apr, May Jul, Aug, Oct.	Dec 76-Oct 77 67 samples	10	<1-70	Table 2-2 p 2-33/37 AAS/FGF
Monthly survey within three mile of Kewaunee Nuclear Power Plant 12 samples per survey	1973	5	<1-120	Nalco (1976)
	1974	1	<1-16	p 2-32
	1975	1	<1-7	AAS/SE
	1976 96samples	3	<1-26	AAS/FGF
Quarterly analyses of intakes at Pullian Power Plant on Lower Green Bay	Jan-Dec 1973 8 samples	10	all <10	Univ of Wisc. (1974)

TABLE 20 (contd.)

Total Lead (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Monthly replicates near Hammond Indiana	May-Nov 1974 40 samples	7	<1-22	Texas Instruments (1975) AAS
Metals Survey Figure 37	July-Aug 77 102 samples	6.6	<6-19	This Study ICAP
Dissolved Lead (ug/l)				
Seventeen kilometer offshore near Grand River	1971 1 sample	0.9		Wahlgren, Edgington, Rawlings (1972) SSMS

Manganese

There is no IJC objective for manganese. EPA (1972) suggested that concentrations less than 20 ug/l represent minimal risk in marine water environments. Recommended drinking water limits are 50 ug/l, based on esthetic reasons (Appendix A).

The median of the means for total manganese from Table 21 is 4.7 ug/l while the median for dissolved manganese is 0.4 ug/l. This correlates with data by Copeland and Ayers (1972) showing a high sediment to water ration for manganese.

During our 1977 survey 81 of the 103 samples were less than the 1 ug/l detection limit, with a maximum value of 8 ug/l. Thirteen of the 22 values above the detection limit were on transect XII to XV which bracket Green Bay's inter-action zones with Lake Michigan (Table 20).

TABLE 21

Total Manganese (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Replicate Monthly determinations Southwestern Lake Michigan	Jan 1970/Apr 1971			Industrial Biotest (1972a)
Lake County Water Intake	44 samples	6.2	<0.4-24	Table X
Kenosha Water Intake	44 samples	5	0.7-14	p II A-23
North Chicago Water Intake	44 samples	7.1	0.6-31	AAS/SE

TABLE 21 (contd.)
Total Manganese (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Six hour composites at the Waukegan Generating Station during a 24 hr. period. (Replicates implied by eight samples)	30-31 May 1972 4 samples	16	14-17	Industrial Biotest (1972b) Table 26 p 129
	29-30 Jun 1972 8 samples	4	2-6	Table 27 p 133 AAS/SE
Lake County Illinois Water Plant Intake Monthly diurnal	Jan-Dec 1972 46 samples	2	<1-8	Industrial Biotest (1972b) Table 5 p 173
Monthly replicate determinations in Southwestern	Jun-Dec 1972 209 samples	3	<1-14	Industrial Biotest (1972b) Table A-37 p 292 AAS/SE
Monthly intake samples of Zion Nuclear Generating Plant	Jul 73-Jun 77 82 samples	66.7	<0.1-500	Nalco (1977) AAS/SE
Monthly duplicates of two stations. 2.3 mi. North & 3.2 mi. South of Pt. Beach Nuclear Power Plant. 3 depths each	Sep 72-Nov 73 144 samples	9	1-60	Wisconsin Electric (1972-77) Table 5.5-4 p 5.0-424/6
	Nov 73-Oct 74 144 samples	5	1-12	Table 2.3-60/82 p 2.0-74//6
	Nov 74-Oct 75 138 samples	3.1	<1-8	Table 2.0-25/35 p 2.0-49/59
	Nov 75-Oct 76 142 samples	4.7	<1-10	Table 2-25/35b p 2-57/68
Sampled Dec, Apr, May, Jul, Aug, Oct.	Dec 76-Oct 77 72 samples	3	<1-7	Table 2-2 p 2-33/37 AAS/FGF
Monthly survey within three mile of Kewaunee Nuclear Power Plant 12 samples per survey	1973	4	<1-17	Nalco (1976)
	1974	4	0.6-49	AAS/SE
	1975	1.7	0.1-52	AAS/FGF
	1976, 96 samples	3.3	0.3-28	
Quarterly analyses of intakes at Pullian	Jan-Dec 1973 8 samples	12.3	11.5-13.0	Univ. of Wisc. (1974)

TABLE 21 (contd.)
Total Manganese (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Monthly replicates near Hammond Indiana	May-Nov 1974 287 samples	7	<1-95	Texas Instruments (1975) AAS
Metals Survey Figure 37	July-Aug 77 103 samples	<1	<1-8	This Study ICAP

Dissolved Manganese (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Three lakewide surveys surface samples	Aug 1969-Jun70 54 samples	1	.29-2.6	Copeland & Ayers (1972) NAA
Nearshore samples Near Cook Nuclear Power Plant	Apr,May, Jul 1974 & Apr & Jul 1975 88 samples	0.4	.1-1.7	Rossman (1980) AAS
Seventeen kilometer offshore	1971 1 samples	0.4		Wahlgren, Edgington, Rawlings (1972) SSMS

Mercury

The Great Lakes Water Quality agreement of 1979 specifies 0.2 ug/l maximum in a filtered water sample to protect aquatic life and fish consuming birds. Illinois has a water quality standard of 0.5 ug/l., Indiana 5.0 ug/l (Appendix A).

Table 22 shows values for dissolved mercury below the IJC objective over the entire lake, however, the nearshore determinations for total mercury range from below the detection limit of 0.05 ug/l to a high of 20 ug/l.

Copeland and Ayers (1972) tested for recovery but they did not indicate the chemical form (elemental mercury, inorganic or organic mercury compounds) that was used for the recovery tests. The nearshore investigators, on the other hand, did not indicate that quality control blanks or other contamination checks were made.

Mercury determinations were not made on thc 1976-77 EPA surveys.

TABLE 22

Total Mercury (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Replicate monthly determinations Southwestern Lake Michigan	Jan 1970/Apr 1971			Industrial Biotest (1972a)
Lake County Water Intake	44 samples	0.75	0.05-2.6	Table X
Kenosha Water Intake	44 samples	0.22	0.11-0.51	p II A-23
North Chicago Water Intake	44 samples	0.56	0.07-3.0	AAS/Flameless
Weekly data obtained Weekly data obtained at the Waukegan Generating Station	Jan 72-Dec 72 46 samples	0.63	<0.05-11.0	Industrial Biotest (1972b) Table 21, p 113 AAS/Flameless
Six hour composites at the Waukegan Generating Station during a 24 hr. period (replicates implied)	30-31 May 1972 4 samples	0.21	<0.05-0.55	Industrial Biotest (1972b) Table 26, p 129
	29-30 Jun 1972 8 samples	0.05	<0.05-0.13	Table 27, p 133
	20 Sep 1972 8 samples	0.15	<0.05-0.49	Table 28, p 140
	6 Dec 1972 8 samples	0.13	<0.05-0.18	Table 29, p 143
Lake County Illinois Water Plant Intake Monthly diurnal	Jan-Dec 1972 58 samples	0.12	<0.05-0.46	Industrial Biotest (1972b) AAS/Flameless Table 5, p 173
Monthly replicate determinations in Southwestern	Aug-Dec 1972 149 samples	0.36	<0.05-3.4	Industrial Biotest (1972b) Table A-38 p 293
Monthly intake samples of Zion Nuclear Generating Palnt	Jul 73-Jun 77 82 samples	0.67	<0.05-10	Nalco (1977) AAS/Flameless
Monthly duplicates of two stations. 2.3 mi. North & 3.2 mi. south of Pt. Beach Nuclear Power Plant. 3 depths each	Sep 72-Nov 73 144 samples	0.8	<0.2-20	Wisconsin Electric (1972-77) Table 5.5-4 p 5.0 p 5.0-424/6
	Nov 73-Oct 74 144 samples	1	<0.2-2.3	Table 2.3-60/82 p 2.0-74/96
	Nov 74-Oct 75 138 samples		<0.2-2.2	Table 2.0-25/35 p 2.0-49/59
	Nov 75-Oct 76 142 samples	0.2	<0.2-2.2	Table 2-25/35b p 2-57/68

TABLE 22 (contd.)
Total Mercury (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Sampled Dec, Apr, May, Jul, Aug, Oct.	Dec 76-Oct 77 72 samples	<0.2	<0.2-0.7	Table 2-2 p 2-33/37 AAS/Flameless
Monthly survey within three mile of Kewaunee Nuclear Power Plant 12 samples per survey	1973 1974 1975 1976, 96 samples	0.09 0.08 0.12 0.21	<0.05-2.9 <0.05-0.89 <0.05-0.32 <0.05-8.9	Nalco (1976) Table 2.12 p 2-32
Quarterly analyses of intakes at Pullian Power Plant on Lower Green Bay	Jan-Dec 1973 8 samples	0.19	0.13-0.21	Univ. of Wisc. (1974)
Monthly replicates snear Hammond Indiana daily nuclear plant	May-Nov 1974 248 samples	0.3	<0.2-3.4	Texas Instrument (1975) AAS/Flameless

Dissolved Mercury (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Three lakewide surveys surface samples	Aug 69-Jun 70 54 samples	0.03	0.011-0.057	Copeland & Ayers (1972) NAA

Molybdenum

There are no water quality or drinking water standards for Molybdenum.

Values from the 136 samples in 1977 resulted in a mean of 2.4 and a standard deviation of 1.1 The quality control blanks indicated a detection limit of 2.2 ug/l. Eighty-eight of the 136 samples exceeded this conservative detection limit. Our values for total molybdenum agree well with the lakewide survey (Copeland and Ayers 1972) for dissolved molybdenum (Table 23).

TABLE 23

Total Molybdenum (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Metals Survey Figure 37	July-Aug 77 106 samples	2.4	<1-4	This Study ICAP

TABLE 23 (contd.)
Total Molybdenum (ug/l)

Sample Description	Date/Number	Mean	Range	Source
	Dissolved Molybdenum (ug/l)			
Three month composites of weekly samples from public water intakes	1962/1967			Kopp & Kroner (1968) DRS
at Milwaukee, Wisc.	10 samples	54*	<11-129	p H6
and Gary, Indiana	9 samples	13*	<13-73	p H7
Three lakewide surveys surface samples	Aug 1969/Jun 1970 54 samples	2*	<1.1-4.8	Copeland & Ayers (1972) NAA
Nearshore samples near Cook Nuclear Power Plant	Apr, May, Jul 1974 Apr & Jul 1975	12.1	2.4-38	Rossman (1980) AAS/FGF

*Mean of samples above detection limit.

Nickel

The U.S. Canada Great Lakes Water Quality agreements specifies a maximum Nickel concentration of 25 ug/l in the boundary waters (Appendix A).

The data from Table 24 show a range of means from <1 to 7.4 ug/l with a range of values from <1 to 29 ug/l.

From the 1977 survey, only 13 out of 102 samples exceeded the 5 ug/l instrument detection limit. Eleven of these were from the same general area of the lake, but since the samples were run in the same sequence as they were collected, and since one of the 23 quality control blanks had a value of 11 ug/l compared to highest sample value of 13 ug/l the significance of these positive values is questionable.

TABLE 24

Total Nickel (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Replicate monthly determination Southwestern Lake Michigan	Jan 1970/Apr 1971			Industrial Biotest (1972a)
Lake County Water Intake	44 samples	2	<1-4	Table X
Kenosha Water Intake	44 samples	2	1-5	p II A-
North Chicago Water Intake	44 samples	2	1-3	AAS/SE

TABLE 24 (contd.)
Total Nickel (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Six hour composites at the Waukegan Generating Station during a 24 hr. period. (replicates implied)	20 Sep 1972 8 samples	4	2-6	Industrial Biotest (1972b) Table 28 p 140
	6 Dec 1972 8 samples	3	3-3	Table 29 p 143 AAS/SE
Lake County Illinois Water Plant Intake Monthly diurnal	Jan-Dec 1972 40 samples	1	<1-6	Industrial Biotest (1972b) Table 5 p 1973 AAS/SE
Monthly replicate determinations in Southwestern Lake Michigan Illinois-Wisconsin state line to Waukegan	Jun-Dec 1972 209 samples	1	<1-7	Industrial Biotest (1972b) Table A-40 p 295 AAS/SE
Monthly intake samples of Zion Nuclear generating plant	Jul 73-Jun 77 82 samples	4	<1-28	Nalco (1977) AAS/SE AAS/FGF
Monthly duplicates of two stations. 2.3 mi. North & 3.2 mi. South of Pt. Beach Nuclear Power Plant 3 depths each	Sep 72-Nov 73 144 samples	6		Wisconsin Electric (1972-77) Table 5.5-4 p 5.0-424/6
	Nov 73-Oct 74 132 samples	<5	<5-10	Table 2.3-60/82 p 2.0-74/96
	Nov 74-Oct 75 138 samples	<5	<5-8	Table 2.0-25/35 p 2.0-49/59
	Nov 75-Oct 76 142 samples	<5	<5-10	Table 2-25/35b p 2-57/68 AAS
Monthly survey within three mile of Kewaunee Nuclear Power Plant 12 samples per survey	1973	1	<1-3	Nalco (1976) AAS/SE
	1974	2	<1-29	
	1975	<1	<1-3	
	1976, 96 samples	<1	<1-6	
Quarterly analyses of intakes at Pullian Power Plant on Lower Green Bay	Jan-Dec 1973 8 samples	<10	all <10	Univ.of Wisc. (1974)
Monthly replicates near Hammond Indiana Bailly Nuclear Plant	May-Nov 1974 40 samples	3	1-22	Texas Instruments (1975) AAS

TABLE 24 (contd.)
Total Nickel (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Metals Survey Figure 37	July-Aug 77 102 samples	<5	<5-12	This Study ICAP

Dissolved Nickel (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Nearshore samples near Cook Nuclear Power Plant	Apr, May, Jul, 1974 & Apr & Jun 1975 88 samples	7.4	2.3-18.6	Rossman (1980) AAS/Flameless
Seventeen kilometer offshore near Grand River	1971 1 sample	7.7		Wahlgren, Edgington, Rawlings (1972) SSMS

Selenium

The Great Lakes water quality agreement specifies 10 ug/l as a maximum for selenium to protect raw water for public water supplies. Applicable water quality and drinking water standards are all 10 ug/l (Appendix A). The values in Table 25 are below 1 ug/l except for the one determination performed with spark source mass spectroscopy (1.3 ug/l). Selenium was not determined on the 1976/77 surveys.

TABLE 25

Total Selenium (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Monthly replicates near Hammond, Indiana Bailly Nuclear Plant	May-Nov 1974 40 samples	0.8		Texas Instruments (1975) AAS/FGF

Dissolved Selenium (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Three lakewide surveys surface samples	Aug.69-June70 54 samples	0.08	.03-0.17	Copeland & Ayers (1972) NAA
Seventeen kilometer offshore near Grand River	1971 1 sample	1.3		Wahlgren, Edgington Rawlings (1972) SSMS

Silver

Applicable drinking water standards for silver are 50 ug/l. Illinois has a water quality standard of 5 ug/l. The IJC has no objective for silver (Appendix A).

The literature on silver determinations in Lake Michigan is sparse and appears limited to dissolved silver (Table 26). The lakewide survey by Copeland and Ayers (1972) found all samples to be within the range of 0.06 to 1.2 ug/l. At the same time they found average sediment values of 0.67 mg/kg. If this value is representative of the suspended sediment, then there is roughly 100 to 1000 times as much silver in the water as there is in the suspended sediment (based on suspended sediment values of 0.5 to 5 mg/l). Regarding the 1977 survey, 98 of the 104 samples and all of the quality control blanks were less than the 3 ug/l detection limit. Seven ug/l was the highest value and it was from the 18 meter contour near the Wisconsin, Illinois state line. Concentrations of 3 ug/l and 5 ug/l were recorded off Racine Wisconsin. Values of 3 ug/l were recorded north of Frankfurt, Michigan. These total silver values are somewhat higher than the dissolved silver values found by others. Also they are very near the detection limit, i.e. only one is more than twice the detection limit.

TABLE 26

Total Silver (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Metals Survey Figure 37	July-Aug 1977 104 samples	<3	<3-7	This Study ICAP
	Dissolved Silver (ug/l)			
Three month composites of weekly samples from public water intakes at Milwaukee Wisc. and Gary, Indiana	1962/ 1967 10 samples 9 samples		 1.6* 	Kopp & Kroner (1968) DRS P-H-7 P-H-7
Three lakewide surveys, surface samples	Aug 1969- June 1970 54 samples	0.3	0.06-1.2	Copeland & Ayers (1972) NAA
Seventeen kilometer offshore near Grand River	1971 1 sample	1.5		Wahlgren, Edgington, Rawling (1972) SSMS

*One composite from Milwaukee was 1.6 ug/l no silver was detected in the other 18 composites.

Vanadium

There are no water quality or drinking water standards for Vanadium (Appendix A).

Of 101 observation and 23 quality control blanks, 6 observations and 1 quality control blank exceeded the detection limit of 10 ug/l. All these positive values were found between transects XVI and XIX.

Other investigators found (Table 27) less than 3 ug/l, but this is the first lakewide survey for total vanadium.

Table 27

Total Vanadium (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Monthly replicates near Hammond Indiana Bailly Nuclear Plant	May-Nov 1974 290 samples	<3	all <3	Texas Instruments (1975)
Metals Survey Figure 37	July-Aug 77 101 samples	<10	<10-25	This Study ICAP
Dissolved Vanadium (ug/l)				
Three lakewide surveys surface samples	Aug 69-June 70 54 samples	0.2	<.15-0.42	Copeland & Ayers (1971) NAA

Zinc

The Great Lakes Water Quality agreement of 1978 specifies an objective for total zinc of less than 30 ug/l for protection of aquatic life (Appendix A).

Table 28 shows a median mean of 12 ug/l with an overall range of 0.1 to 370 ug/l. The 1977 survey resulted in 136 samples and 20 quality control blanks with mean values respectively of 13.6 (S.D = 8.6) and 11.7 (S.D. = 5.0) excluding one outlying blank of 41 ug/l and two outlying samples (<1000 & 236).

Most of the references contain no information on quality control blanks or contamination. Copeland and Ayers (1972) used an all plastic sampling apparatus and tested their procedure for recovery, but make no mention of any contamination checks. Rossman (1980) used acid washed sample bottles and carried a filtered distilled water blank from the storage sample bottle through the analysis, similiar to our quality control blank. He found an average contamination of 1.4 ug/l zinc.

There are several differences between his procedures and ours so that it is impossible to state at this time why our blanks were higher than his or where the contamination in either case was introduced. It seems likely that much of the zinc in Table 28 is the result of contamination.

TABLE 28

Total Zinc (ug/l)

Sample Description	Date/Number	Mean	Range	Source
Replicate Monthly determinations Southwestern Lake Michigan	Jan 1970/Apr 1971			Industrial Biotest (1972a)
Lake County Water Intake	44 samples	41	10-100	Table X
Kenosha Water Intake	44 samples	160	62-370	p II A-22
North Chicago Water Intake	44 samples	8	5-13	AAS/SE
Weekly data obtained at the Waukegan Generating Station	Jul-Dec 1972 47 samples	18	<1-86	Industrial Biotest (1972b) Table 22 p 114 AAS/SE
Six hour composites at the Waukegan Generating Station during a 24 hr. period. (replicates implied).	30-31May 1972 4 samples	<1	all <1	Industrial Biotest (1972b) Table 26 p 129
	29-30Jun 1972 8 samples	14	<1-38	Table 27 p 133
	20 Sep 1972 8 samples	30	11-86	Table 28 p 140
	6 Dec 1972 8 samples	28	18-45	Table 29 p 143 AAS/SE
Lake County Illinois Water Plant Intake Weekly determination	Jan-Dec 1972 58 samples	7	<1-23	IndustrialBiotest (1972b) Table 5, p 173
	Jan-Dec 1972 60 samples	9	<1-25	Table 5, p 173
Monthly replicate determinations in Southwestern Lake Michigan Illinois-Wisconsin state line to Waukegan	Jun-Dec 1972 208 samples	12	<1-54	Industrial Biotest (1972b) Table A-47 p 302 AAS/SE
Monthly intake samples of Zion Nuclear generating plant	Jul 73-Jun 77 81 samples	31	<1-120	Nalco (1977) AAS/SE

TABLE 28 (contd.)
Total Zinc (ug/l)

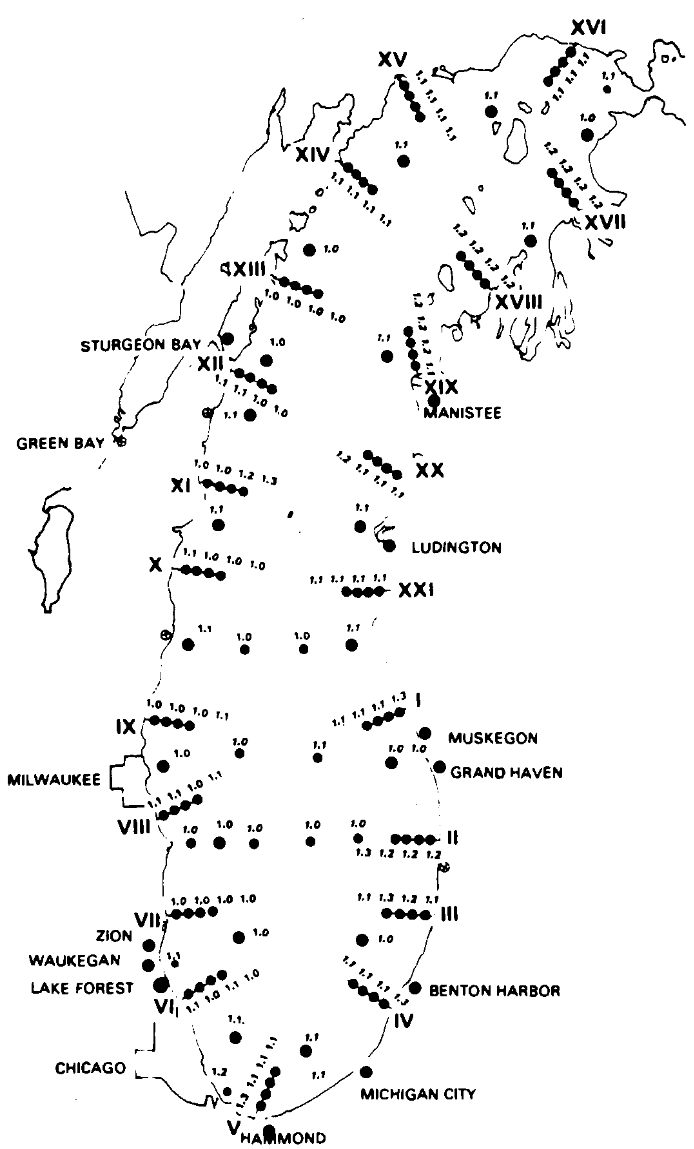
Sample Description	Date/Number	Mean	Range	Source
Monthly duplicates of two stations. 2.3 mi. North & 3.2 mi. south of Pt. Beach Nu clear Power Plant. 3 depths each	Sep 72-Nov 73 144 samples	4	<0.5-30	Wisconsin Electric (1972-77) Table 5.5-4 p 5.0-424/6
	Nov 73-Oct 74 144 samples	5	2-10	Table 2.3-60/82 p 2.0-74/96
	Nov 74-Oct 75 138 samples	4.7	3-8	Table 2.0-25/35 p 2.0-49/59
	Nov 75-Oct 76 142 samples	7	<1-19	Table 2-25/35b p 2-57/68
Sampled Dec, Apr, May, Jul, Aug, Oct.	Dec 76-Oct 77 72 samples	10	<1-26	Table 2-2 p 2-33/37
Monthly survey within three mile of Kewaunee Nuclear Power Plant 12 samples per survey	1973	13	1-86	Nalco (1976)
	1974	10	0.1-62	AAS/SE
	1975	8.5	0.4-50	AAS/FGF
	1976, 96 samples	8.0	0.5-240	
Quarterly analyses of Power Plant on Lower Green Bay	Jan-Dec 1973 8 samples	14	12-17	Univ. of Wisc. (1974)
Monthly replicates near Hammond Indiana Bailly Nuclear Plant	May-Nov 1974 40 samples	15	<1-74	Texas Instruments (1975) AAS
Metals Survey Figure 37	July-Aug 77 38 samples	11	<3-20	This Study ICAP

Dissolved Zinc (ug/l)

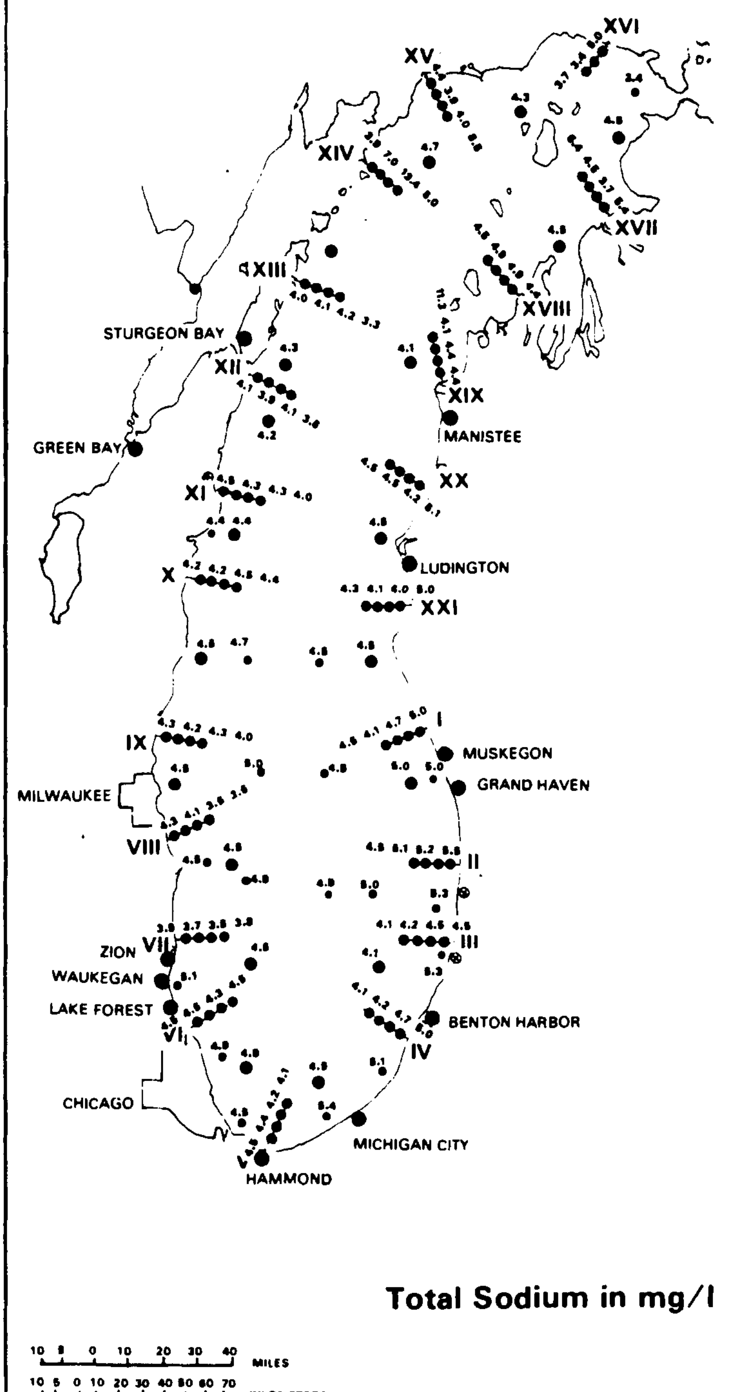
Sample Description	Date/Number	Mean	Range	Source
Three lakewide surveys surface samples	Aug 69-Jun 70 54 samples	16	1.9-82	Copeland & Ayers (1972) NAA
Nearshore samples near Cook Nuclear Power Plant	Apr, May, Jul 1974 7 Apr & Jul 1975	5.2	1-10.4	Rossman (1980) AAS/FGF
Seventeen kilometer offshore near Grand River	1971 1 sample	96		Wahlgren, Edgington Rawlings (1972) SSMS

Lake Michigan - 1977 Metals Survey

Transect locations are schematic only. Actual samples were collected along axis at 9m, 18m, 36m, and 54m contours.



Total Potasium in mg/l



Total Sodium in mg/l

figure 37

Alkaline-Earth and Alkali Metals

Calcium

There are no recommendations for calcium in the water quality or drinking water standards although it is cosidered under hardness (Appendix A). Our 1976 data suggests a seasonal variation in calcium concentrations in the southern basin. Using the TLVWA calculations and data from Appendix B spring levels of 35.1 ± 0.2 mg/l result for both the partial cruise 1 (transect 6) and for cruise 2. Epilimnetic levels increased from 34.9 ± .2 mg/l (Cruise 1) and 35.4 ± 0.1 mg/l (Cruise 2) to 37.0 ± .3 mg/l in June (Cruise 3) and decreased to 36.2 ± 0.1 mg/l (Cruise 4) and 33.7 ± .1 mg/l in late August 1976 (Cruise 6). Lower calcium values occur only in the northern most transects near the Straits of Mackinac. Except for two observations of above 40 mg/l calcium ranged between 31.9-38.4 mg/l in the southern basin in 1976 with mean concentrations of 35.5 mg/l. Higher values tended to be monitored near shore for most of the transects in the 1977 surveys. The spacial variation of calcium in the 1977 survey showed variations of less than 2 mg/l for most transects where samples were collected at 9, 18, 36, and 54 meter depth contours with higher results occurring at the 9 meter depth contour. A typical transect in this area near Holland, Michigan, had values of 36, 34.6, 34.8, and 34.2 mg/l at the four depth contours given earlier. There is a suggestion that calcium values are higher than average in the southern most and southeastern sections of the southern basin. For the two year period calcium averaged 34.9 ± 0.1 mg/l for all samples taken throughout the lake (Table 11).

Magnesium

There are no recommendations for magnesium in the water quality or drinking water standards although it is considered under hardness (Appendix A). Using the TLVWA calculations and data from Appendix B, spring concentrations in 1976 of 10.7 ± 0.05 ug/l for 32 samples and 11.0 ± 0.02 mg/l for 150 samples occurred during the partial cruise 1 (transect 6) and for cruise 2 respectively. Cruise 3, 4 and 6 with about 60 samples each resulted in values of 11.1 ± .04, 11.2 ± .04 and 11.0 ± .03 mg/l in 1976 respectively. Lower magnesium values (~ 8 mg/l) occurred in the northern most transects in 1977. Higher values tended to be monitored nearshore for many of the transects in the 1977 surveys. Combining 1976-1977 monitoring results gave a mean of 10.8 ± .9 mg/l.

Potassium

There are no recommendations for potassium in the water quality or drinking water standards (Appendix A). Using the TLVWA calculations and data from Appendix B, concentration levels in 1976 of 1.11 ± .01 mg/l for 32 samples and 1.06 ± .004 mg/l for 205 samples were monitored in the partial cruise 1 (transect 6) and for cruise 2 respectively. Cruises 3, 4 and 6 showed approximately the same values of 1.01 ± .01, 1.08 ± .01, and 1.07 ± .01 mg/l respectively. These levels were characteristic throughout the Take and in the water column. Figure 37 shows the spacial consistency throughout the lake including the region near the Mackinaw Straits in 1977. Combining 1976-1977 monitoring results gave a mean of 1.1 ± .01 mg/l (Table 11).

Sodium

There are no recommendations for sodium in the water quality or drinking water standards (Appendix A). Using the TLVWA calculations and data from Appendix B, concentration levels for cruises 1, 2, 3, 4, and 6 resulted in a narrow range of values 4.57 ± .03, 4.84 ± .03, 4.87 ± .04, 4.73 ± .03, and 4.59 ± .02 mg/l for 32, 149, 58, 61, and 59 samples respectively. Figure 37 shows the spacial spacial distribution in 1977. Lower sodium values were monitored in the Straits of Mackinaw and in transect VII between Milwaukee and Chicago. Occassional high values appear nearshore and in the southern basin. Combining 1976-1977 monitoring results gave a mean of 4.8 ± 0.7 mg/l (Table 11).

Fluoride

Fluoride concentrations allowable in drinking water vary depending on temperature Torrey (1976). Water quality standards permit 1.2 mg/l to 1.4 mg/l (Appendix A). Using the TLVWA calculations and data from Appendix B, concentration levels for cruises 1, 3, 5, and 7 in 1976 resulted in a narrow range of values 0.102, 0.101, 0.103 and 0.099 mg/l for 33, 57, 61 and 45 samples respectively. Combining 1976-1977 monitoring results gave a mean of 0.102 ± .004 mg/l (Table 11). Maximum level observed was .114 mg/l which is less than 1/10 of the standards.

Discussion

In examining the 1976 and 1977 Lake Michigan intensive survey data, a logical interpretation is to link the results of the latter survey to the earlier one. In doing this, a large and apparently natural removal of phosphorus occurred between the two surveys.

The discussion will begin with the observed decrease of phosphorus and suggest that the severe winter and extensive ice cover of 1976-1977 was the apparent principal causative agent. Subsequent discussion will generally follow the pattern established by the results section.

Phosphorus

Extensive phosphorus data in the Lake Michigan open waters is quite infrequent with substantial time gaps between studies. One open lake area where data has been taken over several year intervals, with five to seven year gaps intervening between studies, is between Milwaukee and Ludington. Beeton and Moffett (1964) gave 13 total phosphorus concentration values for three stations (8, 9, and 11) in this area for 1954 with a mean of 12.7 ± 2.1 ug/l. The same authors gave data of 15.7 ± 4.0 ug/l (n=7) for two stations (12d, 13a) in 1960 which were east and south of Milwaukee. The overall average of all stations exclusive of the extreme southern end was 13 ug/l for the 1954-55 and 1960-61 period Beeton (1969). It should be noted that the winter of 1962-63 had 80% maximum percent ice cover, the most extensive on record at that time (Assel et al 1979), may account in part for the lower P concentration of the latter studies assuming a natural cleansing occurred during the 1962-63 winter. Rousar and Beeton (1973) concluded in reviewing total P data from 1954 through 1971 that the lack of a suitable lakewide water quality monitoring program and analytical differences prevented drawing conclusions regarding total P changes. Risley and Fuller (1965) give total phosphate concentrations as PO_4 of 20 ug/l (6-7 ug/l as P) in this area in 1962-63 with most of their samples in this area being from 1963. Rousar (1973) reports on total phosphorus concentration (as P) at three open lake stations at the 4 meter depth between 27 May 1970 and 20 October 1971. His averages ranged from 8.0 to 8.9 ug/l for 40 cruises in these two years. Our results from stations 22, 26 and 27 in the same area of the southern basin indicate mean surface concentrations at 1 meter depths of total phosphorus (as P) of 6.7 $\pm$ 0.9 ug/l (n=26) in 1976 and 5.0 $\pm$ 1.1 ug/l (n=12) in 1977.

Prior to 1962-63, phosphorus concentrations in Lake Michigan between Milwaukee and Ludington were higher than current levels with some decrease occurring between 1961 and the FWPCA study in 1962-63. The pattern in the area between Milwaukee and Ludington after 1961 is an increase from 1962-63 levels of around 6 or 7 ug/l to concentrations of 8 to 9 ug/l in the early seventies. This declined to around 7 ug/l in 1976 with a sharp decline to around 5 ug/l in 1977. In the entire southern basin total phosphorus concentrations declined from 8.0 $\pm$ .8 in 1976 to 5.2 $\pm$ .2 in 1977. Eighty-five percent of the southern basin stations showed a reduction in total phosphorus concentrations between 1976 and 1977. Total dissolved phosphorus also decreased at 92 percent of the stations from a median of 3 ug/l in 1976 to below detectable limits in 1977. The lake-wide decrease from 1976 to 1977 in both total and total dissolved phosphorus were significant at greater than 95% confidence level using Students T Test and the Mann Whitney Test (Zar, 1974) respectively.

The change in phosphorus concentrations between 1976 and 1977 are of interest due to the unexpected size of the decrease. For the entire basin the estimated total phosphorus load, from industrial, municipal, atmospheric, and tributary sources were 6566 and 4666 metric tons in 1976 and 1977 respectively, a decrease of about 2000 metric tons (IJC GLWQB, 1978). A 1.0 ug/l annual decrease in total phosphorus corresponds to a loss of 5000 metric tons from Lake Michigan (Chapra and Sonzogni, 1979). The 2 to 3 ug/l decrease in phosphorus concentration observed in the southern basin between 1976 and 1977, if characteristic of the entire lake, would suggest a load decrease of between 10,000 and 15,000 metric tons for the entire lake. Thus, natural causes within the lake appear responsible for 80 to 85 percent of the decrease in total phosphorus between 1976 and 1977.

One explanation of this large and apparently natural decrease in total phosphorus may be the severity of the intervening winter. The abnormally large amount and duration of the ice cover was unusual for

for the 1976-77 winter. The onset of freezing conditions was 30 days earlier than normal. The maximum ice extent was 58 days longer than normal. The beginning of early ice decay started 4 days later than normal, Quinn et al (1978). Quinn et al (1978), p.1, summarized the weather and ice condition for the winter of 1976-1977.

"The winter of 1976-77 was the fifth coldest in the past 200 years. Record-breaking low temperatures from mid-October to mid-February, associated with an upper air pressure pattern consisting of a strong ridge in the westerly flow over North America, resulted in extraordinary ice cover on the Great Lakes. Ice was produced almost simultaneously in various shallow protected areas of the Great Lakes in early December. The progression of early winter, mid-winter, and maximum ice extent was from 4 to 5 weeks earlier than normal. At the time of maximum ice extent in early February, Lake Superior was approximately 83 percent ice covered, Lake Michigan over 90 percent, Lake Huron approximately 89 percent, Lake Erie 100 percent, and Lake Ontario approximately 38 percent. Spring breakup started in late February in the southern part of the Great Lakes region and in early March in the northern part. The bulk of ice cover was gone by the fourth week of April".

The severe winter appears to have caused some differences in the lake thermal regime between the two years of this study. Thermal stratification with a discernible epilimnion, thermocline, and cold hypolimnion appears to have been delayed by the cold winter in 1977. The extent of thermal stratification on the May 25-June 2, 1976 cruise was about the same as observed on the June 15-21, 1977 cruise. The epilimnetic waters in 1977 were about 3-4^{o}C cooler than in 1976 throughout the stratified season.

If the deposition of particulate matter during the 1976-1977 winter was enhanced due to the ice cover then many of the observed physical, biological and chemical changes may have a common and interacting cause.

The ice cover would insulate the water mass from prevailing winds which are responsible for mixing. Resuspension of sediments may also be curtailed during ice cover in areas that are normally wind driven (Rodgers 1980). That increased sedimentation of suspended material occurred between 1976 and 1977 is suggested by mean turbidity values which decreased from $1.8 \pm .3$ HTU in 1976 to $0.9 \pm .1$ HTU in 1977. This decrease was significant at the 99% confidence level. This change occurred during the period between cruises ending in 1976 and starting in 1977.

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

To look at possible relationships between the effects of severe winters contributing to the reduction of total phosphorus concentrations in deep Great Lakes basins, available total phosphorus data were regressed using annual freezing degree days and maximum percent ice cover for Lake Michigan and Lake Ontario. Spring total phosphorus concentrations from offshore cold-core water in Lake Ontario was used from Dobson (1980). An average of March and April monthly average total phosphate data from the South Chicago Water Filtration Plant was used with permission (see credits). Annual freezing degree days (Chicago and Toronto) and maximum percent ice cover for the period 1968-1979 is used from Assel (1980). Values for the winters 1977-79 were preliminary estimates provided by R. Assel. Maximum percent ice cover and annual freezing degree days are highly correlated at .86 between Lake Michigan and Chicago, but are correlated only at .63 between Lake Ontario and Toronto.

The best fit using Lake Michigan information cited earlier showed that increasing values of the parameter, annual Chicago freezing degree days was correlated ($p > .995$) with decreasing total phosphate (as P) concentrations at Chicago.

$$\text{Total P } (\text{ug/l}) = \underset{(2.5)^{1}}{39.0} - \underset{(0.0029)^{1}}{0.019} \text{ (Chicago Annual Freezing Degree Days)}$$

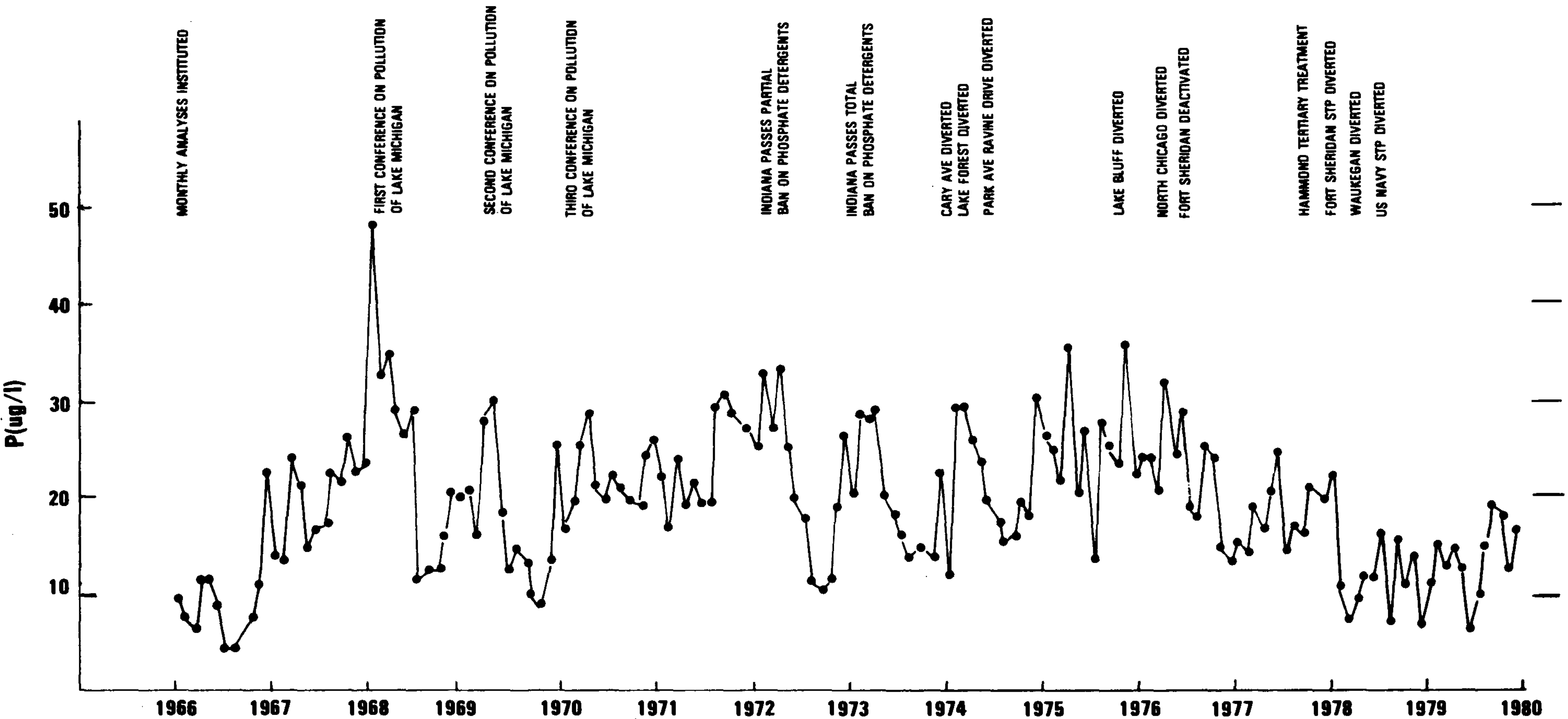
The best fit using Lake Ontario data cited earlier showed that increasing values of the parameter, maximum percent ice cover, was correlated ($p > .995$) with decreasing spring total phosphorus concentrations in offshore cold-core water in Lake Ontario.

$$\text{Total P } (\text{ug/l}) = \underset{(0.44)^{1}}{22.9} - \underset{(0.011)^{1}}{0.074} \text{ (Maximum percent ice cover)}$$

These regressions suggest that severe winters help explain a part of the decrease in total phosphorus concentrations. During the cold winters in 1976 thru 1979 total phosphorus concentrations have been observed to decline. An increase in total phosphorus would be predicted after a mild winter. Increases in total phosphorus concentrations, after mild winter, from the previous year spring levels have also been observed in Lake Michigan. (Lake Michigan Water Quality Report 1979, 1980) Snow (1974) suggests that observed phosphorus concentrations in the near-shore waters are determined largely by stirring up of bottom sediments which contain phosphorus.

The water sampled by the City of Chicago are more representive of near-shore conditions than those of open lake waters. However, open lake decreases found between 1976-1977 in phosphorus concentrations by this study were also found by the City of Chicago and Illinois EPA (Lake Michigan Water Quality Report 1979, 1980) in their ten year survey of south and north shore surveys as well as their open lake survey which

[1]One standard error of the coefficient.



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

figure 38

consists of 14 sampling points located 10 to 30 kilometers offshore between Evanston, Illinois and Burns Harbor, Indiana. Chicago's south water filtration plant record illustrates nearshore decreases in total phosphorus (Figure 38) which began in the mid seventies. Contributing to the observed changes in phosphorus concentrations in the Chicago nearshore area over this decade were phosphate detergent bans implemented by Indiana in 1972-73 and curtailment of municipal and industrial discharges in northeastern Illinois and northwestern Indiana from 1974-1978 (Lake Michigan Water Quality Report 1978, 1980).

Silica

The annual silica cycle in the southern basin surface waters of Lake Michigan shows an apparent decrease in dissolved reactive silica (DRS) in Lake Michigan over the last three decades (Figure 39). Schelske and Stoermer (1971) suggest that silica declined over 4 mg/l from 1926 through 1970 due to phosphorus enrichment which stimulated high levels of diatom productivity depleting available supplies of silica. Edgington et al (1980) question the validity of the earlier data since there does not appear to be sufficient amorphous SiO_2 in the sediments to account for the decrease of soluble SiO_2 in the water. If the earlier silica data were accurately determined, this annual rate of DRS depletion of about 0.1 mg SiO_2/yr. would require phosphorus loads which may not be physically possible (Johnson and Eisenreich, 1979) unless there are some other silica sinks which have not been identified such as crystalline forms or increased standing crops of diatoms.

Seasonal epilimnetic DRS concentration reductions were evident in the open lake in 1976 and 1977 (Figure 13) reflecting biological activity. DRS concentrations were reduced to concentrations around 0.2 mg/l in 1976 and between 0.1 and 0.2 mg/l SiO_2 in 1977 in the open lake. Nearshore DRS levels were reduced to these very low levels along the western shore in 1976 but not along the eastern shore. In 1977 DRS levels in both eastern and western nearshore zones were around 0.5 to 0.6 mg/l.

Almost all the deep lake stations, which are least influence by upwelling effects and cultural impacts, showed declining silica mass between 1976 and 1977 (Rockwell et al 1980). The apparent loss of silica in the deep water stations may be a temporary effect caused by the extensive ice cover which hindered the normal resuspension and remineralization of diatom frustules.

The nearshore stations along the western nearshore showed increasing silica concentrations in 1977 over 1976, while eastern nearshore zones showed a mixed pattern. Both east and west nearshore zones are influenced by upwelling. Cruise data show temperature patterns characteristic of upwelling at various times in both years (Figure 5). To look at possible relationships between water temperature and DRS, DRS data were regressed using sample water temperature and water temperature gradients to characterize the effect upwelling may have had on DRS concentrations for all the cruises in a given year. Water temperature gradients were based on comparing sample water temperatures at the same or equivalent depths

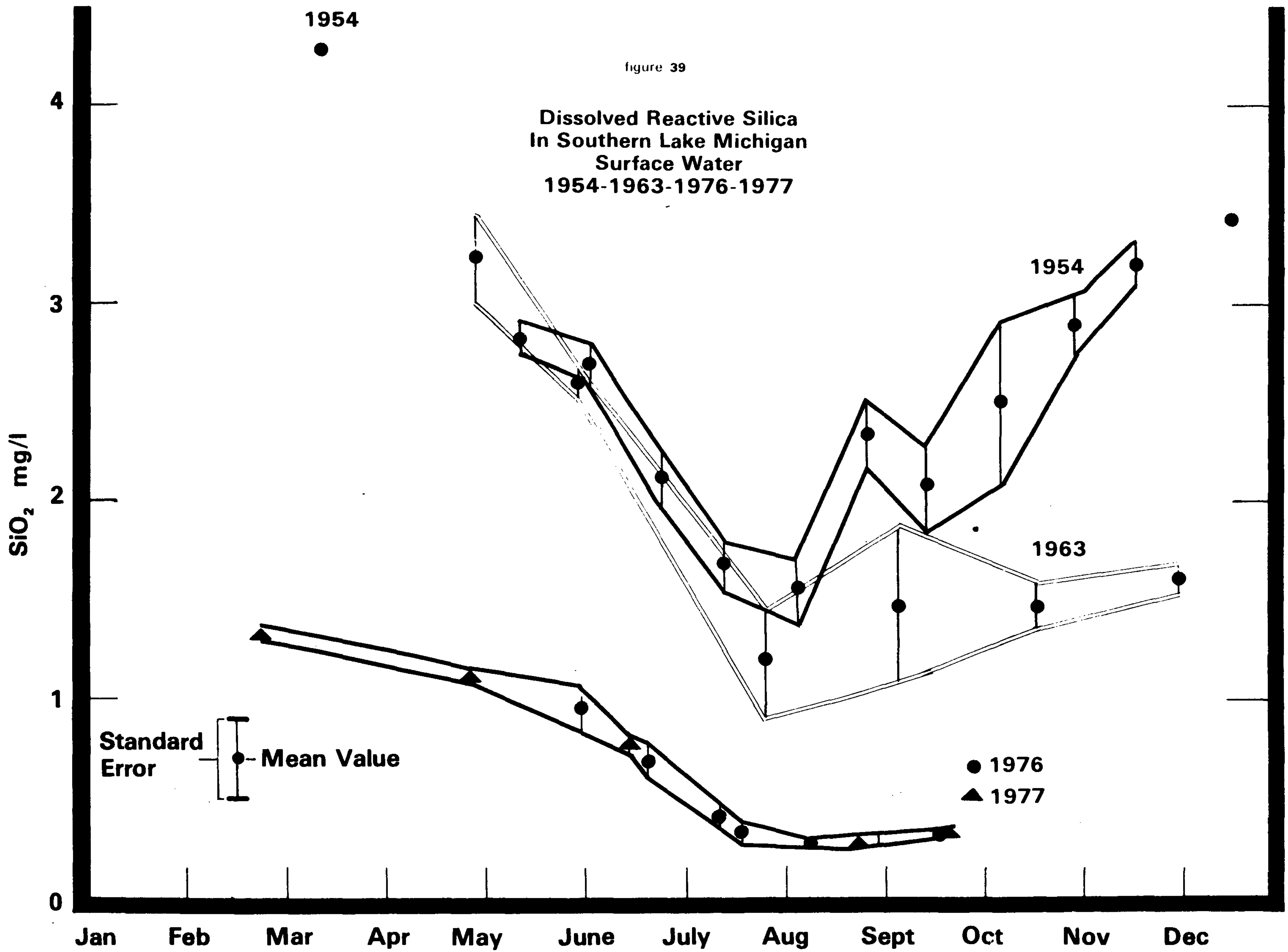


figure 39

Dissolved Reactive Silica
In Southern Lake Michigan
Surface Water
1954-1963-1976-1977

from the nearshore station and a deep water station of the same transect. The regression equation is of the form DRS = K_1 + K_2 • TEMP + K_3 • Δ TEMP. If K_3 is significant in the regression equation it would imply that upwelling helps explain DRS concentration changes.

The station pairs used to determine water temperature gradients and thus to characterize upwelling along each transect and the zones in which they were grouped were as follows:

Group 1)	(5a, 5) (9, 10) (16, 17)	Southern portion western shore
Group 2)	(21, 22) (25, 26)	Northern portion western shore
Group 3)	(6B 6) (13, 12)	Southern portion eastern shore
Group 4)	(20, 19) (24, 23) (28, 27)	Northern portion eastern shore

Regressions for 1976 and 1977 gave results as follows:

Group 1- 1976 $$DRS = \underset{(0.054)^1}{0.81} - \underset{(0.0031)^1}{0.0029} \cdot TEMP - \underset{(0.0067)^1}{0.0063} \cdot \Delta\ Temp$$

Group 1- 1977 $$DRS = \underset{(0.10)^1}{1.28} - \underset{(0.008)^1}{0.051} \cdot TEMP + \underset{(0.011)^1}{0.00050} \cdot \Delta\ TEMP$$

Group 2- 1976 $$DRS = \underset{(0.050)^1}{0.76} - \underset{(0.0033)^1}{0.028} \cdot TEMP - \underset{(0.0046)^1}{0.063} \cdot \Delta\ TEMP$$

Group 2- 1977 $$DRS = \underset{(0.18)^1}{1.59} - \underset{(0.016)^1}{0.083} \cdot TEMP + \underset{(0.0011)^1}{0.0011} \cdot \Delta\ TEMP$$

Group 3- 1976 $$DRS = \underset{(0.15)^1}{0.39} - \underset{(0.0085)^1}{0.015} \cdot TEMP - \underset{(0.013)^1}{0.034} \cdot \Delta\ TEMP$$

Group 3- 1977 $$DRS = \underset{(0.20)^1}{0.78} - \underset{(0.012)^1}{0.019} \cdot TEMP - \underset{(0.018)^1}{0.055} \cdot \Delta\ TEMP$$

Group 4- 1976 $$DRS = \underset{(0.13)^1}{1.31} - \underset{(0.0072)^1}{0.045} \cdot TEMP - \underset{(0.0096)^1}{0.039} \cdot \Delta\ TEMP$$

Group 4- 1977 $$DRS = \underset{(0.04)^1}{1.25} - \underset{(0.0032)^1}{0.048} \cdot TEMP - \underset{(0.0048)^1}{0.061} \cdot \Delta\ TEMP$$

The K_3 coefficients for the Δ TEMP term were characterized as follow at the 95% confidence level for the entire cruise seasons in 1976 and 1977:

Groups	1976	1977
1	Not Significant	Not Significant
2	Significant	Not Significant
3	Significant	Significant
4	Significant	Significant

The results of the individual regressions by area and year showed that upwelling had a statistically significant impact, as expressed by significant Δ TEMP coefficients, on DRS concentrations in the southern basin along the eastern shore for both years. Along the western shore in the southern basin, upwelling had a statistically significant impact on DRS concentrations only along the northern portion of the western nearshore in 1976. The multiple regression showed upwelling did not significantly influence DRS concentration levels in 1976 or 1977 along

[1]One standard error of the coefficient.

the southern portion of the western nearshore. This is the nearshore zone bordering the greater Chicagoland urban complex. The elimination of the municipal discharges in Lake County Illinois and Northern suburbs of Chicago would be expected to reduce nutrient loads in the nearshore zone. These reductions may have resulted in less DRS utilization in 1977. The analysis presented suggest that the increase of DRS along the western shore of the southern basin may not be attributed solely to upwelling leaving open the possibility of other potential factors such as the elimination of municipal discharges and severe winter impacts.

Nitrate-Nitrogen

Schelske and Roth (1973) show the magnitude of nitrate depletion in the epilimnion may be proportional to an increasing degree of eutrophication. To gauge this depletion in the area between Milwaukee and Ludington we have taken the difference between the epilimnetic winter (or earliest cruise data) high and summer epilimnetic low nitrate concentration for the years 1962-63 (F.W.P.C.A., 1968), 1970-71 (Rousar, 1973), and 1976-1977 (this study). These differences ranged from .10-.14 mg/l in 1977. (Note the overlap of the 1962-63 and 1977 results which occured after severe winters and extensive ice cover). Comparisons of the vertical variation within the deep water stations (Appendix Table C1-C3) show a maxium difference of .21 mg/l in 1976 in Southern Basin, .10 mg/l in 1976 Northern Basin, and .14 mg/l in 1977 in Southern Basin. Schelske and Roth (1973) observed a 0.06 mg/l vertical variation at several deep water stations in the northern basin. These results would suggest an impacted lake with a gradual worsening of eutrophication from 1962-63 through 1976 and a return to 1962-63 levels in 1977. By comparison, Lake Superior, an oligotrophic lake (Beeton, 1969), had similar surface and bottom concentrations of nitrate which averaged 0.27 mg-N/l and 0.28 mg-N/l respectively, Rousar (1973).

The changes in phosphorus and nitrate between 1976 and 1977 were, as would be expected, accompanied by decreases in phytoplankton numbers and chlorophyll "a" concentrations. Primary production results (Table 10) also imply more nutrient limitation and less response to light in 1977 in the Southern Basin.

Chlorophyll "a"

Other studies have shown statistical relationships between phosphorus and chlorophyll "a" (IJC Upper Lake Reference Group 1976), (Dobson 1976), (Rast and Lee 1978). Epilimnetic (upper 20m) values of chlorophyll "a" (ug/l), and total phosphorus (ug-P/l) for all stations (generally 2 KM or more from shore) in Lake Michigan were related by regression analysis.

Chlor "a" = 1.0 + 0.18 (total P) for 1976 data Southern Basin
(.15)[1] (0.019)[1]

Chlor "a" = 0.41 + 0.24 (total P) for 1977 data Southern Basin
(0.09)[1] (0.017)[1]

Chlor "a" = 1.1 + 0.14 (total P) for 1976 data Northern Basin
(0.15)[1] (0.019)[1]

[1]One standard error of the coefficient.

Using these equations in southern Lake Michigan, total P values between 5.5 and 7.7 ug/l in 1976 and 6.6 and 8.3 ug/l in 1977 and in nothern Lake Michigan, total P values between 6.4 and 9.3 ug/l in 1976 would correspond to minimum chlorophyll "a" values (2-2.4 ug/l) associated with incipient mesotrophic conditions (Table 28). The range of oligotrophic to mesotrophic indicator transition values (6.5 to 10 ug/l-Table 28) is perhaps high for Lake Michigan total phosphorus concentrations. No significant regressions relationships between chlorophyll "a" and total phosphorus were noted in hypolimnetic waters. These results are probably linked to light limitation in the hypolimnetic waters. Concentrations of chlorophyll "a", except for "bays" in the Great Lakes, increases from the least oligotrophic to the more eutrophic in the Great Lakes (Schelske and Roth, 1973). Lake Michigan falls in the middle of the five Great Lakes with respect to chlorophyll "a" concentrations.

Phytoplankton

The establishment of long term trends in the phytoplankton of the open waters of Lake Michigan is difficult due to the widely varying methodologies employed and the degree of lumping in our data. However, a study in the southern basin in 1962-63 by Stoermer and Kopcznska (1967) used methodology very similar to ours. They sampled every 2 to 3 weeks throughout the navigable season and found populations between 125 and 2700 cells/ml at stations roughly equivalent to our stations 5a, 6, and 16. In 1977 we found total populations ranging from 1190 to 6000 cells/ml in this area. These estimates of populations are conservative, since we used only 400 x magnification while Stoermer and Kopcznska (1967) used 1200x. Total populations in this area in 1977 were typically 1.5 to 3 times those observed at comparable times in 1962-63.

Another interesting comparison between Stoermer and Kopczynska's results and ours is the relative abundance of the major phytoplankton groups. In 1962-63 diatoms were the numerical dominates at all stations, and at all depths throughout the 2 year study. In 1976-77 phytoflagellates dominated at virtually all stations throughout the study. The diatoms were the second most abundant group in the spring (April-June) but were replaced by bluegreen algae in the summer (August) and early fall (September). Diatoms remained abundant in the nearshore areas in August, 1977 where higher silica concentrations and lower water temperatures were recorded apparently as a result of an upwelling event. The effect of this upwelling on the phytoplankton population can be seen in highly significant positive correlations between common diatoms (F. crotonensis, T. fenestrata, A. formosa) and silica concentrations.

Schelske and Stoermer (1971) have predicted that continued phosphorus loading would eventually result in an imbalance with available silica supplies. The phosphorus stimulated diatom population would then deplete the epilimnetic silica concentrations to the point where silica would become limiting to the diatoms. They further hypothesized that this would lead to a shift from diatom dominance to bluegreen or green algae which do not require silica.

This apparently occurred sometime between 1962-63 and the summer of 1971 when Stoermer (1974) observed that as much as 80 percent of total count was bluegreen algae. Unfortunately the difference in methodology used in studies intermediate between 1962-63 and 1976-77 is such that trends in this phenonemon can not be more finely determined.

While blue-green algal blooms were not observed in 1976 or 1977, several genera commonly associated with them such as Anacystis spp. and Anabaena spp. were abundant in the summer period. However, the reporting of bluegreen algal forms as filaments and colonies/ml undoubtly underestimate their numerical importance. Filamentous bluegreens were abundant at stations 6 and 19 in August and station 24 in September when Anabaena spp. comprised 21.6 percent (580 filaments/ml), 9.9 percent (290 filaments/ml), and 5.3 percent (230 filaments/ml) of the total counts respectively. What was identified in this study as Oscillatoria limnetica occurred commonly throughout the basin in April and June and was especially abundant at station 16 in September, 1977, when it contributed 3.3 percent (200 filaments/ml) of the total phytoplankton.

The significance of what would appear to be a large increase in small phytoflagellates since 1962-63 is difficult to determine, primarily as a result of the lumping of these forms as miscellaneous flagellates in our data. Stoermer and Kopczynka (1967) reported Cryptomonads and other flagellates as a numerically minor component of the total plankton. However, Munawar and Munawar (1975; 1976; 1978) have reported small flagellated forms to be abundant and frequently dominate on a biomass bases in all the other St. Lawrence Great Lakes. Based on three samples in July 1973, Munawar and Munawar (1975) reported that phytoflagellates contributed between 6 and 32 percent of the biomass in Lake Michigan. The small size of most of these organisms indicates that such a percentage of the total biomass would require large numbers. Claflin (1975) also found small flagellates (particularly Rhodomanas spp. and Cryptomonas spp.) to be very abundant in Lake Michigan along a transect between Milwaukee and Ludington in 1970-71. Whether these have actually increased from the early 1960's or the increase is a result of differences in methodology can not be determined with the available data.

The abundance of several species of algae would appear to have changed between previous plytoplankton studies and our 1977 survey.

Synedra acus has been reported as infrequent in the phytoplankton by both Alstrom (1936) and Stoermer and Kopczynska (1967). This commonly periphytic species, (Lowe, 1974) while a minor component, was along with Asterionella formosa, the most commonly occurring pennate diatom in 1977. While most abundant nearshore, it was common throughout the southern basin.

Cyclotella spp. were common in the plankton in 1977 yet seldom comprised more than 5 percent of the total and was never dominant. This contrasts sharply with reports by Schelski et al. (1971) and Holland and Beeton (1972) that C. stelligera was among the offshore dominants. That the entire genus was not among the dominants in 1977 may suggest marked decreases in some of the oligotrophic species associated with this genus. This however, may also be the result of the low (400x) magnification used in our study, resulting in underestimates of the smaller centrics some of which may be as small as 2.5 um in diameter (Holland, 1979).

The presence of Cyclotella in areas of severe silica depletion in August 1977 lends support to reports of changes at the species level. Stoermer and Tuckman (1979) have reported the recent introduction of C. comensis to the southern basin. They report that this species is more capable of tolerating higher nutrient and lower silica concentrations than most members of the genus.

Ankistrodesmus falcatus appears to have increased since Alstrom (1936) reported it as rare in the 1930's. Stoermer and Kopczynska (1967) reported that it had increased and commonly occurred in concentrations of 20 to 60 cells/ml in the summer of 1962-63. Our data indicate a further increase with concentrations between 20 and 610 cells/ml in 1977. While occasional populations of A. falcatus are found in the warm season plankton of several types of lakes, large populations are usually associated with eutrophic conditions (Stoermer and Ladewski, 1976).

The three species of Anacystis reported from Lake Michigan (A. cyaneae, A. incerta, A. thermalis) are all characteristic of eutrophic and hypereutrophic lakes. While high populations have been reported from the Chicago area (Griffith, 1955) these appear to have been localized phenomena. Stoermer and Kopczynska (1967) reported low numbers (<5/ml) in the southern basin. Our data indicates that this genus has increased dramatically since 1963 (Stoermer and Kopczynska, 1967).

Oscillatoria limnetica would appear to have increased dramatically in recent years. Neither Alstrom (1936) nor Stoermer and Kopczynska (1967) observed it in any significant abundance. In April and June 1977 O. limnetica was extremely common throughout the southern basin in fairly substantial numbers. There is however, some indication that this species was misidentified in our data. Stoermer and Ladewski (1976) report that O. limnetica has a high (~ 18°C) temperature optimum. The other common species of Oscillatoria in Lake Michigan (O. mougeotii) is typically a spring-early summer form. In our data O. limnetica was most common in April and June suggesting that it may have been O. mougeotti. Unfortunately the samples have been discarded preventing the verification of O. limnetica.

Our data indicate that Rhizosolenia eriensis has decreased markedly since Alstrom (1936) reported it as abundant. However, Holland (1979) observed it as abundant or dominant for short periods in the spring or early summer in 1970, 1971, and 1972. It is possible the relative infrequency of our cruises could have resulted in our missing the short periods of abundance of this species reported by Holland.

While there were an insufficient number of cruises in either year to track seasonal trends, the warming and cooling cycle of the lake appeared to exert a marked influence on both the number and kinds of phytoplankton present. Both the increase in total phytoplankton and the replacement of diatoms by blue green algae appeared to follow the thermal cycle with a nearshore to offshore, south to north trend. Water temperatures around 6°C and above were associated with large increases in diatom populations (particularly F. crotenensis) and decreased silica concentrations.

Some areas of the southern basin had higher phytoplankton populations than others in 1977. These were near major tributaries or population centers and typically corresponded to higher total phosphorus and conservative ion concentrations. These include the nearshore Chicago area, near Milwaukee, station 16b just south of Milwaukee, and stations 20 and 20a just north of the Kalamazoo River. Some of these stations also frequently had higher populations or greater occurrences of eutrophic forms in 1977. These include station 5a off Chicago where Diatoma tenue var. elongatum occurred on all but the September cruise in concentrations between 60 and 170 cells/ml. Station 5a also exhibited the greatest abundance of Nitzschia spp. with concentrations between 30 (0.9%) and 720 (15.0%) cells/ml recorded on all four crusies. D. tenue var. elongatum was also abundant near Milwaukee where it occurred in small (20 to 170 cells/ml) quantities on all cruises in 1977.

While the majority of the phytoplankton encountered in 1977 are forms which long have been associated with Lake Michigan, changes in total numbers of algae and various species indicate continued deterioration of the southern basin since 1962-63. A recent study by Makarewicz and Baybutt (1980) reports algal biomass and eutrophic diatoms in the nearshore Chicago area began to decrease in the mid seventies. However, that the southern basin of Lake Michigan is under stress is indicated by the pronounced shift from diatoms to blue green algae which accompanied epilimnetic silica depletion in the summers of 1976 and 1977.

Conservative Ions

A potential new problem in southern Lake Michigan is the increasing concentrations of sodium which presently ranges from 4-5 mg/l in this basin. Makarewicz and Baybutt (1980) observed, along with the changes previously discussed, an increase in relative abundance of blue green algae. In their data base blue greens (principally Gomphosphaeria and Oscillatoria) appeared and increased once annual sodium concentrations averaged 4.6 ug/l.

Several species of blue-green algae require sodium, frequently at concentrations at 4 to 5 mg/l or above. (Allen, 1952; Kratz and Myers, 1955; Allen and Arnon, 1955). There is a large body of circumstantial evidence which suggests that increased monvalent ion concentrations (particularly sodium and potassium) may favor the development of blue greens (Provasoli, 1969). That sodium, potassium, and other ions can enhance the uptake of phosphate by blue greens has been demonstrated by Jensen et al (1976). The role, if any, that increasing sodium concentrations are playing in southern Lake Michigan is an area where research is urgently needed. Environmental controls which reduce phosphates, ammonia, cyanide and phenol discharges will result in the discharge of large quantities of conservative ions (Na, Cl, and SO_4). These discharges together with road solution sources of NaCl are projected to ultimately increase Cl concentrations from the current 8 mg/l to over 19 mg/l (Richardson, 1980). If sodium increases proportionately, ultimate Na levels could be greater than 10 mg/l throughout the lake.

Sodium concentrations averaged 4.8 mg/l in 1976-1977 (Table 11, Figure 38). These values were about 20 to 40 percent higher than the averages observed by FWPCA (1968a) (3.9-4.0 mg/l) in 1962-1963 and by Beeton and Moffett (1964) during 1954-55 (3.3 to 3.4 mg/l) in the northern and southern basin. A complete accounting for the increase is not possible here, however, sodium values tended to be higher nearshore and in the southeastern part of the southern basin as did chloride concentration.

Increases in conservative ion concentrations have been noted in Lake Michigan water going back into the 1800's (Beeton, 1965). Long term build up of chloride, sodium plus potassium, sulfate, and total dissolved solids, have occurred. As potassium concentrations seems to be a equilibrium around 1 mg/l (Figure 37), (Torrey, 1976 Dobson, 1976), the increase in sodium plus potassium must be due to sodium. Our data shows that chloride, sodium, and sulfate have continued to increase. Of these ions, the rate of increase in chloride appears to be accelerating.

Before the extensive growth of population and industrial development of the Lake Michigan drainage basin, chloride concentration in the 1860's was around 1.2 $\pm$ .3 mg/l (Ackerman et al, 1970). The level may have represented an equilibrium concentration, however, the data were limited and sampling locations not identified. By the turn of the century, chloride concentrations had increased to 3.0 mg/l (Ackerman et al, 1970) in the southern basin near Chicago. FWPCA (1968a) observed mean chloride concentration of 6.5 mg/l at deep water stations which they defined as greater than 10 miles from shore in 1962-63. Volume weighted means in 1976 and 1977 were 8.1 and 8.2 mg/l respectively. The 1976-1977 values are 21 percent higher than the 1962-63 FWPCA results.

Since data collection began, nearshore chloride concentrations have tended to increase from the 1930's through the present at rates of at least .10 $\pm$ .01 mg/l/yr. at Milwaukee, Chicago, and Grand Rapids respectively (Figure 40).[1]

Figure 41 illustrates the increase observed between 1962-63 (FWPCA, 1968a) and our 1976 study. In area's B and C concentrations of 7.2 mg/l were observed in 1970 by Schelske and Roth (1973). During the

[1]For information on these data sources see Powers and Ayers (1967). Water Quality and Eutrophication Trends in Southern Lake Michigan. Special Report #30. Studies on the Environment and Eutrophication of Lake Michigan, J.C. Ayers and D.C. Chandler. Report #30.

last fifteen years the mean rate of chloride accumulation in the southern basin of the open lake has been between .10 and .13 ug/l. The rate of increase appears to have roughly doubled (from about 0.05 mg/l/yr 1860 thru 1960 based on Beeton (1969) data to the current rate greater than 0.10 mg/l/yr. The increase in annual chloride concentrations was 0.10 mg/l between 1976 and 1977, based on averaging cruise TLVWA results in the southern basin.

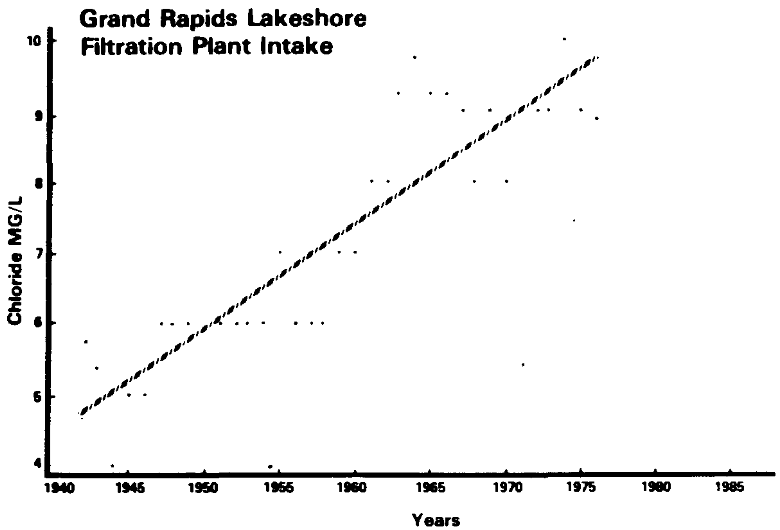
In the 1962-63 study elevated chloride concentrations in comparison with the rest of the lake were higher in areas D and E (Figure 42). While the 1976 concentrations were higher than in 1962-63, the peaks in areas D and E are absent probably as a result of the curtailment of brine discharges in the Manistee area. Higher concentrations of 9 mg/l to 10 mg/l were still observed in the Manistee-Ludington nearshore in 1976. Due to industrial and municipal loads in the southern most part of the basin, the highest concentrations in the open waters were in these areas and tended toward lower levels going northward (Figure 42). Lowest values, around 7 mg/l, were found in the Straits of Mackinac where Lake Huron waters mix with Lake Michigan. Chloride values decline away from shoreline influences throughout the basin.

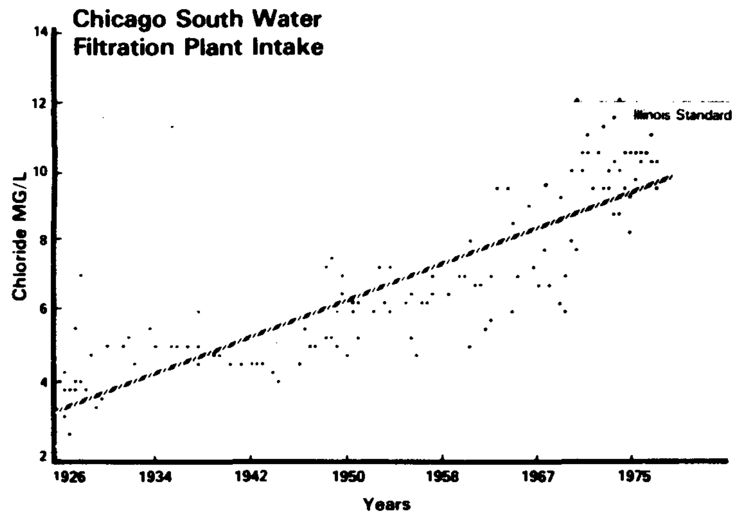
The rate of chloride accumulation in the open lake between 1962 and 1976 would correspond to loadings between 8.3×10^5 and 10.2×10^5 metric tons/yr. The volume of Lake Michigan's discharge is about 0.01 of the total volume (~ 4900 km^3) (Torrey 1976) and discharge concentrations ranged between 7 to 8 mg/l. The annual load of chloride discharged from the lake would be between 3.4×10^5 and 3.9×10^5 metric tons. The increased annual chloride burden for Lake Michigan was between 4.9×10^5 and 6.4×10^5 metric tons.

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

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

Southern basin sulfate concentration averaged 21.1 mg/l in 1976. This value is 30 percent to 35 percent higher than the mean concentrations of 16 to 18 mg/l (Beeton and Moffett, 1964) observed in 1960-61 in the southern and northern basins and 20 mg/l (FWPCA, 1968a) in 1962-1963. Atmospheric dry input of sulfate could be as high as 50 percent of the total load (785 mt.) (Sievering et al, 1979) and may be a possible explanation for the slightly higher epilimnetic sulfate concentrations.





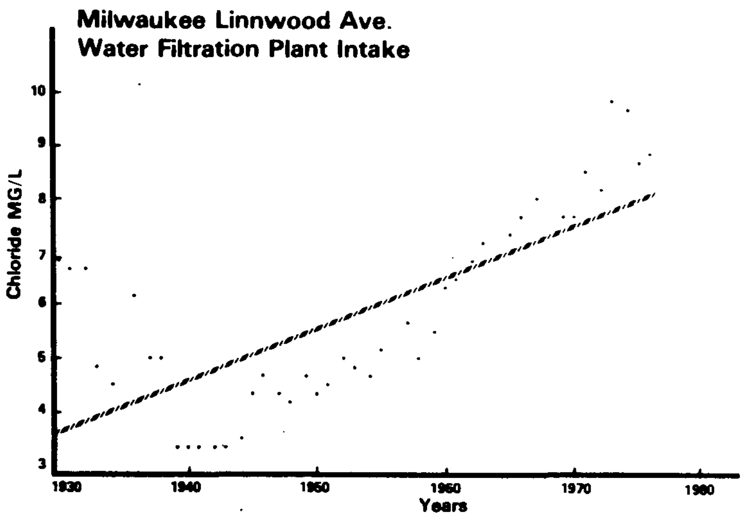


Figure 40

Chloride Time Series At Nearshore Water Intakes

Data Taken From Water Treatment Plant Records

TABLE 29

ENRICHMENT PROBLEM RELATIONSHIPS APPLIED ON LAKE MICHIGAN DATA

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

[1]Estimates of the mid-range of each parameter were made from page 128 of this report.

Chloride mg/l
Open Lake Areas
Mean Plus & Minus Three Standard Deviations

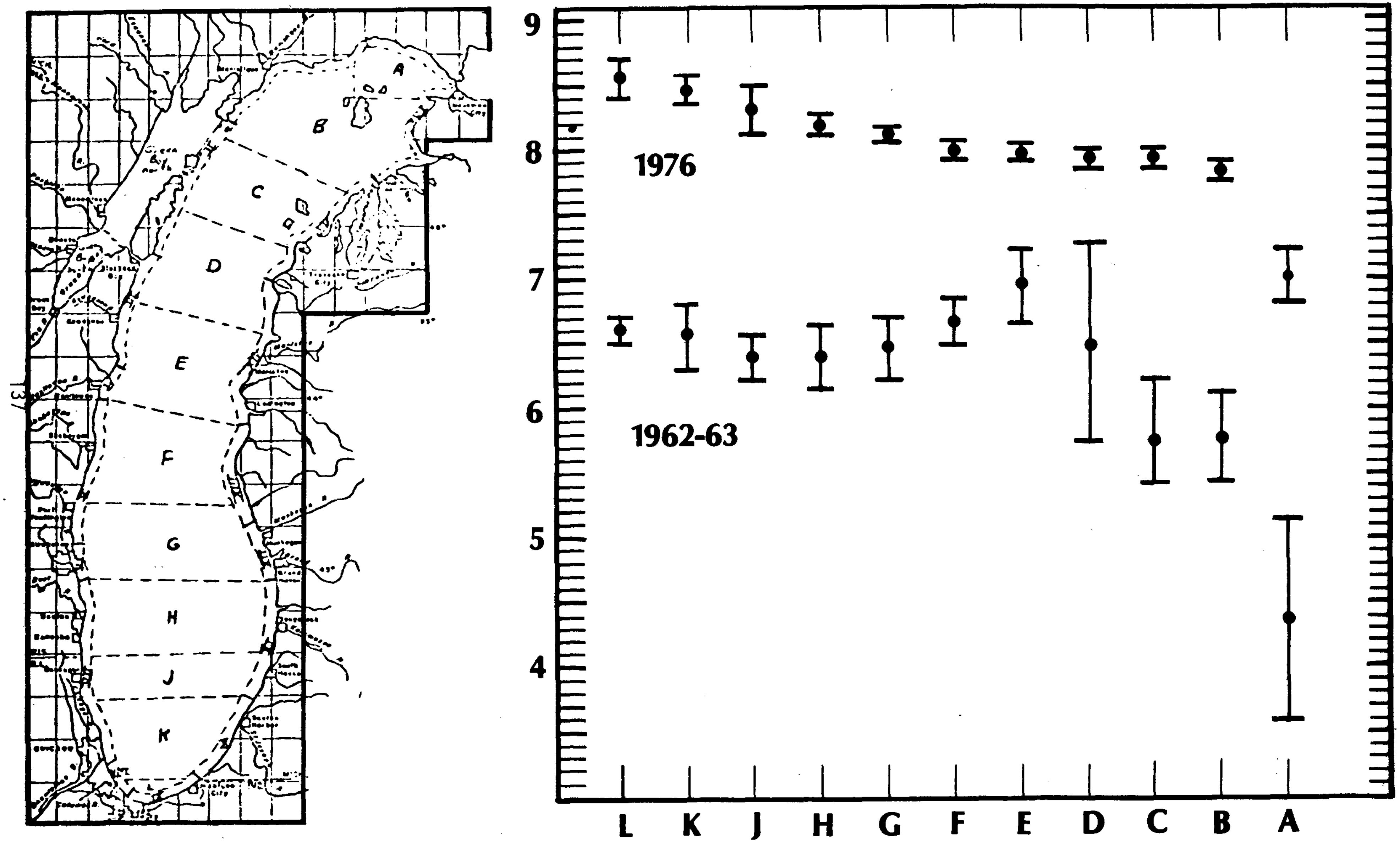


Figure 41

The proximity of the urban-industrial area along the southern shore of Lake Michigan appears to contribute to the slightly higher sulfate concentrations in the southern basin (Figure 33). Based upon climatological data, emissions of a reactive pollutant such as SO_2 in the Chicago urban-industrial area would be expected to oxidize to sulfates and impact north and east of Chicago (Lueck, 1980). Ozone, another reactive pollutant, has had maximum recorded values near Waukegan, Illinois (Illinois Annual Air Quality Reports, 1976, 1977, 1978, 1979). The conversion of SO_2 to sulfates may be reflected in higher sulfate water concentrations offshore from Waukegan and in the southern basin nearshore zones. An increasing atmospheric sulfate level is expected due to long range transport of SO_2 from higher stack heights which were put in place during the past decade and from slightly increasing total SO_2 emission loads within the Ohio River Basin of 11.5 million tons in 1970 to 12.8 million tons in 1975 (Stukel and Keenan, 1980).

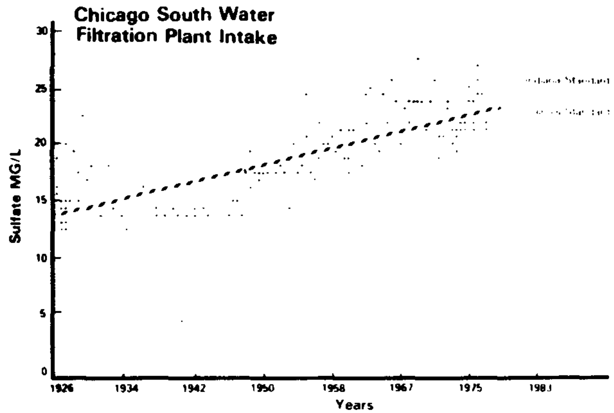
Sulfate concentrations have been increasing since measurements began. The rate of increase projected from data in Beeton (1965) is 0.14 ± 0.03 mg/l per year starting in 1877 (6 mg/l) and ending in 1961 (18 mg/l). The intensive surveys completed by the U.S. Department of the Interior 1962-63 and the present study would indicate that this linear projection, appears to be holding. The sulfate concentration in Lake Michigan has risen 15 mg/l, the most of any ion since 1877. The mean value in the open water stations in the southern basin during 1976 was 21.1 ± 0.4 mg/l, which is well below Indiana's water quality standards for a single value, which lists 50 mg/l as desirable and drinking water standard which permit 250 mg/l. Mean annual rates of increase at the Chicago, Milwaukee and Grand Rapids water filtration plants are $.18 \pm .01$ mg/l/yr., $.09 \pm .02$ mg/l/yr., and $.31 \pm .06$ mg/l/yr. respectively (Figure 42).[1] These rates appear to be accelerating in the nearshore zone over the last five years with the exception of the Chicago data. A recent source of additional sulfate ions is the use of low phosphate detergents. These detergents contain about twice as much sulfate by weight in their builders as phosphate detergents (Fuches 1978).

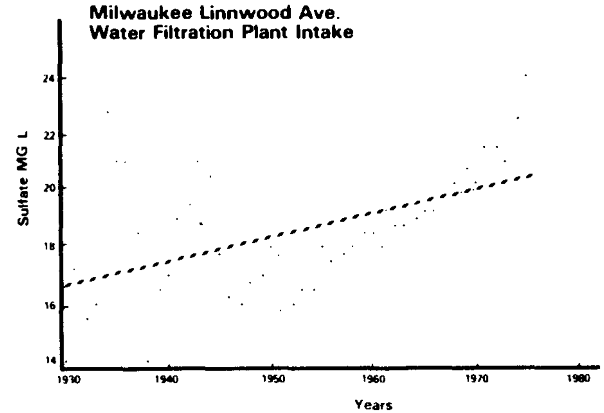
Of all the nearshore records only Chicago's data record indicates approximately the same accumulation rate over the last 10 years. This may be due to deep well injection of sulfuric acid which resulted in a reduction of sulfate being discharged from the Indiana Harbor Canal after 1967.

pH

pH ranged between 7.5 to 8.8 in the entire lake in 1976 and 7.8 to 8.7 in the southern basin in 1977. FWPCA (1968) results indicate a similiar range (7.5-8.9) in the deep water for 1962-1963. There was little spacial variation in pH during a cruise. Seasonal increases in pH tended to occur between June and August probably reflecting the lower CO_2 solubility in warmer waters and its utilization in photosynthetic activity. When CO_2 dissociates it is a weak acid. Any action that tends to remove it from the system would increase the pH values. Nearshore waters tended to have lower pH values. In

[1] op. ct. Power and Ayers.





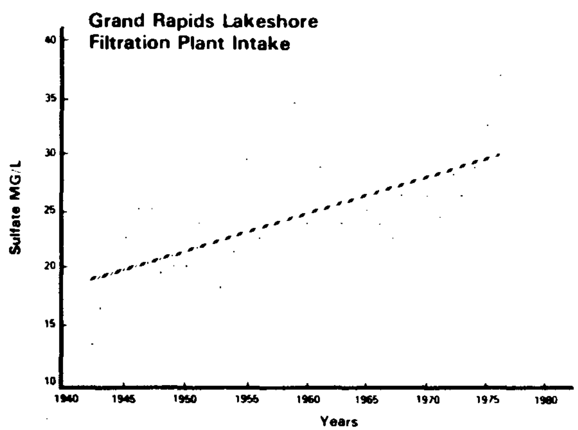


Figure 42

Sulfate Time Series At Nearshore Water Intakes

Data Taken From Water Treatment Plant Records

1976-77 nearshore pH ranged from 7.8 to 8.6 in the southern basin. In 1962-63 FWPCA (1968) reported a nearshore range of 6.4 to 9.3. The difference between the 1962-63 data and this study's data probably results from the 1962-63 study including all stations less than 10 miles from shore in the nearshore category. Our closest nearshore stations are at least 1 kilometer from shore. The FWPCA network included many stations several hundred yards from shore and close to harbor mouths including the Calumet River and Indiana Harbor Canal. pH was approximately .5 units lower in the hypolimnion than in the epilmnion, reflecting both CO_2 introduction via respiratory processes and the lack of its removal via photosynthesis.

Specific Conductivity

Specific conductance decreased during the season in the epilimnetic water. The lack of seasonal trends in the two layer volume weighted average suggest there is a transfer of ionic material from the epilimnion to the hypolimnion.

Transparency

Schelske and Roth (1973) report Secchi disc transparencies for all seasons in the open waters primarily in the southern basin. During the period 1954 through 1966 annual means ranged from a low of 5.7 meters to a high of 7.9 meters while annual maxima ranged from 8.8 to 18.3 meters. In 1976 and 1977 we observed means of $5.5 \pm .2$ and $5.9 \pm .2$ meters in the southern basin with ranges of 2 to 10 meters and 3 to 10 meters respectively. It would appear that secchi disc transparency in the southern basin has decreased from that observed during 1954 through 1966. The southern basin transparency appears to be more uniform even in its deeper areas and lacks the clearer deep zone which still exists in the northern basin. Secchi depth reading at the northern basin deep water stations (>50 meters) averaged 8.4 meters with a range of 3.2 to 21 meters. This mean annual value for 1976 is greater than the upper end of the range Schelske and Roth (1973) reported. This may be due to either the absence of northern basin stations in the earlier summaries where secchi disc readings would be expected to be greater than the southern basin or due to the variable influx of Lake Huron water to the northern lake basin.

Microbiology

Lakes, like all natural bodies of water, maintain an indigenous population of bacteria that are a regular part of the lakes' biological complex (Welch, 1952). The significance of these microorganisms in the biological, physical and chemical transformation of materials in both the sedimentary and aqueous phases of lake systems has been well documented (Brock, 1966; Welch, 1952;). Much of the bacterial activity observed in these systems is attributed to heterotrophic bacteria, presumably the most ecologically important bacteria occurring in most lakes (Cairns, 1971). Heterotrophic bacteria, microorganisms that require complex organic compounds of nitrogen and carbon for their metabolic synthesis, are very sensitive to minute changes of fluctuations in nutrient concentrations. These minute changes in nutrient concentrations, which may not be easily detectable or which may otherwise be considered insignificant, are nevertheless important to the microecosystem in which the bacteria live. The density and biotypes of bacteria in the aquatic system are directly related to nutrient supply. Thus, heterotrophic bacterial densities can be used to indicate the trophic or nutrition status of lakes.

Previous studies on the distribution of bacterial densities in Lake Michigan (FWPCA, 1968a) have shown that the central portion of the lake was virtually free of any detectable levels of coliform bacteria. Heterotrophic counts averaged 5/ml. Bacterial densities were shown to increase sharply in nearshore zones, especially in harbor areas where organic loadings to the lake were the most pronounced. These patterns persisted in this study.

Heterotrophic bacteria were used in conjunction with a trophic status evaluations system that included total phosphorus, chlorophyll "a" and secchi depth (Table 29).

Trophic Status

Many different systems have been developed for characterizing the trophic status of lakes. Systems of linear relationships based on empirical observations from many different water bodies have been derived. The systems which appear to be most aplicable to the Great Lakes are the systems developed by the Upper Lakes Reference Group (1976), Dobson (1976) and Rast and Lee (1978). Although these systems are an improvement over the purely subjective judgment previously used to define the trophic state of the lakes they do not entirely agree with each other. Further, the process of eutrophication which these systems attempt to quantify is non linear and non monotonic. Table 29 provides a summary of the trophic status indicator values, which were developed for total phosphorus, chlorophyll "a", and secchi depth by each observer. Table 29 also contain trophic status indicator transition values for aerobic heterotrophs which are proposed by the Great Lakes Research and Surveillance staff and is used together with each of the previous systems to expand their indicator categories to include microbiology.

The consensus evaluation of the three systems was used as the best estimate for each station. The consensus or median evaluation of the four parameters was used as the best estimate of trophic status for each system. An annual trophic status evaluation for each parameter; total phosphorus, chlorophyll, secchi depth, and aerobic heterotrophs was developed using the ranges shown in Table 29 for each station using averages of seasonal data.

The internal consistency of the three parameter systems fails when two indicators agree and the third disagrees. However, this does not necessarily mean that the two are correct and the third is incorrect. It seems appropriate to comment on the tendencies of each system in this respect. Some changes in the indicator transition values would lead to more internal harmony. The following observations are based on maximizing internal harmony for Lake Michigan data.

For Lake Michigan water it appears that (1) the Rast-Lee secchi depth indicator transition value for oligotrophic-mesotrophic (OM) conditions is more appropriate, that (2) the Dobson or Rast-Lee chlorophyll "a" indicator transition value for mesotrophic-eutrophic (ME) conditions are more appropriate, and that (3) the Upper Lakes Reference Groups' phosphorus scale is more appropriate for Lake Michigan at both OM and ME transition values.

A number of authors, including Godlewska and Lippowa (1976) and Rao and Jurkovic (1977) indicate that aerobic heterotrophs may be a reliable indicator of trophic status. Analysis of Lake Huron and Lake Superior open lake bacteriological baseline data (IJC, ULRG Report, 1977 Vols IIb & IIIb) suggested 50 org/ml and 300 org/ml as limits for oligotrophic and eutrophic classification. This however, is based on data using Foote & Taylor agar with 7-10 day incubation period and is not comparable to the data derived using standard methods agar and a 48 hour incubator period at 20°C.

A ranking technique was used in order to test the suitability of the aerobic heterotrophs data as a trophic index and to develop that index. Geometric means of all 1977 data at each station were calculated and ranked from the lowest value to the highest. The trophic status of each station was determined according to the indicies for phosphorus, chlorophyll "a" and secchi depth. The trophic status of each station was listed beside its ranked aerobic heterotroph geometric mean.

If aerobic heterotrophs are a good indicator of trohpic status, all of the oligotrophic stations should be associated with low numbers and eutrophic stations with the highest numbers. Initially the eutrophic stations were reasonably well separated but the mesotrophic and oligotrophic samples were severely intermixed indicating that it would not be possible to distinguish between oligotrophic and mesotrophic conditions.

The list was segregated into nearshore and offshore stations. Nearshore stations are defined as any station with a water depth of 15 meters or less or within three kilometers of a major shoreline. The trophic states were reasonably well segregated after this separation which indicates that aerobic heterotrophs can be used as a trophic state indicator and that they act differently in nearshore and open lake waters. This is to be expected because of the distinctions in the nutrient and physical characteristics of the two water zones which, in consequence, are supportive of different base levels of bacterial densities. A higher base level of bacteria exist in the nearshore areas than in the open lake because (1) drainage from the watershed provides a constant source of fresh nutrients utilized by bacteria, particulate matter (including suspended food stuffs) which bacteria prefer as a site of adherence, and large numbers of bacteria representing a variety of species many of which are transitory and therefore do not persist long enough to spread very far into the open lake, (2) generally warmer temperatures and nutrients which enhance the growth of phytoplankton that ultimately serve as a source of food for bacteria and (3) topographical characteristics such as embayment, harbors, etc., as well as wind and water currents which tend to retard dispersion of material and bacteria into the open lake.

The open lake on the other hand, has a lower concentration of nutrients, and vitamins which may be essential to the growth of certain bacteria. Such growth factors could be expected to break down before they diffused into the open lake. The open lake is also less affected by contaminating, transitory bacteria from land drainage. Also, bacteria carried on the water surface to the open lake area are subject to a prolonged period of exposure to the bactericidal effects of the ultra-violet portion of sunlight, thus adversely affecting their numbers. Bacteria in the more turbid nearshore waters are more protected from this effect.

Figure 43 shows the Lake's estimated trophic status in 1976 and 1977. The majority of Lake Michigan was classified as an oligotrophic body of water using the method described earlier in both 1976 and 1977. The mesotrophic ring around most of the lake appeared to diminish in 1977.

Metals

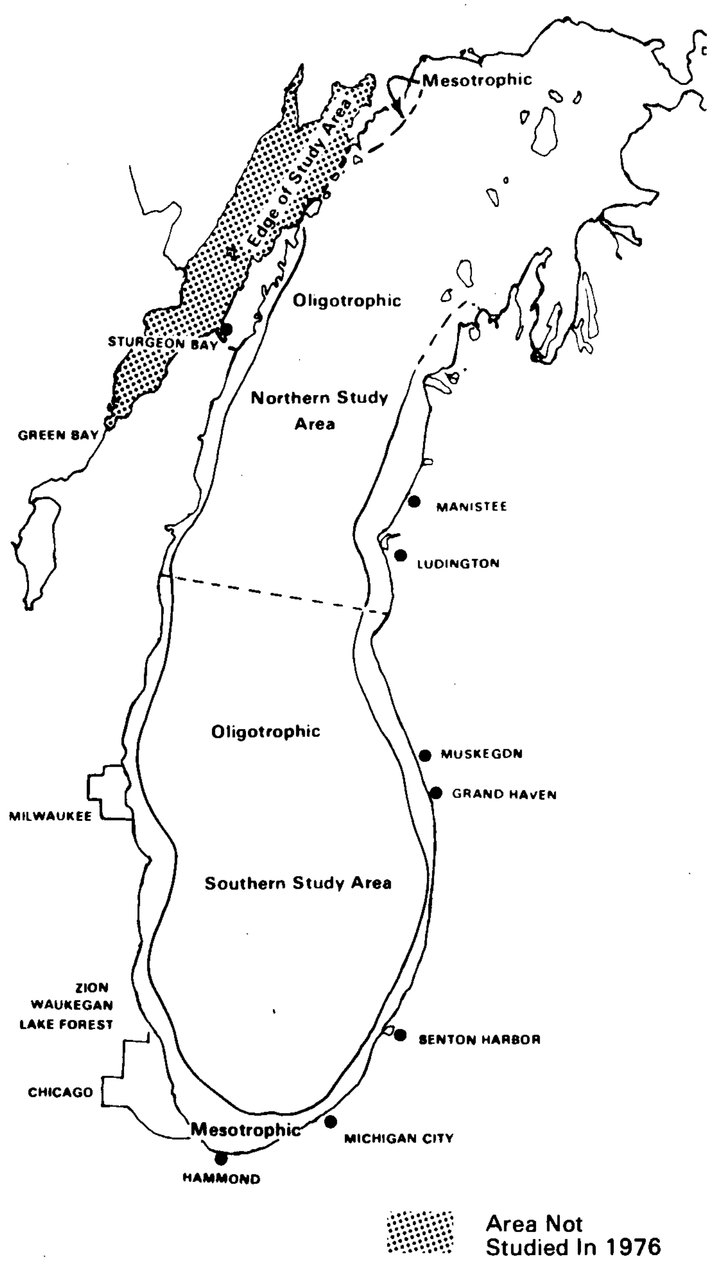
Comparison of the Great Lakes Water Quality Agreement (GLWQA), objectives with our data from Lake Michigan showed there was not a significant trace metal problem in Lake Michigan as far as water concentrations are concerned, but there could be through bioaccumulation of these toxics. An inductively coupled argon plasms emission spectrophotometer (ICAP) was used to measure metals in Lake Michigan. While lacking the sensitivity of atomic absorption, the ICAP could be using to determine over 20 metals in a single operation. The ICAP was therefore used in 1976 on the Lake Michigan samples and in 1977 on a 1:10 concentrate (evaporation) of selected samples. Most of the results were below the detection limit of the method and many more were suspected because of their proximity to the detection limit and/or association with quality control blanks above the detection limit. Of 1040 analyses of lake water concentrates including quality assurance replicates, there were a total of 12 analyses above the GLWQA objectives. None of the samples were verified by a second technique.

Recommendations

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

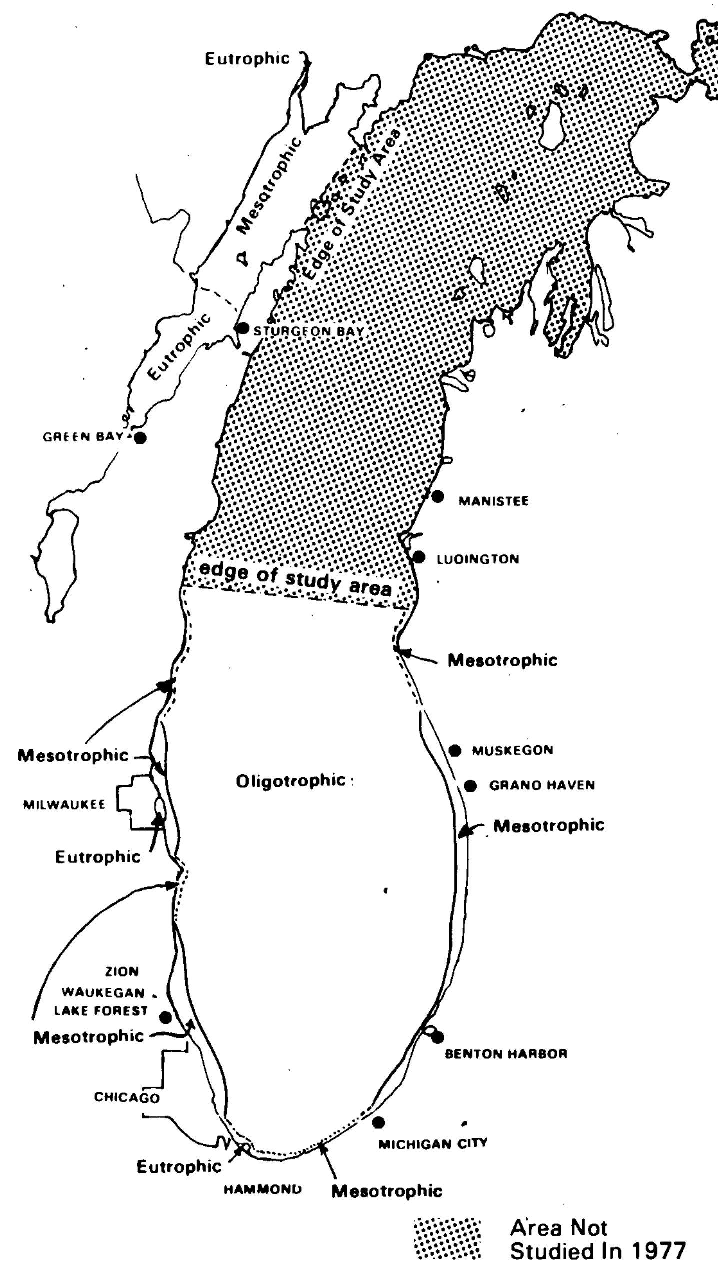
figure 43

Lake Michigan
Estimated Trophic Status



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

1976



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

1977

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

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

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

In summary our recommendations are:

The nutrient monitoring strategy should be modified to improve the ability to predict long term effects of phosphorus control remedial programs. This modification involves:

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

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

c) Conducting limited mid-winter surveys after an intensive Great Lakes field year.

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

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

b) Studies of sodium and conservative ion effect on phytoplankton in the southern Lake Michgian Basin should be initiated.

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REFERENCES

Ackerman, W.C., R.H. Harmeson, and R.A. Sinclair. 1970. Some long trends in water quality of lakes and rivers. American Geophysical Union 15: p.515-522.

Alder and Roessler. 1962. Introduction to Probability and Statistics W.H. Freeman and Company.

Allen, M.B. 1952. The Cultivation of Myxophyceae. Arch. Mikrobiol. 17: p.34-53.

Allen, M.B. and D.I. Arnon, 1955. Studies on nitrogen-fixings blue-green algae, growth and nitrogen fixation by Anabaena cylindrica. Plant. Physiol. 30: p.366-372.

Ahlstrom, E.H. 1936. The deep water plankton of Lake Michigan exclusive of the crustacea. Trans. Am. Microscop. Soc. 55: p.286-299.

American Public Health Association. 1971. Standard methods for the examination of water and wastewater. Thirteenth edition. American Public Health association, Washington, D.C. 844p.

American Public Health Association. 1975. Standard methods for the examination of water and wastewater. Fourteenth edition. American Public Health association, Washington, D.C. 872p.

Anders, A., S. Eisenreich, F. Elder, T. Murphy, M. Sanderson, and R.J. Vet. 1977. Atmospheric loading to the Great Lakes. University of Windsor.

Armstrong, F.A.J., C.R. Sterns, and J.D.H. Strickland. 1967. "The Measurement of Upwelling and Subsequent Biological Processess by Means of the Technicon AutoAnalyzer and Associated Equipment". Deep Sea Res., 14, p. 381-389.

Assel, R.A. 1980. Great Lakes Degree-Day and Temperature Summaries and Norms 1897-1977. NOAA Data Report ERL-GLERL-15.

Assel, R.A., D.E. Boyce, B.H. DeWitt, J. Wartha, and F.A. Keyes. 1979. Summary of Great Lakes Weather and Ice Conditions, Winter 1977-78. NOAA Technical Memorandum ERL-GLERL 26.

Bartone, Carl R., and C.L. Schelske. 1979. Limnological Conditions in Lake Michigan Based On Analysis of 1976 Surveillance Data Large Lakes Laboratory Grosse Ile, Michigan.

Beeton, A.M. 1965. Eutrophication of the St. Lawrence Great Lakes. Limnol. Oceangr. 10: p.240-254.

Beeton, A.M. 1969. Changes in the environment and biota of the Great Lakes, p. 150-187. In: Eutrophication: Causes, Consequences, Correctives. National Academy of Sciences, Washington, D.C. 661 p.

Beeton, A.M. and J.W. Moffet. 1964. Lake Michigan chemical data, 1954-1955; 1960-61. U.S. Dept. Interior, Fish and Wildlife Service Data Report No. 6.

Bowen, H.J.M. 1966. Trace elements in biochemistry. Academic Press., London and New York.

Brock, T.D. 1966. Principles of Microbial Ecology. Prentice-Hall, Inc., Englewood Cliffs, N.J. 306p.

Brooks, A.S. and B.G. Torke. 1971. Vertical and Seasonal Distribution of Chlorophyll "a" in Lake Michigan. J. Fish. Res. Board. Cana. 34: p. 2280-2287.

Cairns, J.F. 1971. The structure and function of fresh water microbiological communities. Research Division Monogram 3. Virgina Polytechic Institute and State University.

Chapra, S.C. and W.C. Sonzogni. 1979. Great Lakes total phosphorus budget for the mid 1970's. Journal WPCF. Vol 51, No. 10 p. 2524-2533.

Claflin, L.W. 1975. A multivariate data analyses of Lake Michigan phytoplankton. PhD Thesis University of Wisconsin-Madison.

Copeland, R.A. and J.C. Ayers. 1972. Trace element distributions in water, sediment, phytoplankton, zooplankton, and benthos in Lake Michigan. Special Report #1 Environ. Environmental Research Group, Inc.

Davis, C.O. and M.S. Simmons. 1979. Manual for field and laboratory procedures. Spec. Rep. No. 70, Great Lakes Research Division, University of Michigan. Pages unnumbered.

Dobson, H.F.H. 1976. Eutrophication status of the Great Lakes. Unpublished manuscript, CCIW.

Dobson, H.F.H. 1980. Observed Phosphorus in Lake Ontario. Great Lakes Focus On Water Quality IJC-Windsor, Ontario Vol. 6. Issue I. p. 12.

Doneth, J. and The Great Lakes Basin Commission. 1975. Material usage usage in the U.S. Great Lakes Basin. Task B for PLUARG.

Edgington, David N. J.I. Parker, and J.A. Robbins. 1980. Has there been a long-term silica depletion in Lake Michigan? Twenty-third conference on Great Lakes Research Program and Abstracts Kingston, Ontario, May 19-22, 1980.

Environmental Protection Agency. 1974. Methods for chemical analysis of water and wastes. U.S.E.P.A., Cincinnati, Ohio.

Federal Water Pollution Control Admin. 1968a. Lake Michigan basin, physical and chemical conditions. U.S. Govt. Printing Office. 81p.

Federal Water Pollution Control Admin. 1968b, "Water quality monitoring program for Lake Michigan and tributary basin" Monitoring Committee, Lake Michigan Enforcement Conference.

Federal Water Pollution Control Administration. 1969. Methods for Chemical Analysis of Water and Wastes, November.

Fuchs, R.J. 1978. Trends in the use of inorganic compounds in home laundry detergents in the United States. Chemical Times and Trends. p.36-41.

Gales, M., Jr., E. Julian, and R. Kroner. 1966. "Method for Quantitative Determination of Total Phosphorus in Water." Jour. AWWA, 58, No. 10, p. 1363.

GLBC. 1978. United States Great Lakes Tributary Loading Final Draft p. 187 Study on Great Lakes Pollution from Land Use Activities.

Godelewska and W.A. Lippowa. 1976. Bacteria as indicators of eutrophication and degradation of Lakes. PolskiArchiwum Hydrobiologii 23: p.341-356.

Grasshoff, K. 1969. Technicon International Congress, June.

Griffith, R.E. 1955. Analysis of Phytoplankton yields in relation to certain physical and chemical factors of Lake Michigan Ecology. 36: p. 543-552.

Handbook of Chemistry and Physics. 1970-71. 51st Edition, Chemical Rubber Company.

Holland, R.E. 1979. Seasonal fluctuations of major diatom species at five stations across Lake Michigan, May 1970-October 1972. U.S. EPA, Environmental Research Lab., Duluth.

Holland, R.E. and A.M. Beeton. 1972. Significance to eutrophication of spatial differences in nutrients and diatoms in Lake Michigan. Limnol-Oceanogr. 17: 88-95.

Illinois Annual Air Quality Reports 1976-1979. Illinois Environmental Protection Agency, 2200 Churchill Road, Springfield, Illinois 62706.

Industrial Biotest, Inc. 1972a. Evaluation of thermal effects in southwestern Lake Michigan (January 1970-April 1971). Inshore Water Quality Evaluation, Project II, IBT No. W88955, Part A-Chemistry, January 1970-April 1971. Rep. to Commonwealth Edison Co., Chicago, IL p. 99

Industrial Biotest, Inc. 1972b. Environmental Monitoring in Lake Michigan near Zion and Waukegan Generating Stations (January 1972 through December 1972). Rep. to Commonwealth Edison Co., Chicago, IL.

International Joint Commission, Great Lakes Water Quality Board. 1976. Proceedings of a workshop on Great Lakes Surveillance and Monitoring.

International Joint Commission, Great Lakes Water Quality Board. 1977. Great Lakes Water Quality Objectives, Vol. II. p. 137.

International Joint Commission Great Lakes Water Quality Board 1978. Great Lakes Water Quality, Appendix B Surveillance Sub-Committee Report.

International Joint Commission, Upper Lakes Reference Group. 1976. The waters of Lake Huron and Lake Superior, Vol. I. summary and recommendation.

International Joint Commission, Upper Lakes Reference Group. 1977. The water of Lake Huron and Lake Superior. Vol IIb. Vol IIIb. Lake Huron, Georgian Bay and the North Channel; and Lake Superior.

Jensen, T.E. and L. Sicko-Goad. 1976. Aspects of Phosphate Utilization By Blue-Green Algae. Corvallis Environmental Research Laboratory, Ecological Research Series EPA-600/3-76-103.

Jirka, A., M. Carter, D. May, and F. Fuller. 1976. Ultramicro Semi-Automated Method for the Simultaneous Determination of Total Kjeldahl Nitrogen in Wastewaters. Env. Sci. & Technology 10, 1038.

Johnson, T.C. and S.J. Eisenreich. 1979. Silica in Lake Superior: Mass balance considerations and a model for dynamic response to eutrophication. Geochemical Cosmochimica Acta, Vol 43, p. 71-91.

Kopp, J.F., and R.C. Kroner. 1968. Trace metals in waters of the United States: a five year summary of trace metals in rivers and lakes of the United States (Oct. 1, 1962-Sept. 30, 1967) USDI, FWPCA, Div. Pollut. Surv. Cincinnati, Ohio 1 Vol.

Kratz W.A. and J. Myers. 1955. Nutrition and growth of several blue-green algae. Am. J. Bot. 42: p.282-287.

Lake Michigan Water Quality Report 1978-1979. 1979-1980. The City of Chicago Department of Water and Sewers and Illinois EPA Division of Water Pollution Control.

Lazrus, A.L., K.C. Hill, and J.P. Lodge. 1965. "A New Colorimetric Microdetermination of Sulfate Ion", Automation in Analytical Chemistry, Technicon Symposia, Mediad, 1966, p. 291-293.

Lind, John E. Jr., R.M. Fuoss, and J.J. Zwolonik. 1959. Calibration of Conductance Cells at 25^{o} with Aqueous solutions of Potassium Chloride Jour. American Chemical Society. vol 81, p. 1557-1559.

Lowe, R.L. 1974. Environmental requirements and pollution tolerance of freshwater diatoms. EPA 7014-74-005.

Lueck, D. 1980. Personal Communication. GLNPO-Atmospheric Monitoring Program.

Makarewicz, J.C. and R.I. Baybutt. 1980. Longterm changes in the structure of the phytoplankton community of Lake Michigan at Chicago. In press.

Menzel, D.W. and N. Corwin. 1965. The measure of the total phosphorus in sea water based on the liberation of organically bound fractions by persulfate oxidation. Limnol. Oceanogr. 10: p. 280-282.

Munawar, M. and I.F. Munawar. 1975. The abundance and significance of phytoflagellates and nanoplankton in the St. Lawrence. Great Lakes. 1. Phytoflagellates. Verh. Int. Verin. Limnol. 19: p. 705-723.

Munawar, M. and I. F. Munawar. 1976. A lakeside study of phytoplankton biomass and its species composition in Lake Erie. J. Fish. Res. Bd. Can. 33: p. 581-600.

Munawar, M. and I. F. Munawar. 1978. Phytoplankton of Lake Superior, 1973. J. Great Lakes Res. 4: p. 415-442.

Murphy J., and J.P. Riley. 1962. A Modified Single Solution Method for the Determination of Phosphate in Natural Waters, anal. Chim. Acta, 27, p.30.

Nalco Environmental Sciences. 1976. Operational Environmental Monitoring Program of Lake Michigan near Kewaunee Nuclear Power Plant. Chemical & Biological Studies. Sixth Annual Report (January-December 1976). Rep. to Wisconsin Public Service Corporation., Green Bay, Wisconsin.

Nalco Environmental Sciences. 1977. Intake Discharge Chemistry Summary Report. Zion station (July 1973 through June 1977). Rep. to Commonwealth Edison Company, Chicago, IL.

O'Brien, J.E. 1962. Automatic analysis of chlorides sewage. Wastes Eng. 33: p. 670.

Provasoli, L. 1969. Algal nutrition and eutrophication. In: Eutrophication: Causes, Consequences, Correctives. National Academy of Sciences, Washington. 661p.

Quinn F.H., R.A. Assel, D.E. Boyce, G.A. Leshkevich, C.R. Snider, and D. Weisnet. 1978. Summary of Great Lakes Weather and Ice Conditions, Winter 1976-77. NOAA Technical Memorandum ERL-GLERL 20.

Rao, S.S., and A.A. Jurkovic. 1977. Differentiation of the trophic status of the Great Lakes by means of bacterial index ratio. J. Great Lakes Res. 3: p. 323-326.

Rast, W. and G.F. Lee. 1978. Summary analysis of the North American OECD eutrophication project: Nutrient loading-Lake response relationships and trophic state indices. EPA-600/3-78-008.

Richardson, W. 1980. Personal communication. EPA Large Lakes Research Station Grosse Ile, Michigan.

Riemann, B. 1978. Carotenoid interference in the spectrophotometric determination of chlorophyll degradation products from natural populations of phytoplankton. Limnol. Oceanogr. 23: p. 1059-1066.

Risley, C., Jr. and F.D. Fuller. 1965. Chemical characteristics of Lake Michigan. Proc. 8th Conf. Great Lakes Res., Great Lakes Res. Div. Publ. No. 13, Univ. of Michigan. p. 168-174.

Rockwell, D.C., C.V. Marion, M.F. Palmer, D.S. DeVault, and R.J. Bowden. 1980. Environmental Trends in Lake Michigan In: Phosphorus Management Strategies for Lake S. RC Loehr, C.S. Martin, W. Rast. Ann Arbor Science.

Rodgers, P. 1980. Personal communication. DePaul University Large Lakes Research Station Grosse Ile, Michigan 48138.

Rossman, R. 1978. Abstracts of Papers p. 153-154 International Association for Great Lakes Research 21 Conference on Great Lakes Research. U. of Windsor, Ontario May 9-11.

Rossman, R. 1980. Soluble Element Concentrations and complexation in Southeastern Lake Michigan. Journal of Great Lakes Research.

Rousar, D.C. 1973. Seasonal and spatial changes in primary production and nutrients in Lake Michigan. Water, Air, and Soil Pollut. 2: p. 497-514.

Rousar, D.C. and A.M. Beeton. 1973. Distribution of Phosphorus, Silica, Chlorophyll "a", and Conductivity in Lake Michigan and Green Bay. Wisconsin Academy of Sciences, Arts, and Letters. Vol 61 p. 117-141.

Schelske, C.L. and E.F. Stoermer. 1971. Eutrophication, silica depletion and predicted changes in algal quality in Lake Michigan. Science 173: p. 423-424.

Schelske, C.L., E.F. Stoermer, and L.E. Feldt. 1971. Nutrients, Phytoplankton productivity, and species composition as influenced by upwelling in Lake Michigan. Proc. 14th Conf. Great Lakes Res. Int. Assoc. Great Lakes Res. p. 102-113.

Schelske, C.L. and J.C. Roth. 1973. Limnological survey of Lakes Michigan, Superior, Huron, and Erie. Great Lakes Research Division Publication No. 17, U. of Michigan, Ann Arbor, Michigan.

Sievering, H., D. Mehul, D.A. Dolske, R.L. Hughes, and P. McCoy. 1979. An Experimental Study of Lake Loading By Aerosol Transport and Dry Deposition in the Southern Lake Michigan Basin. USEPA-GLNPO. EPA-905/4-79-016.

Snow, R.H. 1974. Water Pollution Investigation: Calumet Area of Lake Michigan. Vol IV. USEPA- Great Lakes Initiative Contract Program EPA-90519-74-011-A.

Stoermer, E.F. 1974. Statement In: Conference in the matter of pollution of Lake Michigan and it's tributary basin in the states of Wisconsin, Illinois, Indiana, and Michigan, 4th session, Chicago, Illinois 19-21 September 1972. Vol. I. EPA, U.S. Government Printing Office Washington.

Stoermer, E.F. and E. Kopczynska. 1967. Phytoplankton population in the extreme southern basin of Lake Michigan, 1962-1963. Proc. 10th Conf. Great Lakes Res. p. 88-105.

Stoermer, E.F. and T.B. Ladewski. 1976. Apparent optimal temperatures for the occurence of some common phytoplankton species in southern Lake Michigan. Great Lakes Res. Div., U. of Michigan.

Stoermer, E.F. and M.L. Tuchman. 1979. Phytoplankton assemblage of the nearshore zone of southern Lake Michigan. EPA-905/3-79-001 Great Lakes National Program Office. 89p.

Stoermer, E.F. and R.J. Stevenson. 1979. Green Bay phytoplankton composition, abundance and distribution. EPA-905/3-79-002 Great Lakes National Program Office. 103p.

Stoermer, E.F and J.J. Yang. 1969. Plankton diatom assemblages in Lake Michigan. Water Pollut. Control Res. Series, USDI.

Stoermer, E.F and J.J. Yang. 1970. Distribution and relative abundance of dominant plankton diatoms in Lake Michigan. Great Lakes Res. Div. U. of Michigan, Ann Arbor.

STORET is a computerized data base system maintained by the U.S. EPA for the storage and retrieval of data relating to the quality of the waterways within and contiguous to the United States.

Strickland, J.D.H., and T.R. Parsons. 1972. A practical handbook of seawater analysis. Fish Res. Board Canada. Bulletin No. 167.

Strong, A.E. and B.J. Edie. 1978. Satellite observations of calcium carbonate precipitations in the great Lakes. Limnol. Oceanogr. 23: p. 877-887.

Stukel, J. and B.R. Keenan. 1980. Ohio River Basin Energy Study University of Illinois, Champaign, Illinois.

Texas Instruments Inc. Ecological Services 1975. 1974-1975 Annual Report Bailly Nuclear-1 Site encompassing April 1974 - February 1975. Prepared for Northern Indiana Public Service Company, Hammond, Indiana.

Torrey, M.S. 1976. Environmental statues of the Lake Michigan region. 3. Chemistry of Lake Michigan. Argonne National Laboratory, Argonne, Illinois.

University of Wisconsin Green Bay. 1974. Effects of Wisconsin Public Service Corporation's Pullian Power Plant on Lower Green Bay (January 1973-December 1973). Rep. to Wisconsin Public Service Corporation, Green Bay, Wisconsin.

Van Slyke, D.D. and A.J. Hillen. 1933. BioChemistry, 102, 499p.

Wahlgren, M.A., D.N. Edgington, and F.F. Rawlings. 1972. Determination of selected trace elements in natural water samples using spark source mass spectroscopy. Radiol. Physics Div. Annu. Rep. Environmental Research Jan-Dec 1971. Argonne National Laboratory Rep. ANL-7860 Part III.

Wisconsin Electric Power Company and Wisconsin Michigan Power Company. 1972-1977. Non-Radiological Environmental Surveillance Program. Point Beach Nuclear Plant Units Nos. 1 and 2. Annual Reports Nos. 1 through 5 (September 1972 through October 1977).

Welch, P.S. 1952. Limnology. McGraw-Hill Book Company.

Yui, A.K. 1978. The VWA data base at the Large Lakes Research Station. EPA Large Lakes Research Station Grosse Ile, System Manual.

Zall, D.M., D. Fisher and M.D. Garner. 1956. Anal. Chem. 28: p. 1665.

Zar J.H. 1974. Biostatistical analysis. Prentice-Hall Inc., Englewood Cliffs N.J.

APPENDIX A

STANDARDS, CRITERIA AND OBJECTIVES FOR THE PROTECTION OF AQUATIC LIFE IN LAKE MICHIGAN

Values expressed in mg/l except color (platinum-cobalt units), threshold odor number (units), pH (units), and oxygen (mg/l or % saturation). Values are maximum permissible concentrations except dissolved oxygen and alkalinity which are minimum permissible concentrations. Element concentrations are designated as total or soluble only where clearly indicated as such in the original source. N.R. indicates parameter considered but no recommendation offered; hyphen indicates parameter not considered. Subt. absent = substantially absent; Virt. absent= virtually absent.

Parameter	NAS-NAE Water Quality Criteria 1972	U.S. Canada Great Lakes Water Quality 1972*	U.S. Canada Great Lakes Water Quality 1978*	Water Quality Standards Ill.	Ind.	Mich.	Wis.
Turbidity							
(suspended solids)	25a,b	c/	c/	c/	c/	c/	-
Temperature	a	a	a	a	a	a	a
Color (monthly average)	a/	-		c/	c/	c/	-
Odor	-	Subt. absent		c/	c/	c/	-
Threshold odor no.	-	-	-	-	8	-	-
(daily average)					4		
Total dissolved solids	a/	200	200 k.	180	200	750	-
(monthly average)					172	500	
Dissolved O_2	a/	6.0	6.0	90%	80%	6.0	5.0
(daily average)					90%		
pH range	6.5-8.5e	6.7-8.5	6.5-9.0	7.0-9.0%	7.5-8.5	6.7-8.5	6.0-9.0
Free CO_2	N.R.	-	-	-	-	25	-
Asbestos	-	-	a	-	-	-	-
Alkalinity	a/	-	-	-	-	-	-
Ammonia-N	0.017	-	0.50	0.02	0.05	-	f/
(monthly average)	-	-	-	-	0.02	-	-
un-ionized	-	-	0.020	0	-	-	-
Nitrate-N + Nitrite-N	-	-		10.0	-	-	-
Phosphorus	-	a/	a/	0.007		-	-
Phosphorus, Total					0.04		
(monthly average)					0.03		
Hardness	N.R.	-	-	-	-	-	-
Chloride	-	-		12.0	15	50	-
(monthly average)					10		
Sulfides, Total	0.002	-		-	-	f/	f/
Hydrogen Sulfide							
(unassociated)			0.002				
Sulfate (monthly	-	-		24.0	50	-	-
average)					26		
Aluminum	N.R.	-		-	-	f/	f/
Arsenic	-	-	0.050		0.05	f/	f/
Arsenic, Total				0.01			
Barium	-	-		1.0		f/	f/
Boron	-	-			-	f/	f/
Boron, Total				1.0			
Cadmium	g/	-	0.0002		0.01	f/	f/
Cadmium, Total				0.01			

Parameter	NAS-NAE Water Quality Criteria 1972	U.S. Canada Great Lakes Water Quality 1972*	U.S. Canada Great Lakes Water Quality 1978*	Water Quality Standards Ill.	Ind.	Mich.	Wis.
Chromium		-	0.050		-	f/	f/
Chromium, Total	0.05						
Chromium, Hexavalent				0.05	0.05		
Chromium, Trivalent				1.0			
Copper	a/	-	0.005		-	f/	f/
Copper, Total				0.02			
Fluoride	-	-	1.20	1.4		f/	f/
(monthly average)					1.0		
Iron		-	0.300				f/
Iron, Soluble					0.30	0.3	
(monthly average)					0.15		
Iron, Total		0.3		0.3			
Lead	0.03	-	0.025		0.05	f/	f/
Lead, Total				0.05			
Manganese	-	-			-	f/	f/
Manganese, Total				0.05			
Mercury		-	0.0002			f/	f/
Mercury, Total	0.0002			0.0005	0.005		
(average value)	0.00005						
Nickel	a/	-	0.025		-	f/	f/
Nickel, Total				1.0			
Selenium	-	-	0.010		0.01	f/	f/
Selenium, Total				0.01			
Silver	-	-			0.05	f/	f/
Silver, Total				0.005			
Zinc	a/	-	0.030	1.0	-	f/	f/
Alkyl benzene sulfonates	-	-		-	-		f/
(daily average)						1.0	
Methylene blue active substances	-	-		0.5	-		-
Linear alkylate sulfonates	0.2	-		-	-	0.2	f/
Carbon-chloroform extract	-	-		0.2	-	-	-
Oil	a,h/	Subst. absent		h/	h/	-	-
Oil (hexane-solubles or equivalent)	a/	-		0.1	-	-	-
Cyanide	0.005	-		0.01	0.01	f/	f/
Phenols	0.1[i]	Subst. absent		0.001	0.003	Virt. absent	f/
(monthly average)					0.001		
Phenolic Compounds (tainting subst.)			0.001				
Aldrin	0.00001	-	0.001	-	-	f/	f/
Chlordane	0.00004	-	0.00006	-	-	f/	f/
DDT	0.000002	-		-	-	f/	f/
DDT & Metabolites	-	-	0.00003	-	-	-	-
Dieldrin	0.000005	-		-	-	f/	f/

(contd.) APPENDIX A

Parameter	NAS-NAE Water Quality Criteria 1972	U.S. Canada Great Lakes Water Quality 1972*	U.S. Canada Great Lakes Water Quality 1978*	Water Quality Standards Ill.	Ind.	Mich.	Wis.
Aldrin & Dieldrin	-	-	0.000001	-	-	-	-
Endrin	0.000002	-	0.00002	-	-	f/	f/
Heptachlor	0.0000001	-	0.000001	-	-	f/	f/
Heptachlor Epoxide	-	-	0.000001	-	-	-	-
Lindane	0.00002	-	0.00001	-	-	f/	f/
Methoxychlor	0.000005	-	0.00004	-	-	f/	f/
Mirex	-	-	j/	-	-	-	-
Toxaphene	0.00001	-	0.00008	-	-	f/	f/
Phthalic Acid Esters							
Dibutyl phthalate	-	-	0.004	-	-	-	-
Di (z-ethylhexyl) phthalate	-	-	0.0006	-	-	-	-
Other phthalic acid esters	-	-	0.0002	-	-	-	-
Polychlorinated biphenyls, total	0.000002	-	n/	-	-	f/	f/
Other organic compounds	-	-	j/	-	-	-	-
Diazinon	-	-	0.00008 1/	-	-	-	-
Guthion	-	-	0.000005 1/	-	-	-	-
Parathion	-	-	0.000008 1/	-	-	-	-
Other Pesticides	-	-	m/	-	-	-	-

*Although the Treaty between the United States and Canada (U.S. Treaties, etc., 1972) does not apply to Lake Michigan, those objectives are included for comparison.

a. See Torrey (1976) or state sources listed below for discussion and clarification.
b. Maximum concentration of 25 mg/l suspended solids offers a high level of protection.
c. None other than of natural origin.
d. Limit recommended for cold-water streams and oligotrophic lakes.
e. Nearly maximum level of protection.
f. Permissible levels shall be resolved in accordance with the methods specified in "Water Quality Criteria, Report of the National Technical Advisory Committee to the Secretary of the Interior, April 1, 1968."
g. Aquatic life should be protected in hard water (total hardness = 100 mg/l as $CaCO_3$) if cadmium is 0.03 mg/l, and in soft water (100 mg $CaCO_3$/l) if cadmium is 0.004 mg/l. Habitats should be safe for crustaceans or eggs and larvae of salmon if cadmium is 0.003 mg/l in hard water or 0.0004 mg/l in soft water.
h. No visible oil on surface.
i. Applies only to fish.
j. Less than detection level.
k. Not to exceed present levels.
l. For protection of aquatic life.
m. Concentration should not exceed 0.05 of the median lethal concentration or a 96-hour test for any local sensitive species.
n. Not to exceed 0.1 microgram/gram for the protection.

Sources: National Academy of Sciences ..., 1973; U.S. Treaties, etc., 1972; Illinois Pollution Control Board, 1974; Indiana Stream Pollution Control Board, 1973; Michigan Water Resources Commission, 1973; Wisconsin Administrative Code, 1973 as quote in Torrey, 1976; and Great Lakes Water Quality Agreement of 1978.

APPENDIX B

MICROFICHE - LAKE MICHIGAN

INTENSIVE SURVEY DATA 1976-1977

<u>Errata</u> Units for nearshore primary productitvity are

milligrams/m^3/hr

APPENDIX C

Vertical Chemical Variation at Open Lakes Stations 1976-1977 by Basin

TABLE C1

Lake Michigan Southern Basin Stations* With Total Depth Greater Than 80 Meters, 1976
((Number of Samples) mean ± std error of mean)

Depth M	Turbidity TU	Water Temp °C	Conductivity Micromhs/cm at 25°C	PH	Tot ALK mg/l	Total NH_3-N ug/l	TKN-N mg/l	Tot NO_2+NO_3-N mg/l	Total P ug/l	Chloride mg/l	Diss. Reactive Silica** mg/l	Aerobic Heterotrophs	Chlorophyll a ug/l	Secchi Depth meters
								Cruise #1 1976						
2	(3) 1.6±.7	(3) 4.5±.3	(3) 273±1.0	(3) 7.9±.06	(3) 105±.3	(3) 5.3±1.3	(3) .21±.07	(3) .260±.006	(3) 8.3±1.9	(2) 8.0±.15	(2) 1.32±.005	(3) 3±2	(3) 1.27±.22	(1) 10
5	(3) 1.0±.0	(3) 4.1±.1	(3) 274±.6	(3) 7.9±.03	(3) 105±.3	(3) 4.0± 0	(3) .17±.02	(3) .257±.007	(3) 8.7±1.7	(3) 7.9±.06	(3) 1.33±.012		(3) 1.26±.20	
10	(3) 0.9±.1	(3) 4.1±.2	(3) 275±.9	(3) 7.9±.09	(3) 105±.3	(3) 4.0± 0	(3) .11±.01	(3) .260±.006	(3) 6.7±0.3	(2) 7.9±.00	(2) 1.32±.010		(3) 1.51±.30	
20	(3) 1.1±.1	(3) 4.1±.1	(3) 274± 0	(3) 8.0±.03	(3) 106±1.0	(3) 4.0± 0	(3) .13±.02	(3) .257±.007	(3) 6.7±0.9	(3) 8.0±.07	(3) 1.34±.003		(3) 1.06±.31	
50-165	(7) 0.8±.1	(7) 4.0±.1	(7) 274± 0	(7) 8.0±.05	(7) 106±.4	(3) 4.0± 0	(3) .16±.01	(7) .260±.003	(3) 8.4±1.2	(7) 8.0±.07	(7) 1.36±.018		(7) 0.92±.17	
								Cruise #2 1976						
2	(9) 1.2±.2	(9) 7.3±.5	(9) 272±.5	(9) 8.2±.04	(9) 105±1.0	(9) 3.0±0.4	(9) .15±.01	(6) .230±.010	(9) 5.2±0.3	(9) 7.9±.05	(9) 1.10±.06		(9) 1.81±.30	(9) 6.8±.6
5	(9) 1.2±.2	(9) 6.7±.5	(9) 273±.4	(9) 8.2±.05	(9) 104±.7	(9) 2.4±0.2	(9) .15±.01	(6) .227±.009	(8) 6.2±0.7	(9) 7.9±.06	(9) 1.11±.06		(9) 1.92±.31	
10	(9) 1.2±.2	(9) 6.2±.5	(9) 272±.4	(9) 8.1±.05	(9) 104±.6	(9) 2.8±0.3	(9) .14±.01	(6) .235±.008	(9) 6.2±0.6	(9) 7.9±.05	(9) 1.11±.06		(9) 2.61±.45	
20	(9) 1.0±.2	(9) 5.5±.3	(9) 273±.4	(9) 8.1±.03	(9) 104±.6	(9) 3.2±0.6	(9) .14±.02	(6) .327±.084	(9) 6.8±0.9	(8) 7.9±.06	(9) 1.14±.04		(8) 1.83±.41	
50-165	(22) 1.3±.1	(22) 4.5±.1	(9) 273±.2	(22) 8.1±.02	(9) 104±.4	(22) 4.3±0.4	(22) .12±.01	(14) .254±.004	(22) 6.1±0.3	(23) 7.8±.02	(22) 1.30±.04		(21) 1.45±.14	
								Cruise #3 1976						
2	(9) .5±.0	(9) 13.0±.7	(9) 272±.3	(9) 8.2±.03	(9) 107±.1	(9) 3.1±0.1	(8) .15±.01	(7) .199±.005	(8) 6.4±0.8	(9) 7.9±.04	(9) .81±.06	(9) 4±1	(9) 1.29±.15	(9) 7.7±.3
5	(9) .5±.0	(9) 12.7±.7	(9) 272±.4	(9) 8.2±.03	(9) 107±.2	(9) 3.0± 00	(8) .21±.02	(7) .19 ±.004	(8) 6.9±0.7	(9) 7.9±.03	(9) .83±.05	(1) 1	(9) 1.41±.22	
10	(9) .5±.0	(9) 12.4±.7	(9) 272±.2	(9) 8.2±.03	(9) 107±.5	(9) 3.2±0.1	(8) .21±.02	(7) .217±.004	(8) 6.6±0.5	(9) 7.9±.04	(9) .81±.06		(9) 1.45±.21	
20	(9) .7±.0	(9) 7.7±.4	(9) 273±.3	(9) 8.1±.04	(9) 107±.4	(9) 3.0± 00	(8) .31±.09	(7) .217±.004	(8) 6.8±0.5	(9) 7.9±.04	(9) .74±.03		(9) 3.17±.26	
50-165	(21) 1.0±.1	(22) 5.4±.1	(22) 274±.3	(22) 7.9±.02	(21) 107±.2	(21) 6.1±0.7	(20) .15±.01	(7) .252±.002	(20) 6.0±0.7	(22) 7.8±.02	(21) 1.45±.09	(17) 3±1	(22) 0.74±.09	
								Cruise #4 1976						
2	(9) .8±.1	(9) 17.3±.2	(9) 270±.5	(9) 8.4±.02	(9) 105±.3	(9) 3.3±0.2		(9) .138±.004	(9) 6.7±0.6	(9) 8.1±.05	(9) .45±.04	(9) 6±1	(9) .91±.10	(9) 8.3±.2
5	(9) .9±.1	(9) 16.8±.3	(9) 270±.5	(9) 8.4±.01	(9) 106±.2	(9) 3.6±0.2		(9) .136±.004	(9) 6.2±0.3	(9) 8.1±.04	(9) .44±.04		(9) 1.32±.20	
10	(9) 1.0±.1	(9) 15.3±.3	(9) 270±.3	(9) 8.4±.03	(9) 106±.2	(9) 3.3±0.4		(9) .138±.004	(9) 8.5±0.6	(9) 8.1±.04	(9) .43±.04		(9) 1.42±.24	
20	(9) 1.2±.1	(9) 8.7±.7	(9) 271±.3	(9) 8.3±.04	(9) 106±.4	(9) 4.7±0.8		(9) .177±.005	(9) 9.2±0.3	(9) 8.1±.04	(9) .42±.04		(9) 2.92±.55	
50-165	(21) 1.3±.2	(22) 5.0±.1	(22) 273±.3	(22) 7.9±.01	(22) 106±.4	(20) 5.0±0.4		(20) .268±.004	(21) 8.3±0.7	(22) 7.9±.02	(22) 1.46±.11	(18) 17±5	(21) 1.15±.17	
								Cruise #5 1976						
2	(9) 2.0±.3	(9) 19.6±0.4	(9) 270± .6	(9) 8.4±.03	(9) 106± .5	(7) 3.6±0.4		(9) .12±.003	(9) 6.0±0.4	(9) 8.2±.04	(9) 0.26±.02	(9) 4±8	(8) 1.27±.16	(9) 4.3± .4
5	(9) 2.0±.3	(9) 19.4±0.3	(9) 269± .7	(9) 8.4±.03	(9) 106± .8	(7) 3.6±0.4		(9) .12±.003	(9) 7.3±0.4	(9) 8.2±.10	(9) 0.26±.02		(9) 1.44±.12	
14-20	(12) 1.9±.2	(14) 18.1±0.5	(14) 270± .6	(14) 8.4±.02	(14) 106± .3	(11) 6.4±1.4		(14) .13±.004	(14) 6.7±0.6	(14) 8.0±.03	(14) 0.27±.01	(6) 17±5	(11) 1.40±.11	
22-32	(13) 1.9±.1	(13) 10.3±1.2	(13) 273± .7	(13) 8.3±.05	(13) 107± .3	(10) 10.9±2.3		(13) .19±.012	(13) 8.3±0.5	(13) 8.0±.03	(13) 0.45±.06	(3) 18±12	(11) 1.67±.20	
90-165	(13) 1.7±.2	(13) 4.6±0.1	(13) 276± .2	(13) 7.9±.02	(13) 108± .2	(10) 3.0± 0		(13) .28±.008	(13) 10.4±0.5	(13) 8.0±.04	(13) 1.77±.09	(9) 17±4	(13) 0.62±.10	
								Cruise #6 1976						
2	(9) 2.5±.2	(9) 21.4± .4	(9) 261±0.4	(9) 8.2±.06	(9) 102± .5	(8) 3.8±0.8		(9) .09±.004	(9) 5.6±0.4	(9) 8.1±.06	(9) 0.30±.01	(9) 21±4	(9) 1.72±.18	(9) 2.4±.1
5	(9) 2.6±.2	(9) 21.3± .3	(9) 262±0.5	(9) 8.2±.06	(9) 102± .4	(8) 3.5±0.4		(9) .09±.004	(9) 5.6±0.4	(9) 8.1±.06	(9) 0.33±.02		(9) 1.37±.23	
15	(7) 3.0±.2	(7) 20.1± .5	(7) 263±1.0	(7) 8.2±.09	(7) 103± .6	(8) 8.0±1.2		(7) .09±.006	(7) 4.9±0.5	(7) 8.1±.05	(7) 0.34±.02		(7) 1.83±.20	
20	(9) 2.9±.2	(9) 15.0± .9	(9) 270±1.4	(9) 8.1±.07	(9) 106± .9	(8) 28.0±4.8		(9) .16±.017	(9) 6.4±0.5	(9) 8.1±.05	(9) 0.41±.04	(7) 8±2	(9) 1.42±.15	
25-35	(11) 3.0±.2	(11) 8.2± .3	(11) 274±0.3	(11) 8.0±.06	(11) 109± .3	(10) 23.7±5.8		(11) .23±.016	(11) 6.6±0.4	(11) 8.0±.05	(11) 0.63±.06	(2) 14±9	(11) 1.29±.14	
84-165	(13) 1.5±.1	(13) 5.2± .1	(13) 275±0.3	(13) 7.9±.06	(13) 108± .4	(12) 3.2±0.3		(13) .30±.005	(13) 9.3±0.9	(13) 7.9±.03	(13) 1.89±.10	(2) 11±3	(13) 0.80±.13	
								Cruise #7 1976						
2	(9) 1.7±.1	(9) 19.9± .1	(9) 263±0.7	(9) 8.3±.03	(9) 103±0.9	(6) 3.3±0.2		(9) .10±.005	(9) 5.2±0.2	(9) 8.2±.05	(9) 0.30±.01	(9) 9±2	(9) 1.48±.08	(9) 3.3±.2
5-15	(11) 1.7±.1	(11) 19.7± .2	(11) 263±0.5	(11) 8.3±.02	(11) 102±0.7	(6) 3.2±0.2		(11) .11±.014	(11) 6.2±0.7	(11) 8.2±.04	(11) 0.32±.02		(11) 1.41±.09	
20-28	(7) 1.8±.1	(7) 8.7± .4	(7) 272±1.9	(6) 8.0±.04	(6) 107±1.1	(6) 6.5±2.4		(7) .25±.016	(7) 6.9±0.6	(7) 8.1±.04	(7) 0.61±.05	(6) 7±2	(7) 0.95±.07	
95-130	(2) 1.5±.1	(12) 5.8± .2	(12) 275±0.3	(12) 7.8±.05	(12) 110±0.5	(12) 4.7±1.6		(12) .30±.006	(12) 8.9±0.7	(12) 8.0±.05	(12) 1.84±.08	(6) 7±1	(12) 0.61±.06	
								Cruise #8 1976						
2	(3) 1.1±.0	(3) 13.7±0.6	(3) 270±0.7	(3) 8.4±.03	(3) 107± .1	(3) 3.0±.00			(3) 12.6±7.0	(4) 7.9±.19	(3) 0.50±.03	(3) 2±1	(3) 1.48±.30	(3) 6.0±1.0
5-15	(4) 0.9±.1	(4) 13.6±0.6	(4) 270±0.6	(4) 8.4±.00	(4) 106± .2	(4) 3.0±.00			(4) 6.0±0.4	(5) 8.0±.17	(4) 0.51±.02		(4) 2.00±.40	
20-28	(5) 0.9±.0	(5) 9.8±1.4	(5) 273±1.5	(5) 8.2±.07	(5) 107± .7	(5) 3.0±.00			(5) 6.2±0.5	(5) 7.8±.16	(5) 0.72±.12	(3) 2±1	(5) 1.44±.34	
95-130	(5) 1.2±.1	(5) 4.5±0.2	(5) 278±0.5	(5) 8.1±.02	(5) 109± .2	(5) 3.0±.00			(4) 12.0±1.7	(5) 8.0±.06	(5) 2.21±.17	(3) 3±1	(5) 0.43±.03	

*Stations (Cruises 2-7) are 10, 11, 17, 18, 19, 23, 26, 27, 28a
Cruise 1 and 8 are 26, 27, 28a

**Total Silica Cruise 1

TABLE C2

Lake Michigan Northern Basin Stations* with Total Depth Greater Than 80 meters, 1976

(Number of Samples mean ± std error of mean)

Depth M	Water Temp C	Conductivity Micromhs/cm at 25°C	pH SU	Total Alk mg/l	Dissolved NH_3-N ug/l	Dissolved NO_2+NO_3-N mg/l	Total P ug/l	Tot-Dis P ug/l	Total Suspended Carbon (mg/l)	Chloride mg/l	Diss. Reactive Silica mg/l	Suspended Silica mg/l	Chlorophyll "a" ug/l	Secchi Depth M
Cruise 1- April														
0-6	(13) 3.0±.1		(3)8.3±.02	(13)110±0.4	(7) 5.1±0.7	(13).230±.006	(13) 7.3±0.4	(13) 3.6±.3	(5).228±.047	(13) 7.8±.03	(13)0.96±.07	(13)0.36±.03	(13)1.48±.21	(13)11.0±1.0
6-12	(13) 3.0±.1		(3)8.3±.01		(11) 4.1±0.6	(13).231±.007	(13) 6.8±0.3	(13) 3.8±.3	(6).188±.023	(13) 7.7±.06	(13)0.97±.07	(13)0.35±.03	(13)1.42±.23	
12-24	(13) 3.0±.1		(3)8.3±.02		(9) 7.7±3.6	(13).231±.007	(12) 6.8±0.2	(13) 3.6±.3	(5).182±.042	(13) 7.7±.05	(13)0.97±.06	(12)0.42±.05	(13)1.49±.21	
24-36	(5) 2.9±.2		(2)8.3±.04		(3) 5.0±1.2	(5).240±.009	(5) 6.8±0.4	(5) 4.6±.7	(3).173±.012	(5) 7.7±.06	(5)1.04±.10	(5)0.35±.05	(5)1.15±.37	
36-60	(15) 2.9±.1		(3)8.3±.04		(8) 5.5±1.4	(15).235±.003	(15) 6.5±0.2	(15) 3.6±.2	(6).187±.024	(15) 7.7±.02	(15)0.99±.04	(15)0.35±.05	(15)1.32±.17	
60-100	(16) 3.0±.1		(4)8.3±.02		(13) 6.2±1.3	(16).238±.004	(16) 7.0±0.3	(16) 4.1±.4	(6).173±.042	(16) 7.7±.02	(16)0.99±.04	(16)0.32±.03	(16)1.34±.18	
100-175	(19) 3.1±.1		(6)8.3±.01		(9) 5.0±0.9	(19).242±.003	(19) 6.9±0.2	(19) 3.7±.2	(11).164±.028	(19) 7.8±.04	(19)1.09±.03	(19)0.34±.06	(19)0.97±.12	
175-275	(7) 3.3±.1				(4) 3.8±0.6	(7).240±.000	(7) 7.0±0.6	(7) 3.9±.6	(7).159±.008	(7) 7.8±.07	(7)1.19±.01	(7)0.18±.01	(7)0.75±.09	
Cruise 2- June														
0-3	(1) 12.1	(1) 273	(1)8.5		(1) 6.0	(1).210	(1) 9.0	(1) 2.0		(1) 7.8	(1)0.60	(1)0.45	(1)0.94	
3-6	(15) 6.6±.7	(15) 275±1.2	(15)8.4±.02	(15)109±1.6	(11) 3.8±0.7	(15).215±.007	(14) 6.0±0.3	(15) 2.6±0.2	(4).140±.051	(15) 7.8±.02	(15)0.67±.08	(15)0.31±.02	(15)1.67±.19	(15)10.7±0.9
6-12	(15) 5.2±.4	(15) 276±1.7	(15)8.4±.03		(11) 4.4±0.9	(15).220±.007	(15) 6.5±0.5	(15) 2.8±0.2	(4).225±.088	(15) 7.8±.02	(15)0.68±.08	(15)0.39±.03	(15)2.34±.25	
12-24	(15) 4.7±.2	(15) 276±1.8	(15)8.4±.02		(13) 4.5±0.5	(15).222±.006	(15) 6.8±0.5	(15) 2.7±0.1	(4).160±.036	(15) 7.8±.01	(15)0.71±.07	(15)0.49±.04	(15)2.83±.39	
24-36	(4) 4.6±.3	(4) 274±0.6	(4)8.3±.01		(4) 5.5±1.9	(4).232±.011	(4) 5.0±0.4	(4) 2.8±0.2	(3).200±.042	(4) 7.8±.04	(4)0.85±.16	(4)0.39±.08	(4)1.95±.72	
36-60	(18) 4.4±.1	(18) 276±1.4	(18)8.3±.01		(17) 5.2±0.4	(18).231±.004	(18) 5.6±0.2	(18) 2.7±0.2	(7).160±.021	(18) 7.8±.02	(18)0.80±.06	(18)0.39±.03	(18)1.95±.23	
60-100	(19) 4.4±.1	(19) 276±1.6	(19)8.3±.01		(13) 6.1±0.6	(19).232±.004	(19) 6.1±0.3	(19) 2.8±0.1	(8).164±.014	(19) 7.8±.01	(19)0.81±.06	(19)0.49±.06	(19)2.01±.26	
100-175	(19) 4.3±.1	(19) 275±1.1	(19)8.4±.05		(16) 4.2±0.6	(19).242±.003	(19) 5.9±0.3	(19) 2.7±0.2	(1).143±.034	(19) 7.8±.02	(19)1.02±.06	(19)0.43±.05	(19)1.25±.15	
175-275	(7) 4.3±.1	(7) 274±0.4	(7)8.3±.00		(6) 4.3±0.5	(7).244±.002	(7) 5.9±0.5	(7) 3.0±0.2	(5).112±.015	(7) 7.8±.02	(7)1.14±.04	(7)0.35±.09	(7)0.71±.11	
Cruise 3- July														
0-3	(5)15.2±1.1	(5) 269±0.8	(5)8.3±.07	(5)106±0.5	(5) 4.0±0.5		(5) 5.8±0.7	(5) 3.0±0.2		(5) 8.6±.17	(5)0.28±.08		(4)1.49±.35	
4-6	(26)15.6±0.3	(25)268±0.7	(26)8.6±.03	(25)108±1.3	(21) 6.5±0.7	(21).141±.004	(26) 7.8±1.0	(25) 4.4±0.8	(21).323±.019	(26) 8.1±.04	(26)0.23±.03	(19)0.44±.02	(26)1.58±.07	(19) 7.6±0.7
9-12	(13)14.1±0.7	(13)268±1.5	(13)8.6±.06	(2)106±0.5	(11) 5.7±0.7	(11).145±.006	(13) 9.1±1.3	(12) 3.9±0.9	(4).350±.022	(13) 8.0±.05	(13)0.22±.05	(10)0.51±.04	(13)2.19±.21	
15-18	(11)13.4±1.0	(11)267±1.4	(11)8.5±.08	(5)106±0.5	(6) 7.8±1.2	(6).152±.013	(10) 6.4±0.6	(10) 4.0±1.1		(11) 8.2±.09	(11)0.23±.04	(6)0.54±.05	(10)2.54±.43	
18-24	(17) 9.8±0.6	(17)267±0.9	(17)8.4±.05	(5)107±0.0	(10) 8.9±1.0	(12).181±.009	(17) 8.3±0.3	(17) 3.2±0.1	(3).370±.030	(17) 8.1±.05	(17)0.34±.05	(11)0.56±.04	(16)3.51±.33	
24-30	(25) 7.1±0.3	(25)267±0.7	(25)8.3±.03	(3)106±0.3	(22) 9.7±1.0	(22).205±.006	(23) 7.4±0.7	(23) 3.0±0.1	(5).242±.041	(25) 8.0±.04	(25)0.43±.05	(20)0.53±.03	(24)4.12±.31	
30-36	(10) 6.2±0.4	(10)266±1.1	(10)8.3±.04		(10)11.1±1.2	(10).211±.009	(10) 7.9±1.3	(7) 3.2±0.4	(4).212±.037	(10) 8.0±.03	(10)0.49±.09	(9)0.62±.09	(10)3.86±.41	
36-48	(6) 5.0±0.2	(6) 267±1.0	(6)8.2±.05		(6)12.1±2.3	(6).221±.014	(6) 6.0±0.5	(5) 4.0±1.2	(4).152±.024	(6) 7.9±.04	(6)0.56±.11	(5)0.54±.02	(6)2.39±.41	
48-60	(18) 4.8±0.7	(17)268±0.7	(18)8.2±.02		(18)11.3±0.9	(18).238±.006	(17) 6.8±0.8	(16) 4.5±1.3	(4).135±.023	(18) 7.9±.02	(18)0.70±.05	(17)0.48±.06	(18)1.65±.16	
60-100	(24) 4.8±0.1	(23)268±0.6	(24)8.2±.02		(24)11.6±0.9	(24).234±.006	(23) 6.7±0.6	(21) 4.4±1.0	(8).144±.016	(24) 7.9±.02	(24)0.67±.05	(22)0.50±.05	(24)1.84±.17	
100-175	(32) 4.5±0.4	(32)269±0.9	(32)8.2±.03		(29) 7.8±0.9	(29).264±.003	(31) 5.2±0.3	(31) 5.2±0.3	(13).092±.010	(32) 8.0±.02	(32)1.27±.06	(25)0.97±.11	(31)0.68±.09	
175-275	(11) 4.5±0.0	(11)271±0.4	(12)8.2±0.1		(12) 5.4±0.5	(12).274±.002	(12)10.0±0.8	(12) 9.2±1.9	(8).102±.014	(12) 8.0±.01	(12)1.47±.10	(6)0.81±.06	(12)0.40±.08	
Cruise 4- August														
3-6	(14)18.8 ± .3	(14)270 ± 0.7	(14)8.6 ± .01	(14)109 ± 0.5	(13) 4.6 ± 1.1	(14).121 ± .003	(14) 6.9 ± 0.5	(13) 3.5 ± .3	(14) 0.319 ± .026	(14) 7.9 ± 0.03	(14)0.17 ± .02	(13)0.26 ± .02	(14)1.21 ± .07	(14)6.1 ± .5
14-18	(14)18.1 ± .4	(13)268 ± 0.9	(14)8.6 ± .01		(14) 4.8 ± 0.7	(14).127 ± .006	(14) 7.6 ± 0.9	(14) 3.4 ± .3	(4) 0.268 ± .068	(14) 7.9 ± 0.03	(14)0.20 ± .04	(14)0.31 ± .03	(14)1.44 ± .08	
18-24	(14)15.1 ± .8	(14)271 ± 0.5	(14)8.5 ± .01		(14)11.7 ± 1.4	(14).142 ± .006	(14) 8.0 ± 0.4	(12) 3.5 ± .5	(4) 0.280 ± .094	(14) 7.8 ± 0.02	(13)0.20 ± .03	(14)0.38 ± .03	(14)1.89 ± .16	
24-30	(28) 8.8 ± .4	(28)273 ± 0.4	(28)8.5 ± .02		(28)17.2 ± 1.0	(28).185 ± .006	(28) 9.2 ± 0.5	(27) 4.0 ± .3	(7) 0.331 ± .018	(28) 7.8 ± 0.04	(28)0.37 ± .04	(27)0.42 ± .02	(14)1.44 ± .08	
30-33	(14) 7.5 ± .3	(14)274 ± 0.5	(14)8.4 ± .02		(14)17.3 ± 1.2	(14).200 ± .007	(14) 9.7 ± 0.5	(14) 4.0 ± .6	(4) 0.308 ± .021	(14) 7.8 ± 0.08	(14)0.41 ± .06	(14)0.44 ± .03	(14)2.55 ± .23	
33-48	(15) 6.4 ± .2	(15)274 ± 0.3	(15)8.4 ± .02		(15)14.9 ± 1.9	(15).224 ± .007	(15) 8.1 ± 0.6	(15) 3.5 ± .3	(5) 0.200 ± .018	(15) 7.8 ± 0.08	(15)0.59 ± .06	(14)0.50 ± .03	(15)2.01 ± .14	
48-60	(14) 5.3 ± .1	(14)274 ± 0.4	(14)8.3 ± .01		(14)10.8 ± 2.2	(14).239 ± .006	(14) 6.1 ± 0.6	(13) 3.5 ± .2	(4) 0.160 ± .007	(14) 7.7 ± 0.08	(14)0.84 ± .05	(14)0.47 ± .02	(14)1.38 ± .07	
60-100	(29) 4.9 ± .1	(31)274 ± 0.4	(31)8.3 ± .01		(26) 8.8 ± 1.0	(31).245 ± .004	(31) 7.0 ± 0.5	(29) 3.7 ± .2	(7) 0.110 ± .015	(31) 7.8 ± 0.05	(31)1.01 ± .05	(31)0.55 ± .06	(31)0.86 ± .06	
100-175	(31) 4.5 ± .1	(31)275 ± 0.2	(31)8.2 ± .01		(22) 6.0 ± 0.8	(31).264 ± .003	(31) 9.7 ± 0.6	(30) 5.9 ± .3	(13) 0.090 ± .005	(31) 7.8 ± 0.07	(31)1.51 ± .07	(31)0.72 ± .07	(31)0.42 ± .04	
175-275	(9) 4.4 ± .1	(9)276 ± 0.3	(9)8.2 ± .01		(7) 3.3 ± 0.4	(9).269 ± .004	(9)11.8 ± 1.0	(9) 7.2 ± .6	(8) 0.099 ± .013	(9) 7.9 ± 0.02	(8)1.68 ± .17	(9)0.51 ± .09	(9)0.15 ± .03	
Cruise 5- October														
3-6	(14)13.1 ± .1	(15)267 ± 1.0	(15)8.5 ± .01	(14)110 ± 1.6	(15) 7.9 ± 0.6	(15).141 ± .002	(10) 7.2 ± 0.9	(3) 4.7 ± 1.2	(15) 0.259 ± .010	(15) 8.0 ± 0.07	(15)0.36 ± .02	(15)0.32 ± .02	(13)0.97 ± .13	(4)6.5 ± .1
9-18	(4)13.1 ± .1	(4)265 ± 1.0	(4)8.5 ± .01		(4) 6.2 ± 0.8	(4).142 ± .002	(3) 6.6 ± 2.0		(3) 0.263 ± .018	(4) 8.0 ± 0.04	(4)0.32 ± .02	(4)0.30 ± .07	(4)1.00 ± .04	
18-24	(12)12.8 ± .2	(12)267 ± 0.8	(12)8.5 ± .01		(12) 6.6 ± 1.0	(12).143 ± .003	(9) 7.0 ± 0.6	(2) 2.5 ± 0.5	(3) 0.260 ± .020	(12) 8.0 ± 0.03	(12)0.35 ± .03	(12)0.28 ± .03	(10)0.95 ± .07	
24-30	(24)11.4 ± .5	(26)267 ± 1.0	(26)8.4 ± .02		(25) 7.0 ± 0.5	(26).173 ± .009	(20) 7.9 ± 1.1	(10) 3.1 ± 0.3	(3) 0.180 ± .011	(26) 8.0 ± 0.02	(26)0.50 ± .05	(26)0.28 ± .02	(25)0.75 ± .06	
30-36	(25) 9.9 ± .5	(27)269 ± 0.7	(27)8.3 ± .02		(24) 7.6 ± 0.5	(27).201 ± .009	(21) 7.4 ± 1.1	(11) 2.6 ± 0.2	(4) 0.180 ± .008	(27) 8.0 ± 0.02	(27)0.60 ± .05	(27)0.29 ± .02	(25)0.54 ± .05	
36-60	(18) 5.7 ± .3	(19)271 ± 0.9	(19)8.3 ± .01		(19)15.5 ± 0.7	(19).257 ± .004	(12) 6.0 ± 0.9	(6) 2.5 ± 0.2	(6) 0.178 ± .018	(19) 7.9 ± 0.02	(19)0.84 ± .04	(19)0.25 ± .02	(16)0.22 ± .03	
60-100	(30) 4.6 ± .1	(32)273 ± 0.7	(32)8.2 ± .01		(28) 4.9 ± 0.4	(32).264 ± .002	(22) 6.8 ± 0.6	(15) 5.3 ± 1.4	(6) 0.122 ± .007	(32) 7.9 ± 0.02	(32)1.15 ± .05	(32)0.39 ± .03	(31)0.13 ± .01	
100-175	(27) 4.1 ± .1	(30)272 ± 0.6	(30)8.2 ± .01		(23) 4.8 ± 0.3	(30).272 ± .002	(22) 9.2 ± 1.0	(25) 4.9 ± 0.4	(11) 0.096 ± .004	(30) 7.9 ± 0.02	(30)1.59 ± .07	(29)0.53 ± .04	(31)0.12 ± .02	
175-275	(9) 4.0 ± .0	(9)272 ± 0.6	(9)8.2 ± .02		(7) 4.3 ± 0.9	(9).267 ± .004	(6)12.2 ± 2.9	(9) 6.3 ± 0.9	(9) 0.131 ± .018	(9) 7.8 ± 0.03	(9)2.04 ± .22	(9)0.55 ± .07	(9)0.07 ± .01	

*Northern Basin Stations Numbers 4, 7, 8, 9, 14-20, 23, 25, 27, 34-37, 42, 67, 68

TABLE C3

Lake Michigan Southern Basin Stations* With Total Depth Greater Than 80 Meters, 1977
((Number of samples) mean ± std error of mean)

Depth M	Turbidity TU	Water Temp C°	Conductivity Micromhs/cm at 25°C	PH	Tot ALK mg/l	Tot NH_3-N ug/l	TKN-N mg/l	Tot NO_2+NO_3-N mg/l	Total P ug/l	Chloride mg/l	Diss. Reactive Silica** mg/l	Aerobic Heterotrophs	Chlorophyll a ug/l	Secchi Depth meters
Cruise #1 1977														
2	(8) .8±.1	(9) 2.6±0.2	(9)275±0.7	(9)8.0±.05	(9)109±.4	(4)2.5±0.9	(9).13±.01	(6).257±.004	(9)4.6±0.6	(8)8.2±.06	(9)1.14±.02	(9) 3± 1	(9)1.19±.19	(9)7.7±.4
5	(9) .8±.0	(8) 2.3±0.2	(9)275±0.6	(9)8.0±.04	(9)108±.2	(4)2.2±0.5	(9).16±.05	(6).257±.004	(9)3.7±0.2	(9)8.1±.04	(9)1.14±.02		(9)1.16±.15	
10	(9) .8±.1	(8) 2.1±0.2	(9)275±0.7	(9)8.0±.05	(9)108±.2	(4)2.5±0.6	(9).15±.02	(6).257±.005	(9)4.4±0.5	(9)8.1±.04	(9)1.14±.02		(9)1.07±.13	
20	(9) .6±.0	(8) 2.2±0.2	(9)275±0.7	(9)8.0±.05	(9)108±.4	(4)2.2±0.6	(9).13±.01	(6).258±.004	(9)4.1±0.4	(9)8.1±.03	(9)1.15±.02	(9) 2± 1	(9)1.09±.09	
50	(9) .7±.1	(8) 2.2±0.2	(9)275±0.6	(9)8.0±.05	(9)108±.4	(4)2.0±0.4	(9).13±.01	(6).253±.005	(9)4.0±0.2	(8)8.0±.04	(9)1.13±.02		(9)1.14±.14	
95-141	(12) .9±.1	(13) 2.1±0.2	(14)274±0.5	(14)8.0±.05	(14)108±.3	(6)3.8±0.7	(12).13±.02	(9).257±.006	(11)7.4±2.5	(12)8.1±.05	(14)1.21±.06	(9) 6± 4	(13)1.08±.13	
Cruise #2 1977														
2	(9) .7±.1	(9) 8.7±1.2	(9)274±0.7	(9)8.4±.04	(9)108±.2	(9)3.0±0.0	(9).14±.01	(8).219±.007	(9)5.4±0.8	(9)8.1±.06	(9)0.79±.05	(9) 23± 11	(9)2.11±.30	(4)6.5±.5
5	(9) .7±.0	(9) 7.1±0.8	(9)275±0.5	(9)8.4±.03	(9)108±.2	(9)3.1±0.1	(9).16±.02	(8).221±.007	(9)5.5±0.6	(9)8.1±.05	(9)0.79±.04	(1) 5± 5	(9)1.97±.22	
10	(10) .7±.0	(10) 6.2±0.5	(10)275±0.3	(10)8.4±.03	(10)109±.2	(10)3.3±0.2	(10).16±.01	(8).226±.004	(10)6.3±0.7	(9)8.1±.06	(10)0.79±.04	(6) 6± 3	(10)2.61±.20	
20	(9) .7±.0	(9) 6.4±0.6	(9)274±0.4	(9)8.3±.02	(9)109±.2	(9)3.6±0.3	(9).13±.01	(8).211±.007	(9)5.8±0.4	(9)8.1±.05	(9)0.77±.03	(2) 12± 8	(9)2.31±.27	
50	(7) .7±.0	(7) 4.7±0.2	(7)275±0.5	(7)8.3±.02	(7)108±.3	(7)3.6±0.4	(7).13±.01	(7).234±.005	(7)5.3±0.3	(7)8.1±.06	(7)0.88±.02		(7)2.49±.31	
67-135	(9) .8±.0	(12) 4.5±0.1	(12)275±0.3	(12)8.3±.02	(12)109±.2	(12)4.2±0.4	(12).14±.00	(12).229±.005	(12)4.8±0.2	(12)8.0±.04	(12)0.93±.03	(9) 2± 1	(12)1.96±.22	
Cruise #3 1977														
2	(9) .6±.1	(9)19.3±0.3	(9)127±0.7	(9)8.5±.01	(9)108±.2	(9)3.4±0.3	(9).17±.01	(9).144±.002	(5)3.8±0.4	(8)8.1±.04	(9)0.24±.01	(9)14± 4	(9) .83±.08	(9)6.7±.6
5	(9) .7±.1	(9)19.2±0.4	(9)271±0.3	(9)8.5±.02	(9)108±.2	(9)3.3±0.4	(9).17±.01	(9).143±.002	(9)4.0±0.3	(9)8.2±.03	(9)0.23±.01		(9) .80±.09	
10-15	(10) .6±.1	(10)19.0±0.4	(10)271±0.3	(10)8.5±.01	(10)108±.1	(10)4.0±0.4	(10).18±.00	(10).145±.003	(10)4.2±0.4	(10)8.1±.04	(10)0.23±.01	(1)29	(10) .79±.08	
16-21	(10) .7±.1	(10)14.6±1.2	(10)271±0.4	(10)8.5±.01	(10)108±.2	(10)9.5±1.1	(10).20±.01	(10).158±.004	(10)4.8±0.7	(10)8.1±.05	(10)0.26±.01	(8)33±14	(10)1.04±.26	
22-25	(7) .7±.0	(7)10.8±1.2	(7)273±0.6	(7)8.5±.03	(7)109±.2	(7)10.7±2.7	(7).19±.01	(7).173±.005	(7)5.3±0.7	(7)8.1±.02	(7)0.28±.04		(7)1.24±.22	
75-153	(9) .9±.1	(14) 5.3±0.4	(13)277±0.3	(14)8.0±.02	(14)110±.2	(4)5.1±0.9	(4).20±.05	(14).272±.004	(14)5.1±0.6	(14)8.1±.02	(14)1.57±.12	(9)41±15	(14) .79±.08	
Cruise #4 1977														
2	(9)1.3±.1	(9)17.4±0.3	(9)268±0.8	(9)8.5±.02	(9)105±.3	(9)3.1±0.4	(9).15±0.01	(9).134±.005	(9)3.9±0.3	(9)8.2±.03	(9)0.29±.03	(9)19±6	(8)1.01±.07	(9)4.2±.2
5	(9)1.3±.1	(9)17.2±0.4	(9)269±0.7	(9)8.5±.02	(9)105±.3	(9)3.4±0.5	(9).16±0.01	(9).133±.006	(9)4.7±0.3	(9)8.2±.04	(9)0.29±.03		(9)1.09±.06	
10-15	(8)1.2±.2	(8)16.4±0.7	(8)270±1.0	(8)8.5±.02	(7)106±.5	(8)3.9±0.6	(7).14±.00	(8).139±.006	(7)3.7±0.3	(8)8.2±.04	(8)0.31±.03	(1)24	(8)1.04±.08	
17-20	(8)1.2±.1	(8)15.3±1.6	(8)270±1.1	(8)8.4±.03	(8)106±.5	(8)5.4±1.3	(8).14±.01	(8).149±.009	(8)4.5±0.4	(8)8.2±.03	(8)0.32±.04	(5)32±12	(8)1.06±.13	
22-30	(11)1.3±.1	(11)11.3±1.1	(11)272±0.6	(11)8.4±.02	(11)108±.2	(11)14.4±2.7	(11).14±.01	(11).174±.007	(11)5.2±0.5	(11)8.1±.03	(11)0.33±.03	(3)28±10	(11)1.05±.23	
78-152	(13)0.8±.1	(13) 5.1±0.1	(13)277±0.6	(13)8.1±.02	(13)110±.2	(13)2.0±0.0	(13).11±.01	(13).268±.008	(13)5.4±0.6	(13)8.1±.02	(13)1.67±0.2	(9)43±18	(13) .38±.03	

Stations are 10, 11 17, 18, 19, 23, 26, 27, 28

APPENDIX D

Biological Data

TABLE D1
COMMON PHYTOPLANKTON SPECIES
SOUTHERN LAKE MICHIGAN
Cruise 1 (April 19-24, 1977)

STATIONS

Species	5a #/ml	5a %	5b #/ml	5b %	5 #/ml	5 %	6 #/ml	6 %	6a #/ml	6a %	6b #/ml	6b %
Asterionella formosa	80	1.5	30	1.0	350	22.6	no sample		---	----	90	1.8
Cyclotella spp.	210	3.9	120	4.0	90	5.8			---	----	----	---
Diatoms tenue var. elongatum	60	1.1	30	1.0	---	----			---	----	60	1.2
Fragilaria crontonensis	870	16.2	290	9.6	---	----			290	14.6	1450	29.5
Fragilaria intermedia	80	1.5	---	---	---	----			---	----	----	----
Melosira spp.	390	7.2	550	18.1	200	12.9			200	10.1	170	3.5
Nitzschia spp.	310	5.8	---	---	---	----			30	1.5	200	4.1
Rhizosolenia longiseta	100	1.8	---	---	90	5.8			---	----	----	----
Synedra acus	---	---	140	4.6	---	----			30	1.5	120	2.4
Synedra ulna	150	2.8	60	2.0	60	3.9			60	3.0	200	4.1
Synedra spp.	290	5.4	30	1.0	---	----					90	1.8
Tabellaria fenestrata	100	1.8	30	1.0	---	----			30	1.5	90	1.8
Cryptomonas erosa	---	---	30	1.0	30	1.9			---	----	30	0.6
Cryptomomas ovata	60	1.1	---	---	30	1.9			30	1.5	30	0.6
Cryptomonas spp.	270	5.0	140	4.6	200	12.9			60	3.0	290	5.9
Dinobryon spp.	60	1.4	410	13.5	---	----			230	11.6	290	5.9
Miscellaneous flagellates	830	16.1	960	31.7	290	18.7			670	33.8	1250	25.4
Oscillatoria limnetica	20	0.4	30	1.0	---	----			---	----	200	4.1
Ankistrodesmus falcatus	100	1.8	---	---	120	7.7			200	10.1	140	2.3
Oocystis spp.	40	0.7	---	---	---	---			---	----	---	----
Percent of Total	---	74.6	---	94.1	---	98.1			---	92.4	---	95.7
Total Diatoms	2840	52.7	1370	45.0	880	56.8			700	35.3	2500	50.9
Total Flagellates	2210	41.0	1540	50.8	550	35.5			1020	51.5	2500	39.1
Total Blue Green Algae	100	1.8	60	2.0	0	0			0	0	260	5.3
Total Green Algae	240	4.4	60	2.0	120	7.7			260	13.1	230	4.7
Total Phytoplankton	5390	----	3030	----	1550	----			1980	----	4910	----

TABLE D1
COMMON PHYTOPLANKTON SPECIES
SOUTHERN LAKE MICHIGAN
Cruise 1 (April 19-24, 1977)

STATIONS

	9		9a		10		11		12		13a		13	
Species	#/ml	%	#/ml	%	#/ml	%	#/ml	%	#/ml	%	#/ml	%	#/ml	%
Asterionella formosa	----	----	140	4.6	60	8.2	140	6.4	30	6.4	----	----	60	2.2
Cyclotella spp.	90	1.6	---	---	80	10.9	120	5.2	60	2.6	----	----	90	3.3
Diatoms tenue var. elongatum	----	----	---	---	20	2.7	30	1.4	---	----	----	----	30	1.1
Fragilaria crontonensis	1850	33.6	190	6.2	---	----	780	35.8	870	38.0	----	----	350	12.9
Fragilaria intermedia	----	----	---	---	---	----	60	2.7	120	5.2	----	----	---	----
Melosira spp.	460	8.4	500	16.4	100	13.7	60	2.7	490	21.0	100	9.8	120	4.4
Nitzschia spp.	120	---	40	1.3	20	2.7	30	1.4	---	----	----	----	120	4.4
Rhizosolenia longiseta	60	1.1	20	0.7	---	----	----	----	---	----	40	3.9	30	1.1
Synedra acus	120	2.2	20	0.7	40	5.5	30	1.4	30	1.3	60	5.9	30	1.1
Synedra ulna	90	1.6	20	0.7	---	----	----	----	30	1.3	----	----	30	1.1
Synedra spp.	----	----	----	----	---	----	----	----	---	----	----	----	---	----
qabellaria fenestrata	200	3.6	----	----	---	----	----	----	---	----	----	----	90	3.3
Cryptomonas erosa	----	----	----	----	20	1.0	30	1.0	30	1.3	----	----	---	----
Cryptomomas ovata	30	0.5	40	1.3			140	6.4	---	----	----	----	---	----
Cryptomonas spp.	640	11.6	460	15.1	100	13.7	200	9.2	---	----	120	11.8	---	----
Dinobryon spp.	230	4.2	380	12.5	---	----	60	2.7	---	----	170	16.7	350	12.9
Miscellaneous flagellates	1220	22.2	1000	32.8	190	26.0	350	16.0	410	17.9	270	26.5	1010	37.1
Oscillatoria limnetica	90	1.6	20	0.7	60	8.2	---	----	60	2.6	20	2.0	30	1.1
Ankistrodesmus falcatus	90	1.6	120	3.9	20	2.7	90	4.1	160	7.0	100	9.8	290	10.7
Oocystis spp.	---	----	---	----	---	----	---	----	---	----	80	9.8	---	----
Percent of Total	---	96.2	---	96.7	---	97.3	---	97.2	---	100.0	---	94.1	---	95.7
Total Diatoms	3020	54.9	930	30.4	320	43.8	1250	57.3	1630	71.2	200	19.6	950	34.1
Total Flagellates	2210	40.2	1920	62.9	330	45.2	810	37.1	440	19.2	560	54.9	1360	50.0
Total Blue Green Algae	90	1.6	80	2.6	60	8.2	0	0	60	2.6	60	5.9	90	3.3
Total Green Algae	180	3.3	120	3.9	20	2.7	120	5.5	160	7.0	200	19.6	320	11.8
Total Phytoplankton	5500	----	3050	----	730	----	2180	----	2290	----	1020	----	2720	----

TABLE D1
COMMON PHYTOPLANKTON SPECIES
SOUTHERN LAKE MICHIGAN
Cruise 1 (April 19-24, 1977)

STATIONS

Species	16 #/ml	16 %	16b #/ml	16b %	17 #/ml	17 %	18 #/ml	18 %	19 #/ml	19 %	20a #/ml	20a %	20 #/ml	20 %
Asterionella formosa	20	0.7	150	6.9	40	6.6	---	----	no sample		140	2.0	30	0.6
Cyclotella spp.	170	5.8	80	3.7	---	----	40	2.8			120	1.7	90	1.8
Diatoms tenue var. elongatum	---	----	60	2.7	---	----	---	----			60	0.9	60	1.2
Fragilaria crontonensis	---	----	---	----	40	6.6	150	10.5			2320	33.6	1560	30.8
Fragilaria intermedia	---	----	---	----	---	----	---	----			200	2.9	350	6.9
Melosira spp.	870	29.8	580	26.6	270	44.3	680	47.5			520	7.5	170	3.3
Nitzschia spp.	60	2.0	40	1.8	---	----	40	2.8			30	0.4	60	1.2
Rhizosolenia longiseta	---	----	---	----	---	----	---	----			30	0.4	30	0.6
Synedra acus	20	0.2	20	0.9	20	3.3	20	1.4			170	2.5	----	----
Synedra ulna	---	----	40	1.8	---	----	---	----			60	0.9	----	----
Synedra spp.	---	----	20	0.9	---	----	---	----			---	----	90	1.8
Tabellaria fenestrata	---	----	---	----	---	----	---	----			230	3.3	350	6.9
Cryptomonas erosa	40	1.4	140	6.4	40	6.6	---	----			---	---	---	---
Cryptomomas ovata	20	0.7	40	1.8	20	3.3	20	1.4			460	6.6	170	3.3
Cryptomonas spp.	310	10.6	310	14.2	100	16.4	150	10.5			520	7.5	410	8.1
Dinobryon spp.	---	----	---	----	---	----	---	----			350	5.1	670	13.2
Miscellaneous flagellates	1140	39.0	580	26.6	---	----	150	10.5			810	11.7	550	10.8
Oscillatoria limnetica	40	1.4	---	----	20	3.3	80	5.6			60	0.9	30	0.6
											---	----	----	----
Ankistrodesmus falcatus	190	6.5	40	1.8	20	3.3	20	1.4			290	4.2	60	1.2
Oocystis spp.	---	----	20	0.9	---	----	---	----			120	1.7	60	1.2
Percent of Total	---	98.6		97.2	---	93.4	---	94.4			---	93.9	---	93.4
Total Diatoms	1160	39.7	1010	46.3	370	60.7	970	67.8			3940	57.0	2820	55.6
Total Flagellates	1510	51.7	1070	49.1	200	32.8	320	22.4			2170	31.4	1860	36.7
Total Blue Green Algae	40	1.4	40	1.8	20	3.3	100	7.0			180	2.6	90	1.8
Total Green Algae	210	7.2	60	2.7	20	3.3	40	2.8			590	8.5	270	5.3
Total Phytoplankton	2920	----	2180	----	610	----	1430	----			6910	----	5070	----

D-5

TABLE D1
COMMON PHYTOPLANKTON SPECIES
SOUTHERN LAKE MICHIGAN
Cruise 1 (April 19-24, 1977)

STATIONS

Species	21 #/ml	21 %	21a #/ml	21a %	22 #/ml	22 %	23 #/ml	23 %	24a #/ml	24a %	24 #/ml	24 %
Asterionella formosa	60	2.5	100	5.5	20	0.8	60	3.3	40	0.8	30	3.0
Cyclotella spp.	60	2.5	100	5.5	60	2.5	150	8.2	270	5.7	120	1.3
Diatoms tenue var. elongatum	20	0.8	---	----	---	----	---	----	140	2.9		
Fragilaria crontonensis	---	----	---	----	120	5.0	---	----	100	2.1	1590	17.9
Fragilaria intermedia	---	----	---	----	---	----	---	----	230	4.8		
Melosira spp.	580	24.0	720	39.6	640	26.8	150	8.2	440	9.3	700	7.9
Nitzschia spp.	60	2.5	---	----	80	3.4	40	2.2	---	----	30	0.3
Rhizosolenia longiseta	40	1.6	60	3.5	---	----	20	1.1	---	----	60	0.7
Synedra acus	120	5.0	80	4.4	40	1.7	20	1.1	40	0.8	320	3.6
Synedra ulna	20	0.8	80	4.4	60	2.5	---	----	---	----	90	1.0
Synedra spp.	---	----	---	----	---	----	---	----	---	----		
Tabellaria fenestrata	---	----	---	----	---	----	60	3.3	230	4.8	230	2.6
Cryptomonas erosa	---	----	140	7.7	170	7.1	20	1.1	---	----	290	3.3
Cryptomomas ovata	80	3.3	40	2.2	80	3.5	20	1.1	150	3.2	170	1.9
Cryptomonas spp.	230	9.5	230	12.6	380	15.9	230	12.6	1280	26.9	1590	17.9
Dinobryon spp.	60	2.5	---	----	---	----	---	----	20	0.4	550	6.2
Miscellaneous flagellates	870	35.9	70	3.8	660	27.6	750	41.2	1040	21.9	1970	---
Oscillatoria limnetica	---	----	20	1.1	---	----	140	7.7	---	----	60	0.7
Ankistrodesmus falcatus	140	5.8	100	5.5	60	2.5	140	7.7	---	----	610	6.7
Oocystis spp.	---	----	---	----	---	----	---	----	---	----	---	----
Percent of Total	---	96.7	---	95.6	---	99.2	---	98.9	---	93.9	---	94.6
Total Diatoms	980	40.5	1160	47.7	1040	43.5	370	20.3	1610	38.0	3380	38.0
Total Flagellates	1240	51.2	1090	44.9	1290	54.0	1020	56.0	2550	60.1	4660	52.4
Total Blue Green Algae	20	0.8	0	0	0	0	140	7.7	120	2.8	120	1.4
Total Green Algae	180	7.4	60	2.5	60	2.5	140	7.7	0	0	730	8.2
Total Phytoplankton	2420	----	2390	----	2390	----	1820	----	4240	----	8990	----

TABLE D1
COMMON PHYTOPLANKTON SPECIES
SOUTHERN LAKE MICHIGAN
Cruise 1 (April 19-24, 1977)

STATIONS

Species	25 #/ml	25 %	25a #/ml	25a %	26 #/ml	26 %	27 #/ml	27 %	28a #/ml	28a %	28 #/ml	28 %
Asterionella formosa	---	----	60	3.4	20	1.0	---	----	no sample		---	----
Cyclotella spp.	20	0.8	---	----	60	3.0	80	6.7			100	5.1
Diatoms tenue var. elongatum	20	0.8	20	1.2	---	----	---	----			---	----
Fragilaria crontonensis	---	----	---	----	190	9.6	---	----			100	5.1
Fragilaria intermedia	---	----	---	----	---	----	---	----			---	----
Melosira spp.	310	12.8	270	15.2	620	31.3	380	31.9			440	22.6
Nitzschia spp.	---	----	60	3.4	20	1.0	---	----			60	3.1
Rhizosolenia longiseta	20	0.8	---	----	---	----	---	----			---	----
Synedra acus	20	0.8	40	2.3	20	1.0	20	1.7			20	1.0
Synedra ulna	20	0.8	---	----	---	----	60	5.0			20	1.0
Synedra spp.	---	----	---	----	20	1.0	---	----			---	----
Tabellaria fenestrata	---	----	---	----	---	----	---	----			---	----
Cryptomonas erosa	---	----	---	----	80	4.0	80	6.7			170	8.7
Cryptomomas ovata	80	3.3	---	----	20	1.0	60	5.0			20	1.0
Cryptomonas spp.	640	26.3	330	18.6	380	19.2	230	19.3			80	4.1
Dinobryon spp.	80	3.3	---	----	---	----	---	----			---	----
Miscellaneous flagellates	1040	42.8	890	50.3	330	16.7	120	10.1			460	23.6
Oscillatoria limnetica	---	----	---	----	140	7.1	40	3.4			230	11.8
Ankistrodesmus falcatus	140	5.8	---	----	20	1.0	20	1.7			170	8.7
Oocystis spp.	---	----	---	----	---	----					---	----
Percent of Total	---	98.3	---	94.3	---	97.0	---	91.6			---	95.9
Total Diatoms	450	18.5	450	25.4	970	49.0	580	48.7			820	42.0
Total Flagellates	1840	75.7	1220	[illegible]	810	40.9	490	41.2			730	37.4
Total Blue Green Algae	0	0	0	0	180	9.1	100	8.4			230	11.8
Total Green Algae	140	5.8	100	5.6	20	1.0	20	1.7			0	0
Total Phytoplankton	2430	----	1770	----	1980	----	1190	----			1950	----

TABLE D2
COMMON PHYTOPLANKTON SPECIES
SOUTHERN LAKE MICHIGAN
Cruise 2 (June 11-16, 1977)

STATIONS

	5a		5b		5		6		6a		6b	
Species	#/ml	%	#/ml	%	#/ml	%	#/ml	%	#/ml	%	#/ml	%
Asterionella formosa	60	1.2	---	----	60	2.0	---	----	---	----	140	5.2
Cyclotella spp.	90	1.9	30	1.4	---	----	90	2.6	30	1.3	---	----
Diatoms tenue var. elongatum	170	3.5	30	1.4	30	1.0	---	----	---	----	---	----
Fragilaria crontonensis	430	9.0	---	----	---	----	290	8.4	---	----	350	13.1
Fragilaria intermedia	---	----	---	----	---	----	---	----	---	----	---	----
Melosira spp.	60	1.2	260	12.4	120	4.1	---	----	---	----	60	2.2
Nitzschia spp.	720	15.0	120	5.7	30	1.0	30	0.9	---	----	30	1.1
Rhizosolenia eriensis	---	----	---	----	---	----	---	----	---	----	---	----
Rhizosolenia longiseta	200	4.2	230	10.9	200	6.8	230	6.6	30	1.3	60	2.2
Synedra acus	120	2.5	90	4.3	30	1.0	30	0.9	90	4.0	90	3.3
Synedra ulna	200	4.2	120	5.7	30	1.0	120	3.5	---	----	60	2.2
Tabellaria fenestrata	30	0.6	---	----	---	----	170	4.9	170	7.6	230	8.6
Cryptomonas spp.	580	12.1	---	----	290	9.9	290	8.4	520	23.2	260	9.7
Cryptomonas erosa	30	0.6	---	----	---	----	30	0.9	---	----	---	----
Cryptomomas ovata	90	1.9	30	1.4	30	1.0	30	0.9	90	4.0	60	2.2
Dinobryon spp.	120	2.5	260	12.4	980	33.3	140	4.1	170	7.6	60	2.2
Miscellaneous flagellates	1560	32.6	460	21.9	780	26.5	1680	48.5	810	36.2	1040	38.8
Oscillatoria limnetica	---	----	---	----	120	4.1	90	2.6	60	2.7	60	2.2
Ankistrodesmus falcatus	90	1.9	90	4.3	60	2.0	60	2.0	30	1.3	30	1.1
Oocystis spp.	---	----	---	----	---	----	---	----	---	----	---	----
Quadrigula lacustris	30	0.6	---	----	---	----	---	----	---	----	30	1.1
Percent of Total	---	95.5	---	----	---	93.7	---	94.1	---	89.2	---	95.2
Total Diatoms	2140	44.7	910	43.3	500	17.0	990	28.6	320	14.3	1050	39.2
Total Flagellates	2410	50.3	920	43.8	2080	70.8	2170	62.7	1590	71.0	1450	54.1
Total Blue Green Algae	60	1.2	120	5.7	150	5.1	180	5.2	90	4.0	90	3.4
Total Green Algae	180	3.8	150	7.1	210	7.1	120	3.5	240	10.7	90	3.4
Total Phytoplankton	4790	----	2100	----	2940	----	3460	----	2240	----	2680	----

TABLE D2
COMMON PHYTOPLANKTON SPECIES
SOUTHERN LAKE MICHIGAN
Cruise 2 (June 11-16, 1977)

STATIONS

	9		9a		10		11		12		13a		13	
Species	#/ml	%	#/ml	%	#/ml	%	#/ml	%	#/ml	%	#/ml	%	#/ml	%
Asterionella formosa	170	3.3	no sample		140	4.7	30	1.4	---	----	no sample		60	1.4
Cyclotella spp.	120	2.3			---	----	30	1.4	30	0.9			170	3.9
Diatoms tenue var. elongatum	60	1.2			---	----	---	----	---	----			170	3.9
Fragilaria crontonensis	350	6.8			290	9.8	140	6.5	---	----			90	2.1
Fragilaria intermedia	---	----			---	----	---	----	---	----			---	----
Melosira spp.	290	5.6			900	30.3	120	5.6	60	1.8			200	4.6
Nitzschia spp.	200	3.8			---	----	---	----	30	0.9			60	1.4
Rhizosolenia eriensis	120	2.3			---	----	---	----	60	1.8			---	----
Rhizosolenia longiseta	30	0.6			90	3.0	---	----	---	----			90	2.1
Synedra acus	120	2.3			60	2.0	90	4.2	30	0.9			260	6.0
Synedra ulna	60	1.2			---	----	---	----	30	0.9			90	2.1
Tabellaria fenestrata	230	4.4			---	----	30	1.4	200	6.0			200	4.6
					---	----	---	----	---	----			---	----
Cryptomonas spp.	840	16.2			380	12.8	260	12.0	490	14.7			520	12.0
Cryptomonas erosa	---	----			120	4.0	30	1.4	30	0.9			30	0.7
Cryptomomas ovata	350	6.8			---	----	90	4.2	30	0.9			60	1.4
Dinobryon spp.	120	2.3			30	1.0	290	13.4	140	4.2			380	8.7
Miscellaneous flagellates	1500	29.0			460	15.5	810	37.5	1820	54.5			1240	28.6
													---	----
Oscillatoria limnetica	60	1.2			90	3.0	60	2.8	120	3.6			60	1.4
													---	----
Ankistrodesmus falcatus	170	3.3			230	7.7	30	1.4	60	1.8			120	2.8
Oocystis spp.	90	1.7			---	----	---	----	---	----			---	----
Quadrigula lacustris	90	1.7			---	----	---	----	---	----			30	0.7
Percent of Total	---	96.0			---	93.8	---	93.2	---	[illegible]			---	88.4
Total Diatoms	1750	33.8			1480	49.8	440	20.4	470	14.1			1480	34.1
Total Flagellates	2810	54.2			990	33.3	1480	68.5	2510	75.2			2230	51.4
Total Blue Green Algae	210	4.0			180	6.1	120	5.6	210	6.3			210	4.8
Total Green Algae	410	7.9			320	10.8	120	5.6	120	3.6			420	9.7
Total Phytoplankton	5180	----			2970	----	2160	----	3340	----			4340	----

TABLE D2
COMMON PHYTOPLANKTON SPECIES
SOUTHERN LAKE MICHIGAN
Cruise 2 (June 11-16, 1977)

STATIONS

Species	16 #/ml	16 %	16b #/ml	16b %	17 #/ml	17 %	18 #/ml	18 %	19 #/ml	19 %	20a #/ml	20a %	20 #/ml	20 %
Asterionella formosa	200	8.5	60	1.4	60	3.7	---	----	90	2.5	30	0.5	120	1.6
Cyclotella spp.	---	----	30	0.7	---	----	60	2.5	30	0.8	30	0.5	260	3.6
Diatoms tenue var. elongatum	60	2.5	120	2.7	---	----	30	1.2	---	----	---	----	60	0.8
Fragilaria crontonensis	---	----	290	6.6	---	----	---	----	350	9.8	720	12.4	1500	20.6
Fragilaria intermedia	---	----	---	----	---	----	290	12.1	---	----	---	----	290	4.0
Melosira spp.	120	5.1	230	5.2	350	21.7	610	25.5	120	3.3	200	3.4	720	9.9
Nitzschia spp.	60	2.5	---	----	90	5.6	30	1.2	30	0.8	---	----	120	1.6
Rhizosolenia eriensis	30	1.3	60	1.4	30	1.9	30	1.2	30	0.8	60	1.0	---	----
Rhizosolenia longiseta	350	14.8	60	1.4	30	1.9	---	----	60	1.7	30	0.5	120	1.6
Synedra acus	30	1.3	200	4.5	30	1.9	30	1.2	30	0.8	60	1.0	120	1.6
Synedra ulna	30	1.3	30	0.7	30	1.9	30	1.2	---	----	260	4.5	170	2.3
Tabellaria fenestrata	30	1.3	30	0.7	90	5.6	---	----	120	3.3	350	6.0	230	3.2
Cryptomonas spp.	380	16.1	900	20.4	90	5.6	200	8.4	490	13.7	1360	23.4	920	12.6
Cryptomonas erosa	30	1.3	90	2.0	60	3.7	90	3.8	---	----	30	0.5	---	----
Cryptomomas ovata	---	----	60	1.4	---	----	30	1.2	60	1.7	200	3.4	170	2.3
Dinobryon spp.	170	7.2	350	7.9	---	----	---	----	1240	34.6	---	----	---	----
Miscellaneous flagellates	690	29.2	1390	31.6	230	14.3	610	25.5	660	18.4	1700	29.2	1620	22.2
Oscillatoria limnetica	30	1.3	60	1.4	30	1.9	60	2.5	60	1.7	140	2.4	30	0.4
Ankistrodesmus falcatus	90	3.8	260	5.9	140	8.7	200	8.4	90	2.5	350	6.0	350	4.8
Oocystis spp.	---	----	---	----	---	----	---	----	---	----	30	0.5	---	----
Quadrigula lacustris	60	2.5	---	----	---	----	---	----	---	----	---	----	60	0.8
Percent of Total	---	100.0	---	95.9	---	90.8	---	95.9	---	96.4	---	95.2	---	93.9
Total Diatoms	910	38.6	1110	25.2	1000	62.1	1140	47.7	860	24.0	1770	30.4	3710	51.0
Total Flagellates	1270	53.8	2790	63.4	380	23.6	990	41.4	2450	68.4	3320	57.0	2740	37.6
Total Blue Green Algae	30	1.3	90	2.0	30	1.9	60	2.5	90	2.5	260	4.5	150	2.1
Total Green Algae	150	6.4	410	9.3	200	12.4	200	8.4	180	5.0	470	8.1	680	9.3
Total Phytoplankton	2360	----	4400	----	1610	----	2390	----	3580	----	5820	----	7280	----

TABLE D2
COMMON PHYTOPLANKTON SPECIES
SOUTHERN LAKE MICHIGAN
Cruise 2 (June 11-16, 1977)

STATIONS

Species	21 #/ml	21 %	21a #/ml	21a %	22 #/ml	22 %	23 #/ml	23 %	24a #/ml	24a %	24 #/ml	24 %
Asterionella formosa	---	----	---	----	90	3.0	60	3.0	30	0.8	no sample	
Cyclotella spp.	60	3.6	30	0.6	60	2.0	60	3.0	60	1.7		
Diatoms tenue var. elongatum	30	1.8	---	----	---	----	---	----	60	1.7		
Fragilaria crontonensis	---	----	---	----	430	14.2	---	----	430	12.1		
Fragilaria intermedia	---	----	---	----	---	----	---	----	---	----		
Melosira spp.	---	----	170	3.4	60	2.0	260	13.1	120	3.4		
Nitzschia spp.	30	1.8	---	----	---	----	30	1.5	30	0.8		
Rhizosolenia eriensis	90	5.4	30	0.6	---	----	---	----	120	3.4		
Rhizosolenia longiseta	290	17.4	120	2.4	170	5.6	30	1.5	140	3.9		
Synedra acus	---	----	60	1.2	60	2.0	60	3.0	30	0.8		
Synedra ulna	170	10.2	60	1.2	30	1.0	30	1.5	60	1.7		
Tabellaria fenestrata	---	----	30	0.6	---	----	---	----	350	9.9		
Cryptomonas spp.	140	8.4	380	7.7	350	11.6	380	19.2	580	16.4		
Cryptomonas erosa	---	----	---	----	30	1.0	---	----	---	----		
Cryptomomas ovata	---	----	30	0.6	---	----	60	3.0	90	2.5		
Dinobryon spp.	30	1.8	3240	65.6	950	31.5	60	3.0	170	4.8		
Miscellaneous flagellates	610	36.7	460	9.3	520	17.2	640	32.3	920	26.0		
Oscillatoria limnetica	30	1.8	30	0.6	60	2.0	30	1.5	30	0.8		
									---	----		
Ankistrodesmus falcatus	90	5.4	60	1.2	120	4.0	200	10.1	170	4.8		
Oocystis spp.	---	----	60	1.2	---	----	---	----	---	----		
Quadrigula lacustris	---	----	---	----	---	----	---	----	---	----		
Percent of Total	---	94.3	---	96.2	---	97.1	---	95.7	---	95.5		
Total Diatoms	670	40.4	530	10.7	930	30.8	560	28.3	1430	40.4		
Total Flagellates	780	47.0	4110	83.2	1830	62.2	1040	52.5	1760	49.7		
Total Blue Green Algae	30	1.8	60	1.2	60	2.0	90	4.5	150	4.2		
Total Green Algae	180	10.8	240	4.9	150	5.0	290	14.6	200	5.6		
Total Phytoplankton	1660	----	4840	----	3020	----	1980	----	3540	----		

TABLE D2
COMMON PHYTOPLANKTON SPECIES
SOUTHERN LAKE MICHIGAN
Cruise 2 (June 11-16, 1977)

STATIONS

Species	25 #/ml	25 %	25a #/ml	25a %	26 #/ml	26 %	27 #/ml	27 %	28a #/ml	28a %	28 #/ml	28 %
Asterionella formosa	no sample		60	1.3	no sample		120	3.3	no sample		30	1.1
Cyclotella spp.			30	0.6			90	2.5			30	1.1
Diatoms tenue var. elongatum			90	1.9			30	0.8			30	1.1
Fragilaria crontonensis			920	19.5			920	25.1			580	21.3
Fragilaria intermedia			290	6.1			---	----			---	----
Melosira spp.			90	1.9			350	9.6			90	3.3
Nitzschia spp.			30	0.6			60	1.6			60	2.2
Rhizosolenia eriensis			---	----			30	0.8			---	----
Rhizosolenia longiseta			---	----			30	0.8			60	2.2
Synedra acus			30	0.6			90	2.4			60	2.2
Synedra ulna			---	----			30	0.8			30	1.1
Tabellaria fenestrata			120	2.5			120	3.3			170	6.2
Cryptomonas spp.			1160	24.6			640	17.3			290	10.7
Cryptomonas erosa			30	0.6			120	3.3			60	2.2
Cryptomomas ovata			350	7.4			380	10.4			---	----
Dinobryon spp.			350	7.4			260	7.1			---	----
Miscellaneous flagellates			580	12.3			---	----			900	33.1
Oscillatoria limnetica			30	0.6			60	1.6			60	2.2
											---	----
Ankistrodesmus falcatus			200	4.2			90	2.5			90	3.3
Oocystis spp.			120	2.5			60	1.6			30	1.1
Quadrigula lacustris			---	----			---	----			30	1.1
Percent of Total			---	94.6			---	94.8			---	95.5
Total Diatoms			1690	35.8			1900	51.9			1200	44.1
Total Flagellates			2470	52.3			1400	38.2			1250	46.0
Total Blue Green Algae			30	0.6			150	4.1			90	3.3
Total Green Algae			500	10.6			180	4.9			180	6.6
Total Phytoplankton			4720	----			3660	----			2720	----

TABLE D3
COMMON PHYTOPLANKTON SPECIES
SOUTHERN LAKE MICHIGAN
Cruise 3 (August 20-25, 1977)

STATIONS

Species	5a #/ml	5a %	5b #/ml	5b %	5 #/ml	5 %	6 #/ml	6 %	6a #/ml	6a %	6b #/ml	6b %
Asterionella formosa	30	0.5	30	1.1	---	----	260	9.7	60	1.3	90	2.4
Cyclotella spp.	140	2.3	30	1.1	30	1.3	60	2.2	90	1.9	90	2.4
Diatoms tenue var. elongatum	170	2.8	---	----	---	----	30	1.1	---	----	30	0.8
Fragilaria crontonensis	580	9.7	---	----	---	----	---	----	430	9.0	120	3.1
Fragilaria intermedia	---	----	---	----	---	----	---	----	---	----	---	----
Melosira spp.	90	1.5	30	1.1	---	---	90	3.4	170	3.6	520	13.6
Synedra acus	---	----	---	----	---	----	90	3.4	90	1.9	200	5.2
Tabellaria fenestrata	150	2.5	---	----	---	----	---	----	---	----	---	----
Cryptomonas erosa	---	----	---	----	---	----	---	----	550	11.5	---	----
Cryptomomas ovata	350	5.8	30	1.2	60	2.5	60	2.2	120	2.5	60	1.6
Cryptomonas spp.	780	13.0	90	3.3	350	14.7	660	24.6	---	----	430	11.3
Dinobryon spp.	230	3.8	90	3.3	140	5.9	90	3.4	610	12.8	120	3.1
Miscellaneous flagellates	1130	18.8	1390	50.5	950	39.9	---	----	870	18.3	1010	26.4
Anabaena spp.	---	----	---	----	---	----	580	21.6	30	0.6	---	----
Anacystis spp.	1010	16.8	380	13.8	260	10.9	120	4.5	580	12.2	380	10.0
Aphanothece spp.	460	7.7	290	10.5	260	10.9	---	----	230	4.8	170	4.4
Chroococcus spp.	60	1.0	60	2.2	60	2.5	30	1.1	90	1.9	60	1.6
Coelospaerium kuetzingianum	120	2.0	---	----	30	1.3	---	----	60	1.3	30	0.8
Gomphosphaeria lacustris	30	0.5	30	1.1	90	3.8	60	2.2	60	1.3	60	1.6
Ankistrodesmus falcatus	60	1.0	---	----	---	----	30	1.1	60	1.3	120	3.1
Crucigenia quadrata	---	----	---	----	30	1.3	30	1.1	---	----	---	----
Oocystis spp.	430	7.2	120	4.4	---	----	---	----	30	0.6	90	2.4
Quadrigula lacustris	30	0.5	30	1.1	30	1.3	---	----	60	0.6	30	0.8
Scenedesmus quadricauda	30	0.5	---	----	30	1.3	---	----	---		60	1.6
Percent of Total	---	98.0	---	94.5	---	97.5	---	81.6	---	88.1	---	96.2
Total Diatoms	1190	19.8	180	6.5	30	1.3	560	20.9	930	19.5	1110	29.1
Total Flagellates	2520	42.0	1630	59.3	1530	64.3	1210	45.1	2180	45.8	1620	42.4
Total Blue Green Algae	1710	28.5	760	27.6	700	29.4	820	30.6	1170	24.6	760	19.9
Total Green Algae	580	9.7	180	6.5	120	5.0	90	3.4	390	8.2	330	8.6
Total Phytoplankton	6000	----	2750	----	2380	----	2680	----	4760	----	3820	----

TABLE D3
COMMON PHYTOPLANKTON SPECIES
SOUTHERN LAKE MICHIGAN
Cruise 3 (August 20-25, 1977)

STATIONS

Species	9 #/ml	9 %	9a #/ml	9a %	10 #/ml	10 %	11 #/ml	11 %	12 #/ml	12 %	13a #/ml	13a %	13 #/ml	13 %
Asterionella formosa	200	7.0	90	2.6	---	----	---	----	90	3.3	120	2.9	30	0.9
Cyclotella spp.	60	2.1	140	4.1	60	2.7	---	----	60	2.2	30	0.7	90	2.8
Diatoms tenue var. elongatum	30	1.0	30	0.9	90	4.0	---	----	---	----	90	2.2	---	----
Fragilaria crontonensis	290	10.2	580	16.9	---	----	---	----	---	----	---	----	870	26.9
Fragilaria intermedia	---	----	---	----	---	----	---	----	---	----	---	----	---	----
Melosira spp.	60	2.1	---	----	200	8.9	30	2.0	---	----	60	1.5	140	4.3
Synedra acus	30	1.0	30	0.9	---	----	---	----	30	1.1	170	4.2	30	0.9
Tabellaria fenestrata	---	----	---	----	---	----	---	----	---	----	30	0.7	---	----
Cryptomonas erosa	30	1.0	---	----	---	----	---	----	---	----	---	----	---	----
Cryptomomas ovata	30	1.0	60	1.7	90	4.0	120	8.0	30	1.1	140	3.4	90	2.8
Cryptomonas spp.	230	8.1	200	5.8	1160	51.6	380	25.5	430	16.0	520	12.7	140	4.3
Dinobryon spp.	200	7.0	200	5.8	60	2.7	---	----	60	2.2	120	2.9	120	3.7
Miscellaneous flagellates	1070	37.5	1360	39.8	---	----	380	25.5	640	23.8	1330	32.5	610	18.9
Anabaena spp.	---	----	---	----	---	----	30	2.0	---	----	---	----	---	----
Anacystis spp.	140	4.9	260	7.6	170	7.6	140	9.4	460	17.1	780	19.1	520	16.1
Aphanothece spp.	90	3.2	120	3.5	90	4.0	200	13.4	380	14.1	140	3.4	140	4.3
Chroococcus spp.	60	2.1	---	----	60	2.7	60	4.0	90	3.3	140	3.4	30	0.9
Coelospaerium kuetzingianum	---	----	60	1.7	---	----	---	----	---	----	---	----	30	0.9
Gomphosphaeria lacustris	---	----	30	0.9	60	2.7	60	4.0	30	1.1	90	2.2	60	1.9
Ankistrodesmus falcatus	---	----	---	----	---	----	---	----	---	----	---	----	30	0.9
Crucigenia quadrata	---	----	140	4.1	30	1.3	---	----	---	----	---	----	---	----
Oocystis spp.	30	1.0	---	----	---	----	30	2.0	60	2.2	30	0.7	---	----
Quadrigula lacustris	90	3.2	---	----	---	----	30	2.0	---	----	30	0.7	30	0.9
Scenedesmus quadricauda	---	----	---	----	---	----	---	----	---	----	30	0.7	---	----
Percent of Total	---	92.6	---	96.5	---	92.0	---	98.0	---	87.7	---	94.1	---	91.6
Total Diatoms	760	26.7	990	28.9	470	20.9	30	2.0	330	12.3	620	15.2	1250	38.7
Total Flagellates	1590	55.8	1820	53.2	1340	59.6	910	61.1	1190	44.2	2110	51.6	960	29.7
Total Blue Green Algae	320	11.2	470	13.7	300	13.3	490	32.9	1050	39.0	1240	30.3	840	26.0
Total Green Algae	180	6.3	140	4.1	60	2.7	60	4.0	120	4.5	120	2.9	180	5.6
Total Phytoplankton	2850	----	3420	----	2250	----	1490	----	2690	----	4090	----	3230	----

TABLE D3
COMMON PHYTOPLANKTON SPECIES
SOUTHERN LAKE MICHIGAN
Cruise 3 (August 20-25, 1977)

STATIONS

Species	16 #/ml	%	16b #/ml	%	17 #/ml	%	18 #/ml	%	19 #/ml	%	20a #/ml	%	20 #/ml	%
Asterionella formosa	30	1.4	---	----	30	0.9	60	2.1	---	----	60	1.7	60	1.7
Cyclotella spp.	30	1.4	30	0.7	30	0.9	30	1.0	60	2.0	60	1.7	230	6.7
Diatoms tenue var. elongatum	---	----	---	----	---	----	---	----	---	----	---	----	---	----
Fragilaria crontonensis	140	6.4	---	----	140	4.2	---	----	---	----	290	8.5	430	12.5
Fragilaria intermedia	----	----	---	----	---	----	---	----	---	----	---	----	---	----
Melosira spp.	----	----	---	----	140	4.2	---	----	90	3.1	---	----	380	11.0
Synedra acus	30	1.4	---	----	---	----	30	1.0	30	1.0	60	1.7	60	1.7
Tabellaria fenestrata	90	4.1	---	----	---	----	---	----	---	----	---	----	---	----
Cryptomonas erosa	---	----	---	----	---	----	30	1.0	---	----	---	----	30	0.9
Cryptomomas ovata	60	2.7	90	2.1	230	6.9	90	3.1	120	4.1	60	1.7	30	0.9
Cryptomonas spp.	520	23.8	660	15.6	430	12.9	720	24.8	550	18.7	580	16.9	60	1.7
Dinobryon spp.	120	5.5	60	1.4	---	----	---	----	30	1.0	90	2.6	60	1.7
Miscellaneous flagellates	520	23.9	1070	25.3	920	27.6	170	5.9	1070	36.4	350	10.2	580	16.8
Anabaena spp.	---	----	---	----	---	----	---	----	290	9.9	---	----	30	0.9
Anacystis spp.	230	10.5	1040	25.6	578	17.4	920	31.7	400	13.6	820	24.0	550	15.9
Aphanothece spp.	170	7.8	720	17.0	380	11.4	520	17.9	---	----	350	10.2	90	2.6
Chroococcus spp.	---	----	120	2.8	60	1.8	---	----	120	4.1	90	2.6	---	----
Coelospaerium kuetzingianum	---	----	---	----	---	----	---	----	---	----	---	----	30	0.9
Gomphosphaeria lacustris	90	4.1	60	1.4	120	3.6	90	3.1	90	3.1	120	3.5	30	0.9
Ankistrodesmus falcatus	30	1.4	---	----	---	----	---	----	---	----	---	----	30	0.9
Crucigenia quadrata	---	----	90	2.1	---	----	---	----	---	----	---	----	30	0.9
Oocystis spp.	---	----	140	3.3	30	0.9	30	1.0	---	----	---	----	---	----
Quadrigula lacustris	---	----	30	0.7	120	3.6	---	----	---	----	200	5.8	30	0.9
Scenedesmus quadricauda	---	----	---	----	---	----	---	----	---	----	---	----	260	7.5
Percent of Total	---	94.5	---	97.2	---	96.4	---	92.8	---	97.0	---	91.5	---	87.1
Total Diatoms	350	16.1	60	1.4	370	11.1	180	6.2	180	6.1	500	14.6	1250	32.2
Total Flagellates	1220	56.0	1910	45.1	1610	48.4	1040	35.9	1830	62.2	1080	31.6	850	24.6
Total Blue Green Algae	550	25.2	1940	45.9	1198	36.0	1560	53.8	930	31.6	1520	44.4	760	22.0
Total Green Algae	60	2.7	320	7.6	150	4.5	120	4.1	0	0	320	9.4	590	17.1
Total Phytoplankton	2180	----	4230	----	3328	----	2900	----	2940	----	3420	----	3450	----

TABLE D3
COMMON PHYTOPLANKTON SPECIES
SOUTHERN LAKE MICHIGAN
Cruise 3 (August 20-25, 1977)

STATIONS

	21		21a		22		23		24a		24	
Species	#/ml	%	#/ml	%	#/ml	%	#/ml	%	#/ml	%	#/ml	%
Asterionella formosa	610	18.5	90	1.6	---	----	230	12.8	120	3.0	120	3.2
Cyclotella spp.	60	1.8	90	1.6	---	----	30	1.7	30	0.7	60	1.6
Diatoms tenue var. elongatum	30	0.9	30	0.6	30	1.7	---	----	---	----	---	----
Fragilaria crontonensis	430	13.1	1160	21.1	---	----	430	23.9	230	5.7	430	11.4
Fragilaria intermedia	---	----	490	8.9	---	----	---	----	580	14.4	---	----
Melosira spp.	---	----	60	1.1	120	6.7	---	----	---	----	---	----
Synedra acus	30	0.9	30	0.5	---	----	---	----	30	0.7	---	----
Tabellaria fenestrata	140	4.3	290	5.3	---	----	---	----	60	1.5	---	----
Cryptomonas erosa	---	----	---	----	---	----	---	----	---	----	---	----
Cryptomomas ovata	30	0.9	490	8.9	60	3.4	30	1.7	90	2.2	120	3.2
Cryptomonas spp.	460	14.0	1300	23.7	400	22.5	230	12.8	490	12.2	580	15.3
Dinobryon spp.	140	4.7	460	8.4	120	6.7	90	5.0	120	3.0	90	2.4
Miscellaneous flagellates	1240	37.7	490	8.9	720	40.4	350	19.4	550	13.7	870	22.9
Anabaena spp.	60	1.8	30	0.5	---	----	---	----	---	----	30	0.8
Anacystis spp.	---	----	60	1.4	120	6.7	230	12.8	1010	25.1	750	19.8
Aphanothece spp.	---	----	90	1.6	90	5.1	60	3.3	200	5.0	260	6.9
Chroococcus spp.	---	----	---	----	30	1.7	---	----	60	1.5	60	1.6
Coelospaerium kuetzingianum	---	----	---	----	---	----	---	----	60	1.5	---	----
Gomphosphaeria lacustris	---	----	---	----	---	----	60	3.3	30	0.7	30	0.8
Ankistrodesmus falcatus	---	----	120	2.2	---	----	---	----	30	0.7	30	0.8
Crucigenia quadrata	---	----	---	----	---	----	---	----	---	----	120	3.2
Oocystis spp.	---	----	30	0.5	60	3.4	60	3.3	60	1.5	---	----
Quadrigula lacustris	---	----	---	----	---	----	---	----	60	1.5	30	0.8
Scenedesmus quadricauda	---	----	---	----	---	----	---	----	---	----	---	----
Percent of Total	---	98.2	---	96.7	---	98.3	---	100.0	---	94.8	---	94.5
Total Diatoms	1330	40.4	2300	41.9	150	8.4	690	38.3	1230	30.6	640	16.9
Total Flagellates	1900	57.7	2740	49.9	1330	74.7	700	38.9	1250	31.1	1780	47.0
Total Blue Green Algae	60	1.8	210	3.8	240	13.5	350	19.4	1360	33.8	1130	29.8
Total Green Algae	---	----	240	4.4	60	3.4	60	3.3	180	4.5	240	6.3
Total Phytoplankton	3290	----	5490	----	1780	----	1800	----	4020	----	3790	----

TABLE D3
COMMON PHYTOPLANKTON SPECIES
SOUTHERN LAKE MICHIGAN
Cruise 3 (August 20-25, 1977)

STATIONS

Species	25 #/ml	25 %	25a #/ml	25a %	26 #/ml	26 %	27 #/ml	27 %	28a #/ml	28a %	28 #/ml	28 %
Asterionella formosa	400	11.0	140	5.5	90	2.1	60	2.5	no sample		60	2.2
Cyclotella spp.	---	----	30	1.2	---	----	60	2.5			---	----
Diatoms tenue var. elongatum	---	----	---	----	30	0.7	---	----			60	2.2
Fragilaria crontonensis	660	18.1	350	13.7	1790	41.8	430	18.2			580	21.7
Fragilaria intermedia	---	----	---	----	---	----	---	----			---	----
Melosira spp.	---	----	120	4.7	30	0.7	---	----			140	5.2
Synedra acus	30	0.8	30	1.2	---	----	30	1.3			60	2.2
Tabellaria fenestrata	90	2.5	---	----	200	4.7	---	----			60	2.2
Cryptomonas erosa	---	----	---	----	---	----	---	----			---	----
Cryptomomas ovata	60	1.6	90	3.5	60	1.4	90	3.8			90	3.4
Cryptomonas spp.	840	23.0	780	30.5	520	12.1	380	16.1			260	9.7
Dinobryon spp.	170	4.7	90	3.5	120	2.8	30	1.3			140	5.2
Miscellaneous flagellates	1130	31.0	430	16.8	900	21.0	920	39.0			610	22.8
Anabaena spp.	---	----	---	----	---	----	---	----			---	----
Anacystis spp.	---	----	60	2.3	120	2.8	120	5.1			170	6.4
Aphanothece spp.	---	----	60	2.3	90	2.1	60	2.5			60	2.2
Chroococcus spp.	---	----	---	----	---	----	60	2.5			---	----
Coelospaerium kuetzingianum	---	----	---	----	---	----	---	----			---	----
Gomphosphaeria lacustris	---	----	---	----	---	----	---	----			---	----
Ankistrodesmus falcatus	---	----	---	----	30	0.7	---	----			140	5.2
Crucigenia quadrata	---	----	---	----	---	----	---	----			---	----
Oocystis spp.	90	2.5	230	9.0	90	2.1	90	3.8			---	----
Quadrigula lacustris	---	----	60	2.3	120	2.8	---	----			---	----
Scenedesmus quadricauda	---	----	---	----	---	----	---	----			---	----
Percent of Total	---	95.1	---	96.5	---	97.9	---	98.7			---	91.0
Total Diatoms	1360	37.3	670	26.2	2170	50.7	580	24.6			990	37.1
Total Flagellates	2200	60.3	1450	56.6	1600	37.4	1450	61.4			1100	41.2
Total Blue Green Algae	---	----	120	4.7	270	6.3	240	10.2			290	10.9
Total Green Algae	90	2.5	320	12.5	240	5.6	90	3.8			290	10.9
Total Phytoplankton	3650	----	2560	----	4280	----	2360	----			2670	----

TABLE D4
COMMON PHYTOPLANKTON SPECIES
SOUTHERN LAKE MICHIGAN
Cruise 4 (September 17-24, 1977)

	STATIONS											
	5a		5b		5		6		6a		6b	
Species	#/ml	%	#/ml	%	#/ml	%	#/ml	%	#/ml	%	#/ml	%
Asterionella formosa	60	1.8	60	1.9	60	4.3	---	----	30	0.9	---	----
Cyclotella spp.	170	5.2	120	3.9	30	2.2	90	3.6	---	----	30	1.1
Diatoms tenue var. elongatum	---	----	30	1.0	60	4.3	---	----	30	0.9	---	----
Fragilaria crontonensis	---	----	550	17.7	---	----	430	17.1	150	4.4	60	2.1
Melosira spp.	---	----	200	6.4	---	----	---	----	120	3.5	---	----
Nitzchia spp.	30	0.9	---	----	30	2.2	---	----	30	0.9	30	1.1
Rhizosolenia eriensis	140	4.3	---	----	---	----	---	----	60	1.8	---	----
Rhizosolenia longiseta	30	0.9	60	1.9	---	----	---	----	---	----	---	----
Synedra acus	140	4.3	170	5.5	60	4.3	30	1.2	30	0.9	60	2.1
Tabellaria fenestrata	---	----	---	----	---	----	---	----	---	----	---	----
Tabellaria flocculosa	---	----	---	----	---	----	---	----	---	----	---	----
Cryptomomas ovata	30	0.9	---	----	60	4.3	30	1.2	30	0.9	30	1.1
Cryptomonas spp.	90	2.9	200	6.4	230	17.4	460	18.3	580	17.1	200	7.2
Dinobryon spp.	260	7.9	30	1.0	30	2.2	---	----	320	9.4	230	8.2
Miscellaneous flagellates	750	22.7	810	26.0	490	35.5	920	36.6	1040	30.7	430	15.4
Anabaena spp.	30	0.9	30	1.0	---	----	---	----	---	----	30	1.1
Anacystis spp.	1130	34.5	580	18.6	90	6.5	490	19.5	580	17.1	980	35.1
Aphanothece spp.	90	2.9	---	----	---	----	---	----	90	2.6	140	5.0
Chroococcus spp.	90	2.9	---	----	120	8.7	---	----	---	----	60	2.1
Gomphosphaeria lacustris	30	0.9	90	2.9	90	6.5	---	----	120	3.5	120	4.3
Microcoleus lyngbyacus	---	----	---	----	---	----	---	----	---	----	120	4.3
Oscillatoria limnetica	30	0.9	60	1.9	---	----	30	1.2	60	1.8	90	3.2
Ankistrodesmus falcatus	30	0.9	---	----	---	----	---	----	30	0.9	90	3.2
Crucigenia quadrata	---	----	---	----	---	----	30	1.1	---	----	---	----
Crucigenia rectangularis	---	----	---	----	---	----	---	----	---	----	---	----
Percent of Total	---	95.7	---	96.1	---	98.4	---	99.8	---	97.3	---	96.6
Total Diatoms	570	17.4	1280	41.2	240	17.4	550	21.9	450	13.3	180	6.4
Total Flagellates	1190	36.3	1040	33.4	810	58.7	1410	56.2	2000	59.0	920	33.0
Total Blue Green Algae	1400	42.7	790	25.4	300	21.7	550	21.9	820	24.2	1480	53.1
Total Green Algae	120	3.6	---	----	30	2.2	---	----	120	3.5	210	7.5
Total Phytoplankton	3280	----	3110	----	1380	----	2510	----	3390	----	2790	----

TABLE D4
COMMON PHYTOPLANKTON SPECIES
SOUTHERN LAKE MICHIGAN
Cruise 4 (September 17-24, 1977)

	STATIONS													
	9		9a		10		11		12		13a		13	
Species	#/ml	%	#/ml	%	#/ml	%	#/ml	%	#/ml	%	#/ml	%	#/ml	%
Asterionella formosa	90	2.7	---	----	---	----	140	5.6	230	3.8	---	----	---	----
Cyclotella spp.	60	1.8	290	7.5	120	4.4	60	2.4	150	2.5	200	6.0	290	6.4
Diatoms tenue var. elongatum	---	----	30	0.7	---	----	60	2.4	---	----	120	3.6	---	----
Fragilaria crontonensis	290	8.7	170	4.4	---	----	---	----	60	1.0	---	----	30	0.7
Melosira spp.	---	----	---	----	---	----	120	4.8	120	2.0	200	6.0	200	4.4
Nitzchia spp.	30	0.9	30	0.7	---	----	---	----	30	0.5	90	2.7	40	0.9
Rhizosolenia eriensis	---	----	60	1.5	---	----	180	7.3	---	----	---	----	---	----
Rhizosolenia longiseta	---	----	30	0.7	---	----	---	----	90	1.5	---	----	---	----
Synedra acus	---	----	30	0.7	---	----	30	1.2	150	2.5	---	----	---	----
Tabellaria fenestrata	90	2.7	---	----	---	----	30	1.2	120	2.0	---	----	---	----
Tabellaria flocculosa	---	----	---	----	150	5.5	---	----	---	----	---	----	---	----
Cryptomomas ovata	90	2.7	30	0.7	---	----	170	6.8	170	2.8	90	2.7	90	2.0
Cryptomonas spp.	610	18.3	1010	26.0	640	23.4	610	24.6	950	15.6	640	19.1	290	6.4
Dinobryon spp.	30	0.9	170	4.4	60	2.2	120	4.8	---	----	30	0.9	---	----
Miscellaneous flagellates	950	28.5	1390	35.8	520	19.0	380	15.3	2310	38.1	1360	40.6	1560	34.5
Anabaena spp.	---	----	460	11.8	---	----	---	----	---	----	30	0.9	---	----
Anacystis spp.	610	18.3	---	----	980	35.8	400	16.1	1180	19.4	30	0.9	1450	32.1
Aphanothece spp.	---	----	---	----	30	1.1	60	2.4	60	1.0	30	0.9	90	2.0
Chroococcus spp.	60	1.8	---	----	150	5.2	---	----	90	1.5	90	2.7	---	----
Gomphosphaeria lacustris	30	0.9	30	0.7	30	1.1	---	----	120	2.0	120	3.6	120	2.6
Microcoleus lyngbyacus	30	0.9	---	----	---	----	---	----	---	----	290	8.7	---	----
Oscillatoria limnetica	30	0.9	30	0.7	---	----	---	----	---	----	---	----	---	----
Ankistrodesmus falcatus	60	1.8	30	0.7	---	----	60	2.4	120	2.0	30	0.9	90	2.0
Crucigenia quadrata	---	----	90	2.3	30	1.1	---	----	30	0.5	---	----	120	2.6
Crucigenia rectangularis	---	----	---	----	---	----	---	----	---	----	---	----	---	----
Percent of Total	---	91.8	---	99.3	---	98.8	---	97.3	---	98.7	---	100.0	---	96.6
Total Diatoms	590	17.7	640	16.5	270	9.8	620	25.0	980	16.1	610	18.2	560	12.4
Total Flagellates	1710	51.3	2600	67.0	1250	45.6	1280	51.6	3430	56.5	2120	63.3	1940	42.9
Total Blue Green Algae	760	22.8	520	13.4	1190	43.4	460	18.5	1480	24.4	590	17.6	1660	36.7
Total Green Algae	270	8.1	120	3.1	30	1.1	120	4.8	180	3.0	30	0.9	360	8.0
Total Phytoplankton	3330	----	3880	----	2740	----	2480	----	6070	----	3350	----	4520	----

TABLE D4
COMMON PHYTOPLANKTON SPECIES
SOUTHERN LAKE MICHIGAN
Cruise 4 (September 17-24, 1977)

	STATIONS													
	16		16b		17		18		19		20a		20	
Species	#/ml	%	#/ml	%	#/ml	%	#/ml	%	#/ml	%	#/ml	%	#/ml	%
Asterionella formosa	290	4.8	380	10.0	---	----	---	----	90	2.9	60	2.2	150	3.3
Cyclotella spp.	120	2.0	120	3.1	60	3.2	30	1.0	90	2.9	30	1.1	150	3.3
Diatoms tenue var. elongatum	---	----	30	0.8	---	----	---	----	90	2.9	30	1.1	---	----
Fragilaria crontonensis	1270	20.8	260	6.8	---	----	---	----	---	----	---	----	920	20.5
Melosira spp.	60	1.0	---	----	---	----	---	----	---	----	---	----	---	----
Nitzchia spp.	30	0.5	30	0.8	---	----	---	----	---	----	---	----	---	----
Rhizosolenia eriensis	60	1.0	---	----	30	1.6	---	----	---	----	---	----	---	----
Rhizosolenia longiseta	---	----	60	1.6	30	1.6	---	----	---	----	---	----	---	----
Synedra acus	90	1.5	30	0.8	---	----	---	----	---	----	30	1.1	60	1.3
Tabellaria fenestrata	140	2.3	60	1.6	---	----	---	----	---	----	---	----	---	----
Tabellaria flocculosa	---	----	---	----	---	----	---	----	---	----	---	----	---	----
Cryptomomas ovata	170	2.8	---	----	30	1.6	60	2.0	90	2.9	60	2.2	90	2.0
Cryptomonas spp.	840	13.8	690	18.1	430	23.1	430	14.1	640	20.3	750	27.4	550	12.2
Dinobryon spp.	30	0.5	290	7.6	60	3.2	---	----	---	----	---	----	---	----
Miscellaneous flagellates	2140	35.1	1270	33.3	460	24.7	690	22.7	1360	43.2	580	21.2	1160	25.8
Anabaena spp.	---	----	---	----	---	----	30	1.0	---	----	---	----	---	----
Anacystis spp.	170	2.8	260	6.8	400	21.5	1590	52.3	520	16.5	720	26.4	1110	24.7
Aphanothece spp.	---	----	30	0.8	60	3.2	90	3.0	60	1.9	120	4.4	90	2.0
Chroococcus spp.	---	----	---	----	30	1.6	---	----	30	0.9	140	5.1	60	1.3
Gomphosphaeria lacustris	30	0.5	---	----	30	1.6	60	2.0	150	4.8	90	3.3	---	----
Microcoleus lyngbyacus	30	0.5	---	----	---	----	---	----	---	----	---	----	---	----
Oscillatoria limnetica	200	3.3	30	0.8	---	----	---	----	---	----	---	----	30	0.7
Ankistrodesmus falcatus	30	0.5	60	1.6	---	----	---	----	---	----	30	1.1	30	0.7
Crucigenia quadrata	---	----	---	----	---	----	---	----	---	----	---	----	---	----
Crucigenia rectangularis	120	2.0	---	----	---	----	---	----	---	----	---	----	---	----
Percent of Total	---	95.7	---	94.5	---	87.1	---	98.1	---	99.2	---	96.6	---	97.8
Total Diatoms	2060	33.8	1000	26.2	120	6.4	30	1.0	180	5.7	150	5.5	1280	28.5
Total Flagellates	3210	52.7	2250	59.1	1040	59.1	1180	38.8	2090	66.3	1420	52.0	1830	40.8
Total Blue Green Algae	490	9.0	320	8.4	580	31.2	1770	58.2	760	24.1	1100	40.3	1290	28.7
Total Green Algae	330	5.4	240	6.3	120	6.4	60	2.0	30	0.9	60	2.2	120	2.7
Total Phytoplankton	6090	----	3810	----	1860	----	3040	----	3150	----	2730	----	4490	----

TABLE D4
COMMON PHYTOPLANKTON SPECIES
SOUTHERN LAKE MICHIGAN
Cruise 4 (September 17-24, 1977)

	STATIONS											
	21		21a		22		23		24a		24	
Species	#/ml	%	#/ml	%	#/ml	%	#/ml	%	#/ml	%	#/ml	%
Asterionella formosa	350	4.1	60	1.9	60	2.0	---	----	---	----	---	----
Cyclotella spp.	170	2.0	90	2.8	60	2.0	120	3.6	120	4.2	60	1.4
Diatoms tenue var. elongatum	170	2.0	---	----	---	----	---	----	30	1.0	---	----
Fragilaria crontonensis	1330	15.4	---	----	---	----	---	----	---	----	---	----
Melosira spp.	60	0.7	---	----	---	----	60	1.8	---	----	---	----
Nitzchia spp.	120	1.4	---	----	---	----	---	----	---	----	---	----
Rhizosolenia eriensis	90	1.0	60	1.9	---	----	---	----	---	----	---	----
Rhizosolenia longiseta	120	1.4	---	----	60	2.0	---	----	---	----	---	----
Synedra acus	90	1.0	---	----	---	----	---	----	30	1.0	---	----
Tabellaria fenestrata	350	4.1	60	1.9	60	2.0	---	----	---	----	---	----
Tabellaria flocculosa	350	4.1	---	----	---	----	---	----	---	----	---	----
Cryptomomas ovata	230	2.7	120	3.8	30	1.0	---	----	120	4.2	60	1.4
Cryptomonas spp.	810	9.4	430	13.6	400	13.6	870	26.4	720	25.3	920	21.3
Dinobryon spp.	750	8.7	350	11.0	140	4.7	---	----	---	----	---	----
Miscellaneous flagellates	2800	32.5	1470	46.4	430	14.6	1160	35.2	1010	35.4	610	14.1
Anabaena spp.	---	----	30	0.9	30	1.0	90	2.7	---	----	230	5.3
Anacystis spp.	260	3.0	140	4.4	1530	51.9	840	25.5	640	22.5	2250	52.2
Aphanothece spp.	---	----	90	2.8	90	3.0	90	2.7	120	4.2	---	----
Chroococcus spp.	---	----	---	----	30	1.0	---	----	---	----	---	----
Gomphosphaeria lacustris	---	----	---	----	30	1.0	---	----	30	1.0	---	----
Microcoleus lyngbyacus	30	0.3	---	----	---	----	---	----	---	----	---	----
Oscillatoria limnetica	150	1.7	30	0.9	---	----	---	----	---	----	---	----
Ankistrodesmus falcatus	200	2.3	---	----	---	----	---	----	---	----	---	----
Crucigenia quadrata	---	----	---	----	---	----	---	----	---	----	30	0.7
Crucigenia rectangularis	---	----	---	----	---	----	---	----	---	----	---	----
Percent of Total	---	97.8	---	99.8	---	99.8	---	97.9	---	98.8	---	96.4
Total Diatoms	3200	37.2	180	6.1	180	6.1	180	5.5	180	6.3	60	1.4
Total Flagellates	4650	54.0	1060	35.6	1060	35.9	2030	61.7	1850	64.9	1650	38.3
Total Blue Green Algae	500	5.8	1710	58.0	1710	58.0	1020	31.0	790	27.7	2540	58.9
Total Green Algae	260	3.0	---	----	---	----	60	1.8	30	1.0	60	1.4
Total Phytoplankton	8610	----	2950	----	2950	----	3290	----	2850	----	4310	----

TABLE D4
COMMON PHYTOPLANKTON SPECIES
SOUTHERN LAKE MICHIGAN
Cruise 4 (September 17-24, 1977)

	STATIONS											
	25		25a		26		27		28a		28	
Species	#/ml	%	#/ml	%	#/ml	%	#/ml	%	#/ml	%	#/ml	%
Asterionella formosa	90	3.5	60	2.2	30	0.7					30	0.5
Cyclotella spp.	90	3.5	---	----	30	0.7					320	5.8
Diatoms tenue var. elongatum	30	1.2	---	----	---	----					60	1.1
Fragilaria crontonensis	120	4.7	---	----	430	10.5					150	2.7
Melosira spp.	---	----	---	----	---	----					230	4.2
Nitzchia spp.	30	1.2	30	1.1	---	----					30	0.5
Rhizosolenia eriensis	30	1.2	---	----	---	----					---	----
Rhizosolenia longiseta	---	----	---	----	---	----					---	----
Synedra acus	30	1.2	---	----	30	0.7					30	0.5
Tabellaria fenestrata	---	----	---	----	---	----					30	0.5
Tabellaria flocculosa	---	----	---	----	---	----					---	----
Cryptomomas ovata	---	----	120	4.4	60	1.5					---	----
Cryptomonas spp.	430	16.7	290	10.7	840	20.4					870	15.8
Dinobryon spp.	200	7.8	120	4.4	---	----					60	1.1
Miscellaneous flagellates	1010	39.3	1390	51.3	950	23.1	no sample		no sample		1180	21.5
Anabaena spp.	---	----	60	2.2	---	----					---	----
Anacystis spp.	60	2.3	430	15.9	1330	32.4					1910	34.8
Aphanothece spp.	---	----	90	3.3	170	4.1					200	3.6
Chroococcus spp.	90	3.5	30	1.1	120	2.9					---	----
Gomphosphaeria lacustris	30	1.2	60	2.2	60	1.5					150	2.7
Microcoleus lyngbyacus	60	2.3	---	----	---	----					---	----
Oscillatoria limnetica	90	3.5	---	----	---	----					60	1.1
Ankistrodesmus falcatus	---	----	---	----	---	----					---	----
Crucigenia quadrata	---	----	---	----	---	----					---	----
Crucigenia rectangularis	---	----	---	----	---	----					---	----
Percent of Total	---	93.1	---	98.8	---	98.5					---	96.4
Total Diatoms	420	16.3	90	3.3	520	12.6					880	16.0
Total Flagellates	1670	65.0	1920	70.8	1850	45.0					2140	39.0
Total Blue Green Algae	360	14.0	640	23.6	1680	40.9					2320	42.3
Total Green Algae	120	4.7	60	2.2	60	1.5					150	2.7
Total Phytoplankton	2570	----	2710	----	4110	----					5490	----

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